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Enjoy & Master Advanced Geography

Topical Questions and Examinations: Physical Geography

Ngaiza Series of Advanced Geography

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PREFACE

This book was written because you deserve better.

Advanced Level Geography rewards understanding, yet many students arrive in Form Five having learned to name landforms they cannot explain and to recite processes they cannot reason through. Physical Geography feels familiar, because we all watch rivers rise after the rains, climb the hills, and feel the weather turn, so it is easy to believe you understand it when you have only memorised it. Students memorise what a feature looks like, sit examinations that ask how and why, and leave believing Geography is a list of names and facts to be recalled under pressure. That is not Geography. That is memorisation dressed as understanding.

Physical Geography is the study of the living Earth itself: how a continent drifts and a rift valley opens, how a river carves a gorge and builds a delta, how solid rock crumbles into soil, and how water moves without end between the sea, the sky and the land. It is the science written across the very landscape you live in, in the Rift Valley at your doorstep, the snows of Kilimanjaro, the great lakes and the long coast. It is powerful, rooted in real places, and far more logical than its reputation suggests. But mastering it under examination conditions takes more than a textbook to read. It takes practice: attempting real questions, building real answers, and learning, answer by answer, how to turn what you know into marks. That is what this book sets out to give you.

Why a book of questions and answers?

You do not learn to swim by reading about water, and you do not learn Geography by reading model answers. You learn it by attempting a question, getting it wrong, finding out exactly why, and trying again. This book is built entirely around that truth. Every concept in the Physical Geography syllabus is turned into questions you must answer yourself, each followed by a full model answer that shows not only the correct geography but the exact, connected English that earns examination marks. Used honestly, with the answer covered until you have written your own, it trains the two things the examination really tests: understanding the process, and explaining it clearly.

How this book is organised

The book covers the whole Physical Geography branch, Forms Five and Six, in six chapters: Theories of Landform Formation, Earth as a System, Endogenic Processes of the Earth, Exogenic Processes of the Earth, Rocks and Soils, and Hydrology.

The first part, Topical Questions and Answers, takes each chapter in turn. Every question is followed at once by its model answer, so you can attempt it and then check yourself immediately. Within each chapter the questions rise through three tiers.

BINDER questions anchor the core process. Even here they ask you to explain how and why, never merely to state what. If you can answer these, you own the concept.

REAL questions carry the geography into real Tanzanian and African settings, from the rift lakes to the soils of the highlands and the landforms of the coast, where the subject actually lives.

HOT questions push you to examination standard and beyond, drawing several topics together and demanding genuine reasoning rather than recall.

The second part, the Examination Questions, brings together short-answer and essay questions at full examination standard. The questions come first, and their model answers follow in a separate section, so that every question in this book, from the first to the last, has a complete, well-reasoned answer you can learn from, but only after you have attempted it with the solutions closed.

Before the questions begin, a short Student Survival Guide shows you how to study Geography, how to use this book, and how to beat the two traps, false confidence and description in place of explanation, that quietly cost good students their marks. Read it first. It is the shortest and most important part of the book.

The team behind this book

Enjoy and Master Advanced Geography is the work of the Ngaiza Education Hub, built by a team of experienced geography educators who share one conviction: that Tanzanian students deserve world-class materials written for their context, their syllabus, and their aspirations.

Writers: Mr. Lazaro Kinabo and Mr. Jonas Joram.

Editors: Mr. Ahmed Karim.

Designer: Mr. Frank Mwita.

I am grateful to every member of this team for their dedication, their expertise, and their refusal to settle for "good enough." I thank too the students whose hard questions and honest struggles shaped every answer in this book. They reminded us, again and again, that a question a student cannot learn from has failed, no matter how correct its geography may be.

To every student of Advanced Geography opening this book for the first time: Geography is not as hard as its reputation, and it is not as easy as it first feels. It is as logical as the Earth that shaped its own landscapes, and as satisfying as a puzzle that finally clicks. Give it your honest effort, with the answer covered and your pen moving, and this book will give you its honest best in return.

Ngaiza, Lusima
Series Creator and Director

STUDENT SURVIVAL GUIDE

How to turn what you know into marks.

Why Physical Geography Feels Easy, Then Betrays You

You have lived inside Physical Geography all your life. You have watched rivers swell after the rains, climbed hills, seen the soil change colour from one field to the next, and felt the heat of midday give way to the chill of a highland night. The landscape is the one subject you can point at, and that is exactly what makes it the most deceptive paper on your timetable.

The first trap is false confidence. Because you can see a landform and name it, it feels understood, and that easy feeling fools thousands of candidates every year. The examination does not ask what a feature looks like; it asks how it forms and why. You can point to a rift valley, but explain how the crust was stretched, faulted and dropped to make it, and the easy feeling vanishes. The distance between naming a feature and explaining its formation is where most marks are won or lost.

The second trap is description instead of explanation. Even when you know the process, under pressure the pen slips into describing the scene: what the river looks like, how grand the falls are, where the lake lies. Description answers the question what; the examiner is paying for how and why. To call a delta a fan of land at the river mouth earns almost nothing, while to explain how the river loses speed, drops its load and builds that fan earns the marks.

On the answer sheet the two traps look identical: a confident, fluent paragraph that names and describes and still bleeds marks. The cure for both is the same discipline, and this book is built to drill it into you, for every model answer leads with the process and follows the chain of cause and effect to its end, anchored to a real, named place.

One example makes the difference clear.

The same question, answered by two students.

The question. Explain how a waterfall is formed.

The confident answer that fails. A waterfall is a place where a river falls over a steep cliff, often looking very beautiful and drawing many tourists. (It names and describes, yet explains nothing, and scores almost nothing.)

The answer that scores. A waterfall forms where a band of hard rock lies across the course above softer rock. The softer rock is worn away faster by hydraulic action and abrasion, so a step develops in the river bed. Undercutting then leaves the hard rock unsupported until it collapses, and as this is repeated the fall retreats upstream, leaving a gorge, as at the Kalambo Falls on the border of Tanzania and Zambia.

Both students had seen a waterfall; only the second explained one, and only the second scores. That gap, repeated across a three-hour paper, separates a pass from a distinction. This guide, and every answer that follows it, exists to put you on the right side of it: from knowing to answering.

How to Use This Book

This is not a book to read. It is a book to work. A model answer you have only read feels learned and is forgotten by morning; a model answer you have struggled toward, and then compared against your own, is learned for good. Work every question in four steps.

1. **Cover the model answer.** Read the question, then answer it in full on paper, in proper sentences, before you look at anything.
2. **Uncover and compare.** Read the model answer twice, once for the geography and once for the way it is built. Did you get the process? Did you connect it as the model does, and did you name a real place?
3. **Mark yourself honestly.** Award yourself a point only where your answer truly made the same point. A near miss is a miss.
4. **Fix one thing, then move on.** Correct your single biggest error in your own words, and carry that lesson into the next question.

Climb the ladder, and do not skip the bottom rung. The questions rise through three tiers. BINDER builds the core explanation of each process, several with the help of a labelled diagram. REAL carries that

understanding into real Tanzanian and African settings, from the rift at Lake Natron to the soils of the Southern Highlands. HOT pushes into higher-order reasoning, weighing one process against another and judging a claim. A student who jumps to HOT before owning BINDER is trying to enter a house through the top window. Work each chapter in order.

Treat the examination questions as real examinations. The questions at the end of this book, the short-answer questions worth fifteen marks and the essays worth twenty, are not extra reading. Sit them in a quiet room, against the clock, with the solutions closed, then mark yourself against the model answers. That is the closest rehearsal for the real day you can get.

How to Write Geography for Marks

Marks in geography are not awarded for knowing. They are awarded for showing that you know, in writing, in the right order. Three habits carry most of those marks.

Lead with the point, then explain it. State the named process or landform the question asks for first, in a few words, then give the reasoning behind it. The examiner is trained to find the point, tick it, and read on for the explanation that earns the rest. Bury the point at the end of a long sentence and you force a tired examiner to hunt for it, and a point that cannot be found cannot be marked.

Join your ideas with the words that carry cause and effect. A geography explanation is a chain in which one event causes the next. The words that build that chain are because, so, as a result, which in turn, consequently, leading to and therefore. Use them on purpose. They are the whole difference between a list of true statements and an explanation.

Anchor every answer in a real, named place. Physical geography is the study of the real Earth, and the examiner rewards the candidate who proves it with an example. Name the river, the lake, the mountain or the region, the Rufiji, Kilimanjaro, Lake Tanganyika, the Usambara, rather than writing in the abstract. A process tied to a place is worth more than the same process floating free.

One example shows the habits at work.

The same geography, written two ways.

The question. Explain how an ox-bow lake is formed.

A list of true facts (low marks). A meander becomes very curved, the neck is cut through, and an ox-bow lake is left behind. (Every statement is true, yet nothing is joined, so it reads as memory, not understanding.)

The same facts as a chain (full marks). On the outer bank of a meander the current is faster, so erosion by hydraulic action and abrasion wears the bank back, while on the slower inner bank the river deposits sediment. As a result the loop grows more pronounced and its neck narrows, until in a flood the river cuts straight across the neck. Deposition then seals off the old bend, which is left as a crescent-shaped ox-bow lake, as on the floodplain of the Kilombero.

Notice that the second answer adds no new facts. It only connects the ones already there, and ties them to a place. That connecting is the skill this whole book is teaching you, answer after answer.

How to Draw Geography for Marks

Diagrams carry marks that most students give away. A sketch, a cross-section or a map is not decoration; it is an answer made of lines, and it is marked as strictly as a sentence.

Show the process, not just the shape. A landform sketch must reveal how the feature forms, not merely its outline. A waterfall must show the hard rock overhanging the undercut soft rock; a rift valley must show the faults and the block dropped between them. Draw the cause, not only the silhouette.

Get the proportions right, and rest every feature on its ground line. A volcano taller than it is wide, or a meander loop floating above the valley floor, loses marks before a label is read. Look first, then draw what is actually there, and let every slope and feature sit on the surface.

Use single, clean lines. One firm line, not a furry sketch built from many short strokes. Keep a sharp pencil, and use a ruler wherever the line is straight, as along the axis of a cross-section.

Rule your label lines, and never let them cross. Each label line is straight, drawn with a ruler, and touches the exact feature it names. Crossing or wandering label lines confuse the examiner and cost marks.

Give a sketch its furniture where the question asks for it. A title, a key for the symbols, a scale and a north point earn their own marks on a map or sketch-map, and an answer that omits them is capped. A few diagrams return again and again, among them the three plate boundaries, the long profile of a river, the cave, arch and stack sequence, and the soil profile. Practise each until you can draw it cleanly from memory in two minutes.

How to Fail Productively

You will get questions wrong. Every strong student does. What decides your grade is the five minutes after you get one wrong.

The unproductive response is to erase your attempt, read the model answer, nod, and move on. Your page looks complete and your memory has learned nothing, because you only watched someone else answer.

The productive response is to stop, and not erase. Set your answer beside the model and find the exact point where they part. Then name the cause: was it the geography, because you did not know the process; the structure, because you described the feature instead of explaining how it forms; or the question, because you answered what you expected instead of what was asked? Fix that one thing, cover the model again, and rewrite the answer from the start.

Those three causes need three different cures, and naming yours is half the cure. A wrong answer you have diagnosed is worth more than a right answer you copied.

How to Revise on Your Own

Most revision feels productive and is not. Be honest about which kind you are doing. Re-reading model answers, highlighting them and copying them out neatly all feel like work, but your eyes move while your memory rests. A beautiful notebook is not understanding. These methods are.

Sit the examination questions under the clock. The questions at the back of this book are your single best revision tool. Work a set in a quiet room, timed, with the solutions closed, then mark yourself. Nothing else rehearses the real pressure.

Explain a process out loud, as if to someone who knows nothing. Trace how a meander becomes an ox-bow, or how the rift valley formed, in spoken sentences. Where you stumble is precisely what you have not understood yet. The silence is the lesson.

Teach a friend, and let them ask why. The moment you cannot answer their question is your revision target for the evening.

Redo the questions you got wrong, not the ones you got right. Return after a week to the answers you missed and work them again from a blank page.

Learn your examples, not only your processes. A process you can explain but cannot illustrate is half an answer. Keep a list of named Tanzanian and African examples for each topic, and learn it as carefully as the processes themselves.

Revise your weakest topic first, not your favourite. The topic you enjoy is the one you already know; the topic you avoid is the one the paper will ask.

How to Face the Examination

The examination does not test how clever you are. It tests whether you can show what you know, clearly, under pressure, in a fixed time. That is a skill, and skills can be practised.

Read every question twice before you write. Most lost marks come from answering the question you expected instead of the one on the paper. The second reading catches the word the first reading missed.

Obey the command word. Each command word asks for a particular kind of answer, and giving the wrong kind loses marks even when your geography is correct.

Command word	What it asks for
Describe	Give an orderly account of what a feature looks like or what happens, step by step, with no reasons.
Explain; Account for	Give the reason why, and the process behind it. Every explain answer needs a because.
Distinguish; Differentiate	Give the differences directly, side by side, not two separate descriptions.
Compare	Give similarities and differences together, point against point.
Examine	Look closely at the parts of a topic, setting out and weighing each in turn.
Assess; Evaluate	Weigh the strengths against the weaknesses and reach a clear judgement.
To what extent	Argue how far a statement is true, giving both sides, then a reasoned verdict.
Justify	Support a statement with reasons and evidence drawn from real examples.
Classify	Group the items by a clear basis, with a named example of each.
Suggest	Apply what you know to an unfamiliar case; a sensible, reasoned answer is rewarded.
With the aid of a diagram	A diagram is compulsory and carries its own marks; an answer without one is capped.

Plan an essay before you write it. Jot the points you will make, then write a short introduction that defines the terms, a paragraph for each point led by its key idea, and a brief conclusion. A planned essay scores more than a longer one written without a plan.

Scale your answer to the marks. When a question asks for six points, give six developed points, not three long ones or ten thin ones. The number of points asked, and the marks beside the question, tell you how much to write.

Show your reasoning, not just the conclusion. A bare statement scores little; the marks live in the steps between the question and the answer. Write the chain.

Watch the clock, and leave nothing blank. Marks are easiest to win at the start of an answer and hardest at the end, so a question half answered is worth more than a question never reached. Spend your time by the marks, not by your interest.

The night before, do not cram. Your brain files what you have learned while you sleep. A calm student who rests well outperforms a tired one who revised until midnight. Rest is part of the preparation.

You now carry what the strongest students bring into the hall and most never receive: a way to use this book that turns reading into practice, the language to write geography that scores, the technique to draw it for full marks, an honest method of revision, and a clear plan for the examination itself. Turn the page, cover the first model answer, and begin. The geography is waiting, and it is better than its reputation.

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PART ONE
TOPICAL QUESTIONS AND ANSWERS

Chapter 1

THEORIES OF LANDFORMS FORMATION

This chapter sets out the four great theories of how the Earth builds and balances its crust: continental drift, seafloor spreading, plate tectonics and isostasy. Its sixty-three questions run in three tiers, and are best worked in order.

BINDER questions build the core explanation of each theory, several with the help of a labelled diagram. **REAL** questions carry that understanding into real Tanzanian and African settings: the East African Rift, Kilimanjaro and the great lakes. **HOT** questions ask you to weigh the theories against one another, to judge a claim and to predict.

BINDER QUESTIONS

Question 1

With the help of a series of simple sketches, explain how continental drift accounts for the present arrangement of the continents, from the single super-continent of Pangaea, through Laurasia and Gondwanaland, to the continents of today.

Model Answer

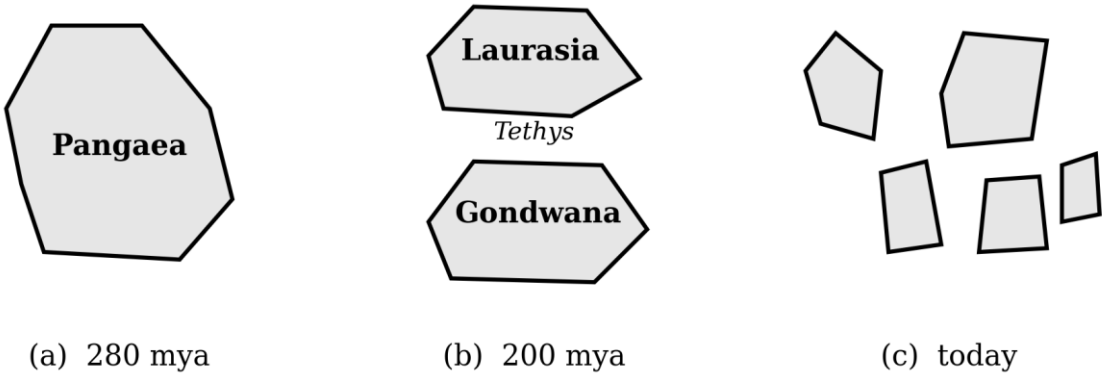


Figure 1.1: *The break-up of Pangaea and the drift of the continents*

Continental drift is the theory that the continents were once joined in a single super-continent and have since drifted to their present positions. Wegener, building on Frank Taylor's earlier idea of 1908, proposed that about 280 million years ago all the land formed one mass, Pangaea, surrounded by a single ocean, Panthalassa. Around 200 million years ago Pangaea split into a northern block, Laurasia, and a southern block, Gondwanaland, separated by the shallow Tethys sea. Laurasia carried what became Europe, Asia and North America, while Gondwanaland carried Africa, South America, Australia, Antarctica and the Indian sub-continent. These fragments then drifted slowly apart to the spread of continents we see today.

How to Draw It
Show three stages and label Pangaea, then Laurasia and Gondwanaland with the Tethys between them, then the modern continents. The marks are for the sequence and the correct names, not for artistic shapes.

False Confidence Alert
It is wrong to say Pangaea broke straight into today's seven continents. It first parted into just two masses, Laurasia and Gondwanaland; the familiar continents came only with later drifting.

Question 2

A continent is lighter than the ocean floor that borders it. Explain how this difference in the crust is what allows a continent to drift at all, in Wegener's view.

Model Answer

A continent can drift because the light continental crust, the SIAL, rides on the denser ocean-floor and mantle material, the SIMA. The continental blocks are built largely of silica and aluminium, which gives the name SIAL, and have a low density of about 2.7. The ocean floor and the layer beneath are built of silica and magnesium, the SIMA, and are denser. Wegener pictured the sialic continents floating in the simatic layer like rafts in water, so that a force acting on a continent could push it slowly through the yielding sima beneath. This same floating relationship is the idea on which the isostasy theory later rests.

False Confidence Alert
Do not call the ocean floor 'water'. The continent floats on dense rock, the sima, not on the sea.

Question 3

Wegener needed a force to drive his drifting continents. Explain how the centrifugal force and the pole-fleeing force were said to move the continents towards the Equator.

Model Answer

Wegener proposed that the spinning of the Earth flung the continents away from the poles and towards the Equator. As the Earth rotates, a centrifugal force acts on every mass and is strongest at the Equator, tending to throw material outward from the axis. Because Pangaea lay near the South Pole, this gave rise to a pole-fleeing force, an equator-ward pull on the sialic blocks helped by gravity and by their buoyancy in the sima. The lighter continents, floating on the denser layer, were therefore driven slowly away from the poles and towards the Equator. These were Wegener's main driving forces, although both were later shown to be far too weak.

Question 4

Besides the spin of the Earth, two further forces were offered for continental drift. Explain how tidal attraction and, later, mantle convection were said to drive the continents.

Model Answer

Tidal attraction and mantle convection were offered as further engines of drift, the second far stronger than the first. Wegener argued that the gravitational pull of the Sun and the Moon, the same pull that raises the ocean tides, dragged the sialic continents slowly westward, against the direction of the Earth's rotation; this tidal force, however, was tiny. A stronger engine came from Arthur Holmes in 1929: heat from radioactivity deep in the mantle sets up convection currents, in which hot material rises, spreads sideways and drags the crust along before cooling and sinking. Holmes' convection gave drift the powerful mechanism that Wegener's own forces had lacked.

False Confidence Alert
Do not credit Wegener with the convection idea. Wegener offered the weak forces, centrifugal, pole-fleeing and tidal; it was Holmes, in 1929, who supplied convection.

Question 5

With the help of a labelled sketch, explain how the jig-saw fit of South America and Africa supports continental drift, and why the closest fit is found at the edge of the continental shelf rather than at the present coastline.

Model Answer

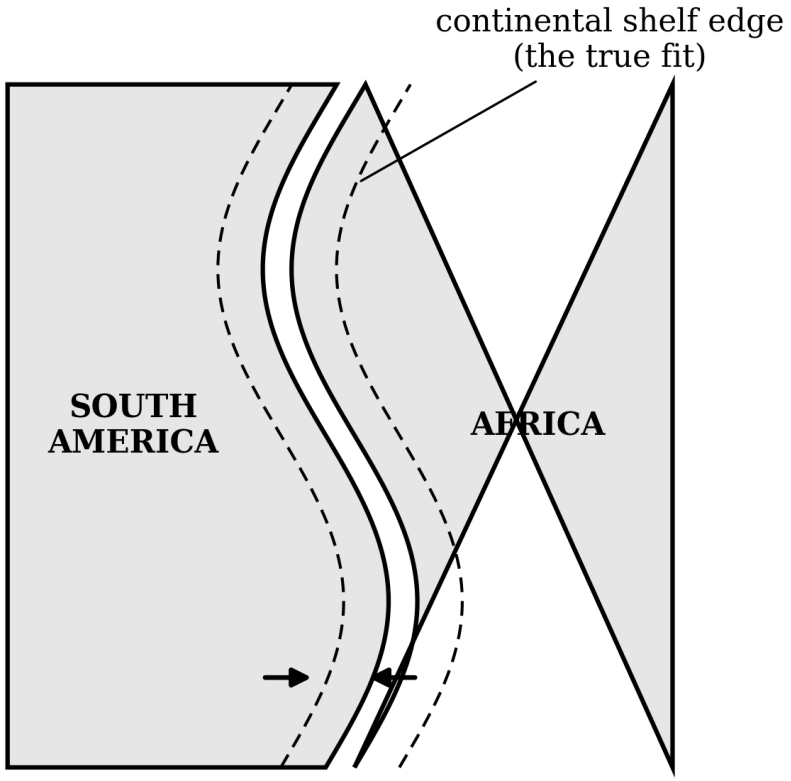


Figure 1.2: *The jig-saw fit of South America and Africa*

The continents support drift because their coastlines fit together like the pieces of a jig-saw, most exactly at the edge of the continental shelf. The eastern coast of South America matches the western coast of Africa so closely that, slid together, they close almost without a gap, which is hard to explain unless the two were once joined. The fit at the present shoreline is only rough, because waves and rivers have worn the coasts and sea level has changed. The true edge of a continent, however, is not the beach but the outer rim of the continental shelf, and when the continents are matched there the fit is almost perfect. This near-perfect fit is strong evidence that they were once a single mass.

How to Draw It
Draw the two coasts meeting with only a thin gap, and mark the continental-shelf edge with a dashed line. The mark is for showing the fit is closest at the shelf, not at the worn shoreline.

False Confidence Alert
Saying simply that 'the coastlines look similar' is a description, not an explanation, and scores little. State that the fit is best at the continental shelf and that this implies a former join.

Question 6

Identical fossils lie on the shores of continents now separated by wide oceans. Explain how this fossil evidence supports continental drift.

Model Answer

Matching fossils on now-separated continents support drift because the living things they came from could not have crossed the oceans that divide those lands. The remains of Mesosaurus, a small freshwater reptile, are found in both Brazil and West Africa, yet it could not have swum the salt Atlantic, so the two lands must once have touched. The land reptile Lystrosaurus is found alike in Africa, India and Antarctica, and the fern-like Glossopteris flora is spread across South America, Africa, India, Australia and Antarctica. Such a shared distribution makes sense only if these continents were joined as Gondwanaland when the organisms were alive, and have drifted apart since.

False Confidence Alert
Listing fossil names alone is not enough. The marks come from the reasoning: a freshwater or land organism found on two shores proves the shores were once connected.

Question 7

Where two continents were once joined, their rocks should still match across the join. Explain how the geological evidence supports continental drift.

Model Answer

The rocks of now-separated continents match in type, age and structure across the line where they were once joined, and this supports drift. The Karroo rock system of South Africa is continued by the Santa Catarina system of Brazil, the two being of the same age and character though now an ocean apart. In the same way the Appalachian mountains of North America line up with ranges of similar age and structure in Greenland and north-west Europe, as though one belt had been torn in two. Rocks of one age and kind do not form identically by chance on separate continents, so the matching geology shows the lands were once continuous.

Question 8

Grooves cut by ancient ice are found today in the hot heart of Africa. Explain how this evidence of past glaciation supports continental drift.

Model Answer

Signs of ancient glaciation in lands that are now hot show that those lands have drifted out of colder latitudes. In the Congo basin and in parts of southern Africa, India and South America there are striations, scratches and deposits left by ice sheets of about 250 to 300 million years ago. Such ice could never form in these places at their present warm, low latitudes. If, however, the southern continents were once joined as Gondwanaland over the South Pole, a single ice sheet could have covered them all and left these matching marks. The continents have since drifted apart and towards the Equator, carrying the glacial scars into the tropics.

False Confidence Alert
Do not stop at 'there was once ice in Africa'. The point is that the ice marks now lie in the tropics, which proves the land has moved away from the pole.

Question 9

When a rock forms, it locks in the direction of the Earth's magnetism at that moment. Explain how palaeomagnetism gives evidence for continental drift.

Model Answer

Palaeomagnetism supports drift because old rocks point to a magnetic north different from today's, showing that the rocks, and the continents carrying them, have moved. As molten rock cools and hardens, the iron minerals within it set like tiny compass needles aligned with the Earth's magnetic field of the time. In rocks more than a few hundred thousand years old, these frozen needles no longer point to the present magnetic north but to a different position. Since the magnetic pole has stayed roughly fixed, the simplest explanation is that the continent holding the rock has itself turned and drifted since the rock formed. Reading these old magnetic bearings even lets geographers reconstruct where each continent once lay.

False Confidence Alert
It is the rocks and their continents that moved, not the magnetic pole that wandered while the land stood still; read the evidence the right way round.

Question 10

Two further clues to drift come from warm-water reefs in cold seas and from mountain ranges on facing continents. Explain how each of these supports continental drift.

Model Answer

Stranded coral reefs and matching mountain ranges both show that continents have drifted into new positions. Coral reefs grow only in warm tropical seas, yet fossil reefs are found in the cold waters of the Arctic; this can only mean that those areas once lay in the tropics and have since drifted to high, cold latitudes. In the same way, the Atlas mountains of north-west Africa match the Alps of southern Europe in age, structure and alignment, as though a single belt had been raised when the African plate pushed northward against Europe. Both clues, like the others, point to continents that have changed their places on the globe.

Question 11

The drifting of the continents did far more than rearrange the map. Explain four consequences that continental drift has had for the physical and living world.

Model Answer

Continental drift reshaped the physical and living world in several lasting ways:

1) **New physical features:** as the lands split and moved, new oceans and seas opened between them, and where they later collided, fold mountains such as the Atlas were raised.
2) **Changed climates:** as continents drifted into new latitudes, their climates changed, so that lands once polar became tropical and lands once tropical grew cold.
3) **Altered ocean currents:** the opening and closing of oceans rerouted the great ocean currents, which in turn cooled or warmed the coasts they passed.
4) **The evolution of new species:** once-joined populations were carried apart and evolved separately, which is why related but distinct animals, such as the ostrich of Africa and the rhea of South America, live on continents now far apart.

Question 12

Despite its evidence, Wegener's theory was rejected for nearly fifty years. Account for the main criticisms levelled against continental drift.

Model Answer

Continental drift was rejected mainly because Wegener could not supply a convincing force to move the continents. His proposed engines, the centrifugal, pole-fleeing and tidal forces, were shown to be far too weak to shift anything as vast as a continent. The physicist Harold Jeffreys calculated that a tidal force strong enough to drive the continents would also be strong enough to stop the Earth from spinning within a year, which plainly does not happen. Critics added that the idea of a solid continent ploughing through solid ocean floor was physically impossible, and that the coastline fit was imperfect at the shore. Lacking a workable mechanism, the theory was set aside until seafloor spreading later supplied one.

False Confidence Alert
The theory was not rejected because its evidence was poor, for the evidence was strong. It was rejected because Wegener had no force that could actually move the continents.

Question 13

With the aid of a labelled cross-section, explain how seafloor spreading makes new crust at the mid-ocean ridge and destroys old crust at the trench.

Model Answer

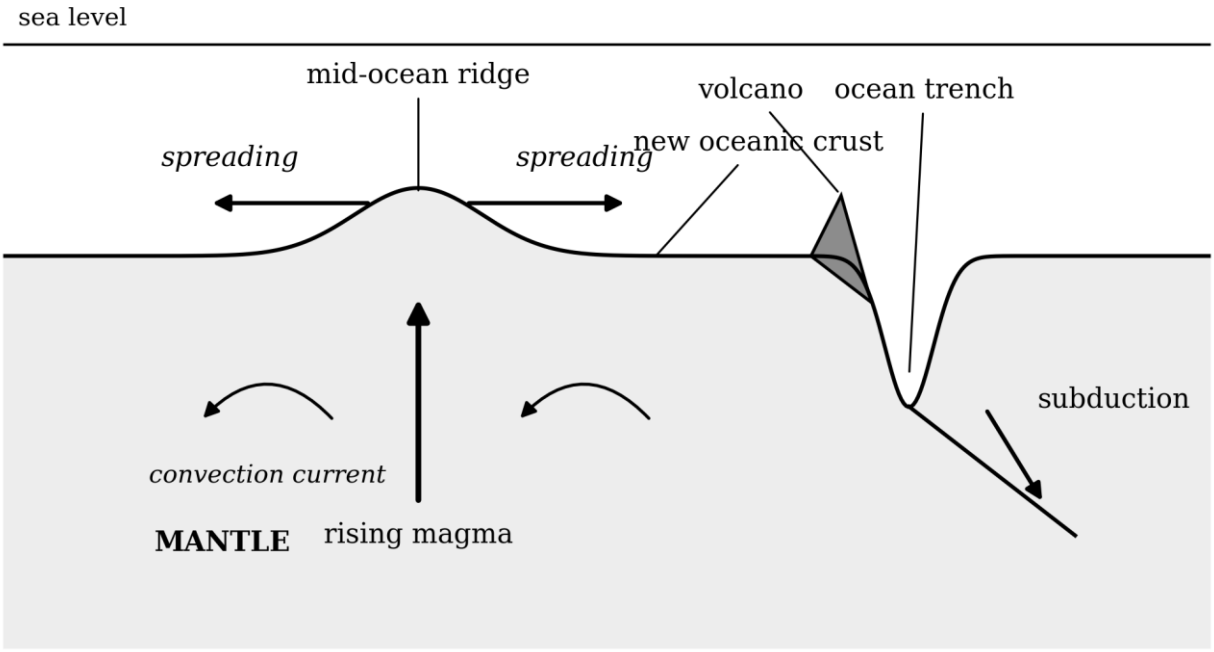


Figure 1.6: *Seafloor spreading: crust made at the ridge, destroyed at the trench*

Seafloor spreading is the theory that new oceanic crust forms at the mid-ocean ridges and spreads outward, widening the ocean and carrying the continents with it. Hess proposed that hot material from the mantle, driven by convection currents, rises along the mid-ocean ridge and cools to form new ocean floor. As fresh material keeps rising, it pushes the older floor away on both sides of the ridge, so the seafloor spreads outward at about one to ten centimetres a year. The Atlantic, for example, widens at roughly this rate, carrying the Americas away from Europe and Africa. In this way the ocean basin grows and the continents are moved passively, riding on the spreading floor.

How to Draw It
Label the ridge with rising magma and outward-spreading arrows, the new crust, and the trench with the slab sinking. The arrows showing the direction of movement carry the marks.

False Confidence Alert
Seafloor spreading does not mean the continents themselves push through the ocean floor. The floor itself grows and moves, and the continents are carried along on top of it.

Question 14

The clearest sign of seafloor spreading lies in the great ridges that run along the ocean floors. Explain how the mid-ocean ridges and the rift along their crest support the theory.

Model Answer

The mid-ocean ridges and the rift at their crest support spreading because they mark the very place where new ocean floor is being born. A mid-ocean ridge is a long mountain chain on the ocean floor, raised where hot mantle material wells up. Running along the crest of the ridge is a deep central rift, a steep-sided valley formed as the floor is pulled apart and molten rock rises into the gap. The fresh lava cools to make new crust exactly here, at the ridge axis. The presence of these ridges and their central rifts, found in every ocean, is direct evidence that the floor is splitting and spreading from the ridge outward.

Question 15

If the ocean floor spreads from the ridge, its rocks should not all be the same age. Explain how the ages of the oceanic rocks prove seafloor spreading.

Model Answer

The ages of the oceanic rocks prove spreading because they are youngest at the ridge and grow steadily older with distance away from it. Rocks sampled from the ocean floor show a clear pattern: those at the ridge crest are the newest, having only just formed, while those further from the ridge are progressively older. This is exactly what spreading predicts, since the floor at the ridge has just been made and is then carried outward over millions of years. The oldest ocean-floor rocks are also far younger than the oldest continental rocks, showing that the floor is constantly renewed. This orderly increase in age away from the ridge could not arise unless the floor were spreading.

Question 16

If new ocean floor is made at the ridges all the time, the Earth does not grow larger. Explain how the ocean trenches keep the size of the Earth constant.

Model Answer

The Earth stays the same size because the old ocean floor is destroyed in the deep trenches as fast as new floor is made at the ridges. As the spreading floor moves away from the ridge it cools, grows denser, and at last reaches a deep ocean trench. There it bends downward and sinks back into the mantle in a process called subduction. The descending crust melts and is absorbed into the mantle, from which it may one day rise again as new material. Because crust is consumed at the trenches at the same rate as it is created at the ridges, the total amount of crust, and so the size of the Earth, stays unchanged.

Question 17

As new ocean floor cools it records the direction of the Earth's magnetism, and that field has reversed many times. Explain how the magnetic stripes on the ocean floor support seafloor spreading.

Model Answer

The magnetic stripes support spreading because they record the Earth's reversing magnetism in matching bands on either side of the ridge, like a tape rolling out from the centre. When new crust forms at the ridge and cools, the iron minerals in it line up with the Earth's magnetic field of that moment

and are locked in. From time to time the field reverses, north becoming south, so crust forming at different times carries opposite magnetism. As the floor spreads, it preserves these periods as a series of magnetic stripes running parallel to the ridge. Crucially, the pattern of stripes on one side of the ridge mirrors the pattern on the other, which can only happen if the floor is spreading symmetrically away from the ridge in both directions.

False Confidence Alert
The stripes are not bands of different rock or colour. They are bands of opposite magnetism, frozen into the crust as the Earth's magnetic field reversed over time.

Question 18

Plate tectonics rests on the idea that the Earth's hard shell floats on a soft layer beneath. Explain how the structure of the lithosphere and the asthenosphere makes the movement of plates possible.

Model Answer

Plate movement is possible because the rigid lithosphere is broken into plates that ride on the hot, partly molten and mobile asthenosphere beneath. The lithosphere is the Earth's outer shell, made of the crust and the rigid upper part of the mantle, and it is cracked into a number of large slabs called plates. Beneath it lies the asthenosphere, a hotter layer of the mantle that behaves like a very stiff fluid and can slowly flow. Because the plates sit on this mobile layer rather than on solid rock, they can be carried along by the slow currents within it. Without a yielding asthenosphere beneath a broken lithosphere, the plates could not move at all.

Question 19

Not all plates are alike: some carry continents and some carry ocean floor. Explain how continental plates differ from oceanic plates, and what marks the boundary between crust and mantle.

Model Answer

Continental plates are thick, light and old, while oceanic plates are thinner, denser and young, and both are separated from the mantle below by the Moho discontinuity. A continental plate is built of granitic SIAL, rich in silica and aluminium, with a low density of about 2.7, and its rocks may be over a thousand million years old. An oceanic plate is built of basaltic SIMA, rich in silica and magnesium, is denser, and is far younger because it is constantly renewed at the ridges. The base of the crust, where it meets the denser mantle, is marked by a sharp change in density called the Moho, or Mohorovicic discontinuity. This difference in density between the two kinds of plate is what decides which one sinks when they meet.

False Confidence Alert
Oceanic crust is not lighter because it is thinner. It is in fact denser than continental crust, which is exactly why it sinks beneath the lighter continental crust when the two collide.

Question 20

Like any theory, plate tectonics is built on a set of starting assumptions. Explain the main assumptions on which the plate tectonic theory rests.

Model Answer

Plate tectonics assumes that the lithosphere is broken into rigid plates which float on a mobile asthenosphere and are kept in motion by currents within the mantle. First, it assumes the Earth's outer shell is not continuous but divided into a number of rigid plates. Second, it assumes these plates rest on the partly molten asthenosphere, which can flow and so allow them to move. Third, it assumes the plates are driven by convection currents in the mantle, set up by heat from radioactive decay deep within the Earth. Finally, it assumes that almost all the Earth's major activity, the earthquakes, the volcanoes and the building

of mountains, happens at the margins where these moving plates meet. Together these assumptions let the theory explain how landforms are made.

Question 21

The Earth's shell is divided into a small number of large plates and several smaller ones. Explain how these plates are arranged and how convection currents in the mantle set them moving.

Model Answer

The lithosphere is divided into about seven major plates and several minor ones, which are kept moving by convection currents rising and sinking in the mantle beneath. The major plates include the African, Eurasian, North American, South American, Pacific, Antarctic and Indo-Australian plates, with smaller plates such as the Arabian and Nazca filling the gaps. Deep in the mantle, heat from radioactive decay warms the rock, which rises towards the surface, spreads sideways beneath the lithosphere, then cools and sinks again, forming a convection current. As the current spreads sideways it drags the plate resting above it along with it, like a sheet carried on a slowly boiling liquid. In this way the convection currents are the chief engine of plate movement.

Question 22

Convection is not the only force said to move a plate; the plate's own edges help to drive it. Explain how ridge push and slab pull contribute to the movement of a plate.

Model Answer

Ridge push and slab pull move a plate from its two edges: new crust pushes the plate away from the ridge, while the old, cold edge sinking at a trench pulls the rest behind it. At a mid-ocean ridge, hot new crust is raised slightly higher than the older floor, and as it cools and slides down this gentle slope it pushes the plate ahead of it; this is ridge push. At the far edge, the old oceanic crust has grown cold and dense, and as it sinks into the mantle at a trench it drags the rest of the plate down behind it like a tablecloth slipping off a table; this is slab pull. Working with the mantle convection beneath, these two edge forces help to keep the plate moving steadily.

Question 23

With the help of a labelled cross-section, explain how the stretching and faulting of the crust forms a rift valley, naming a Tanzanian example.

Model Answer

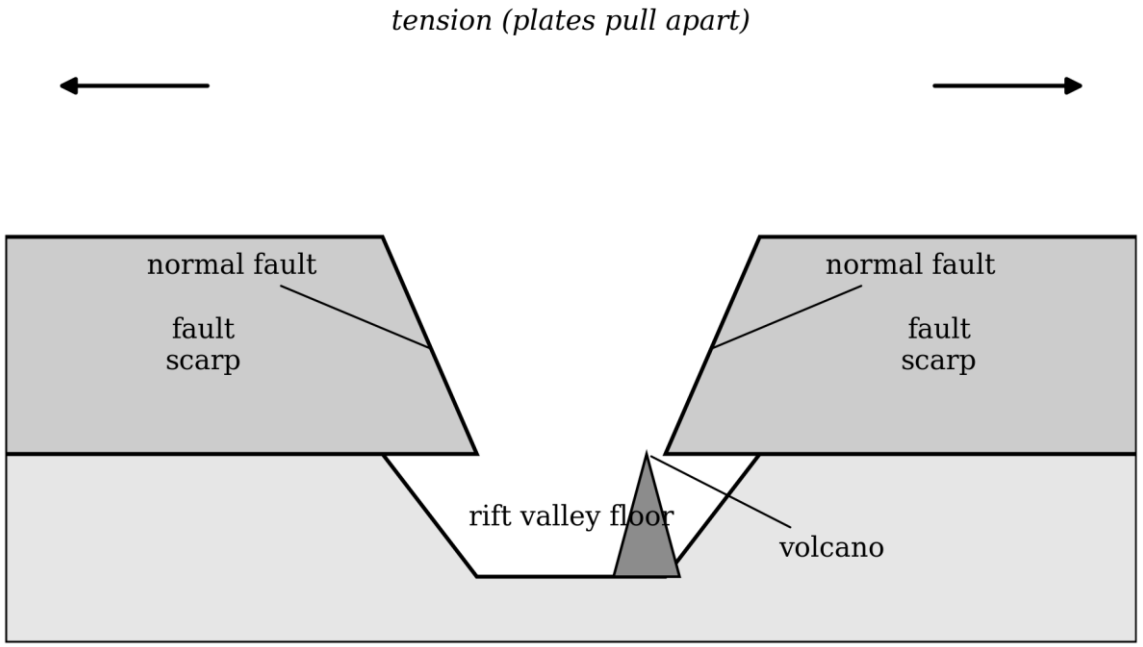


Figure 1.4: *Cross-section of a rift valley (the East African Rift)*

A rift valley forms where two plates pull apart beneath a continent, stretching the crust until a central block subsides between two parallel faults. As the plates move apart, the continental crust above is stretched and put under tension. The stretching cracks the crust along two roughly parallel faults, and the block of land between them, no longer supported, drops down to form a steep-sided trough called a rift valley. Molten rock often rises along the faults, building volcanoes on the valley floor and shoulders. The Great East African Rift Valley, running the length of Tanzania, is the classic example, formed as the African plate is slowly splitting apart.

How to Draw It
Draw two outward tension arrows, two normal faults, and the central block dropped between them. The mark is for the faults and the dropped block, not for a smooth, rounded valley.

False Confidence Alert
A rift valley is not cut out by a river or by erosion. It forms where the crust is stretched and a central block drops down between faults as the plates pull apart.

Question 24

Where plates pull apart beneath the sea, the result is not a valley but a mountain chain. Explain how a divergent boundary on the ocean floor builds a mid-ocean ridge.

Model Answer

A mid-ocean ridge forms where two oceanic plates pull apart and molten mantle rises into the gap, cooling to build a chain of new crust along the boundary. As the two oceanic plates move apart, the pressure on the mantle beneath is released and hot material wells up into the opening. This molten rock erupts along the boundary and cools to form new ocean floor, piled into a long submarine mountain range, the mid-ocean ridge. Because eruption goes on continually, the ridge is a zone of active vulcanicity and

shallow earthquakes, and it may build volcanic islands where it rises above the sea, as Iceland does on the Mid-Atlantic Ridge.

Question 25

With the help of labelled diagrams, explain what happens at each of the three types of plate boundary, the divergent, the convergent and the transform.

Model Answer

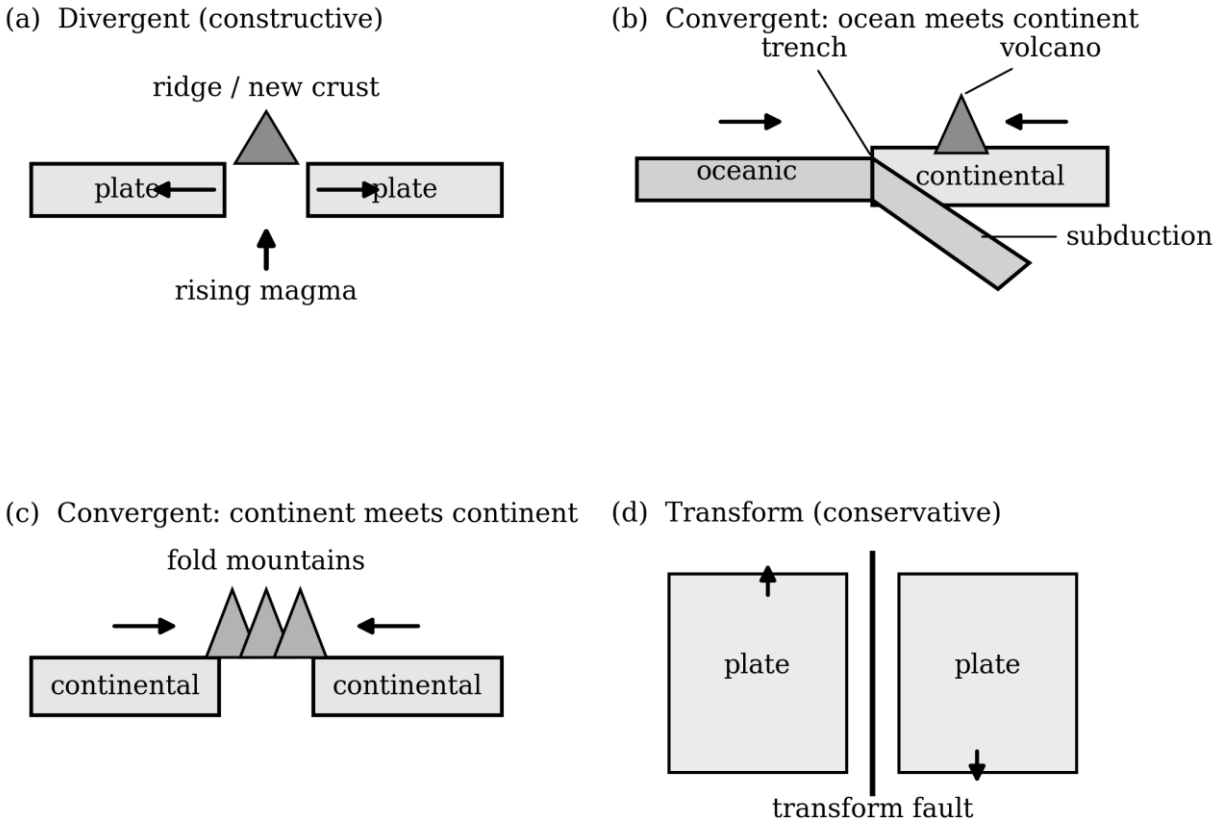


Figure 1.9: *The three types of plate boundary*

The three types of plate boundary, drawn above, each build their own landforms:

Divergent boundary: the plates pull apart and magma rises into the gap, building a mid-ocean ridge under the sea or a rift valley with volcanoes on land.

Convergent boundary: the plates push together, and the denser plate subducts to give an ocean trench and volcanoes, or, where two continents meet, fold mountains are pushed up.

Transform boundary: the plates slide past one another along a fault, making and destroying no crust, but locking and slipping to cause powerful earthquakes.

How to Draw It
For each boundary draw arrows showing the plate movement and label the landform it makes. The commonest error is to draw volcanoes at a transform boundary, which makes none.

Question 26

When two plates each carrying a continent collide, neither can sink, so the land has nowhere to go but up. Explain how the collision of two continental plates forms fold mountains.

Model Answer

Fold mountains form where two continental plates collide and, neither being dense enough to sink, the rocks caught between them are crumpled upward into great folds. As the two continental plates move together, the thick layers of sediment that had gathered in the sea between them are caught in the closing gap and squeezed. Because both plates are light, neither can subduct, so the compressed rocks have nowhere to go but upward and sideways, buckling into a series of folds. Over millions of years these folds are pushed higher and higher to form fold mountains. The Himalaya, still rising as the Indo-Australian plate drives into the Eurasian plate, are the greatest living example, and the Atlas of north-west Africa formed in the same way.

Question 27

Two plates carrying ocean floor can also collide, and where they do a curved chain of volcanic islands rises from the sea. Explain how the convergence of two oceanic plates forms a volcanic island arc.

Model Answer

A volcanic island arc forms where two oceanic plates converge, the denser one subducting beneath the other and feeding a curved line of volcanoes that grow into islands. When two oceanic plates meet, the older and denser of the two bends down and is subducted beneath the other, opening a deep trench along the line of contact. The descending plate melts in the mantle, and the molten rock rises through the overriding plate to erupt on the sea floor. Eruption after eruption builds the volcanoes upward until they break the surface as a curved chain of islands, an island arc. Japan and the islands of the West Indies are well-known arcs formed in this way.

Question 28

At some boundaries the plates neither pull apart nor collide but slide past one another, and yet these are among the most dangerous of all. Explain how a transform boundary works and why it produces severe earthquakes.

Model Answer

At a transform boundary two plates slide horizontally past one another along a great fault, making no new crust and destroying none, but locking and slipping to release violent earthquakes. Here the two plates move in opposite directions, or in the same direction at different speeds, grinding past each other along a transform fault. Because they only slide sideways, no crust is created and none is destroyed, so there are no volcanoes. The rough edges of the plates, however, snag and lock together, and the strain builds until they suddenly jerk free, releasing the stored energy as a powerful, shallow earthquake. The San Andreas Fault in California, where the Pacific and North American plates slide past each other, is the classic example.

False Confidence Alert
A transform boundary does not build volcanoes, because no crust is made or melted. Its hazard is the earthquake, caused by the plates locking and then suddenly slipping past each other.

Question 29

If you mark the world's earthquakes and volcanoes on a map, they do not scatter evenly but trace out lines. Explain why earthquakes and volcanoes are concentrated along the plate boundaries.

Model Answer

Earthquakes and volcanoes cluster along the plate boundaries because it is there, and almost only there, that the plates grind, split or dive and so disturb the crust. In the stable heart of a plate the crust

is quiet, but at the margins the plates are constantly moving against one another. Where they slide or collide, the rocks lock and then snap, sending out the shock waves of an earthquake; where they pull apart, or one dives beneath another, molten rock reaches the surface to feed volcanoes. This is why the great belts of earthquakes and volcanoes, such as the Pacific Ring of Fire, follow the plate edges so faithfully. The pattern itself is strong evidence that the plates are real and moving.

Question 30

Why do the light continents stand high above the sea while the heavy ocean floors lie low? The answer is a quiet balance called isostasy. Explain what isostasy means and how it keeps the crust in balance.

Model Answer

Isostasy is the state of balance in which the lighter crust floats in equilibrium on the denser mantle beneath, so that lighter blocks stand high and denser blocks lie low. The crust does not rest on a solid base but floats on the denser, yielding mantle, much as a raft floats on water. Continental crust, with a density of about 2.7, is lighter than the mantle beneath, of about 3.3, so it floats high, while the denser oceanic crust rides lower. Each block sinks into the mantle until the weight pushing down is balanced by the support pushing up, and there it comes to rest. This gravitational balance between the floating crust and the mantle is what is meant by isostasy.

Question 31

A high mountain is matched, out of sight, by a deep root pushing down into the mantle. Explain the relationship between the height of a mountain and the depth of its root under isostasy.

Model Answer

Under isostasy the higher a mountain stands, the deeper its root reaches into the mantle, because a taller block must sink further to stay in balance. Since the crust floats on the mantle, a thick block of crust behaves like a large iceberg: the more of it that rises above the surface, the more must lie hidden below. A high mountain range is therefore underlain by a deep root of light crust pushing down into the denser mantle, and this buried root gives the buoyancy that holds the mountain up. The taller the mountain, the deeper the root needed to support it. This is why mountains do not simply sink under their own weight, and why they can keep their height for long ages.

Question 32

With the aid of a labelled diagram of a floating iceberg and of a mountain with its root, explain how isostasy keeps the crust floating in balance on the denser mantle.

Model Answer

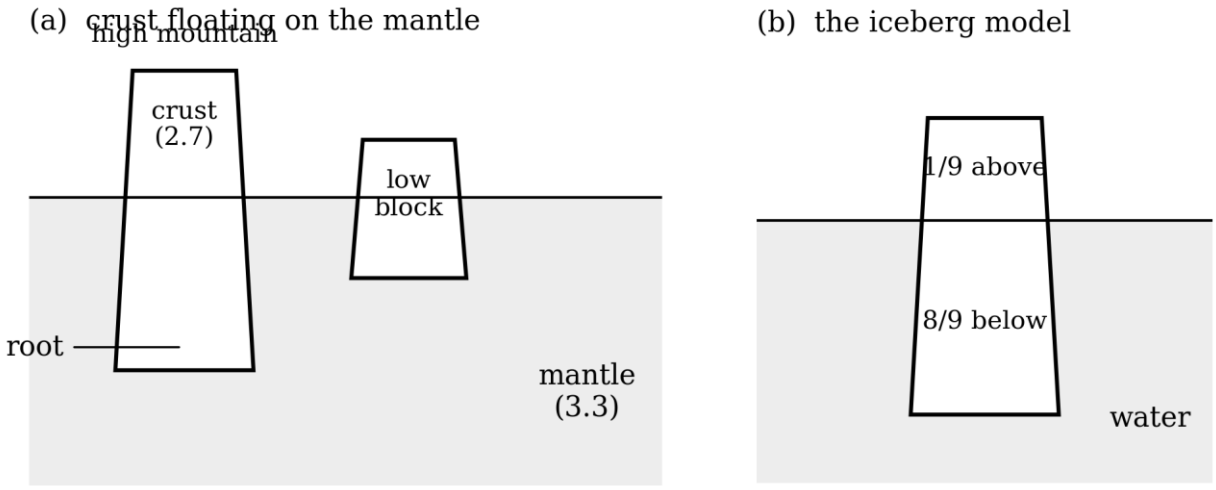


Figure 1.14: ***Isostasy:*** *the crust floats on the mantle like an iceberg on water*

The floating iceberg illustrates isostasy because, like a block of crust, most of its bulk lies hidden below the surface, supporting the part that shows above. An iceberg floats because ice is lighter than water, and it sinks into the water until the weight of water it pushes aside equals its own weight; about nine-tenths of it then lies below the surface and only one-tenth shows. In the same way the light crust floats on the denser mantle, sinking until it is balanced, with a deep root hidden below for the part that rises above. A taller iceberg, like a higher mountain, has a deeper submerged portion. The iceberg thus models both the floating balance and the hidden root of isostasy.

How to Draw It
Show most of the iceberg below the waterline, and the mountain with a deep root reaching into the mantle. Marks for the large hidden portion, the root, and the labels crust and mantle.

Question 33

When weight is piled onto the crust or stripped from it, the crust slowly answers by sinking or rising. Explain how vertical isostatic movement restores the balance of the crust.

Model Answer

Vertical isostatic movement restores balance by letting the crust sink when a load is added and rise again when that load is removed. If a great weight is placed on the crust, such as a thick sheet of ice, a pile of sediment or an outpouring of lava, the loaded block presses down and slowly sinks deeper into the mantle until a new balance is reached. If instead weight is taken away, by the melting of ice or the wearing down of mountains by erosion, the lightened block is no longer held so deep and slowly rises to restore the balance. These slow up-and-down adjustments, taking thousands of years, are vertical isostatic movements. The steady rise of Scandinavia since its ice melted is a living example.

Question 34

Isostatic adjustment is not only up and down; material can also flow sideways deep below. Explain how horizontal isostatic movement helps to keep the crust in balance.

Model Answer

Horizontal isostatic movement keeps the crust in balance by letting heated mantle material flow sideways, from beneath areas that are sinking towards areas that are rising. Heat from radioactive decay in the asthenosphere softens the dense mantle material and lets it flow. Where the crust is pushed down under a heavy load, the mantle beneath is squeezed and flows sideways to regions where the crust is rising or lightly loaded. This sideways transfer of material at depth supports the uplift of one area at the expense of the subsidence of another, so the two adjust together. Such horizontal movement can cause broad warping and tilting of the crust over wide areas.

Question 35

Along some coasts, old beaches now stand stranded high above the reach of the waves. Explain how raised beaches provide evidence of isostatic movement.

Model Answer

Raised beaches are evidence of isostasy because they show coastal land that has risen out of the sea as its old ice load melted away. A raised beach is a former shoreline, with its wave-cut platform and beach deposits, now lying well above the present sea level. During the last ice age these coasts were pressed down by the great weight of ice resting on the land. When the ice melted the load was removed, and the lightened crust slowly rose in isostatic rebound, lifting the old beaches clear of the sea. Such raised beaches are common in Scandinavia and around Hudson Bay, lands that are still rising today, and they record the crust restoring its balance.

Question 36

Just as unloading lifts the crust, loading pushes it down, leaving great hollows in the surface. Explain how the depression of the crust and the deep continental shelf of Antarctica give evidence of isostasy.

Model Answer

Crustal depressions and the unusually deep continental shelf of Antarctica are evidence of isostasy because they show the crust sinking under a heavy load of ice. Where a thick ice sheet rests on the land, its enormous weight presses the crust down into the mantle, creating a broad depression beneath the ice. Antarctica shows this clearly: its continental shelf has been pushed down to around seven hundred and fifty metres below sea level, far deeper than the usual shelf of about two hundred metres, because the great ice cap has loaded and depressed the whole continent. Greenland, also buried under ice, is depressed in the same way. These hollows, made by loading, are the mirror image of the uplift seen where ice has melted, and both show the crust seeking balance.

Question 37

The idea of isostasy is more than a curiosity; it helps the geographer make sense of the whole crust. Explain the significance of the isostasy theory in understanding the Earth's surface.

Model Answer

Isostasy is significant because it explains why the crust stands at the heights it does, how mountains keep their height, and how the surface constantly adjusts towards balance. First, it explains the basic shape of the Earth's surface, why the light continents stand high and the dense ocean floors lie low. Second, it explains how a mountain such as Kilimanjaro can keep its height for thousands of years despite endless erosion, because its root pushes it up almost as fast as the summit is worn down. Third, it accounts for the slow rising and sinking of land, the raised beaches and the depressed ice-loaded shields. By linking the floating crust to the mantle beneath, it also connects to continental drift and plate tectonics, since all three depend on a crust that can move over a yielding interior.

REAL QUESTIONS

Question 38

A Form Six class in Dodoma is asked to defend continental drift using only evidence from their own continent. Using examples drawn from Africa, support the theory of continental drift.

Model Answer

Africa offers several powerful lines of evidence for continental drift:

The jig-saw fit: the bulge of West Africa fits neatly into the hollow of the South American coast, showing the two were once joined.

Matching rocks: the Karroo system of South Africa continues as the Santa Catarina system of Brazil, the same rocks now split by the Atlantic.

Shared fossils: Mesosaurus is found in both West Africa and Brazil, and the Glossopteris flora across Africa, India and Antarctica, lands once united as Gondwanaland.

Ancient glaciation: glacial scratches and deposits in the now-warm Congo basin show that Africa has drifted north out of colder southern latitudes.

Active splitting: the Great East African Rift and the widening Red Sea show the African plate tearing apart even today.

False Confidence Alert
Do not simply describe the shapes of the continents. Each African example must be linked to the conclusion that the lands were once joined or are still moving.

Question 39

Geographers say that in East Africa and along the Red Sea, continental drift can be watched happening today. Explain how the Great East African Rift Valley and the widening Red Sea show drift in action, naming the plates involved.

Model Answer

The East African Rift and the Red Sea show drift in action because both mark lines where the African plate is splitting and the pieces are pulling apart. Beneath East Africa the African plate is being torn into two smaller plates, the Nubian plate to the west and the Somali plate to the east. As they pull apart, the crust between them has cracked and dropped to form the Great East African Rift Valley, with its volcanoes and lakes. Further north the same splitting separates the African plate from the Arabian plate, opening the Red Sea, which has already widened into a narrow sea and is still growing by a few centimetres a year. Both are young divergent boundaries, drift caught in its earliest stages.

False Confidence Alert
The Red Sea is not an old, permanent sea. It is a young and widening ocean basin, opening as Africa and Arabia drift apart.

Question 40

The floor of the Red Sea has a central ridge and grows wider each year, just like the great oceans. Explain how the Red Sea shows seafloor spreading in its early stages.

Model Answer

The Red Sea shows early seafloor spreading because new ocean floor is being made along a central ridge as Africa and Arabia pull apart. As the African and Arabian plates diverge, molten material rises into the gap along a central rift in the Red Sea floor and cools to form new oceanic crust, exactly as at a mid-ocean ridge. The sea floor is therefore youngest along this central line, and the sea grows wider year by year. Given enough time the Red Sea will widen into a full ocean, just as the Atlantic once began as a narrow rift between the Americas and Africa. It is a living, early example of the process Hess described.

Question 41

Plates move no faster than a fingernail grows, about one to ten centimetres a year, yet they have reshaped whole continents. Explain how such slow movement has been able to reshape the African continent over time.

Model Answer

Slow plate movement reshapes Africa because, although tiny each year, it acts over many millions of years, and small annual movements add up to enormous change. A few centimetres a year seems like nothing, but over a million years that is tens of kilometres, and over the hundreds of millions of years of Earth history it is enough to split a super-continent and open an ocean. In this slow way Africa has drifted north from near the South Pole, broken away from South America to open the Atlantic, and is now splitting along the East African Rift. The slowness is hidden because a human lifetime sees almost none of it, but the rocks record the vast distances travelled. It is time, not speed, that makes plate movement so powerful.

Question 42

During a debate, one student argues that the Great East African Rift Valley was carved out by a huge ancient river, while another argues that it formed where the African plate is splitting apart. Decide which student is correct, and justify your answer.

Model Answer

The second student is correct: the Great East African Rift Valley formed where the African plate is splitting apart, not by river erosion. A river cuts a narrow V-shaped valley by wearing the land down, but the rift is a wide, flat-floored trough with steep, straight, parallel walls, which is the shape made by

faulting, not by erosion. It formed where the crust was stretched as the Nubian and Somali plates began to pull apart, cracking along two parallel faults so that the central block dropped to make the valley floor. The volcanoes along it, such as Ol Doinyo Lengai, and the deep faulted lakes, such as Tanganyika, are signs of plate divergence that a mere river could never produce. The first student has confused a tectonic landform with a river valley.

False Confidence Alert
A rift valley is not a river valley widened over time. Its straight, steep, parallel sides are made by faulting as the plates pull apart, not by a river wearing down the land.

Question 43

Not all of Africa's mountains were made by splitting; some were made by collision. Explain how the Atlas mountains of north-west Africa record the convergence of plates.

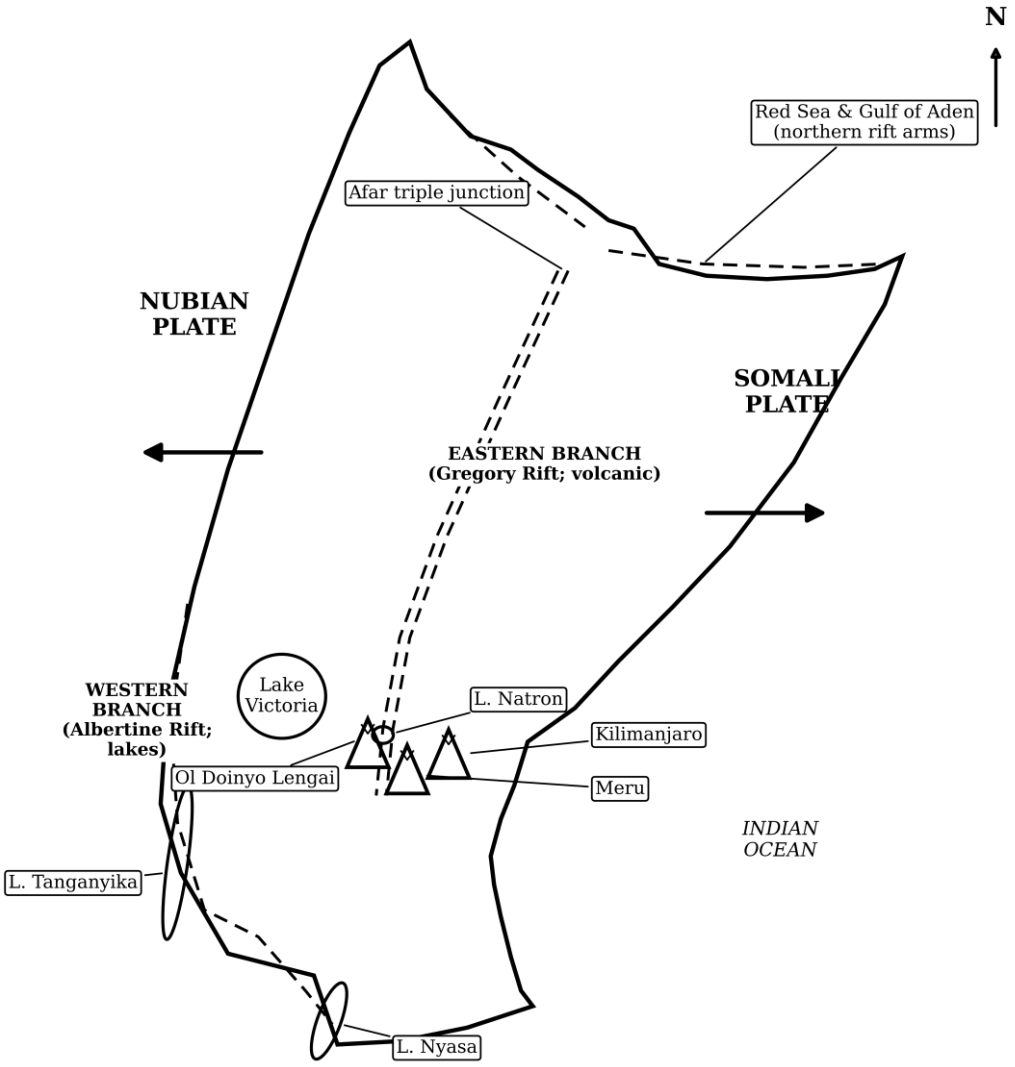
Model Answer

The Atlas mountains record convergence because they were folded upward where the African plate pushed north against the Eurasian plate. As the African plate has drifted slowly northward, its northern edge has collided with the Eurasian plate along the Mediterranean. The layers of rock caught between the two plates were squeezed and, because neither plate could easily sink, were crumpled and pushed upward into the folds of the Atlas mountains. They belong to the same great belt of fold mountains as the Alps of Europe, raised by the same collision. The Atlas thus shows that, while East Africa is being torn apart by divergence, the north of the continent has been built up by convergence.

Question 44

With the help of a sketch map, explain how the East African Rift System, with its two branches, its lakes and its volcanoes, records the splitting of the African plate.

Model Answer



(schematic sketch map of the East African Rift System, not to scale)

Figure 1.5: *The East African Rift System*

The East African Rift System records the splitting of the African plate as a great divergent boundary, marked by two branches of faulted valleys studded with lakes and volcanoes. As the Nubian and Somali plates pull apart, the crust has cracked into two arms: an eastern branch, running through Kenya and northern Tanzania, and a western branch, curving along the region's great lakes. Along the deep faults, blocks have dropped to hold long, deep lakes such as Tanganyika and Nyasa, while molten rock has risen to build volcanoes such as Kilimanjaro, Meru and the active Ol Doinyo Lengai. Together the twin valleys, the faulted lakes and the line of volcanoes are the surface signs of a continent slowly tearing in two.

How to Draw It
Show the two branches, place the main lakes (Victoria between the branches, Tanganyika and Nyasa on the west) and the chief volcanoes, and arrow the Nubian and Somali plates apart. Marks for correctly placed and named features.

Question 45

A group of Form Six students plans a field visit to the rift area of northern Tanzania, around Lake Natron and Ol Doinyo Lengai. Predict four landforms they are likely to see there, and explain how each was formed.

Model Answer

In the rift of northern Tanzania the students should expect the landforms of an active divergent boundary:

1) **Steep fault scarps:** the high, straight walls of the rift, formed where the crust cracked along faults and the central block dropped.
2) **A volcanic cone:** Ol Doinyo Lengai, built where molten rock has risen along the rift faults to the surface.
3) **A rift-floor lake:** shallow, salty Lake Natron, lying in a basin on the dropped floor of the rift.
4) **Hot springs and fresh lava:** signs of the heat and molten rock close beneath the thinning, splitting crust.

False Confidence Alert
Do not merely name the features. Each must be explained by the splitting of the plates, the faulting and the rising magma, not simply listed.

Question 46

Mount Kilimanjaro has stood at almost five thousand nine hundred metres for thousands of years, even though wind, rain and ice wear at it every day. As a geographer, explain how isostasy allows the mountain to keep its height.

Model Answer

Kilimanjaro keeps its height because isostasy lifts it from below almost as fast as denudation wears it down from above. The mountain floats, like all crust, on the denser mantle, and beneath it lies a deep root of light rock that holds it up. As erosion strips material from the summit, the mountain grows lighter, and the lightened block slowly rises in isostatic compensation, its root pushing it up to restore the balance. So the height lost at the top is made good by uplift from below, and the mountain stays high age after age. Only when the root is at last used up would the mountain finally be worn down.

False Confidence Alert
Do not say the mountain simply resists erosion or is made of very hard rock. It keeps its height because it is slowly pushed up from below as its summit is worn away.

Question 47

Rivers pour sediment into Lake Tanganyika and into the Indian Ocean year after year, yet they do not silt up and vanish. Explain how isostasy accounts for the survival of such deep water bodies despite the sediment poured into them.

Model Answer

Deep water bodies survive because, as sediment loads their floors, isostasy lets those floors sink, keeping the basins deep instead of filling them up. Each load of sediment adds weight to the floor of the lake or sea. Because the crust floats on the mantle, this added weight presses the floor down in vertical isostatic adjustment, so the basin deepens even as it is filled. In Lake Tanganyika, one of the deepest lakes on Earth, the steep faulted floor keeps sinking under its sediment, and the same happens beneath the Indian Ocean off the Tanzanian coast. The sinking floor makes room for the sediment, so the water body stays deep over very long periods instead of silting up.

Question 48

When a cargo ship is loaded at the port of Dar es Salaam it settles lower in the water, and rises again when it is unloaded. Use this everyday observation to explain how the crust responds to the adding and removing of weight.

Model Answer

The loaded ship sinking and the unloaded ship rising model how the crust sinks under added weight and rises when weight is removed, because both float in balance. A ship floats by sinking into the water until the weight it pushes aside equals its own weight; load it with cargo and it must sit lower to push aside more water, while unloading lets it rise. The crust floats on the mantle in just the same way. When weight is added, such as a thick ice sheet, a pile of sediment or a sheet of lava, the crust sinks lower into the mantle; when that weight is removed by melting or erosion, the crust rises again. The harbour ship is thus a simple, everyday picture of vertical isostatic adjustment.

HOT QUESTIONS

Question 49

The ostrich of Africa and the rhea of South America are flightless birds, alike yet living on continents now separated by a wide ocean. Reason how the drifting apart of the continents could have driven the evolution of such separate but related species.

Model Answer

Related species came to live on separated continents because drift split a single ancestral population, after which each isolated group evolved on its own. When the southern continents were joined as Gondwanaland, a single population of early flightless birds could spread across the whole landmass. As the continents drifted apart, that population was torn into separate groups, each marooned on its own continent and cut off from the others by ocean. With no interbreeding between them, each group evolved independently, shaped by its own surroundings, until they became distinct species: the ostrich in Africa, the rhea in South America, the emu in Australia. Their underlying likeness records their common ancestor on Gondwanaland, while their differences record millions of years of separate evolution. By isolating populations, drift is thus a powerful driver of the formation of new species.

Question 50

When Wegener died his theory was widely dismissed, yet today continental drift is regarded as one of the great ideas in geography. Evaluate the claim that continental drift was a failed theory.

Model Answer

Continental drift was not a failed theory but an incomplete one: its evidence was sound, and only its missing mechanism delayed its acceptance. It is true that the theory was rejected for nearly fifty years, because Wegener could not name a force strong enough to move the continents, and his proposed forces were shown to be far too weak. In that narrow sense it appeared to fail. Yet the evidence he gathered, the fit of the coasts, the matching rocks and fossils, the glaciation and the rest, was strong and has never been overturned. The theory failed only for want of an engine, and once seafloor spreading and then plate tectonics supplied that engine, the whole idea was vindicated and built upon. A theory whose evidence endures and whose central claim proves correct cannot fairly be called a failure; it was simply ahead of the evidence needed to explain it.

Question 51

'The continents are restless.' Assess this contention, drawing together the strongest evidence that the continents have moved and are moving still.

Model Answer

The contention is well founded: a wide range of evidence, past and present, shows that the continents have moved across the globe and are moving even now. The evidence of the past is powerful. The

continents fit together at their shelves; the same rocks, fossils and glacial scars are split across oceans; and old rocks carry a frozen magnetism pointing away from today's pole. The evidence of the present is just as telling. The ocean floors are spreading from their ridges at measurable rates, their rocks youngest at the ridge; magnetic stripes record the spreading symmetrically on both sides; and along the East African Rift and the Red Sea the African plate can be seen splitting today. Brought together, the testimony of the rocks, the oceans and the active rifts leaves little room for doubt. The continents are not fixed but restless, carried on plates that have never stopped moving.

Question 52

To what extent has continental drift, rather than any other process, shaped the physical map of Africa as we see it today?

Model Answer

Continental drift, working through plate movement, has shaped the broad framework of Africa's physical map, though surface processes have carved the detail. At the largest scale, drift has done most of the work. It set Africa's very outline by tearing it from South America to open the Atlantic; it raised the Atlas in the north by collision with Europe; and it is splitting the east of the continent along the Great Rift Valley, with its lakes such as Tanganyika and its volcanoes such as Kilimanjaro. These great features, the coast, the mountains, the rift and its lakes, are the direct work of moving plates. Yet drift sets the stage rather than finishing the scene. The plains, valleys and escarpments in detail are the work of weathering, rivers and erosion acting on the framework that drift provides. So drift explains the continent in outline to a very great extent, while the finer landscape is shaped by the everyday agents of denudation.

Question 53

Seafloor spreading is often praised for completing the case for moving continents, yet it too has a weakness. Evaluate the strengths and the weakness of the seafloor spreading theory, and show how it answered the question that had defeated continental drift.

Model Answer

The great strength of seafloor spreading is that it supplied the mechanism continental drift had lacked, though its weakness is that it does not by itself explain how the rigid continents move. Its strengths are considerable. It explained the major features of the ocean floor, the ridges, rifts and trenches; it was backed by hard evidence in the ages of the rocks and the symmetrical magnetic stripes; and, above all, it gave drift the engine it needed, for if the ocean floor itself grows and spreads, the continents can be carried along without ploughing through solid rock. This answered the very objection that had sunk Wegener's theory. Its weakness is that, on its own, it described the spreading of the ocean floor but not the full movement of the rigid continents, which is why it was soon absorbed into the larger theory of plate tectonics. On balance, its strengths far outweigh this limitation.

Question 54

Assess the claim that continental drift and seafloor spreading are two halves of one story rather than two separate theories.

Model Answer

The claim is sound: drift and spreading describe the same moving Earth, drift providing the evidence that continents move and spreading providing the mechanism that moves them. Continental drift came first and assembled the evidence, the fit of the coasts, the shared rocks and fossils, that the continents had once been joined and had since parted. What it could not give was a believable means of moving them. Seafloor spreading came later and supplied exactly that, showing that new ocean floor forms at the ridges and spreads outward, carrying the continents passively along. Neither is complete without the other: drift without spreading is evidence without a cause, and spreading without drift is a mechanism without its grand consequence. Joined together they form one coherent account, which plate tectonics then completed. They are best seen not as rivals but as two stages in the growth of a single idea.

Question 55

A new stretch of plate boundary is found where two plates are moving directly towards each other, one carrying ocean floor and one a continent. Predict the landforms and the hazards a geographer would expect to develop there, and justify each prediction.

Model Answer

At a converging ocean-continent boundary a geographer should predict a deep ocean trench, a chain of volcanoes and frequent earthquakes, all following from the subduction of the denser oceanic plate. Because the oceanic plate is denser, it will be forced down beneath the continental plate, so first a deep ocean trench should form along the line of contact, marking the subduction zone. As the descending plate sinks and melts, the molten rock will rise through the continent above, so a line of volcanoes should grow inland, parallel to the trench. The grinding of the two plates will lock and slip, so the area should suffer frequent and powerful earthquakes, and fold mountains may be pushed up along the continental edge. The hazards, then, are volcanic eruptions and earthquakes, and the landforms are the trench, the volcanic mountains and the fold belt, exactly as seen along the Andes and the Peru-Chile trench.

Question 56

"The plate tectonic theory is nothing more than the continental drift theory completed." Substantiate this contention, showing how the theories of continental drift, seafloor spreading and plate tectonics build, one upon another, into a single explanation of the moving Earth.

Model Answer

Plate tectonics is continental drift completed because it keeps Wegener's moving continents but adds the mechanism, drawn from seafloor spreading, that he could never supply. Continental drift began the story, with strong evidence that the continents had once been joined and had drifted apart, but it failed for want of a driving force. Seafloor spreading supplied half the answer, showing that new ocean floor forms at the ridges and spreads outward. Plate tectonics then drew everything together: it pictured the whole lithosphere as a set of rigid plates, carrying both continents and ocean floor, moved by convection currents and by ridge push and slab pull, and meeting at boundaries where land is built and destroyed. In this single framework Wegener's drifting continents become plates riding on a spreading, subducting floor. The theory keeps all that was right in drift and adds the engine it lacked, so it is fairly called drift completed.

Question 57

Relate the theory of plate tectonics to the formation of landforms in Africa, and evaluate how far the theory explains the continent's major features.

Model Answer

Plate tectonics explains most of Africa's major landforms, from the rift in the east to the Atlas in the north, though everyday erosion shapes the rest. Africa shows plate tectonics at work in several ways. In the east, the divergence of the Nubian and Somali plates has opened the Great Rift Valley, with its faulted lakes such as Tanganyika and its volcanoes such as Kilimanjaro and Ol Doinyo Lengai. In the north, the convergence of the African and Eurasian plates has folded up the Atlas mountains. The very shape of the continent, and its long stable coasts, record the drift that opened the Atlantic and the Indian Ocean. To this extent the theory explains the great framework of African relief very well. It is less needed for the detail: the plateaux, river valleys and plains are the work of weathering and erosion on that framework. Plate tectonics therefore explains the large features convincingly, while surface processes finish the picture.

Question 58

Assess which type of plate boundary has done the most to shape the landscape of Tanzania, and justify your choice.

Model Answer

The divergent boundary has done the most to shape Tanzania, since the splitting of the African plate has created the country's most striking relief. Tanzania lies astride the eastern arm of the Great Rift Valley, a classic divergent boundary where the Nubian and Somali plates are pulling apart. This divergence has given the country its most dramatic features: the long fault scarps of the rift, the deep faulted lakes such as Tanganyika and Nyasa, the soda lakes of the rift floor such as Natron, and the great volcanoes Kilimanjaro, Meru and the active Ol Doinyo Lengai. No convergent or transform boundary runs through the country to rival these. While weathering and rivers have since worked on the land, the framework of Tanzania's highland relief is overwhelmingly the work of plate divergence. The divergent boundary is therefore clearly the chief architect of the Tanzanian landscape.

Question 59

Some geographers say that East Africa is a new ocean in the making. Assess this claim in the light of what is happening along the East African Rift.

Model Answer

The claim is reasonable: East Africa shows the early stages by which an ocean is born, though the sea itself lies far in the future. An ocean begins when a continent is split by divergence, its crust thinning and dropping along faults until the sea floods in and new ocean floor begins to form, exactly the path the Red Sea has already taken. East Africa is at the first stage of this path. The African plate is splitting into the Nubian and Somali plates; the crust has cracked and dropped along the rift; volcanoes mark the thinning crust; and in places the floor has sunk below sea level. If the splitting continues for tens of millions of years, the rift could widen, flood and become a new ocean, separating the Somali plate from the rest of Africa. The claim is therefore well grounded in the present evidence, provided one remembers that the ocean is a prediction for the distant future, not a present fact.

Question 60

Predict what will happen to the crust beneath a great ice sheet as that ice slowly melts away, and explain the process that follows.

Model Answer

As the ice melts, the crust beneath it will slowly rise, in the process called isostatic rebound, because the great weight that pressed it down has been removed. While the ice sheet lay on the land, its enormous weight pressed the crust down into the mantle, holding it in a depressed position. As the ice melts, that load is steadily removed, and the crust is left out of balance, floating too low for its new lighter weight. To restore the balance, the lightened block slowly rises, the mantle flowing back beneath it to support the uplift. This rebound is slow, taking thousands of years, so that land may still be rising long after the ice has gone. Scandinavia and the shores of Hudson Bay, freed from their ice-age sheets, are rising in just this way today, lifting old beaches above the sea. The crust, in short, springs slowly back towards balance.

Question 61

Examine the interrelationship between erosion in the highlands and deposition in the lowlands in keeping the crust in isostatic balance.

Model Answer

Erosion and deposition work together as a single balancing system: erosion unloads the highlands so they rise, while deposition loads the lowlands so they sink, each helping to keep the crust in balance. The two processes are joined by the material that passes between them. In the highlands, rivers and

weathering strip rock from the mountains and carry it away; this unloading lightens the highland block, which rises by isostatic compensation, so the mountains keep their height. The very same material is carried down and dumped in the lowlands and the sea, where it loads the crust; this added weight presses the lowland floor down, which sinks to make room for more sediment. So the highlands are kept up by losing weight and the lowlands kept low by gaining it, the one feeding the other. Erosion and deposition are therefore not opposites but partners, endlessly shifting load across the crust to hold it in isostatic balance.

Question 62

'Isostasy theory has never been realistic.' Argue for or against this view.

Model Answer

The view is largely unfair: isostasy is a realistic and well-supported theory, even though it cannot explain everything about the crust. Much speaks for isostasy. It rests on the sound physical principle of floating balance, the same that governs an iceberg; it is supported by real evidence, from the post-glacial rebound of Scandinavia to the enduring height of Kilimanjaro and the depressed continental shelf of Antarctica; and it successfully predicts how the crust will rise or sink when load is added or removed. These are the marks of a realistic theory. Yet it has limits: it does not by itself explain undersea mountains or volcanic islands, where other forces are at work, and it treats the crust as floating freely when in truth the crust has some strength of its own. These are real shortcomings, but they limit the theory rather than discredit it. On balance, isostasy is a realistic theory with a few gaps, not an unrealistic one, and the contention should be rejected.

Question 63

Assess the contention that 'isostasy is isostatic adjustment', explaining the crust's endless search for balance.

Model Answer

The contention captures an important truth: isostasy is not a fixed state but a constant process of adjustment, as the crust forever moves to restore a balance that is forever being disturbed. Isostasy is often pictured as a settled balance, but in reality that balance is never left undisturbed. Erosion is always stripping weight from some areas, while deposition, ice and lava are always adding it to others, so the crust is continually thrown out of balance. Each time, it responds by adjusting, the unloaded areas rising and the loaded areas sinking, in the vertical and horizontal movements of isostatic adjustment. Because the disturbing forces never stop, the adjusting never ends; the crust is always on its way towards a balance it never quite reaches. In this sense isostasy is better understood as the ceaseless adjustment itself than as any final resting state. The contention is therefore sound: isostasy is best defined by the act of adjusting.

Chapter 2

EARTH SYSTEM

This chapter sets out how the Earth works as one connected system of four interacting spheres: the atmosphere, the hydrosphere, the biosphere and the geosphere, all powered by the Sun. Its sixty-eight questions run in three tiers, and are best worked in order.

BINDER questions build the core explanation of each process, from the radiation balance to the cycles of carbon and nitrogen, several with the help of a labelled diagram. REAL questions carry that understanding into real Tanzanian and African settings: the retreating snow on Kilimanjaro, the hydropower stations at Kidatu and Julius Nyerere, and the ocean carbon sink off the coast. HOT questions ask you to weigh the spheres and their cycles against one another, to judge a claim and to predict the consequences of disturbing the balance.

BINDER QUESTIONS

Question 1

A Form Five student revises the air, the oceans, living things and the rocks as four separate topics. Explain why the Earth is better treated as a single system than as a collection of such separate parts.

Model Answer

The Earth is treated as a system because its four spheres are interacting subsystems that constantly exchange energy and matter, not sealed compartments. Energy enters from the Sun and flows through every sphere, so it drives the winds, lifts water into the air and runs photosynthesis at the same time. Matter, by contrast, is not imported but cycled within the system, which is why the same carbon and nitrogen pass repeatedly between air, water, life and rock. Consequently a change forced on one part spreads to the rest: when farmers clear woodland on the slopes of Kilimanjaro, the disturbed biosphere releases carbon to the atmosphere while the bared soil washes into the rivers. It is therefore this constant two-way exchange, rather than the mere presence of four parts, that makes the Earth one working whole.

False Confidence Alert
Naming the four spheres is not the same as showing a system. A script that defines atmosphere, hydrosphere, biosphere and geosphere and then stops has described the parts, not the interactions, and the interactions are where the marks sit.

Question 2

At the shore of Lake Victoria, air, open water, living reeds and rock all meet at a single spot. With the aid of a labelled diagram, identify the four spheres of the Earth system and give the defining content of each.

Model Answer

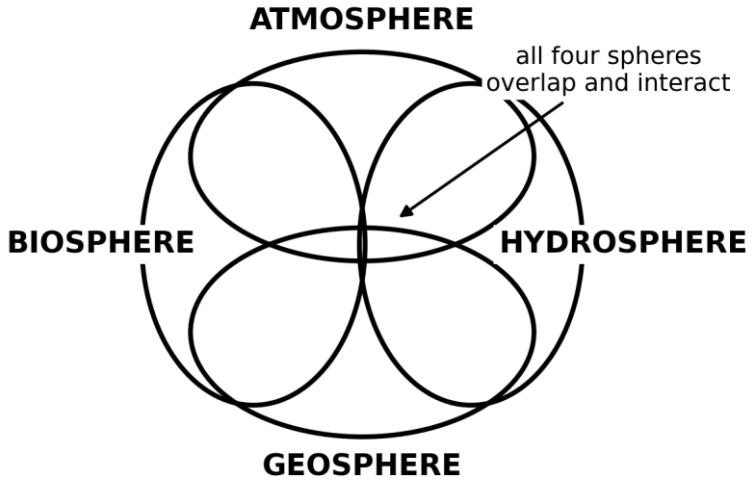


Figure 2.1: *The four interacting spheres of the Earth system*

The Earth system is built of four overlapping spheres, each defined by what it contains:

1) **Atmosphere:** the envelope of mixed gases held by gravity, dominated by nitrogen and oxygen, in which all weather occurs.
2) **Hydrosphere:** all the planet's water, the oceans holding about 97 per cent of it, together with rivers, lakes and the frozen cryosphere.
3) **Biosphere:** the narrow zone of life, reaching from the lower air down into the soil and ocean, and including even the undecomposed dead.
4) **Geosphere:** also called the lithosphere, the solid Earth of rock, mineral and soil.

Because these spheres overlap rather than stack, all four are present at once on the shore of Lake Victoria.

How to Draw It

Show the four spheres as overlapping regions, not a rigid stack: the geosphere as the solid base, the hydrosphere as water resting on it, the atmosphere above, and the biosphere reaching across all three. One clear label per sphere and a visible overlap carry the marks, not artistic shapes.

Question 3

When a hillside above the Pangani is stripped of its trees, the loss does not stay with the trees alone. Explain how a change forced on one sphere is passed on to the others, tracing a worked example.

Model Answer

A change in one sphere is handed on to the others because every sphere acts as a source or a store for the rest. Take the clearing of woodland, a change in the biosphere. Because trees return moisture to the air through transpiration, felling them cuts the water vapour passed up to the atmosphere, so the local rainfall tends to fall. The burnt timber also releases carbon dioxide, which thickens the greenhouse blanket. Meanwhile the bared soil, now exposed geosphere, is no longer held by roots, so the rain strips it and washes the sediment into the Pangani, silting the river and the reservoir behind its hydropower dam. Thus one act in the biosphere dries the air, warms the climate and muddies the water, which is exactly why the Earth must be studied as one connected system.

False Confidence Alert
Listing separate effects is not the same as tracing a chain. Saying that forests give oxygen, soil grows crops and rivers carry water states three facts about three spheres; the marks come from showing how one change causes the next.

Question 4

Switch off the Sun for a single week and Tanzania's winds would die, its rains would stop and its crops would fail. Explain why solar radiation is described as the engine of the Earth system.

Model Answer

Solar radiation is the engine of the Earth system because it is the one external energy source that powers a process in every sphere:

Atmosphere: it creates the temperature contrasts that set the monsoon winds blowing over the coast.

Hydrosphere: it evaporates water from Lake Victoria and the ocean, so it lifts the whole water cycle that brings the rains.

Biosphere: the green plants of the miombo woodland trap it in photosynthesis, which becomes the food energy for all other life.

Geosphere: it drives the weathering and the wind-driven shaping of the land.

Because each of these processes halts the moment the Sun is removed, insolation drives the entire system.

Question 5

Of all the Sun's energy aimed at Tanzania, under half survives the journey down to the ground. Account for the main uses to which that surviving 46 per cent of insolation is put.

Model Answer

The 46 per cent of insolation that reaches the surface is put to four main uses that keep the planet working:

1) **Heating:** the surface absorbs the radiation and re-radiates it as long-wave heat, which warms the air from below.
2) **Evaporation and melting:** the heat turns water into vapour and melts ice, so it feeds the hydrological cycle and the rains over the highlands.
3) **Weather and climate:** the uneven heating of the land and of the waters of Lake Tanganyika builds the pressure differences that breed winds.
4) **Photosynthesis:** green plants lock a small but vital share into food, on which all other life depends.

Thus the surviving 46 per cent becomes the working energy of the whole system.

Question 6

Although we feel the Sun simply as warmth and see it as light, the insolation arriving above Tanzania is a mixture of very different rays. Account for the make-up of insolation at the top of the atmosphere, and explain why it travels as short-wave energy.

Model Answer

Insolation arrives as a mixture of electromagnetic waves of differing lengths, and because the Sun is intensely hot, most of it travels as short-wave radiation, set apart from the long-wave heat the Earth later gives back. By proportion it divides into three bands:

1) **Infrared and heat rays:** the largest share, at about 50 per cent of the total.
2) **Visible light:** the rays the eye can see, forming the next part at about 41 per cent.
3) **Ultraviolet and shorter rays:** the ultraviolet with the X-rays, gamma rays and alpha rays, the most energetic at about 9 per cent.

Because these proportions are fixed by the Sun's temperature, every beam reaching Tanzania carries the same mixture before the atmosphere begins to filter it on the way down.

Question 7

Even on a cloudless morning the air itself quietly takes a share of the Sun's energy before any of it reaches the ground. Explain how absorption depletes incoming solar radiation as it passes through the atmosphere.

Model Answer

Absorption depletes insolation because certain atmospheric substances retain the radiation and convert it into heat, removing about 19 per cent before it reaches the ground. As the radiation descends, gases and particles intercept it, and because they take in the energy rather than pass it on, they warm and later emit their own long-wave radiation. The chief absorbers are water vapour and carbon dioxide, helped by ozone, dust and ice. The share is only modest, however, because most insolation is short-wave, and short waves slip through the gases with little check, so only a limited part is held back. A useful rule is that a good absorber is also a good radiator, which is why the dark soil of the central plateau both takes in and gives out radiation far more readily than bright snow.

Question 8

The snow on Kilimanjaro's summit throws back most of the light that strikes it, while the dark water of the Indian Ocean swallows nearly all of its own. With the aid of a diagram, define albedo and explain how reflection reduces the insolation reaching the surface.

Model Answer

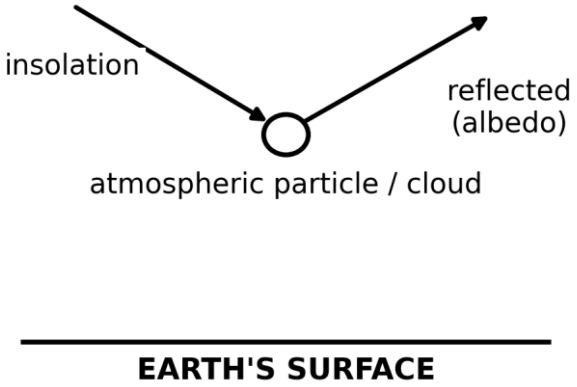


Figure 2.2: *Reflection of solar radiation*

Albedo is the proportion of incoming radiation that a surface or cloud reflects back, and reflection in this way returns about 25 per cent of insolation to space before it can warm the Earth. When insolation strikes a bright surface or a cloud top, the rays are turned back instead of being absorbed, so that energy leaves the system. The brighter the surface, the higher its albedo: fresh snow on Kilimanjaro reflects up to 85 per cent, light desert sand about 40 per cent, the grassland of the Serengeti around 25 per cent, while the dark ocean and dark soils reflect under 10 per cent and so absorb the most. Because a high albedo means more radiation is rejected, bright surfaces stay cool whereas dark ones heat quickly under the very same Sun.

How to Draw It
Draw a single incoming ray striking a cloud or particle and a reflected ray leaving at an angle back towards space; label the incoming ray insolation and the returning one reflected (albedo). One clear pair of arrows and the two labels carry the marks, so resist drawing the whole energy budget here.

False Confidence Alert
Albedo is reflection, not absorption. A high-albedo surface takes in less energy, so it is the cooler one; candidates often reverse this and call the bright surfaces the warmest.

Question 9

The same atmosphere that makes the Tanzanian sky blue by day turns its clouds brilliant white. With the aid of a diagram, distinguish the three forms of scattering of solar radiation.

Model Answer

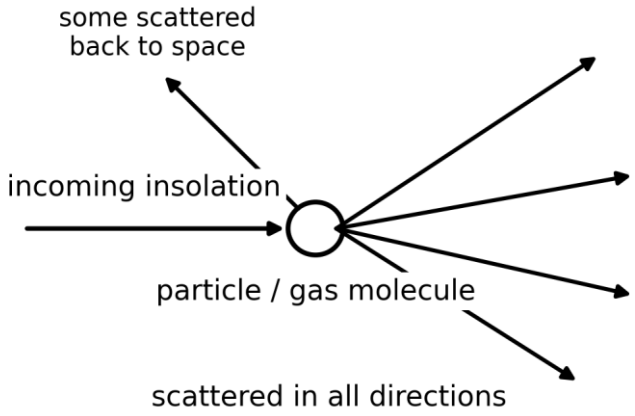


Figure 2.3: *Scattering of solar radiation*

Scattering diverts insolation from its straight path in all directions, and it takes three forms, set apart by the size of the particle compared with the wavelength of the light:

1) **Rayleigh scattering:** the particles are smaller than the wavelength, so the shortest waves scatter most; because blue light has the shortest visible wavelength, the daytime sky over Tanzania appears blue.
2) **Mie scattering:** the particles, such as dust and smoke, are about the size of the wavelength, so all the visible colours scatter fairly evenly.
3) **Non-selective scattering:** the particles, such as cloud droplets, are far larger than the wavelength, so every colour scatters equally and the cloud appears white.

Across all three forms about 8 per cent of insolation is lost, some of it back to space.

How to Draw It
Show one incoming ray meeting a particle and several arrows leaving in different directions to capture all directions; label the particle and mark one back-scattered ray returning skyward. The spread of arrows is the mark-bearing feature that separates scattering from reflection's single bounce.

Question 10

Picture a hundred parcels of sunlight setting out for the Tanzanian surface; barely forty-six arrive, and what they deliver is soon handed back to the sky in a changed form. With the aid of a diagram, trace what happens to incoming solar radiation as it passes to the surface and back.

Model Answer

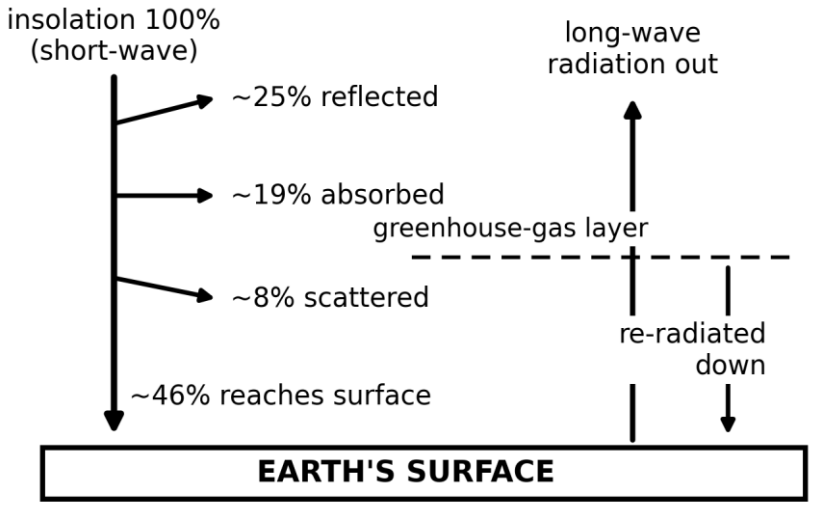


Figure 2.4: The passage and balance of solar energy

Of every 100 units of insolation, only about 46 reach the surface, the rest being stripped away on the journey down, after which the warmed ground returns its energy to space as long-wave radiation. As the radiation descends, about 19 units are absorbed by gases such as water vapour and ozone, about 25 are reflected by cloud tops and bright ground, and about 8 are scattered, some back to space. The surviving 46 units are absorbed at the surface and converted into heat. The warm ground then re-radiates this energy upward, but now as long-wave, and the greenhouse gases, chiefly water vapour and carbon dioxide, absorb much of it and send part back down, which keeps the lower air over Tanzania warm. Because the energy leaving equals the energy arriving over time, the system holds the balance called the heat budget.

How to Draw It
Draw a downward arrow of 100 units splitting into labelled losses, about 19 absorbed, 25 reflected and 8 scattered, with about 46 reaching the surface, then an upward long-wave arrow partly held by a greenhouse-gas layer. The marks are for the labelled split adding towards 100 and for showing short-wave in against long-wave out, not for neatness.

False Confidence Alert
The Earth does not simply soak up the Sun's heat and keep it. Incoming radiation is short-wave and outgoing is long-wave, and missing that switch makes the greenhouse effect, and therefore climate change, impossible to explain.

Question 11

If the Earth takes in heat from the Sun every single day, a student wonders why it does not grow hotter and hotter without end. Explain the heat budget of the Earth, and why greenhouse gases are essential to it.

Model Answer

The heat budget is the long-term balance between the energy the Earth receives from the Sun and the energy it loses to space, and greenhouse gases are essential because they slow that loss enough to keep the planet warm. Although only about 46 per cent of insolation reaches the surface, the Earth neither heats nor cools without limit, because over time the incoming short-wave and outgoing long-wave flows are equal. When the warmed ground re-radiates long-wave heat, gases such as water vapour and carbon dioxide absorb much of it and re-emit part downward, so the energy lingers in the lower air instead of escaping at once. As a result the surface stays far warmer than it otherwise would, which is why nights in Tanzania do not turn bitterly cold. Because the balance is delicate, however, adding extra gas tips it and warms the globe.

False Confidence Alert
The greenhouse effect is not in itself a problem; without it the Earth would be too cold for life. The danger is only the extra greenhouse gas from human activity, which over-thickens a blanket the planet actually needs.

Question 12

Dar es Salaam bakes under a near-vertical noon Sun while, on the same day, the Sun barely climbs the sky over northern Europe. Account for the variation in the amount of insolation received from one place to another.

Model Answer

Insolation varies from place to place mainly because of astronomical factors that govern how directly, and for how long, the Sun's rays strike a surface:

The angle of the rays: where the Sun is overhead, as over Tanzania near the Equator, the rays strike vertically and concentrate their energy on a small area, whereas towards the poles they arrive slanting and spread thinly, so less is received.

The length of day: a place with more hours of daylight is exposed to the Sun for longer and so gains more energy.

Atmospheric transparency: cloud and dust intercept radiation, so a clear sky lets more insolation through than a cloudy one.

The Earth-Sun distance and the solar constant: the slight change in distance through the year, with the steady output of the Sun, fixes the total energy available.

Because these controls combine, the Equator receives far more insolation than the poles, and this uneven supply drives the global differences in temperature, pressure and wind.

Question 13

We picture the sky as endless emptiness, yet it is a real envelope of gas, weighed down onto the planet and only a few hundred kilometres deep. Explain what the atmosphere is, and why it stays wrapped around the Earth.

Model Answer

The atmosphere is the envelope of mixed gases, suspended solids and liquids that surrounds the Earth, held in place by the planet's gravity. The word itself joins two Greek roots, atmos meaning vapour and sphaira meaning sphere, so it names a sphere of vapour. It is a mixture of odourless gases dominated by nitrogen and oxygen, together with dust, water droplets and even living microbes, and it reaches about 600 to 1000 kilometres above the surface before it fades into space.

The reason it does not drift away is gravity, because the Earth's mass pulls the gas molecules downward, packing them densely near the ground and thinning them with height, so that over Tanzania the air is thick enough to breathe easily at the coast yet dangerously thin on the summit of Kilimanjaro. Without gravity to hold it, the atmosphere would escape and the planet would be as lifeless as the Moon.

Question 14

Some gases in the air never change their share from one place to another, while others swell and shrink with the weather and the seasons. Explain the difference between the permanent and the variable components of the atmosphere.

Model Answer

The atmosphere is divided into permanent components, whose proportions stay almost constant everywhere, and variable components, whose amounts rise and fall with place, season and human activity. The permanent gases are led by nitrogen at about 78 per cent and oxygen at about 21 per cent, with argon making up most of the small remainder; because they are not easily added or removed, their shares are the same over the Serengeti as over the open ocean. The variable components, by contrast, change from hour to hour and place to place. Chief among them is water vapour, which ranges from almost nothing in a dry season to as much as 4 per cent over the humid coast, and carbon dioxide, which human burning is steadily raising. Dust, aerosols and the reactive minor gases are variable too, since they pour into the air from fires, factories and dry winds and then settle out again. A constituent is called variable, therefore, precisely because there is an active source adding it and a sink removing it.

Question 15

Three gases together make up almost the whole of the air a Tanzanian breathes, yet each does a very different job. Account for the roles of the major gases of the atmosphere.

Model Answer

The air is dominated by three gases, each with its own part in supporting life and combustion:

1) **Nitrogen:** at about 78 per cent it is the most abundant gas; it dilutes the oxygen so that burning and breathing stay gentle rather than violent, and living things draw on it to build proteins.
2) **Oxygen:** at about 21 per cent it is the gas of life, used by every organism in respiration and required for any combustion, from a cooking fire to a power station.
3) **Argon:** at about 0.93 per cent it is an inert gas that takes no part in life, though it is put to use in filling electric light bulbs.

Beyond these three lies less than one per cent of carbon dioxide, water vapour and trace gases, small in quantity but far from small in effect, for it is carbon dioxide that feeds plants and helps to warm the planet.

Question 16

Carbon dioxide is so scarce that it forms barely three parts in ten thousand of the air, yet a small rise in it can warm the whole planet. Explain why carbon dioxide matters out of all proportion to its quantity.

Model Answer

Carbon dioxide matters far more than its 0.03 per cent share suggests because it does two jobs no abundant gas can do: it feeds all plant life and it traps the Earth's heat. First, it is the raw material of photosynthesis, so every crop in a Tanzanian field and every tree in the miombo woodland builds its tissue from carbon drawn out of the air, and without this trace of gas the food chain would have no base. Second, carbon dioxide acts as a blanket, because it absorbs the long-wave heat radiated by the warmed ground and re-emits part of it downward, keeping the surface warm enough for life. It is exactly this blanketing power that makes the gas dangerous in excess, for as human burning lifts its share it thickens the blanket and tips the heat balance towards warming. Thus a gas measured in hundredths of a per cent governs both the growth of plants and the temperature of the planet.

False Confidence Alert
A gas is not unimportant just because it is scarce. Judging carbon dioxide by its tiny percentage misses the point; its effect on photosynthesis and on the heat balance is what the marks reward.

Question 17

Some gases present in the air in the barest traces are the very ones that sour the rain and thicken the greenhouse blanket. Explain how the reactive minor gases of the atmosphere produce acid rain and add to the greenhouse effect.

Model Answer

A handful of reactive minor gases, though present in tiny amounts, cause two serious effects: some turn rainfall acidic, while others trap extra heat:

1) **Acid rain:** sulphur dioxide and the nitrogen oxides, released mainly by the burning of fuels, dissolve in the water droplets of cloud and fall as a dilute acid that corrodes metal, damages crops and harms lakes.
2) **Extra greenhouse warming:** methane and nitrous oxide, though far scarcer than carbon dioxide, absorb long-wave heat strongly, so each added molecule adds out of all proportion to the warming of the air.

Because both effects flow from gases measured in thousandths of a per cent, controlling their sources matters more than their small share suggests, as the haze over a growing Tanzanian town shows when the first rains wash the soured air.

Question 18

The same blue sky carries almost no moisture above the dry central plateau yet hangs heavy and damp over the coast at Tanga. Explain the distribution of water vapour in the atmosphere and the roles it plays.

Model Answer

Water vapour is the most variable gas in the air, ranging from about 0.2 to 4 per cent, and it is at once the engine of weather and a powerful greenhouse gas. Its amount is greatest in the hot, wet tropics, where strong evaporation loads the air, and least over deserts and cold lands, so it falls away both with rising latitude and with rising altitude. Nearly 90 per cent of it lies within the lowest 6 kilometres, and about half within 2 kilometres of the ground, because the warm lower air holds moisture that the cold upper air cannot.

Its roles are two. As the source of all cloud and rain it is the raw material of the hydrological cycle that waters Tanzania's farms. As a greenhouse gas it absorbs long-wave heat and so helps hold the planet's temperature steady, which is why a humid, cloudy night at Tanga stays warm while a clear, dry night on the plateau turns cold.

Question 19

Strange as it sounds, a sky entirely free of dust would be a sky almost unable to rain. Explain how dust enters the atmosphere and why it is essential to the formation of cloud and rain.

Model Answer

Dust consists of tiny solid particles carried into the air from the land, and far from being mere dirt, it is essential because each particle can serve as a nucleus on which water vapour condenses. It enters the atmosphere from both natural and human sources: desert sand and bare soil lifted by the wind, ash from fires and volcanoes, and the fine debris of burnt meteors. Concentrations are highest over dry regions and in the dry season, because loose, unbound soil is easily raised, which is why the air above the central plateau grows hazy with dust before the rains break.

The importance of this dust lies in condensation, since water vapour cannot easily turn to droplets in clean air but gathers readily on a solid surface, so the grains act as hygroscopic nuclei around which cloud droplets, and in time raindrops, form. Without these particles the vapour would linger as gas and rain would seldom fall.

Question 20

Among the finest particles floating in the air, some greedily soak up moisture while others stay stubbornly dry, and the difference decides whether rain will form. Distinguish the two kinds of aerosol and explain the part the moisture-loving kind plays in precipitation.

Model Answer

Aerosols are extremely fine particles that stay suspended in the air for long periods, and they fall into two kinds according to how they treat water:

1) **Hygroscopic aerosols:** these absorb and hold atmospheric moisture, so that water vapour readily condenses on them; sea salt and certain soot particles are examples.
2) **Non-hygroscopic aerosols:** these do not absorb moisture and so play little part in condensation; many mineral dusts and pollen grains are examples.

It is the hygroscopic kind that matters for rain, because by drawing vapour onto themselves they become the nuclei for condensation and so trigger the cloud droplets that grow into precipitation. Their concentration is greatest over industrial and urban areas, where the burning of fuels pumps them into the air, which is one reason a large city like Dar es Salaam can brew its own showers.

Question 21

A child believes the sky simply ends where the blue fades, but a pilot, a weather balloon and a satellite each travel through a different world of air. On what basis is the atmosphere divided into layers, and, with the aid of a labelled diagram, name them in order from the ground.

Model Answer

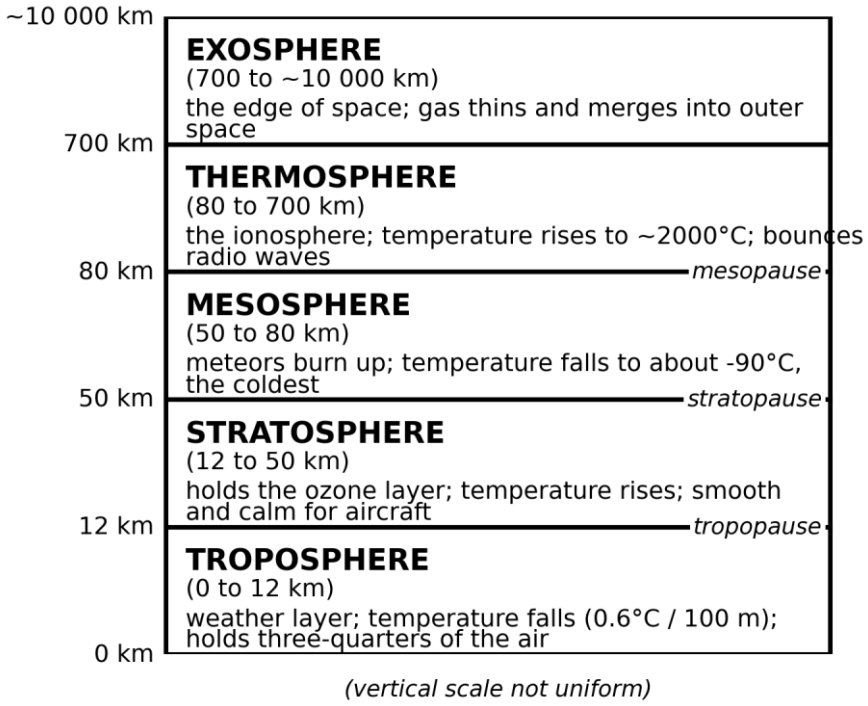


Figure 2.6: *The vertical structure of the atmosphere*

The atmosphere is divided into five layers on the basis of how temperature behaves with height, and from the ground upward they run as follows:

1) **Troposphere:** from the surface to about 12 kilometres, where temperature falls with height and all weather occurs, including the storms that build over Lake Victoria.
2) **Stratosphere:** from about 12 to 50 kilometres, where temperature rises because the ozone layer absorbs ultraviolet rays.
3) **Mesosphere:** from about 50 to 80 kilometres, where temperature falls again to the coldest of all, about minus 90 degrees Celsius.
4) **Thermosphere:** from about 80 to 700 kilometres, where temperature rises steeply to around 2000 degrees Celsius.
5) **Exosphere:** from about 700 kilometres outward, the thin edge of space that merges into the void.

Each layer is separated from the next by a pause, the tropopause, stratopause and mesopause, where the temperature trend turns around.

How to Draw It
Draw five stacked bands with the troposphere at the base, mark the boundary heights of 12, 50, 80 and 700 km up the side, and label each layer with whether its temperature rises or falls. The marks are for the correct order and the rise-fall-rise pattern, not for scale.

Question 22

Climbers on Kilimanjaro pass from the heat of the plains to ice at the summit, though they have moved only a few kilometres nearer the Sun. Explain why temperature falls with height in the troposphere, and why this layer holds the weather and most of the air.

Model Answer

In the troposphere temperature falls with height at about 0.6 degrees Celsius for every 100 metres, the environmental lapse rate, and this lowest layer holds both the weather and about three-quarters

of the atmosphere's mass. The fall in temperature occurs because the air is warmed not directly by the Sun but from below, by the long-wave heat radiated off the ground, so the higher one climbs the further one is from that heat source, which is why the summit of Kilimanjaro carries ice while its base bakes.

The layer holds the weather because nearly all the water vapour is concentrated here, so cloud, rain and storms form within it while rising air and strengthening winds stir it constantly. It also contains the greatest share of the air's mass, because gravity packs the molecules most densely near the surface, leaving the pressure at the top of the troposphere only about a tenth of that at sea level.

Question 23

Pilots flying above Tanzania climb out of the bumpy lower air into a smooth, calm layer where the temperature, strangely, begins to rise. Explain why temperature rises through the stratosphere and why the layer is well suited to flying.

Model Answer

Temperature rises through the stratosphere because it holds the ozone layer, which absorbs the Sun's ultraviolet radiation and releases the energy as heat, and this same calm, cloudless layer is ideal for aviation. In the layers near the ground the air is warmed from below, but in the stratosphere the warming comes from above and within, since ozone high in the layer soaks up incoming ultraviolet rays, so the temperature climbs with height instead of falling. Because the air is warm at the top and cool at the base it does not overturn, and this stability has two results. There is almost no cloud, storm or turbulence, so aircraft crossing Tanzania fly smoothly and economically once they climb above the troposphere, and the ozone shield strips out the dangerous ultraviolet rays before they reach the cabin. The stratosphere therefore offers a flight both a steady ride and natural protection from the Sun.

Question 24

High above the Earth a faint band of a rare gas stands between every living thing and a stream of radiation that would otherwise blind and burn. Account for the role of the ozone layer in protecting life, and the threat it now faces.

Model Answer

The ozone layer, a thin band of the three-atom form of oxygen lying mainly between about 16 and 50 kilometres up, protects life by absorbing the Sun's harmful ultraviolet radiation before it reaches the surface. Ultraviolet rays carry enough energy to damage living tissue, causing skin cancers and eye damage in people and harming crops and the tiny life of lakes and seas. Ozone intercepts the bulk of these rays high in the stratosphere, turning their energy into heat and so acting as a shield for everything below, from a farmer in the field to the fish in Lake Tanganyika. The shield is constantly created and destroyed by sunlight yet has stayed roughly steady over the ages, which is why the threat from human-made CFC gases is so grave, for by thinning the ozone they let more ultraviolet through, and the harm then falls on the very life the layer protects.

False Confidence Alert
The ozone layer and the greenhouse blanket are not the same thing. Ozone high up blocks incoming ultraviolet rays, whereas the greenhouse gases lower down trap outgoing heat; confusing the two, or blaming CFCs for global warming, loses marks.

Question 25

The shooting stars that streak across a clear night over the Serengeti never reach the ground, and the layer that destroys them is also the coldest in the whole atmosphere. Account for the role of the mesosphere in burning up meteors and for its extreme cold.

Model Answer

The mesosphere, lying between about 50 and 80 kilometres, is the layer that burns up incoming meteors and is also the coldest part of the atmosphere, falling to about minus 90 degrees Celsius.

Meteors and small asteroids entering the atmosphere meet enough air in the mesosphere to be slowed by friction, which heats them until they glow and vapourise, and it is this burning that we see as the shooting stars over the Serengeti, so the layer acts as a shield that stops most space debris reaching the surface. The layer is bitterly cold because it lies above the warm ozone of the stratosphere yet below the Sun-facing thermosphere, so it is heated from neither side, and its very thin air holds little energy. The cold reaches its lowest at the mesopause, the boundary that marks the layer's top, beyond which the temperature trend reverses once more.

Question 26

A thermometer carried into the thermosphere would read two thousand degrees, yet an astronaut there would freeze, while far below a radio in Dodoma can speak to one across the country. Explain how the thermosphere can be so hot yet feel cold, and how it carries radio signals around the world.

Model Answer

The thermosphere reaches about 2000 degrees Celsius because its few molecules absorb intense solar radiation, yet it feels cold because those molecules are so sparse, and its electrically charged layer, the ionosphere, lets radio signals travel far around the curved Earth. Temperature measures how fast molecules move, and in the thermosphere the oxygen and nitrogen atoms absorb short-wave solar energy and move extremely fast, so the temperature is genuinely high. It still feels cold, however, because the air is so thin that there are too few molecules to pass that heat to a body, which would lose more heat than it gained. The same solar energy strips electrons from the atoms to form the ionosphere, a shell of charged particles, and although radio waves sent up from a station in Dodoma cannot follow the curve of the Earth on their own, they bounce off this charged layer and back to the ground, and by repeating the bounce they reach receivers far beyond the horizon, carrying broadcasts across Tanzania.

False Confidence Alert
Hot and warming are not the same. The thermosphere's 2000 degrees describes the speed of a few molecules, not the heat a body would feel; with almost no air to carry the energy, it would chill, not warm, anything placed there.

Question 27

Where does the air finally give out and space begin, and what marks the joins between one layer of the sky and the next? Explain why the exosphere is regarded as the edge of space, and the role of the pauses that separate the layers.

Model Answer

The exosphere is the outermost layer of the atmosphere, beginning at about 700 kilometres, where the gas grows so thin that it merges into space, while the pauses are narrow transition zones that separate each layer from the next. In the exosphere the few remaining atoms, mostly hydrogen and helium with traces of nitrogen, oxygen and carbon dioxide, are so widely spaced that they seldom meet, and many drift off into space altogether, which is why this layer is treated as the boundary between the atmosphere and the void and a first barrier against incoming cosmic rays; it is within and above this layer that the satellites relaying Tanzania's telephone and television signals orbit. Between the main layers lie the pauses, the tropopause, stratopause and mesopause, each a thin zone where the temperature stops changing in one direction before reversing into the next layer. They matter because they mark exactly where one set of conditions ends and another begins, so the tropopause caps the weather of the troposphere and the stratopause caps the warm ozone layer, giving the atmosphere its clear, ordered structure.

Question 28

Although water seems to be everywhere in Tanzania, from Lake Victoria to the Indian Ocean, almost none of it can be drunk or poured on a field. Explain what the hydrosphere is, why it covers most of the planet, and why so little of its water is fresh.

Model Answer

The hydrosphere is all the water of the planet, in liquid, frozen or vapour form, and it covers about 71 per cent of the Earth's surface, yet only about 3 per cent of that water is fresh. Water covers so much of the planet because the low ocean basins, sunk in the heavy oceanic crust, hold vast quantities of it, so the blue of the sea dominates any view of the Earth from space. Of all this water about 97 per cent is the salt water of the seas and oceans, leaving only about 3 per cent as fresh, and even that small share is mostly locked away, for nearly 69 per cent of the fresh water is frozen in ice caps and glaciers and about 30 per cent is held underground, so less than one per cent lies in the rivers and lakes that people actually use. This is why a country ringed by great water bodies like Lake Victoria and the Indian Ocean can still face shortages of usable fresh water, and why that thin surface share must be carefully shared.

Question 29

However much water Tanzania's rivers pour into the Indian Ocean each year, the lakes do not run dry and the sea does not overflow. Explain how the hydrological cycle, driven by the Sun, keeps the supply of fresh water roughly constant.

Model Answer

The hydrological cycle keeps fresh water at a roughly constant level because the Sun continually lifts water from the oceans and returns it to the land, so that what flows away is steadily replaced. The Sun's heat evaporates water from the ocean and from lakes such as Lake Victoria, turning it into vapour that rises into the atmosphere, where it cools, condenses into cloud and falls again as rain. Some of this rain feeds the rivers and groundwater that supply farms and towns, and the rivers carry it back to the sea, completing the loop. Because the rate of evaporation and the rate of rainfall stay broadly in balance over time, the total store of fresh water neither vanishes nor grows without limit, even though any single drop is constantly on the move. It is this Sun-driven recycling, rather than any fixed reservoir, that makes fresh water a renewable resource, so long as the cycle is not disturbed by deforestation or a warming climate.

Question 30

On the Equator itself, where the noon Sun blazes hottest, a cap of ice has survived for thousands of years on the summit of Kilimanjaro, though it is now shrinking fast. Explain what the cryosphere is and why it is the Earth's greatest store of fresh water, and say what the retreat of Kilimanjaro's ice signals.

Model Answer

The cryosphere is the frozen part of the hydrosphere, all the snow and ice of the planet, and it is the Earth's largest reservoir of fresh water, with the ice of Antarctica alone holding about 80 per cent of it. Ice forms wherever temperatures stay below freezing, so the cryosphere covers the polar regions around the North and South Poles and caps high mountains far from the poles, including the summit of Kilimanjaro near the Equator. It is the greatest freshwater store because so much of the planet's fresh water is frozen rather than liquid, held in the vast ice sheets and glaciers. The ice on Kilimanjaro matters far beyond Tanzania, because as the climate warms that ancient ice is melting away, and its retreat is a visible warning that the heat balance of the whole Earth system is being disturbed. A glacier surviving on the Equator is a delicate thing, and its loss is a sign read around the world.

False Confidence Alert
The melting of Kilimanjaro's ice is not merely a local change of weather. Treating it as a one-off misses the point; it is one sign among many that the global heat balance is shifting, which is why scientists watch it so closely.

Question 31

Every living thing on Earth, from the fish deep in Lake Tanganyika to the birds above Kilimanjaro, is crowded into a film of life so thin that, set against the whole globe, it is thinner than the skin of an orange. Explain what the biosphere is and why it is described as a narrow zone.

Model Answer

The biosphere is the zone of the Earth in which all life exists, a thin shell reaching from a few kilometres up in the air down into the soil and the deep ocean, and it overlaps all the other spheres. Life is confined to this narrow band because it needs the conditions that only the surface zone provides: air to breathe, water to drink, sunlight for plants and a temperature neither too hot nor too cold. Above a height of about 10 kilometres the air is too thin and cold, and far below the surface there is no light and little oxygen, so living things cannot survive much beyond this layer. The biosphere is remarkable for its richness, holding millions of species packed into so slim a zone, and it includes not only the living but their undecomposed remains, which feed the next generation. Because it borrows air from the atmosphere, water from the hydrosphere and minerals from the geosphere, the biosphere is the meeting place of all the spheres, as the crowded shore of Lake Tanganyika shows.

Question 32

The rock beneath a Tanzanian farmer's feet seems the very picture of something fixed and dead, yet it is slowly being made, destroyed and remade all the time. Explain why the geosphere, though solid, is described as dynamic.

Model Answer

The geosphere is the solid Earth of rock, mineral and soil, and although it appears fixed, it is described as dynamic because its materials are constantly recycled through the rock cycle. The geosphere is built mainly of a few elements, with oxygen, iron, silicon and magnesium together making up about 94 per cent of its mass, combined into the minerals that form rocks. It is dynamic because rock is never permanent, for molten material cools into igneous rock, which is worn down by weathering into sediment, which is buried and pressed into sedimentary rock, which heat and pressure may change into metamorphic rock, which may melt once more, so the same matter cycles endlessly. This slow churning, driven by the Earth's internal heat and by surface weathering, raises the mountains, yields the minerals and forms the soil on which a Tanzanian farmer depends. The geosphere, then, is less a dead foundation than a slow but ceaseless recycler of rock.

False Confidence Alert
Solid does not mean unchanging. Picturing the geosphere as dead, permanent rock misses the rock cycle entirely; the marks come from showing that its materials are continually made and remade.

Question 33

The same atom of carbon may sit in the air today, in a maize plant next month and in a grazing cow next year, before returning to the air once more. Explain what a biogeochemical cycle is, breaking down the term, and why such cycles keep life going.

Model Answer

A biogeochemical cycle is the continual movement of a chemical element between the living and non-living parts of the Earth system, and the name itself shows what is involved: bio for the biosphere, geo for the geosphere, and chemical for the elements that move. Elements vital to life, such as carbon, oxygen and nitrogen, do not stay in one place but pass round and round between the atmosphere, the hydrosphere, the geosphere and the biosphere. Because the Earth gains almost no new matter from space, these same atoms must be used again and again, so a cycle that broke would soon starve life of the element it carries. The cycles run chiefly through gaseous exchange, since animals breathe in oxygen and breathe out carbon dioxide while plants take in that carbon dioxide and release oxygen, so the two groups keep each other supplied. It is this constant recycling of a fixed stock of elements, rather than any fresh supply, that allows life on a Tanzanian farm, and everywhere else, to continue.

Question 34

Burn a lump of coal today and you release carbon that a fern locked away from the air three hundred million years ago. With the aid of a diagram, trace the carbon cycle through the four spheres of the Earth.

Model Answer

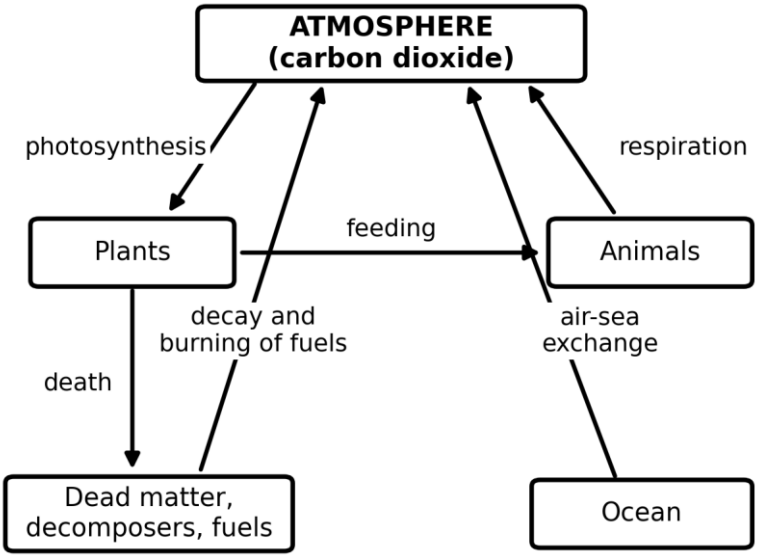


Figure 2.8: *The carbon cycle*

The carbon cycle is the continual circulation of carbon, chiefly as carbon dioxide, between the atmosphere, plants, animals, the ocean and the rocks. It turns first in the atmosphere, where plants draw in carbon dioxide and, using sunlight, build it into their tissue through photosynthesis. Animals then eat the plants, taking the carbon into their own bodies, and both plants and animals return some of it to the air as they respire. When living things die, decomposers break down their remains and release the carbon again, while over long ages buried remains harden into the coal, oil and gas we call fossil fuels. The ocean plays its part too, dissolving carbon dioxide from the air and storing some as the lime of shells and rock, which weathering later returns through carbonation. Human burning of fossil fuels now adds a further, rapid flow of carbon back to the air, which is why the cycle, once balanced, is tipping towards more carbon over Tanzania and the world.

How to Draw It
Draw the atmosphere as a box of carbon dioxide and link it by labelled arrows to plants (photosynthesis), animals (feeding and respiration), dead matter and fuels (decay and burning) and the ocean (air-sea exchange). The marks are for the labelled flows, not for artwork.

False Confidence Alert
Burning fossil fuels does not create new carbon; it releases carbon locked away for millions of years. The harm lies in returning that ancient store to the air far faster than the cycle can take it back.

Question 35

Every breath a person takes in Dodoma was made by plants, and every breath they let out feeds those same plants. With the aid of a diagram, explain the oxygen cycle and how it links the living and the non-living world.

Model Answer

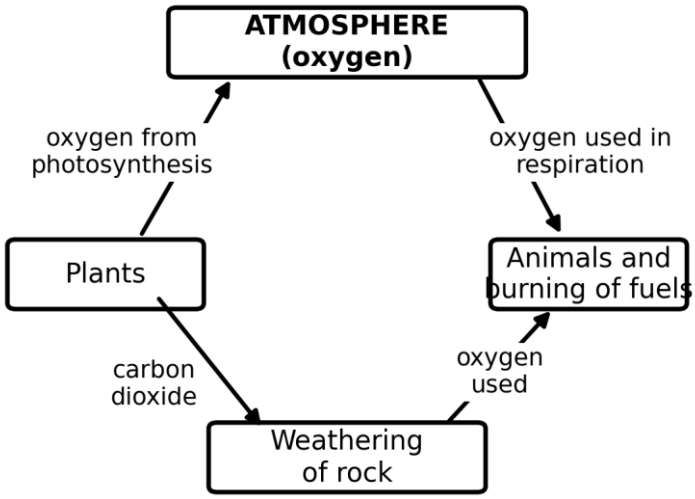


Figure 2.9: *The oxygen cycle*

The oxygen cycle is the process by which oxygen, the second most abundant gas in the air, is continually produced and used up, linking plants, animals and the rocks. Oxygen is added to the atmosphere almost entirely by plants, which during photosynthesis split water and carbon dioxide and release oxygen as a by-product, so the miombo woodland and every green field is quietly refilling the air. That oxygen is then used in two main ways, since animals and people breathe it in during respiration, combining it with food to release energy and giving back carbon dioxide, and human beings consume it when they burn fuels such as wood and charcoal. A slower exchange takes place as oxygen is used in the weathering of rock, where it is locked into new minerals. Because the oxygen released by plants balances the oxygen taken up by breathing and burning, the share of oxygen in the air stays steady, and the cycle quietly keeps the planet breathable.

How to Draw It
Draw the atmosphere of oxygen linked to plants (which release oxygen in photosynthesis) and to animals and the burning of fuels (which use oxygen and give back carbon dioxide), with a further arrow for the weathering of rock. The marks are for the labelled two-way exchange.

Question 36

Nitrogen makes up nearly four-fifths of every breath, yet a maize plant standing in it can starve for want of nitrogen, while a bean plant beside it thrives. With the aid of a diagram, explain biological nitrogen fixation and trace the nitrogen cycle.

Model Answer

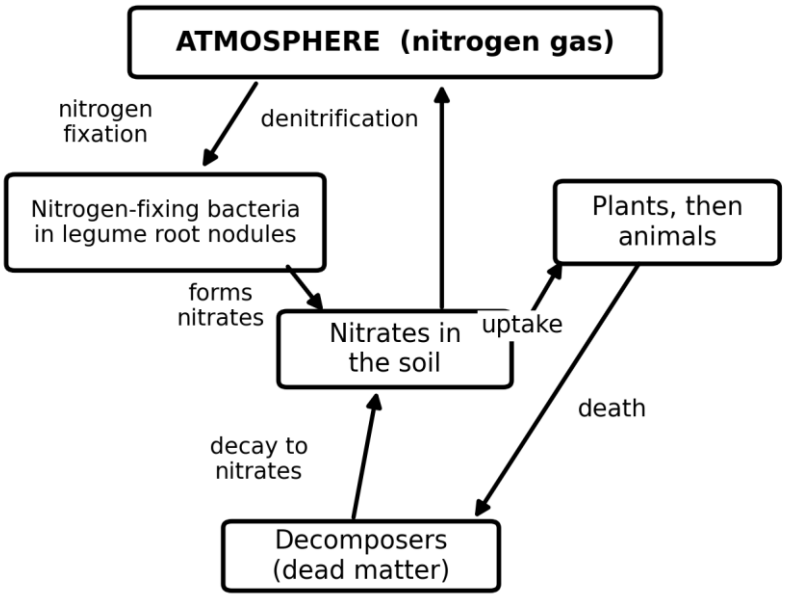


Figure 2.10: *The nitrogen cycle*

The nitrogen cycle is the movement of nitrogen between the air, the soil and living things, and its key step is biological nitrogen fixation, in which bacteria turn the nitrogen gas that plants cannot use into nitrates that they can. Although nitrogen forms about 78 per cent of the air, plants cannot take it in as a gas, so it must first be fixed. This is done chiefly by bacteria living in the root nodules of legumes such as beans and soybeans, which convert nitrogen gas into nitrates in the soil. Plants absorb these nitrates to build their proteins, and animals gain their nitrogen by eating the plants. When plants and animals die, decomposers break down their remains and return nitrogen to the soil as nitrates once more, while denitrifying bacteria release some back to the air as nitrogen gas, closing the loop. This is why a Tanzanian farmer who plants beans or soybeans enriches the soil for the next crop, since the legumes leave behind the fixed nitrogen their root bacteria have made.

How to Draw It
Draw the atmosphere of nitrogen gas linked by arrows to the legume root-nodule bacteria (fixation), the nitrates in the soil, the plants and animals (uptake and feeding), the decomposers (decay) and back to the air (denitrification). The marks are for the named steps in order.

False Confidence Alert
Plants cannot feed on nitrogen straight from the air, even though they stand surrounded by it. Forgetting the fixation step, and imagining that plants breathe in nitrogen as they do carbon dioxide, is a common and costly error.

Question 37

The air and the living world are forever trading breaths, the one giving exactly what the other needs. Explain how the atmosphere and the biosphere interact.

Model Answer

The atmosphere and the biosphere interact constantly, chiefly by trading gases and by the passing of particles between them:

Gaseous exchange: animals breathe in oxygen and breathe out carbon dioxide, while plants take in that carbon dioxide and release oxygen, so each keeps the air fit for the other, and the biosphere also draws nitrogen from the air to build its proteins.

Deposition of particles: the atmosphere drops dust and the nutrients it carries onto soils and seas, and even seeds the rain that waters the land.

In return the biosphere shapes the air, for the great forests and the miombo woodland of Tanzania remove carbon dioxide and release oxygen on a scale that influences the whole atmosphere.

Question 38

The ocean off the Tanzanian coast does more than carry dhows and fish; it quietly drinks in the very gas that is warming the planet. Explain how the atmosphere and the hydrosphere interact.

Model Answer

The atmosphere and the hydrosphere interact in three main ways, exchanging water, gases and heat:

Water circulation: the Sun evaporates water from the ocean into the air, which returns it as the rain that feeds the land and the rivers.

The ocean as a carbon sink: the sea dissolves carbon dioxide from the air, so the ocean off the Tanzanian coast absorbs some of the gas human activity releases and slows its build-up.

Temperature regulation: because water warms and cools slowly, the ocean stores heat by day and releases it by night, keeping the coast at Dar es Salaam milder than the dry interior.

Through these exchanges the air and the water hold each other in balance and moderate the climate of the whole planet.

Question 39

The same falling water that gives a fish its home in the Great Ruaha is harnessed at Kidatu to light the towns of Tanzania. Explain how the hydrosphere and the biosphere interact, and how that link is turned into energy.

Model Answer

The hydrosphere and the biosphere are bound together because water sustains life and houses much of it, and the same moving water can be harnessed for energy:

Life support: water is the first need of every organism and the medium of the chemistry of life, so the biosphere depends on it for the sap of plants and the blood of animals.

Habitat: the lakes, rivers and seas are home to fish, plants and countless smaller organisms, as the crowded waters of Lake Tanganyika show.

Energy: the Sun lifts water that falls as rain and runs down the rivers, and Tanzania captures that energy at hydropower stations such as Kidatu and Mtera on the Great Ruaha and the Julius Nyerere station on the Rufiji.

In this way the bond between water and life also powers human development.

Question 40

A bare rock face, given roots, rain and time, slowly crumbles into the soil that feeds a forest. Explain how the geosphere interacts with the biosphere and the hydrosphere through weathering.

Model Answer

The geosphere interacts with the biosphere and the hydrosphere chiefly through weathering, the breaking down of rock into soil and sediment, in two ways:

1) **Biological weathering links it to the biosphere:** the roots of plants prise rock apart and the acids of lichens and decaying matter dissolve it, slowly making the soil in which crops grow.
2) **Chemical weathering links it to the hydrosphere:** rainwater, made slightly acid by dissolved carbon dioxide, eats into rock and carries the dissolved minerals away in solution.

Together these feed the land and the rivers, for the loosened rock becomes the fertile soil of a Tanzanian farm while the dissolved minerals and washed sediment travel down the rivers to nourish the lakes and the sea.

Question 41

The wind that scours a hillside and the rain that splits a rock are the atmosphere reaching down to reshape the solid Earth. Explain how the atmosphere interacts with the geosphere.

Model Answer

The atmosphere interacts with the geosphere by delivering the energy and water that reshape the land, and by receiving material from it in return:

Energy for weathering: the Sun's heat expands and cracks rock by day while the cold contracts it by night, and wind drives sand against rock faces and strips away the loosened material.

Precipitation onto the land: the rain, and the rivers it feeds, carve valleys, dissolve rock and carry sediment from the highlands of Tanzania down to the plains and the sea.

Return of material: the geosphere gives back dust from dry soils, ash and gases from volcanoes, and the carbon dioxide released by weathering rock.

Through this exchange of energy, water and material, the restless air and the solid ground continually shape each other, so that no part of the Earth system stands truly apart.

REAL QUESTIONS

Question 42

A teacher in Kilakala Secondary School tells her class that there is no part of the modern Earth that human hands have not touched. Substantiate the claim that humans now impact all four spheres of the Earth, giving one Tanzanian example for each sphere.

Model Answer

Humans now leave a mark on every sphere, because our daily activities of burning, building, farming and digging add to, remove from or reshape each one.

1) **Atmosphere:** the exhaust and factory smoke of Dar es Salaam pour carbon dioxide and soot into the air, changing the gas balance of the atmosphere.
2) **Hydrosphere:** damming the Rufiji at the Julius Nyerere station holds back and re-routes a great river, altering how and where its water flows.
3) **Biosphere:** clearing miombo woodland for tobacco farms around Tabora strips away habitat and the species that depended on it.
4) **Geosphere:** open-pit gold mining at Geita digs out and reshapes the solid rock of the land surface.

Because the four spheres are linked, none of these changes stays where it begins, which is why human pressure on one sphere is felt across the whole Earth system.

Question 43

Walking from the bright sand of a Zanzibar beach onto the dark, wet soil behind it, you notice the pale sand dazzles the eye while the dark ground does not. Account for the very different albedo of fresh snow, light desert sand, grassland and dark soil or ocean, and explain what these differences mean for heating across Tanzania's varied landscapes.

Model Answer

Albedo is the share of incoming radiation a surface reflects, and it differs so widely because pale, smooth surfaces throw the Sun's rays back while dark, rough surfaces drink them in.

Fresh snow, about 85 per cent: its bright white surface reflects almost all the sunlight that strikes it, so very little is absorbed, as on the icy summit of Kilimanjaro.

Light desert sand, about 40 per cent: the pale, dry grains reflect a large share, which is why the dry sandy plains around Dodoma stay bright and lose much of their insolation.

Grassland, about 25 per cent: the green cover of the Serengeti reflects a moderate amount and absorbs the rest, warming steadily through the day.

Dark soil or ocean, under 10 per cent: the dark cultivated soils and the open Indian Ocean reflect almost nothing, so they absorb nearly all the radiation that reaches them.

Consequently the darker landscapes of Tanzania heat up fastest while the bright surfaces stay cooler, because the lower the albedo, the more of the Sun's energy a place keeps.

False Confidence Alert
A bright, dazzling surface is not the one that gets hottest. It is the dark, low-albedo surface, such as wet soil or the open ocean, that absorbs the most radiation and heats the most, while glaring snow or sand reflects its heat away.

Question 44

Above the busy roads and factories of Dar es Salaam the Sun's energy no longer passes through clean air. Explain how human activities alter the radiation processes of absorption, reflection and scattering in the Earth system.

Model Answer

Human activity changes how the atmosphere handles incoming and outgoing radiation, because the gases and particles we add intercept that energy in new ways.

More absorption: burning fossil fuels and clearing forest raise carbon dioxide and methane, which absorb outgoing long-wave radiation and trap heat near the surface, warming the air over industrial Dar es Salaam.

More scattering and reflection: smoke, dust and aerosols from vehicles, factories and burning fields scatter and reflect incoming sunlight, so hazy city air can dim the radiation that reaches the ground.

Changed surface albedo: replacing dark forest with bright bare ground, or dark soil with pale rooftops and tarmac, alters how much radiation the surface reflects rather than absorbs, as when miombo woodland is cleared for farmland.

As a result, human action disturbs the natural radiation balance, tilting it most often towards extra warming.

Question 45

When the rains arrive late and the heat grows harsher year by year, an elder in a village near Dodoma concludes that the changing weather is a curse from God. Using the greenhouse mechanism and the heat balance, explain why this belief is mistaken and identify what is really disturbing the climate.

Model Answer

The warming is not a curse but a measurable disturbance of the Earth's heat balance, caused by the extra greenhouse gases that human activity adds to the air. Normally the Earth holds a steady temperature because the energy it absorbs from the Sun is matched by the long-wave heat it radiates back to space. Greenhouse gases such as carbon dioxide and methane let sunlight in but slow this outgoing heat, which keeps the planet warm enough for life. Since the spread of industry, vehicles and large-scale burning, the amount of these gases has risen sharply, so more outgoing heat is held back and the balance tips towards warming. Consequently the village near Dodoma feels hotter days and less reliable rain, exactly as the science predicts. The change therefore has a physical cause that people can understand and act upon, rather than a supernatural one beyond their control.

False Confidence Alert
Calling climate change a curse or an act of fate removes both the real cause and the remedy. The warming follows directly from greenhouse gases trapping heat, so it can be slowed by cutting those emissions, not by accepting it as punishment.

Question 46

In the dry months the air over the central plateau around Dodoma turns hazy and brown with dust, yet after the rains it runs clear again. Account for why dust concentrations in the air are greatest over subtropical and temperate lands and during the dry season, using a Tanzanian dry-season example.

Model Answer

Dust is most plentiful where the ground is dry, bare and wind-swept, which is why subtropical and temperate lands and the dry season produce the haziest air. Dust enters the air when wind lifts loose particles from exposed ground, so the supply depends on how dry and bare that ground is. Over subtropical deserts and dry temperate interiors the soil is dry, the plant cover is thin, and strong winds sweep freely, so great quantities of fine material are raised. The wet tropics, by contrast, are held down by moisture and dense vegetation. The same contrast appears within one place across the year, because in the long dry season around Dodoma the soil bakes, the grasses wither and the wind raises a brown haze, whereas in the rains the wet ground is bound together and washed clean, so the air clears. Dryness, bare soil and wind, rather than latitude alone, therefore control how much dust the air carries.

Question 47

A Form Five pupil dismisses the air as just empty space we happen to breathe. Speaking to the class, argue in six points how the atmosphere is useful to humankind and the ecosystem, tying each point to a named gas or process.

Model Answer

The atmosphere is far from empty, because each of its gases and processes does a job that keeps humans and the ecosystem alive.

1) **Oxygen for respiration:** its oxygen, about a fifth of the air, lets humans, animals and plants release energy by breathing.
2) **Carbon dioxide for photosynthesis:** its carbon dioxide feeds the green plants and crops, such as the maize of the southern highlands, on which all food chains rest.
3) **Nitrogen for growth:** its nitrogen, the largest share of the air, is fixed into the soil to build the proteins of living things.
4) **The ozone shield:** its ozone layer absorbs the Sun's harmful ultraviolet rays, protecting life from burning and disease.
5) **A warm planet:** its greenhouse gases trap enough heat to keep the Earth warm enough for life, instead of frozen.

6) **Weather and rain:** its water vapour and moving air bring the clouds and rainfall that water the farms and rivers, such as the rains that feed the Rufiji.

Because every one of these depends on a gas or process of the air, the atmosphere is one of the ecosystem's most useful resources.

Question 48

Looking up on a clear day over Mwanza, a pupil declares that where the blue sky ends, the atmosphere ends. Correct this misconception by classifying the vertical structure of the atmosphere, and support your answer with a labelled diagram.

Model Answer

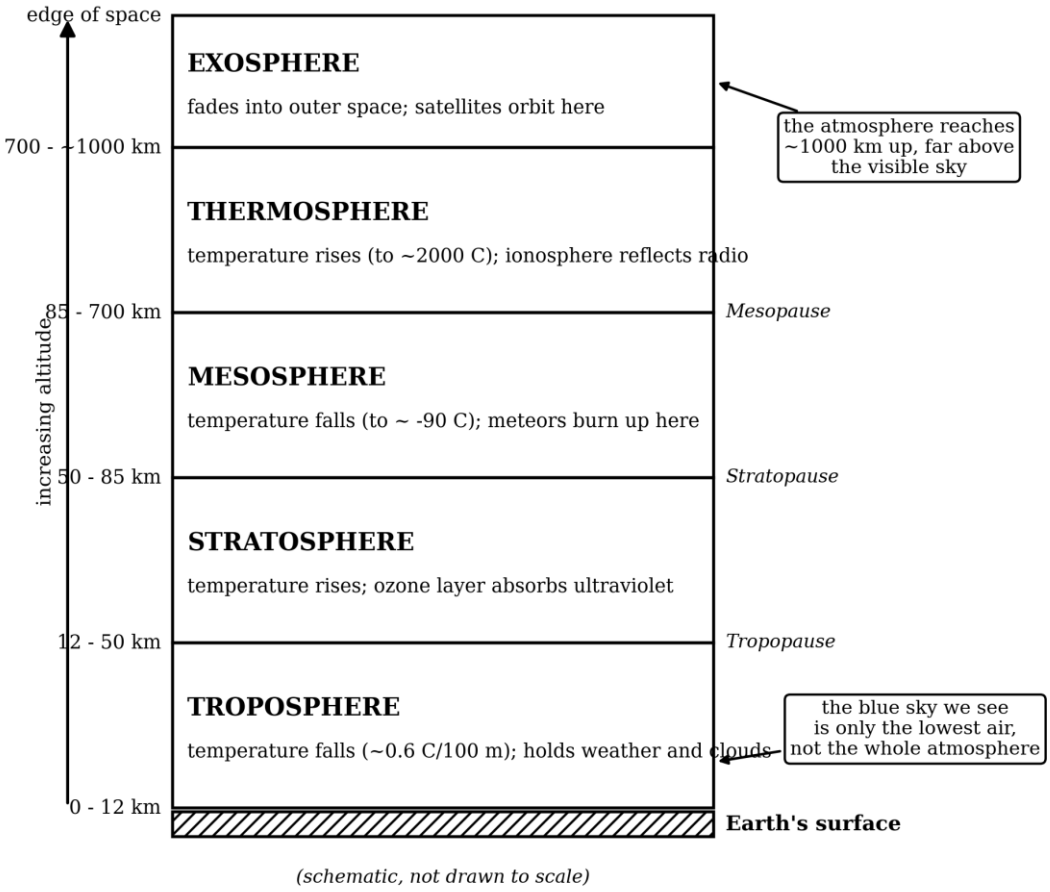


Figure 2.11: *The vertical structure of the atmosphere*

The atmosphere does not end where the blue sky seems to fade, because that blue is only sunlight scattered in the lowest air, while the atmosphere itself reaches far higher and is classified into five layers by the way temperature changes with height.

1) **Troposphere:** the lowest layer, where temperature falls with height and nearly all weather, cloud and rain occur.
2) **Stratosphere:** above it temperature rises, because the ozone layer here absorbs ultraviolet radiation, giving the smooth air used by aircraft.
3) **Mesosphere:** higher still temperature falls again to about minus ninety degrees, and meteors burn up as they enter it.

4) **Thermosphere:** temperature climbs steeply to around two thousand degrees, and its ionosphere reflects radio waves around the curved Earth.

5) **Exosphere:** the outermost layer, which thins gradually into outer space at about one thousand kilometres up, where satellites orbit.

So the visible sky over Mwanza is merely the floor of a deep, layered envelope, and the atmosphere reaches hundreds of kilometres beyond the height at which its blue colour disappears.

How to Draw It

Draw the five layers as horizontal bands in order from the surface upward, label each with its height and whether temperature rises or falls, and mark the pauses between them. The marks lie in the correct order, the temperature behaviour of each layer, and a clear note that the atmosphere reaches about one thousand kilometres, far above the visible sky.

Question 49

Appointed as an environmental officer for your district, you are asked at a public meeting how ordinary choices can help defend the ozone layer. As an expert in Earth-system interactions, explain how you would contribute to protecting the ozone layer from human-made CFCs.

Model Answer

I would act on the source of the damage, because the ozone layer is thinned by chlorofluorocarbons, the CFCs once used in fridges, air conditioners and sprays, so cutting them off protects it.

1) **Phase out CFC products:** I would encourage households and businesses to choose CFC-free refrigerators, air conditioners and aerosols, removing the gases at their source.

2) **Safe disposal:** I would set up proper collection and recycling of old fridges and coolers so their CFCs are not released when the appliances are dumped, a common problem in town dumpsites.

3) **Public education:** I would teach the community, in schools and at meetings across the district, why the ozone shield matters and how their choices affect it.

4) **Support the ban:** I would help enforce Tanzania's commitments under the Montreal Protocol, which phases out ozone-destroying chemicals, and promote the approved substitutes.

Because CFCs linger for many years after release, these steps work by stopping new emissions now, so that the ozone layer can slowly repair itself over the skies of Tanzania.

Question 50

Almost astride the Equator, where travellers expect only heat, the summit of Kilimanjaro has carried ice for thousands of years. Account for the presence of this permanent ice so near the Equator, and explain what its retreat signals for the Earth system.

Model Answer

The ice survives because of Kilimanjaro's great height, not its latitude, since air grows colder with altitude until, near the summit, it stays below freezing all year. Although the mountain sits close to the Equator, temperature falls by about six degrees for every thousand metres of climb, so the air at almost five thousand nine hundred metres is far below freezing even under a tropical sun. At that height snow does not melt away but builds into permanent ice and a small glacier, which belongs to the cryosphere, the frozen part of the hydrosphere. In recent decades, however, the ice on Kilimanjaro has been shrinking fast, and because only a rise in temperature can melt ice that the altitude once preserved, its retreat is a clear local signal that the wider Earth system is warming. The melting therefore acts as a visible warning that the planet's heat balance is being disturbed.

False Confidence Alert
Kilimanjaro is not frozen because it is far from the Equator, since it is not. The ice is kept by altitude, where the air stays permanently below freezing, and its retreat is a sign of a warming Earth system, not an ordinary seasonal change.

Question 51

A farmer in Iringa notices that the maize he plants after a season of beans grows greener and stronger, even though he added no fertiliser. Account for how a bean or soybean plot enriches the soil, using the nitrogen-fixing bacteria in the root nodules.

Model Answer

The bean plot enriches the soil because nitrogen-fixing bacteria living in its root nodules capture nitrogen from the air and turn it into a form that plants and soil can use. The air is almost four-fifths nitrogen, but plants cannot take this gas in directly. Beans and soybeans, however, host Rhizobium bacteria in swellings called nodules on their roots, and these bacteria carry out biological nitrogen fixation, changing nitrogen gas into nitrates and ammonium compounds. The plant uses some of this fixed nitrogen to build its proteins, while the rest enriches the surrounding soil. When the bean roots and stalks are left to decay after harvest, their nitrogen is released into the ground, so the next crop of maize finds a richer seedbed and grows greener without added fertiliser. This is why farmers in Iringa rotate beans with maize, harnessing a link between the atmosphere, the biosphere and the soil of the geosphere.

False Confidence Alert
The bean plant does not make nitrogen, nor does it draw it from the soil. The nitrogen comes from the air, captured by the bacteria in the root nodules, and it is the decay of the roots and residues that finally enriches the soil.

Question 52

As more carbon dioxide collects in the air above the Indian Ocean, the seawater along the Tanzanian coast is slowly turning more acidic. Account for this ocean acidification as atmospheric carbon dioxide rises, and explain the threat it poses to marine life.

Model Answer

The sea grows more acidic because it absorbs some of the extra carbon dioxide from the air, and the dissolved gas forms a weak acid in the water. The ocean acts as a vast carbon sink, taking in carbon dioxide from the atmosphere at its surface. As the amount of the gas in the air rises, more of it dissolves into the seawater, where it reacts with water to form carbonic acid and lowers the water's pH. This matters for marine life because many sea creatures, such as the corals of the reefs off Mafia Island and the shellfish of the coast, build their skeletons and shells from carbonate, and a more acidic sea dissolves that carbonate and starves them of it. Consequently the corals weaken and the reefs that shelter the coast's fish begin to break down, which in turn threatens the fishing communities that depend on them. The same interaction that helps remove carbon from the air therefore carries a hidden cost beneath the waves.

Question 53

The rivers that tumble from Tanzania's highlands are turned into electric light for its cities. Explain how Tanzania harnesses the link between the Sun, the hydrosphere and the land to generate hydropower at Kidatu, Kihansi, Mtera and the Julius Nyerere station.

Model Answer

Tanzania generates this power by capturing the energy of falling water, which is really solar energy passed through the water cycle and the highland forests into the rivers. The Sun evaporates water from the ocean and lakes, and the moist air rises and falls as rain over the highlands, where the forests and soils of the biosphere hold the water and release it steadily into the rivers. Rivers such as the Great Ruaha and the Kihansi then carry this water downhill under gravity. By damming them, the country stores a great head

of water and lets it fall through turbines, whose spinning generators turn the energy of the moving water into electricity. This is done at Mtera and Kidatu on the Great Ruaha, at the steep Kihansi falls, and at the large Julius Nyerere station on the Rufiji. Because the rains keep refilling the rivers, the supply renews itself, so the interaction of Sun, water and land becomes a lasting source of power for homes and industry.

HOT QUESTIONS

Question 54

An examiner claims the Earth is generous with energy but mean with matter, letting energy pass through while keeping its matter locked inside. Assess the claim that the Earth is an open system for energy but a closed system for matter, using insolation and the biogeochemical cycles as evidence.

Model Answer

The claim is largely correct, because energy enters and leaves the Earth freely while matter is almost entirely recycled within the planet rather than gained or lost. For energy the system is plainly open. Insolation arrives without pause from the Sun, drives the winds, the water cycle and photosynthesis, and an equal amount of heat is radiated back to space as long-wave radiation, so energy passes through the Earth instead of being stored for ever. For matter the system is effectively closed, because the Earth gains only a faint dribble of meteoric dust and loses only a little light gas to space. The carbon, oxygen and nitrogen the planet holds are not imported but cycled endlessly through the biogeochemical cycles, so the same carbon moves between air, ocean, life and rock again and again, as in the carbon cycle that links the Tanzanian miombo woodlands to the air above them. The claim therefore holds, with the single qualification that the closure of matter is very nearly, yet not perfectly, complete.

Question 55

A child in Mwanza asks why the daytime sky is blue while the night sky and outer space are black. Explain why the daytime sky appears blue, and why, without the scattering of light, it would appear black even by day.

Model Answer

The sky is blue because air molecules scatter the Sun's blue light across the whole sky, and without that scattering nothing would light the sky, so it would look black even with the Sun shining. Sunlight is a mixture of all colours, and as it passes through the atmosphere the tiny gas molecules scatter the shorter blue wavelengths far more strongly than the longer red ones, in what is called Rayleigh scattering. This scattered blue light then reaches the eye from every direction, so the whole dome of the sky over Mwanza glows blue. If the air did not scatter light, the Sun's rays would travel straight to the ground without being spread out, so away from the Sun's disc the sky would be as dark as space, exactly as it appears to astronauts above the atmosphere. The blue of the day is therefore made by the air itself, not by the colour of the space behind it.

> **False Confidence Alert**
> The sky is not blue because it reflects the blue of the sea, nor because space is blue. It is blue because air molecules scatter the Sun's blue light in every direction; remove the air and the daytime sky would be black.

Question 56

Sailors have long seen a ship's hull vanish over the horizon before its mast, and the midday Sun blazes far hotter at the Equator than near the poles. With the aid of a diagram, justify the statement that the Earth is an oblate sphere, and explain why that shape makes insolation vary from the Equator to the poles.

Model Answer

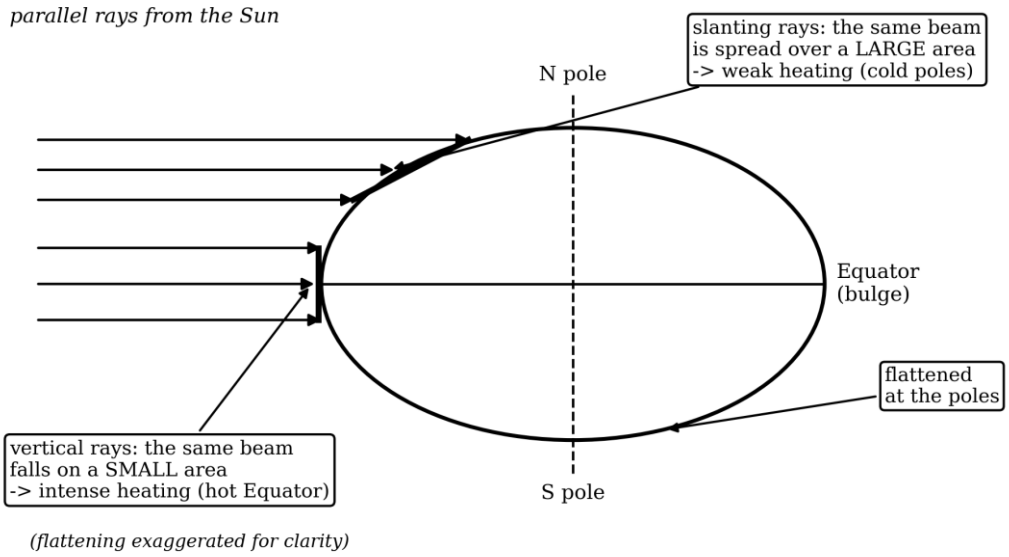


Figure 2.12: *The oblate Earth and the unequal heating of its surface*

The Earth is an oblate sphere, slightly flattened at the poles and bulging at the Equator, and because its curved surface tilts away from the Sun toward the poles, the same sunlight is spread over ever larger areas, so insolation falls from the Equator to the poles. The Earth is not a perfect ball, because its spin makes it bulge a little at the Equator and flatten at the poles, giving the oblate shape drawn in the diagram. The Sun's rays arrive almost parallel, yet they meet this curved surface at different angles. At the Equator they strike nearly straight down, so a beam of energy is concentrated on a small area and heating is intense. Toward the poles the surface tilts away from the rays, so the same beam is spread across a much larger area, and the rays also lose more energy on their longer slanting path through the air, giving feeble heating. This is why the Equator, including the warm lowlands of Tanzania, receives strong insolation all year while the poles stay frozen.

How to Draw It
Draw the Earth as an ellipse that is clearly wider than it is tall, and mark the Equator and the two poles. Show the Sun's parallel rays striking it. Make the rays at the Equator fall straight onto a small area, and the same width of rays near the pole spread over a larger, slanted area. Label the heating concentrated and intense at the Equator and spread and weak at the poles.

Question 57

Whenever climate change is discussed, some insist the climate has always changed on its own, while others blame human industry. Examine the claim that climate change is driven by both natural and human factors, and weigh which of the two now dominates.

Model Answer

Both natural and human factors do change the climate, but the evidence shows that human activity now dominates the rapid warming of the present age. It is true that natural factors have always altered the climate, because slow changes in the Earth's orbit, swings in the Sun's output and great volcanic eruptions have warmed and cooled the planet across the ages, and these still act today. However, the warming of the last century has been far faster than any natural cycle can explain, and it matches closely the sharp rise in carbon dioxide and methane from burning fossil fuels, clearing forests and expanding industry. The natural drivers move slowly and, if anything, should be cooling the Earth slightly now, so they cannot account for the speed of the change. The reasonable conclusion is that, while nature sets the slow background, human emissions are the dominant force behind today's warming, a warming already read in the failing rains and the shrinking ice on Kilimanjaro.

False Confidence Alert
Saying the climate has always changed naturally is true but is not a defence. The present warming is far too fast for natural cycles and it tracks human emissions closely, so the dominant cause today is human, not natural.

Question 58

A student remarks that greenhouse gases are dangerous and the world would be better off without them. Evaluate the heat budget as a double-edged balance, explaining why without greenhouse gases the Earth would be too cold for life, yet with too many it overheats.

Model Answer

Greenhouse gases are neither simply good nor simply bad, because the right amount keeps the Earth warm enough for life while too much tips the heat budget into harmful warming. The heat budget is the balance between the solar energy the Earth absorbs and the long-wave heat it radiates back to space, and greenhouse gases such as carbon dioxide and water vapour slow the escape of that outgoing heat. With a natural amount of them the planet holds a comfortable average of about fifteen degrees, whereas with none at all the Earth would freeze to roughly minus eighteen degrees, far too cold for life or farming, so the blanket of greenhouse gas is essential. However, when human activity thickens that blanket, too little heat escapes, the balance tips, and the planet overheats, bringing the droughts and fiercer storms now troubling Tanzanian farmers. The gases are therefore double-edged, and the student is mistaken to wish them away, because the goal is the right balance, not their removal.

False Confidence Alert
The greenhouse effect is not wholly harmful. Without it the Earth would be frozen and lifeless; the real problem is only the extra gases that human activity adds, which push a life-giving balance too far.

Question 59

Asked which part of the air they could least afford to lose, a class names oxygen at once, but their teacher is not so sure. Assess which single component of the atmosphere is the most indispensable to life, defending your choice against the rival candidates.

Model Answer

Oxygen is the strongest single choice, because almost all life releases its energy by breathing oxygen, although the defence must answer serious rivals. Oxygen, about a fifth of the air, is indispensable because humans, animals and plants all depend on it for respiration, and without it complex life would die within minutes, so no Tanzanian forest or fishery could survive. The rivals are real, however. Carbon dioxide, though tiny in amount, feeds the photosynthesis that makes all food and, in time, the oxygen itself, so a case can be made for it. Nitrogen builds the proteins of every cell, and the ozone form of oxygen shields life from ultraviolet rays. Yet carbon dioxide and nitrogen support life slowly and indirectly, whereas the loss of oxygen would end animal life almost at once. Weighing immediacy against importance, oxygen is the most indispensable, with carbon dioxide its closest challenger because it ultimately renews the oxygen supply.

Question 60

A meteorologist in Dar es Salaam says the air above us is never the same from one day to the next. Examine the claim that the atmosphere is never stable, using its variable gases, its water vapour and its load of particles as evidence.

Model Answer

The claim is well founded, because the very components that make up the atmosphere are constantly changing in amount from place to place and from hour to hour.

1) **Variable gases:** carbon dioxide and ozone rise and fall with the seasons, with plant growth and with human burning, so the make-up of the air is never fixed.
2) **Water vapour:** its share swings from almost nothing in dry air to about four per cent over the humid coast at Dar es Salaam, changing with heat, place and weather by the hour.
3) **Particle load:** dust, smoke and aerosols pour into the air in the dry season and after fires, then are washed out by the rains, so the air thickens and clears again and again.

Because each of these is forever shifting, the atmosphere is indeed a restless, ever-changing envelope rather than a stable one, which is exactly why weather can be forecast only a few days ahead.

Question 61

Before a flight from Kilimanjaro International Airport climbs to its cruising height, its crew must know the air it will pass through. Examine why studying the layers of the atmosphere is useful to the aviation industry.

Model Answer

Studying the layers is useful to aviation because each layer offers very different flying conditions, and crews must match their aircraft and route to them.

1) **Avoiding weather in the troposphere:** nearly all storms, cloud and turbulence sit in the lowest layer, so knowing this helps crews plan to climb above the worst weather.
2) **Cruising in the stratosphere:** the air just above the tropopause is smooth and storm-free because temperature there rises with the ozone, so airliners cruise in the lower stratosphere to save fuel and ride steadily.
3) **Thin air and pressurisation:** the air thins quickly with height, so engineers must pressurise the cabin and supply oxygen, a need drawn straight from the vertical structure.
4) **Radio beyond the horizon:** the ionosphere high above reflects radio waves, allowing controllers to keep contact with aircraft far beyond the curve of the Earth.

Knowing the layers therefore guides safe heights, fuel-saving routes, aircraft design and communication for every flight out of Kilimanjaro.

Question 62

Asked which layer of the atmosphere life could least do without, a student picks the highest one, nearest the Sun. Assess which single layer of the atmosphere is the most indispensable to life, and defend your choice.

Model Answer

The troposphere is the most indispensable layer, because it holds the air we breathe, the weather and almost all the water vapour, although the stratosphere is a powerful rival. The troposphere, the lowest layer, is where life actually lives. It contains about three-quarters of the atmosphere's mass, the oxygen and carbon dioxide that breathing and photosynthesis need, and nearly all the cloud and rain that water the farms and rivers of Tanzania. Without it there would be no weather and no breathable air, so life would be impossible, which already shows the student's choice of a high layer to be mistaken. One rival deserves respect, since the stratosphere holds the ozone layer that screens out deadly ultraviolet rays, and without that shield the surface would be sterilised. Weighing the two, the troposphere still wins, because it supplies the immediate needs of every living thing whereas the stratosphere only protects them; both matter, but life depends on the troposphere first and most directly.

Question 63

In a debate, each group defends a different sphere as the one the others could not exist without. Assess which of the four spheres is the most fundamental to the existence of the other three.

Model Answer

The geosphere has the strongest claim to be the most fundamental, because it provides the solid platform and the raw materials on which the other three spheres rest, though the case is finely balanced. The geosphere, the solid Earth, came first and supplies the ground that holds the oceans, the minerals that build the soil, and the gases that, released by ancient volcanoes, first formed the atmosphere and the seas. Without it there would be no basin for the hydrosphere, no land for the biosphere and no original source for much of the atmosphere. Its rivals are genuine, since the atmosphere gives the air and warmth that life needs and the hydrosphere gives the water, so neither can be dismissed. Yet both the air and the water ultimately depend on the rock that released and still contains them, as the rich volcanic soils of the Tanzanian highlands show by feeding the whole web of life there. The geosphere is therefore the foundation, even though the spheres are so linked that none could truly stand alone.

Question 64

Although the frozen world is a small part of the planet, scientists watch it more closely than almost anything else. Examine the view that the cryosphere, though small, influences global climate out of all proportion to its size.

Model Answer

The view is correct, because the cryosphere, despite its small size, controls how much sunlight the Earth reflects and how sea levels and ocean currents behave, giving it a reach far beyond its bulk. The cryosphere is the frozen water of the planet, its ice sheets, glaciers and snow, and although it is a thin and shrinking part of the hydrosphere it works as a powerful regulator. Its bright white surface has a very high albedo, so it reflects most of the sunlight that strikes it and helps to keep the whole Earth cool. When it melts, dark ocean or land is uncovered, which absorbs far more heat and speeds up the warming, a runaway link that magnifies its influence. Melting ice also raises sea levels across the world and pours cold fresh water into the oceans, which can disturb the currents that share out global heat. Even the small tropical glacier on Kilimanjaro serves as a sensitive gauge of this change. The cryosphere therefore steers the climate out of all proportion to its size.

False Confidence Alert
A small sphere is not a minor one. The cryosphere's bright ice reflects sunlight for the whole planet, so its shrinking speeds global warming; size is no measure of importance.

Question 65

No living thing in Tanzania, from the miombo tree to the farmer, is fed by one sphere alone. With the aid of a diagram, explain how the interactions among the four spheres support the lives of humans and other organisms.

Model Answer

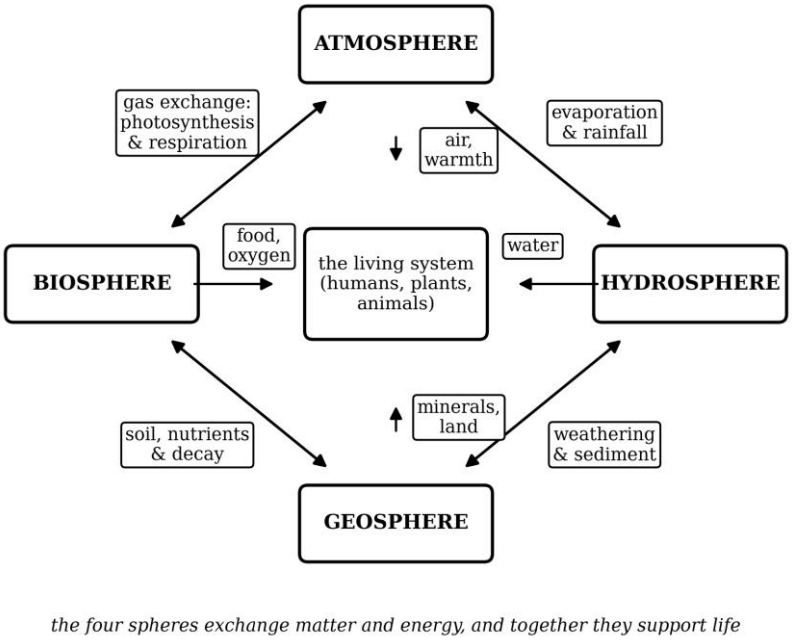


Figure 2.13: *How the interactions among the four spheres support life*

Life is supported not by any single sphere but by the constant exchanges between all four, each interaction supplying something that living things need, as the diagram shows.

1) **Atmosphere and biosphere:** the air gives oxygen for breathing and carbon dioxide for photosynthesis, so the gas exchange between them powers every food chain.
2) **Atmosphere and hydrosphere:** the Sun lifts water from the sea into the air and returns it as rain, watering the crops and filling the rivers that people drink from and farm beside.
3) **Geosphere and biosphere:** the weathering of rock builds the soil and releases the minerals that plants need, turning bare rock into the fertile land of the highlands.
4) **Hydrosphere and geosphere:** water shapes the land and carries nutrients downstream, while the rock holds and channels the water on which life depends.

Because these exchanges meet at the centre, where humans, plants and animals draw air, water, food and minerals from the linked spheres, it is the web of interactions, not any one part, that makes life possible.

How to Draw It
Place the four spheres around a central box marked life. Join each neighbouring pair with a double-headed arrow labelled with their exchange, such as evaporation and rainfall or gas exchange, and draw an arrow from each sphere to the centre showing what it gives life, such as air, water, food and minerals.

Question 66

Human hands now reach into every sphere, and what we change in one returns to us through the others. Explain how human actions alter the natural interactions of the spheres, and outline the consequences for human development.

Model Answer

Human actions break into the natural exchanges between the spheres, and because the spheres are linked, each disturbance returns to affect human development.

Burning and the air: burning fossil fuels and forests floods the atmosphere with carbon dioxide, which warms the climate and in turn brings the droughts and floods that harm farming and health.

Deforestation and water: clearing the highland forests that feed Tanzania's rivers weakens the water cycle, so streams run dry or flood, threatening hydropower and irrigation.

Mining and soil: stripping land for mining and farming exposes the geosphere, speeding the erosion that silts rivers and dams and ruins fertile soil.

Pollution and the sea: waste and excess carbon dioxide pollute and acidify coastal waters, damaging the reefs and fisheries that coastal people live on.

Because every one of these alterations feeds back through the linked spheres, careless development undermines the very resources, the water, soil, climate and sea, on which lasting development depends.

Question 67

When a factory dumps its waste into a river, officials treat it as only a water problem. Evaluate the statement that the spheres are so interconnected that no environmental problem ever stays inside a single sphere.

Model Answer

The statement is sound, because the spheres exchange matter and energy so freely that a problem starting in one of them quickly spreads into the others. A disturbance rarely stays where it begins. Carbon dioxide released into the atmosphere does not remain there, since it dissolves into the ocean and acidifies it, and it warms the climate that melts the ice and shifts the rains. The waste poured into a river, as in the example, passes from the hydrosphere into the soil and crops of the geosphere and biosphere, and finally into the people who eat them. Even an apparently local act, the clearing of a Tanzanian hillside, sends soil into the rivers, alters the local rainfall and releases carbon to the air. Because every sphere is joined to the others by the cycles of water, carbon and nutrients, the effects leak across the boundaries. The statement therefore holds as a fair general rule, with only the mild qualification that some problems spread faster and farther than others, while almost none stays sealed in one sphere.

False Confidence Alert
Do not treat a problem as belonging to one sphere alone. River pollution becomes a soil, crop and health problem, and air pollution becomes an ocean and climate problem, because the spheres are all connected.

Question 68

Two scientists argue over what truly keeps the Earth's temperature in check: one points to the gases of the air, the other to the green world of plants. Using the carbon cycle, assess whether the atmosphere or the biosphere is the more powerful regulator of the Earth's temperature.

Model Answer

Using the carbon cycle, the atmosphere is the more powerful regulator, because it holds the greenhouse gases that set the temperature directly, while the biosphere mainly adjusts how much of that gas the air contains. Temperature is governed by the heat budget, and the atmosphere controls it directly through its greenhouse gases, chiefly carbon dioxide, which decide how much heat escapes to space. In the carbon cycle the biosphere is a mighty pump, since plants such as the Tanzanian miombo and the ocean plankton draw carbon dioxide out of the air by photosynthesis and return it by respiration and decay, so the biosphere strongly influences the level of the gas. Yet the biosphere acts on the temperature only by changing the atmosphere's carbon load, for it has no direct hold on the heat budget. The atmosphere, by contrast, sets the temperature whatever the source of its gases. The biosphere is therefore the more powerful regulator of carbon, but the atmosphere is the more powerful regulator of temperature, because it is where the greenhouse control finally rests.

Chapter 3

ENDOGENIC PROCESSES OF THE EARTH

This chapter turns from the Earth as a system to the forces that build the land from within. Driven by the Earth's own internal heat, the endogenic processes raise mountains, tear open valleys, shake the ground and pour out molten rock. Its sixty-four questions run in three tiers and are best worked in order.

BINDER questions build the core explanation of each process: the earthquakes and their waves, the volcanoes and their features, and the faults and folds and the landforms they leave, many with the help of a labelled diagram. REAL questions carry that understanding into real Tanzanian settings, the Kagera earthquake, the volcanoes and lakes of the Rift, and the reversed rivers of the plateau. HOT questions ask you to weigh these forces against one another and to judge their work on the land and on human life.

BINDER QUESTIONS

Question 1

Standing on the floor of the Great Rift Valley near Dodoma, it is hard to believe the solid ground was lifted and dropped by forces deep inside the Earth. Explain what the endogenic processes are, and account for the internal energy that drives them.

Model Answer

Endogenic processes are the movements and forces that originate within the Earth and shape its crust from below, powered by the planet's own internal energy rather than by the Sun. They work from inside the Earth, so they raise and lower the land, crack it and pour molten rock onto it, building the major relief features. Their energy comes from several internal sources acting together: the heat left over from the Earth's fiery origin, called primordial heat, and the steady heat released by the decay of radioactive minerals deep within, together with the lesser effects of the Earth's rotation and the tidal friction of the Moon's pull. Because this energy keeps the interior hot and restless, the crust above is never still, which is why the land around Dodoma carries the marks of uplift and rifting.

Question 2

The crust beneath Tanzania has been pushed sideways to crumple it and snapped downward to drop a valley floor, two very different kinds of movement. Explain how the horizontal movements of the crust differ from the vertical ones, and the landforms each produces.

Model Answer

Endogenic forces move the crust in two ways, horizontally and vertically, and each builds a different family of landforms. Horizontal movements act sideways, and they are of two kinds: compression, which squeezes the crust face to face and folds it into ridges and fold mountains, and tension, which pulls it apart and cracks it into faults. Vertical movements act up and down, raising large areas in up-warping and lowering them in down-warping, so they lift plateaus and continental blocks or let basins sink. Because the two work together, a single region such as the Tanzanian highlands can show both the broad uplift of vertical movement and the faulting of horizontal tension. The direction of the force, sideways or up and down, therefore decides the shape of the land it leaves.

Question 3

Geographers group the slow, building movements of the crust under one name, diastrophism, yet within it lie two very different forces. Explain diastrophism, and distinguish its orogenic forces from its epirogenic forces.

Model Answer

Diastrophism is the group of slow endogenic forces that move, lift and build large parts of the Earth's crust, and it works through two kinds of force, orogenic and epirogenic. Orogenic forces are the mountain-building forces. They act horizontally, squeezing or stretching the crust along narrow belts to fold and fault it into mountain ranges and rift systems, as along the East African Rift. Epirogenic forces,

by contrast, act vertically over very large areas, raising the land in broad uplift, called emergence, or lowering it, called submergence, without much folding. So orogenic forces build the narrow mountain belts while epirogenic forces raise and lower whole plateaus and coasts, such as the broad upwarp of the central Tanzanian plateau. Both are slow and both reshape the crust, but one crumples it locally while the other lifts it wholesale.

False Confidence Alert
Orogenic is not the same as epirogenic. Orogenic forces build mountain belts by horizontal squeezing, whereas epirogenic forces raise or lower whole regions vertically; the first makes ranges, the second makes plateaus and coasts.

Question 4

From the deep trough of Lake Tanganyika to the snow-capped cone of Kilimanjaro, the boldest features of the Tanzanian landscape are the work of forces from within. Account for the major relief features that endogenic forces build.

Model Answer

The great relief features of the Earth are built by endogenic forces working from within, which raise, crumple, crack and pile up the crust. Where the crust is squeezed, it is folded upward into fold mountains and ridges. Where it is stretched, it cracks along faults and drops to form rift valleys and the deep lakes that fill them, such as Tanganyika and Nyasa. Where molten rock breaks through, it builds volcanoes and lava plateaus, such as the cone of Kilimanjaro. On the ocean floor the same forces raise mid-ocean ridges and open deep trenches. Because these features are all the product of internal movement and heat, the endogenic processes are rightly called the builders of the Earth's major relief, on which the exogenic forces of weather and water then go to work.

Question 5

In September 2016 the ground beneath the Kagera region of north-west Tanzania shook violently for a few seconds, toppling buildings. Explain what an earthquake is, and what is meant by the seismicity of an area.

Model Answer

An earthquake is a sudden shaking or trembling of the Earth's surface caused by the rapid release of energy stored in the rocks of the crust. Over many years the slow movement of the crust builds up stress in the rocks along zones of weakness. When the rocks can bend no further, they suddenly break or slip, and the stored energy is released at once as seismic waves that spread out and shake the ground, as happened at Kagera. The point where the rupture begins is the focus, and the waves race outward from it. The seismicity of an area is its earthquake character, meaning the frequency, the type and the size of the earthquakes that have occurred there over time. A place on an active fault, like the East African Rift, therefore has high seismicity, while a stable interior has low seismicity.

Question 6

Not every earthquake has the same origin: some are born of moving plates, others of erupting volcanoes, and some of human hands. Classify earthquakes according to their cause, with an example of each.

Model Answer

Earthquakes are classified by cause into four kinds, three of them natural and one human-made.

1) **Tectonic:** caused by the movement and displacement of crustal plates along faults, the commonest and most destructive kind, as along the East African Rift.
2) **Volcanic:** caused by the movement of magma and the explosions of an erupting volcano, felt around active volcanoes such as Oldonyo Lengai.
3) **Isostatic:** caused by the sudden adjustment of the crust as it seeks balance after a great load is added or removed at a regional scale.

4) **Artificial (human-made):** caused by human activity such as blasting in mining, the building of large dams and underground explosions.

Because the tectonic kind springs from the same plate movement that built the Rift, it is the type that most concerns East Africa.

Question 7

Earthquakes are also grouped by how deep below the surface they begin, because depth changes the damage they do. Distinguish the three classes of earthquake based on the depth of focus, and explain why the shallow ones are the most destructive.

Model Answer

By the depth of their focus, earthquakes fall into three classes, and the shallower the focus, the greater the surface damage.

1) **Shallow earthquakes:** the focus lies between 0 and 70 kilometres deep; these are the commonest and the most destructive, because their energy reaches the surface with little weakening.
2) **Intermediate earthquakes:** the focus lies between 70 and 300 kilometres deep, so the shaking at the surface is more spread out and weaker.
3) **Deep earthquakes:** the focus lies between 300 and 700 kilometres deep, and these do the least surface damage because the energy is spent rising through so much rock.

This is why the shallow earthquakes of the East African Rift, such as the Kagera shock, threaten buildings far more than a deep one of the same magnitude would.

Question 8

When the Kagera earthquake was reported, the news spoke of both its focus deep underground and its epicentre at the surface. With the aid of a diagram, explain the difference between the focus and the epicentre of an earthquake.

Model Answer

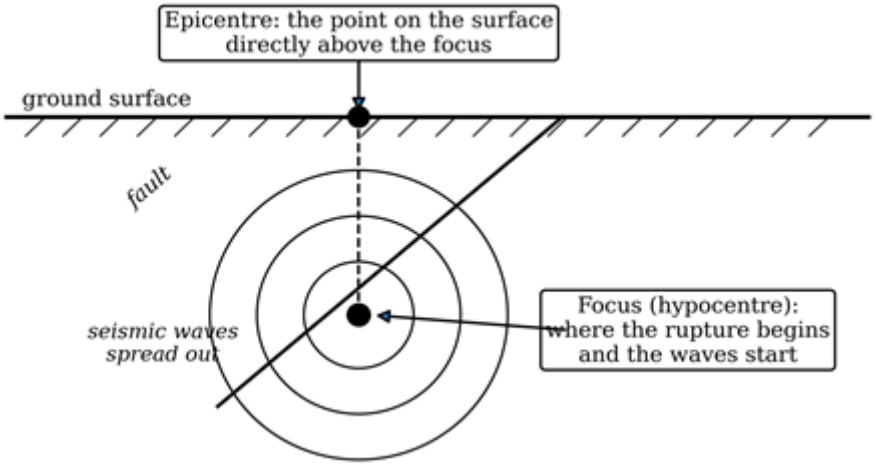


Figure 3.1: *The focus and epicentre of an earthquake*

The focus is the point inside the Earth where an earthquake begins, while the epicentre is the point on the surface directly above it. The focus, also called the hypocentre, is the place underground, along a fault, where the rocks first rupture and the seismic waves are released, and from there the waves spread outward in all directions. The epicentre is the point on the ground vertically above the focus, and because it is nearest to the focus it usually suffers the strongest shaking, as the area above the Kagera focus did. The deeper the focus, the further the waves must travel to reach the surface, so a deep-focus earthquake shakes its epicentre less than a shallow one. The two terms therefore describe the same event from two places: the focus where it starts, the epicentre where it is felt most.

How to Draw It
Draw a cross-section of the crust with the ground surface on top. Mark a fault, place the focus on it underground, and draw a dot on the surface directly above for the epicentre, joined by a vertical dashed line. Add arcs spreading from the focus for the seismic waves, and label all three.

False Confidence Alert
The focus and the epicentre are not the same point. The focus is underground where the rupture starts; the epicentre is on the surface directly above it. Marks are lost for placing the focus on the surface.

Question 9

A seismograph in Dar es Salaam recording a distant earthquake catches its fast P-waves first and its slower S-waves moments later. With the aid of a diagram, distinguish the P-waves from the S-waves of an earthquake.

Model Answer

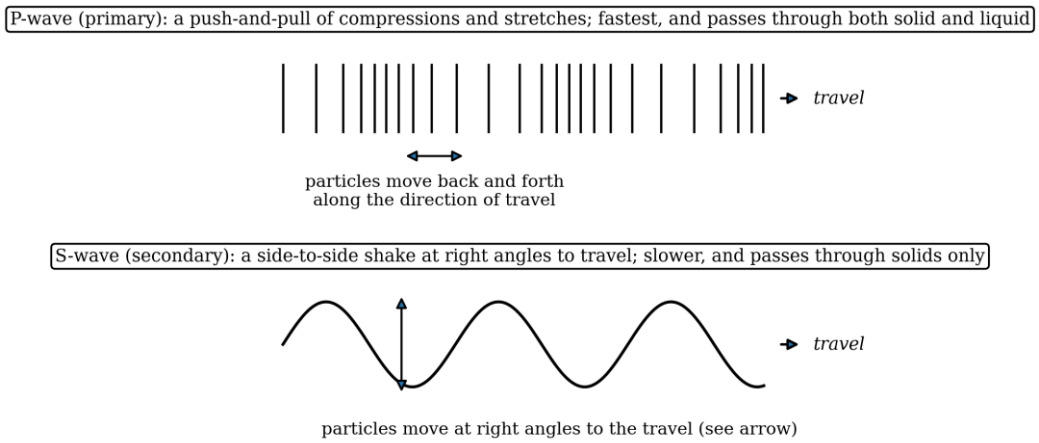


Figure 3.2: *The P-waves and S-waves of an earthquake*

P-waves and S-waves are the two body waves of an earthquake, and they differ in how their particles move, in their speed and in what they can pass through. P-waves, the primary waves, move the rock particles back and forth along the direction the wave travels, in a push-and-pull of compressions and stretches. They are the fastest waves, so they arrive first, and they pass through both solids and liquids. S-waves, the secondary waves, move the particles from side to side at right angles to the direction of travel. They are slower, so they arrive second, and they pass through solids only, being stopped by liquids. This difference is useful, because the gap in arrival time between the P and S waves at a station like Dar es Salaam tells geologists how far away the earthquake was.

How to Draw It
Draw two strips. For the P-wave show bands of bunched and stretched lines with a back-and-forth arrow along the travel direction; for the S-wave show a sideways wavy line with an arrow at right angles to travel. Label the speed of each and what each passes through.

False Confidence Alert
P-waves and S-waves are told apart by their motion, not their size. P-waves push and pull along the line of travel and cross liquids; S-waves shake across it and cannot. Confusing the two loses the marks.

Question 10

Although the surface waves of an earthquake arrive last, it is they that flatten the houses. With the aid of a diagram, explain why the surface waves (Love and Rayleigh waves) cause most of an earthquake's destruction.

Model Answer

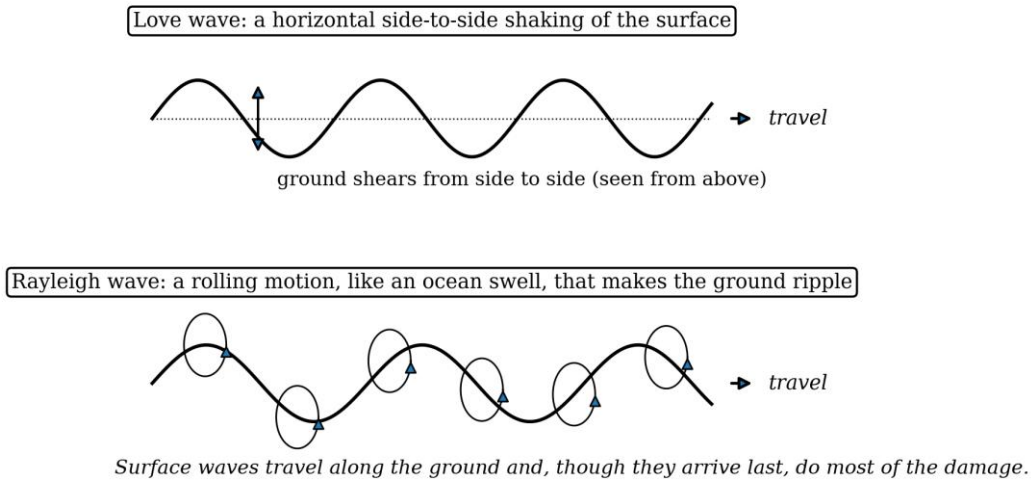


Figure 3.3: *Surface waves: the Love wave and the Rayleigh wave*

Surface waves cause most of the destruction because they travel along the ground itself, shake it most strongly and last longest, even though they arrive last. Surface waves form when the body waves reach the surface, and they are of two kinds. Love waves shake the ground from side to side in the horizontal plane, while Rayleigh waves roll it in an up-and-down, circular motion like an ocean swell. Because they are trapped at the surface where buildings stand, and because they move more slowly while their shaking is larger and lasts longer, they rock and twist structures far more violently than the deeper body waves. This is why the worst damage to buildings, such as those that collapsed at Kagera, comes from the surface waves rather than from the faster P and S waves that arrive first.

How to Draw It
Draw two strips: a Love wave as a line shearing from side to side seen from above, and a Rayleigh wave as a rolling, swell-like ripple seen in section. Note that both run along the surface and arrive last but shake hardest.

False Confidence Alert
Arriving last does not mean doing least. The surface waves come after the P and S waves, yet because they run along the surface and shake hardest and longest, they cause most of the damage.

Question 11

Earthquakes are not all caused in the same way, and East Africa feels several of their causes at once. Account for the main causes of earthquakes.

Model Answer

Earthquakes are caused by anything that suddenly disturbs the balance of the crust and releases stored energy.

1) **Lack of crustal equilibrium:** stress builds where the crust is out of balance until the rocks break, which is the basic cause of most earthquakes.

2) **Faulting and folding:** the sudden slipping of rocks along a fault, or their sharp bending, jolts the ground, as along the East African Rift.
3) **Vulcanicity:** the movement of magma and the explosions of an erupting volcano shake the surrounding ground, as near Oldonyo Lengai.
4) **Warping and gases:** the vertical up-warping and down-warping of large blocks, and the expansion of gases within the Earth, release energy as tremors.
5) **Human activity:** mining blasts, underground explosions and the filling of large dams can also trigger shaking.

In East Africa the causes tied to the splitting of the plate along the Rift, the faulting and the vulcanicity, are the most important.

Question 12

However far away an earthquake strikes, a delicate instrument in a Tanzanian observatory can record it. With the aid of a diagram, explain how a seismograph records an earthquake.

Model Answer

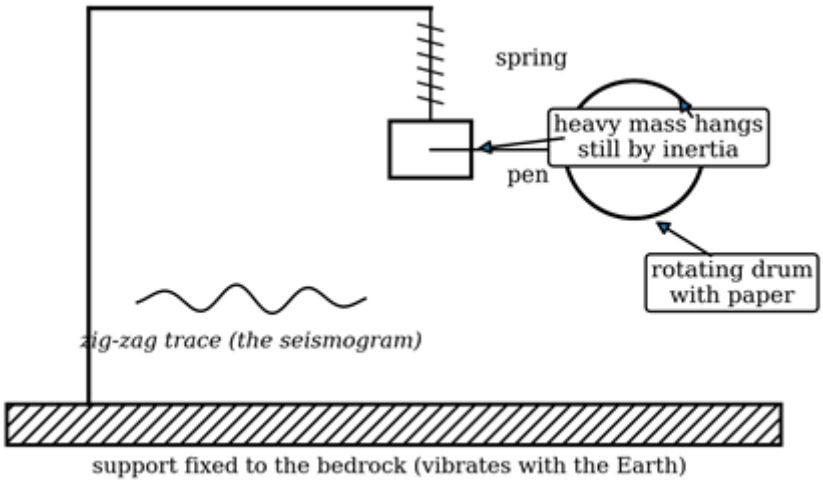


Figure 3.4: *How a seismograph records an earthquake*

A seismograph records an earthquake by keeping one heavy part still while the rest of the instrument shakes with the ground, so the difference between them is traced on paper. The instrument has a heavy mass hung from a spring on a frame that is fixed firmly to the bedrock. When seismic waves arrive, the frame, the drum and the bedrock all vibrate with the Earth, but the heavy mass, because of its inertia, tends to stay still. A pen attached to the still mass rests against a sheet of paper wrapped around a slowly rotating drum. As the drum shakes beneath the steady pen, the pen draws a zig-zag line on the paper. This record, the seismogram, shows the arrival and the strength of the P, S and surface waves, so geologists can read the size and the distance of even a far-off earthquake.

How to Draw It
Draw a frame fixed to the bedrock, a heavy mass hanging on a spring, a pen from the mass touching a rotating drum of paper, and a zig-zag trace. Label the still mass, the spring, the drum and the trace, and note that the base shakes while the mass stays still.

Question 13

The Kagera earthquake was reported both as magnitude 5.9 and as intensity seven, two numbers that measure different things. Distinguish the magnitude of an earthquake from its intensity.

Model Answer

Magnitude measures the energy an earthquake releases, while intensity measures the strength of its shaking and damage at a particular place. Magnitude is a single figure for the whole earthquake, fixed by the energy released at the focus and read from the size of the waves on a seismograph. It is given on scales such as the Richter scale, devised by Charles Richter, and the moment magnitude scale used for the largest shocks, so the Kagera earthquake had one magnitude, 5.9, wherever it was measured. Intensity, by contrast, varies from place to place, because it describes how strongly the ground shook and how much damage was done at each spot, judged from observations and given in Roman numerals on the Mercalli scale. Intensity is greatest near the epicentre and fades with distance, so one earthquake has a single magnitude but many intensities.

False Confidence Alert
Magnitude and intensity are not the same. Magnitude is one number for the whole earthquake, the energy released; intensity is the shaking felt at one place and changes with distance from the epicentre.

Question 14

In 2004 an earthquake under the Indian Ocean sent waves that reached the Tanzanian coast and killed people as far away as the East African shore. With the aid of a diagram, explain how an undersea earthquake generates a tsunami.

Model Answer

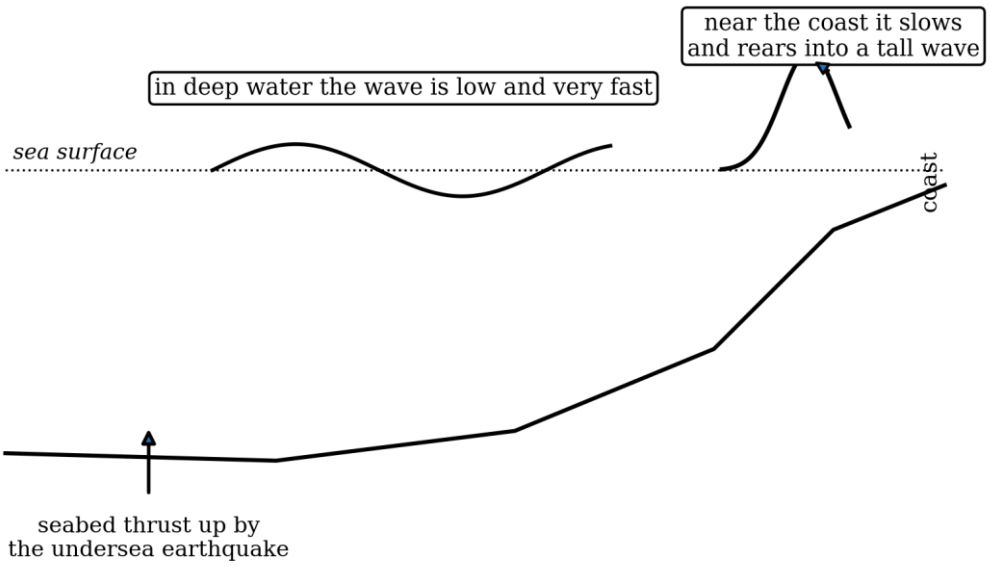


Figure 3.5: *How an undersea earthquake generates a tsunami*

A tsunami is generated when a large undersea earthquake suddenly lifts or drops the seabed, displacing a huge mass of water that travels outward as fast, low waves which rear up at the coast. When a shallow undersea earthquake of about magnitude 7.5 or more jerks the seafloor upward, the whole column of water above is pushed up with it, and this displaced water spreads out in all directions as a series of waves. In the deep ocean the waves are very low, often less than a metre high, with great distances between them, so they race along at hundreds of kilometres an hour and pass unnoticed beneath ships. As they reach the shallow water near a coast, they slow down and the water piles up into a tall, fast wall that floods far inland, as happened along the East African coast in 2004. The energy spread thinly across the open ocean is thus concentrated onto the shore.

How to Draw It
Draw a sea-floor section rising to a coast on the right. Show the seabed thrust up by a fault on the left, a low long wave in deep water, and the same wave rearing into a tall wave near the shore. Label the deep-water and the shore stages.

False Confidence Alert
A tsunami is not one single giant wave that is visible far out at sea. In deep water it is low and unnoticed; it only rears into a towering wave as it reaches the shallow coast.

Question 15

When Oldonyo Lengai pours out its dark lava, it shows only the surface of a process that also works hidden in the crust. Explain what vulcanicity is, distinguishing magma from lava and intrusive from extrusive activity.

Model Answer

Vulcanicity is the whole range of processes by which molten rock, gases and fragments move from the Earth's interior into or onto the crust. Deep in the Earth the rock is kept solid by great pressure, but where folding or faulting releases that pressure it melts into a mobile molten rock. While this molten rock is still below the surface it is called magma; once it escapes onto the surface it is called lava. Vulcanicity covers both fates of the molten rock. When the magma cools and hardens within the crust, the activity is intrusive and forms hidden bodies such as the batholith. When it breaks through and cools on the surface, the activity is extrusive and builds volcanoes and lava plateaus, such as the cone of Oldonyo Lengai. Vulcanicity is therefore the entire journey of molten rock, both the part that stays buried and the part that erupts.

False Confidence Alert
Magma and lava are the same material in different places, not two different substances. It is magma while below the surface and lava once it erupts; the names mark where it is, not what it is.

Question 16

Some volcanoes pour lava quietly from a long crack, while others blast it from a single throat. Distinguish a fissure eruption from a central eruption, and the landforms each builds.

Model Answer

An eruption is either a fissure eruption, where lava escapes quietly along a long crack, or a central eruption, where it is forced through a single vent. In a fissure eruption the lava wells up along a long, narrow crack in the crust and spreads out widely before it cools. The lava is usually thin and runny, so the eruption is quiet, and the spreading sheets pile up into broad, flat lava plateaus. In a central eruption the molten rock is driven up through one central pipe and out of a single vent, often with great violence as gases explode. The material falls around the vent and builds a cone or dome, sometimes with a crater at the top, as at Kilimanjaro and Oldonyo Lengai. So the shape of the opening, a long crack or a single vent, decides whether the land gains a wide plateau or a built-up cone.

Question 17

Tanzania's volcanoes are not all alike: one still erupts, one only sleeps, and one is long dead. Explain the classification of volcanoes by their state of activity, with a Tanzanian example of each.

Model Answer

By their state of activity, volcanoes are classified as active, dormant or extinct, according to how recently and how likely they are to erupt.

1) **Active:** a volcano that erupts frequently or has erupted in recent times and may erupt again, such as Oldonyo Lengai in northern Tanzania, which still erupts today.
2) **Dormant:** a sleeping volcano that has not erupted for a long time but could erupt again, such as Mount Kilimanjaro and Mount Meru.
3) **Extinct:** a volcano that has not erupted in recorded history and is not expected to again, its vent often worn down, such as Mount Rungwe in the southern highlands.

The line between dormant and extinct is not always sharp, so a volcano thought to be sleeping must still be watched.

False Confidence Alert
A dormant volcano is not a dead one. Kilimanjaro only sleeps and could erupt again, whereas an extinct volcano like Rungwe is not expected to; treating a dormant volcano as extinct is a dangerous error.

Question 18

The lava that builds a steep, dangerous cone is not the same as the lava that spreads into a gentle plain. Account for the difference between acidic and basic lava, and what each tends to build.

Model Answer

Acidic and basic lava differ in how much silica they contain, and this makes acidic lava thick and explosive while basic lava is thin and free-flowing. Acidic lava is rich in silica, which makes it very viscous, or sticky, so it flows slowly and hardens quickly near the vent. Because gases cannot escape easily through it, pressure builds and the eruption is violent and explosive, piling up steep-sided cones and domes. Basic lava is low in silica, so it is fluid and runny; it flows quietly and travels a long way before it solidifies, and its gases escape gently. It therefore spreads into broad, gentle shield volcanoes and lava plateaus, as the fluid lavas of the Rift floor have done. The chemistry of the lava thus decides both the violence of the eruption and the shape of the land it builds.

False Confidence Alert
Acidic lava is not the runny kind. Being rich in silica it is the thick, sticky, explosive lava that builds steep cones, whereas the runny, far-flowing lava is the basic, silica-poor kind.

Question 19

Beneath many a worn-down highland lies a mass of igneous rock that never reached the surface. With the aid of a diagram, explain how the batholith, the sill and the dyke are formed within the crust.

Model Answer

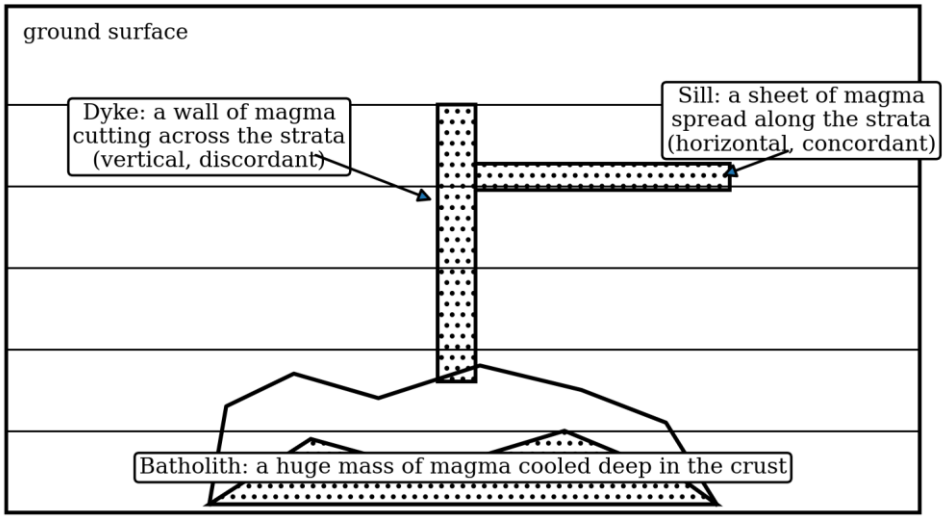


Figure 3.6: *Intrusive features: the batholith, sill and dyke*

Intrusive features form where magma cools and hardens inside the crust, and the batholith, the sill and the dyke differ in their size and in how they sit among the surrounding rocks.

1) **Batholith:** a very large mass of magma that cools slowly deep in the crust, often beneath a mountain range, forming coarse granite that appears at the surface only after the rocks above are worn away.
2) **Sill:** a thin sheet of magma that spreads along the bedding planes of the rocks, lying parallel to them (concordant), and may stand out as a hard ledge when exposed.
3) **Dyke:** a wall-like sheet of magma that cuts across the bedding planes (discordant), usually standing vertical or steeply inclined.

Once erosion strips the overlying rock, these hidden bodies stand out at the surface, the resistant dyke as a wall and the sill as a ledge, while ancient granite batholiths underlie much of the central Tanzanian plateau.

How to Draw It
Draw a layered crust in section. Place a large irregular batholith deep at the base, a horizontal sill spread along a bedding plane, and a vertical dyke cutting across the layers. Label the sill concordant and the dyke discordant.

Question 20

Not all hidden igneous bodies are alike; some arch the rocks up, some sag them down, and some nestle in the bends of a fold. With the aid of a diagram, distinguish the laccolith, the lopolith and the phacolith.

Model Answer

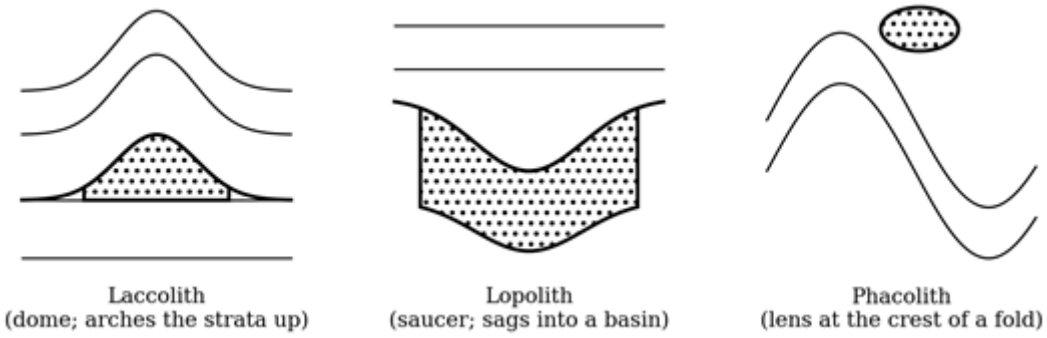


Figure 3.7: *Intrusive features: the laccolith, lopolith and phacolith*

The laccolith, the lopolith and the phacolith are intrusive bodies that lie along the rock layers (concordant), and they differ in their shape.

Laccolith: a dome-shaped body of viscous magma that collects and pushes the overlying strata up into an arch, like a blister beneath the layers.

Lopolith: a very large, saucer-shaped body that sags down into a shallow basin under the weight of the rocks above, as in the great Bushveld lopolith of South Africa.

Phacolith: a small, lens-shaped body that forms in the bend of a fold, at the crest of an anticline or the base of a syncline.

All three follow the rock layers rather than cutting across them, but one arches up, one sags down and one fills the curve of a fold.

How to Draw It
Draw three small sections: a dome arching the strata up (laccolith), a saucer sagging into a basin (lopolith), and a lens sitting in the crest of a fold (phacolith). Label each and show the strata.

Question 21

The volcanoes of the world are not all the same shape; some are steep and small, some tall and layered, some broad and low. With the aid of a diagram, distinguish the ash-and-cinder cone, the composite cone and the shield volcano.

Model Answer

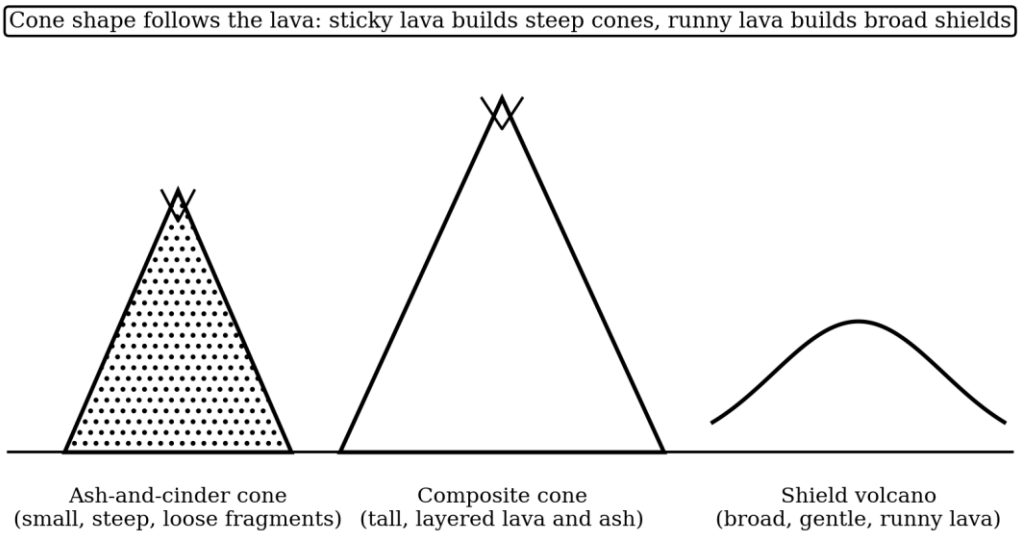


Figure 3.8: *The three volcanic cones*

The three chief volcanic cones differ in the material that builds them and so in their shape and steepness.

1) **Ash-and-cinder cone:** built of loose fragments, ash and cinders thrown out and piled around the vent, so it is small and steep-sided with a symmetrical shape.
2) **Composite cone:** built of alternating layers of lava and ash from many eruptions, so it is tall, with concave slopes and a summit crater, the classic shape seen in Kilimanjaro.
3) **Shield volcano:** built of thin, runny basic lava that spreads far before cooling, so it is broad and low with very gentle slopes.

So loose fragments make a small steep cone, layers of lava and ash make a tall composite cone, and runny lava makes a broad shield.

How to Draw It
Draw three profiles on one base line: a small steep symmetrical cone (ash and cinder), a tall layered cone with concave sides and a crater (composite), and a broad gentle dome (shield). Label the material of each.

Question 22

At the summit of a volcano sits a small hollow, but the great basin of Ngorongoro is something far larger. With the aid of a diagram, explain the difference between a crater and a caldera, and how each is formed.

Model Answer

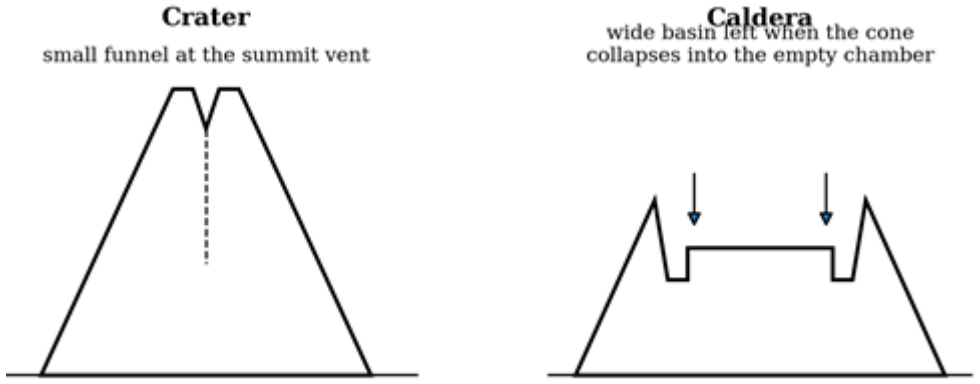


Figure 3.9: *Crater and caldera*

A crater is the small hollow at the mouth of a volcano's vent, while a caldera is a far larger basin left when the volcano collapses. A crater is the funnel-shaped depression at the top of a volcanic cone, formed around the vent by the explosive ejection of material and the outpouring of lava; it is usually small, a few hundred metres across. A caldera is a much larger, roughly circular basin, formed in a different way: after a great eruption empties the magma chamber beneath, the unsupported summit of the volcano collapses inward into the void, leaving a wide depression many kilometres across. The Ngorongoro crater in Tanzania is in fact such a collapsed caldera. So a crater is built around the vent and is small, whereas a caldera is formed by collapse and is large.

How to Draw It
Draw two sections: a cone with a small funnel at its summit vent (crater), and a wide, shallow basin with a broken rim and inward collapse arrows where the cone has fallen in (caldera). Label each and note the difference in size.

False Confidence Alert
A caldera is not just a big crater. A crater is built around the vent by eruption; a caldera is formed when the volcano collapses into its emptied chamber, which is why it is so much larger.

Question 23

Long after the lava has cooled, the heat below can still drive boiling water and steam to the surface, as in the hot springs near the Tanzanian Rift. Explain how geysers, hot springs and fumaroles are formed.

Model Answer

Geysers, hot springs and fumaroles all form where groundwater meets the volcanic heat still stored in the rocks below, and they differ in what reaches the surface. Where hot igneous rock lies near the surface, it heats the groundwater that seeps down to it. A hot spring forms where this heated water rises and flows out gently and steadily at the surface. A geyser forms where the heated water is trapped in a narrow channel until the pressure of the steam below throws it out violently as a fountain of hot water and vapour, from time to time, before the pressure builds again. A fumarole forms where only gases, steam and smoke escape, with little or no liquid water. All three are signs that volcanic heat survives beneath the ground, as the warm springs along the floor of the East African Rift show.

Question 24

Where the crust along the Tanzanian Rift has snapped and slipped, the broken blocks carry names that every geographer must know. With the aid of a diagram, explain what faulting is and name the parts of a fault.

Model Answer

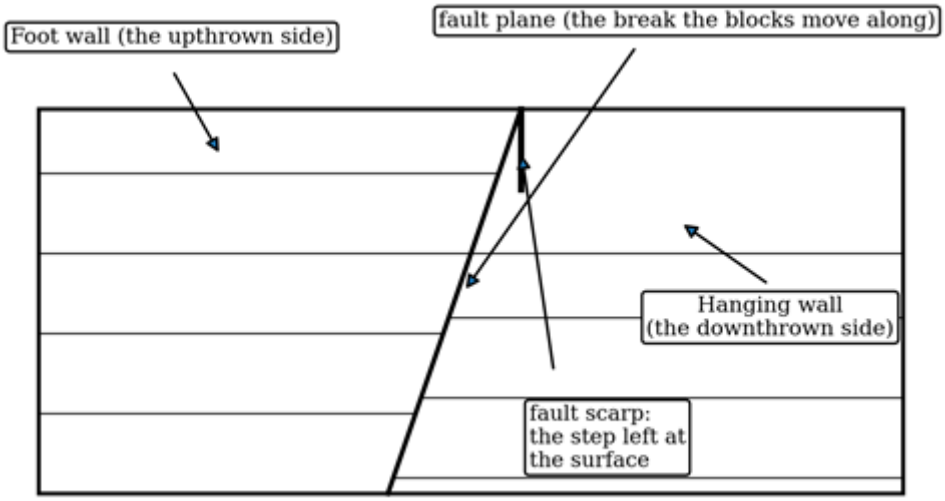


Figure 3.10: *The parts of a fault*

Faulting is the breaking and displacement of crustal rocks along a fracture, and the broken structure has several named parts. Faulting happens when the stresses in the crust grow too great, so the rocks fracture and the blocks on either side are displaced past each other. The fracture along which they move is the fault plane. The block that lies above the inclined fault plane is the hanging wall, and the block below it is the foot wall. Where one block is raised, its top is the upthrow side, and where the other is lowered it is the downthrow side. The steep step left at the surface where the blocks have moved is the fault scarp. These parts are seen all along the faulted edges of the East African Rift, where great blocks have been displaced against one another.

How to Draw It
Draw two blocks of layered rock separated by an inclined fault plane, with one block raised and one dropped so the strata are offset. Label the fault plane, the hanging wall, the foot wall, the upthrow and downthrow sides, and the fault scarp.

Question 25

Whether the crust is pulled apart or squeezed together decides the kind of fault it makes. With the aid of a diagram, distinguish a normal fault from a reverse fault.

Model Answer

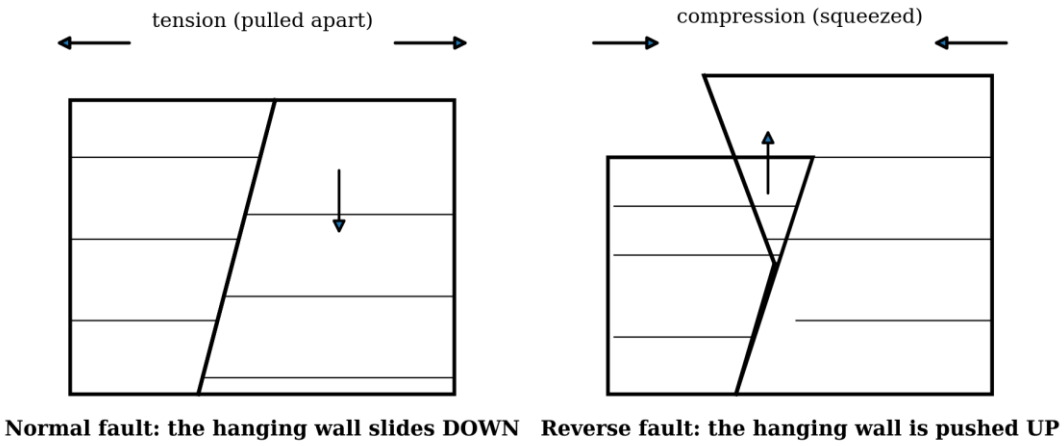


Figure 3.11: *Normal and reverse faults*

A normal fault is made by tension that pulls the crust apart, while a reverse fault is made by compression that squeezes it together. In a normal fault the crust is stretched by tension, so the rocks are pulled apart and the hanging wall, the block above the inclined fault plane, slides down relative to the foot wall. Normal faults are the kind that drop the floor of a rift valley, as along the East African Rift. In a reverse fault the crust is squeezed by compression, so the rocks are pushed together and the hanging wall is forced up and over the foot wall, shortening and thickening the crust. So the direction of the force is the key difference: tension and a dropped hanging wall give a normal fault, compression and a raised hanging wall give a reverse fault.

How to Draw It
Draw two sections, each with an inclined fault plane and offset strata. For the normal fault add outward tension arrows and show the hanging wall dropped; for the reverse fault add inward compression arrows and show the hanging wall pushed up over the foot wall.

False Confidence Alert
The two faults are told apart by the force and the movement, not by the look alone. Tension drops the hanging wall in a normal fault; compression drives it up in a reverse fault.

Question 26

Besides the faults that drop and raise blocks, some slide the crust sideways and some shove it bodily over itself. Explain how a tear (transform) fault and an overthrust fault are formed.

Model Answer

A tear fault moves the crust horizontally past itself, while an overthrust fault pushes one mass of rock a long way over another. A tear fault, also called a transform or strike-slip fault, forms where the

blocks slide horizontally past one another along a near-vertical fracture, with little up or down movement, as at the famous San Andreas fault in California. An overthrust fault forms under strong compression, where a low-angle fracture lets the upper mass of rock ride forward and override the rocks in front of it for a great distance. The tear fault therefore shifts the land sideways, offsetting rivers and roads across the fracture, while the overthrust piles rock over rock, and both are found in the strongly stressed crust of mountain belts and rift zones such as East Africa's.

Question 27

The Usambara mountains of north-east Tanzania rise as a great block lifted between cracks in the crust. With the aid of a diagram, explain how a block (horst) mountain is formed.

Model Answer

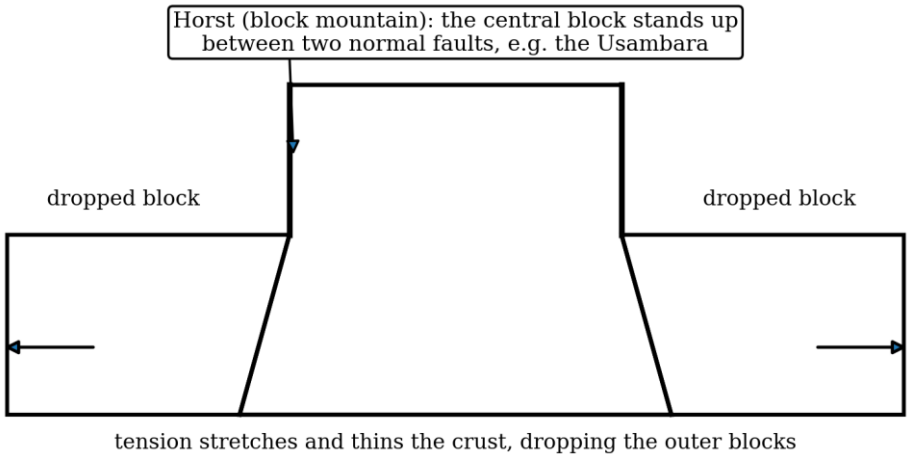


Figure 3.12: *A block (horst) mountain*

A block or horst mountain is formed when a block of the crust stands up between two parallel normal faults, either by being uplifted or by the blocks on either side dropping away. When the crust is stretched by tension, it cracks along two roughly parallel normal faults. The central block between them may be pushed up, or, more often, the blocks on either side may sink while the middle stands firm. Either way, the central block is left standing above its surroundings as a steep-sided, flat-topped upland, the horst or block mountain, with a fault scarp along each side. The Usambara and Uluguru mountains of Tanzania are block mountains of this kind, raised between the faults of the Rift system. So a horst is a block left high between two faults, and its straight, steep edges mark the faults that bound it.

How to Draw It
Draw three blocks separated by two normal faults. Show the central block standing high (the horst) with the outer blocks dropped, a fault scarp on each side, and tension arrows pulling outward. Label the horst or block mountain.

Question 28

The greatest single feature of the East African landscape is the long trough of the Rift Valley, running the length of the region. With the aid of a diagram, account for the formation of a rift valley, and explain how it differs from a river valley.

Model Answer

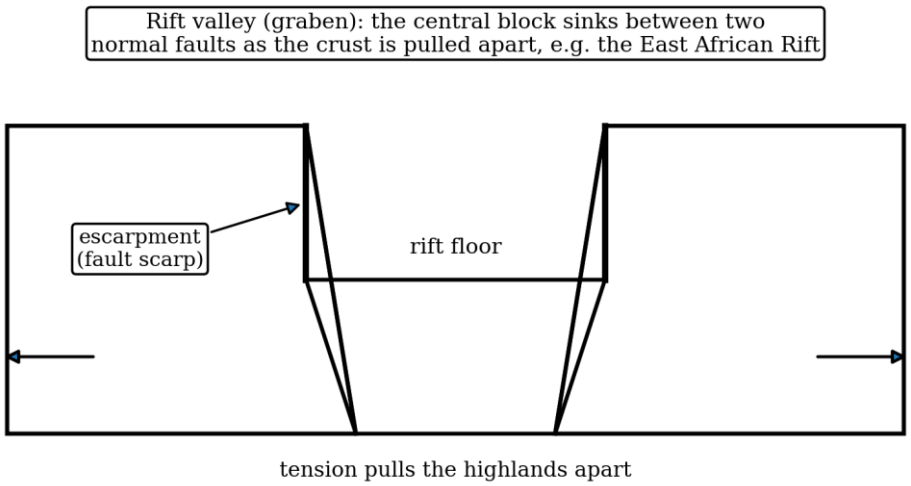


Figure 3.13: *A rift valley (graben)*

A rift valley is a long trough formed where the crust is pulled apart by tension and a central block sinks between two parallel normal faults. When tension stretches the crust, it cracks along two roughly parallel normal faults. The block of land between them, no longer supported, drops down to form a long, steep-sided valley with a flat floor, called a rift valley or graben, bordered by escarpments which are the fault scarps. The East African Rift Valley was formed in just this way, as the African plate began to split apart. A rift valley differs from a river valley in both origin and shape: a river valley is cut by erosion and is usually narrow and V-shaped, whereas a rift valley is made by faulting, not erosion, and is wide and flat-floored with straight, steep, parallel walls.

How to Draw It
Draw a section with two parallel normal faults and the central block dropped to make a flat-floored trough between two escarpments. Add outward tension arrows and label the rift floor, the escarpments (fault scarps) and the faults.

False Confidence Alert
A rift valley is not a river valley made large. It is formed by faulting as the crust is pulled apart, which is why it is wide and flat-floored with steep parallel walls, not cut by a river.

Question 29

Along the edge of the Tanzanian Rift the land often falls to the floor not in one cliff but in a flight of giant steps. Explain how fault scarps and step faulting are formed, and why the scarp is later changed by erosion.

Model Answer

A fault scarp is the steep slope left where faulting lifts one block above another, and step faulting is a series of such scarps descending like a staircase. A fault scarp forms where vertical movement along a fault leaves one block standing higher than the next, so a steep, straight, cliff-like slope marks the line of the fault. Where the crust breaks not along one fault but along several roughly parallel faults, each block drops a little more than the last, so the land descends in a series of steps, called step faulting, often seen on the shoulders of a rift valley. Over time, however, rivers and weathering attack the fresh scarp, wearing back its straight face and cutting gullies into it, so an old fault scarp becomes ragged and less steep than when it was first formed, as along the worn edges of the East African Rift.

Question 30

Faulting does more than raise and drop the land; it quietly redraws the rivers and lakes of a region. Account for the indirect effects of faulting on drainage.

Model Answer

By raising, dropping and cracking the land, faulting reshapes the rivers and lakes that flow across it, in several indirect ways.

1) **Waterfalls:** where a fault drops the land across a river's course, the river plunges over the scarp as a waterfall.
2) **Lake basins:** where faulting encloses or drops a basin, rivers fill it to form a lake, as with the deep rift lakes Tanganyika and Nyasa.
3) **River offset:** a tear fault sliding the land sideways shifts a river's channel where it crosses the fault.
4) **Reversed and guided rivers:** up-warping across a valley can force a river to reverse its flow, while shattered fault lines guide rivers along them, as with the Kagera draining into Lake Victoria.

So the faulting that built the Rift also gave East Africa its great lakes and rerouted its rivers.

Question 31

Where the crust is squeezed, it buckles into arches and troughs, the basic shapes of all fold mountains. With the aid of a diagram, explain what folding is and name the parts of a fold.

Model Answer

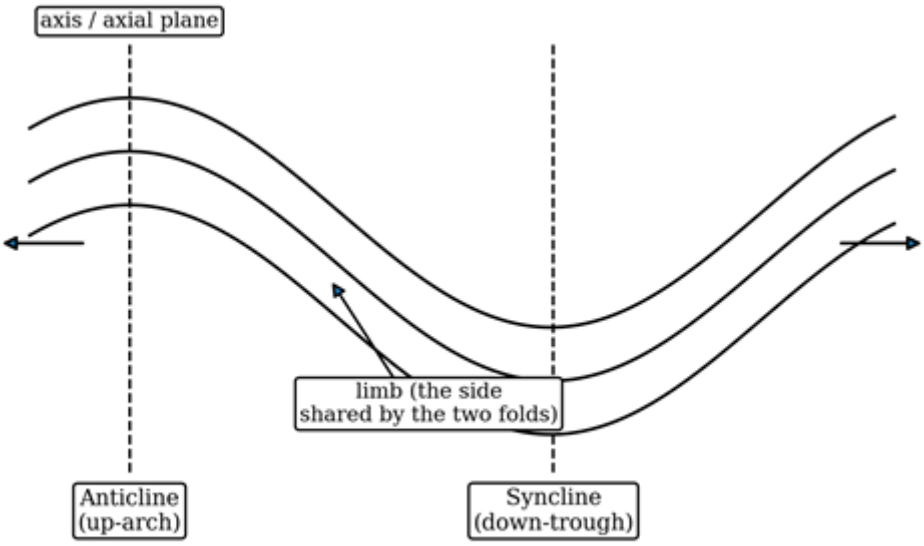


Figure 3.14: *The parts of a fold*

Folding is the bending of crustal rocks into waves under compression, and each fold has named parts. Folding happens where the crust is squeezed by compression, usually where plates move towards each other, so that the rock layers, instead of breaking, bend into a series of waves. An upward arch of the bend is called an anticline, and a downward trough is called a syncline. The two sloping sides shared by an anticline and the neighbouring syncline are the limbs of the fold, and the imaginary plane that divides a fold symmetrically down its middle is the axis or axial plane. These shapes, repeated across a squeezed belt of crust, build the ridges and valleys of fold mountains. Tanzania shows little major folding, but the same process raised the great fold ranges of Africa such as the Cape Mountains.

How to Draw It
Draw a set of wavy rock layers showing one anticline (arch) and one syncline (trough). Label the anticline, the syncline, a limb and the axial plane, and add compression arrows from both sides.

Question 32

As the squeezing of the crust grows stronger, a neat, even fold is pushed into a lopsided one. With the aid of a diagram, distinguish a simple (symmetrical) fold from an asymmetrical fold.

Model Answer

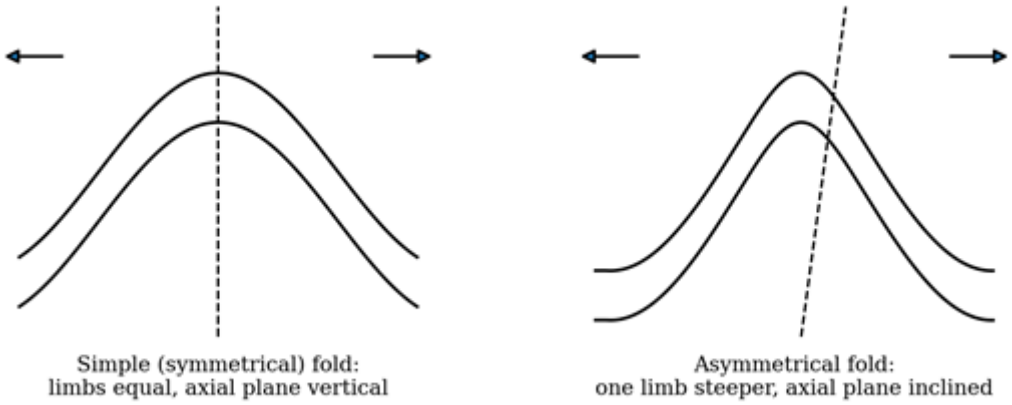


Figure 3.15: *Simple and asymmetrical folds*

A simple fold is even, with matching limbs and an upright axis, while an asymmetrical fold is lopsided, with one limb steeper than the other and a leaning axis. A simple fold, also called a symmetrical fold, forms under gentle, even compression. Its two limbs slope away from the crest at about the same angle, and its axial plane stands vertical, so the fold is balanced. As the compression grows stronger and acts more from one side, the fold is pushed over and becomes asymmetrical: one limb becomes steeper than the other, and the axial plane leans from the vertical, dipping in the same direction as the gentler limb. So the difference is one of balance, with equal limbs and an upright axis in the simple fold, and unequal limbs and an inclined axis in the asymmetrical one. The asymmetrical fold marks the greater squeezing that builds the higher fold ranges, such as the Cape Fold Mountains.

How to Draw It
Draw two folds. For the simple fold show equal limbs and a vertical dashed axial plane; for the asymmetrical fold show one limb steeper and the axial plane leaning over. Add compression arrows.

Question 33

Squeeze a fold hard enough and it will lean, then lie down, then break and ride over itself. With the aid of a diagram, account for how growing compression turns a fold into an overfold, then a recumbent fold, then an overthrust.

Model Answer

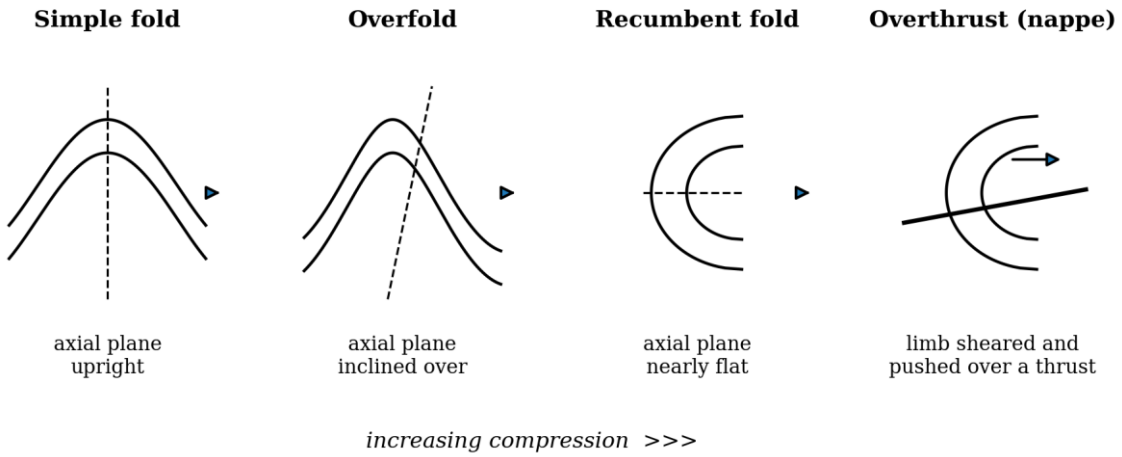


Figure 3.16: *The progression of fold types under increasing compression*

As compression increases, a fold passes through a series of ever more extreme forms, leaning further over until it lies flat and finally breaks. Under gentle compression the crust makes a simple, upright fold. As the squeezing strengthens, the fold is pushed over to one side into an overfold, whose axial plane is now inclined and whose limbs dip the same way. Stronger compression still pushes the fold right over until its axial plane is almost horizontal and it lies on its side, a recumbent fold. If the pressure continues beyond what the rock can bear, the over-ridden limb snaps along a low-angle fracture, and the upper part is thrust bodily forward over the rocks in front as an overthrust, or nappe. So the same compression, growing in strength, carries a fold from upright, to leaning, to lying flat, to broken, and these intense forms build the great young fold mountains such as the Alps and the Atlas of north-west Africa.

How to Draw It
Draw four stages in a row: an upright simple fold, an overfold leaning to one side, a recumbent fold lying nearly flat, and an overthrust where the fold has broken and ridden forward along a thrust plane. Label each and show compression increasing from left to right.

Question 34

The greatest mountain ranges on Earth, from the Atlas to the Alps, were raised not by volcanoes but by the slow crumpling of the crust. Explain how fold mountains are formed.

Model Answer

Fold mountains are formed where thick piles of sediment are squeezed by the collision of plates and crumpled upward into great folds. Over long ages, thick layers of sediment collect in the seas and basins between the moving plates. When two plates drift towards each other, these sediments are caught between them and squeezed by immense compression. Unable to escape, the layers buckle and fold upward into a belt of anticlines and synclines, which is uplifted into a range of fold mountains. Because the squeezing can be very strong, the folds may become overturned and even overthrust, as in the highest ranges. The Atlas Mountains of north-west Africa were raised in just this way, where the African plate pushed against Europe. Fold mountains are therefore the crumpled record of plates colliding and of the sediments between them being driven upward.

Question 35

Some fold mountains still rise sharp and snow-capped, while others have been worn to low, rounded stumps. Distinguish the young fold mountains from the old fold mountains, with examples.

Model Answer

Young fold mountains are high, sharp and still rising, while old fold mountains are low, worn and long stable, the difference being chiefly their age and the erosion they have suffered. Young fold mountains were folded fairly recently, in the most recent era of mountain-building, so they are still tall, steep and rugged, with high snow-capped peaks, and they form the two great young belts of the world: the circum-Pacific belt, with the Andes and the Rockies, and the Eurasian belt, with the Alps and the Himalayas. Old fold mountains were folded far longer ago and have since been worn down by long ages of erosion, so they are low, rounded and gentle, often only the worn roots of once-great ranges. The Cape Fold Mountains of South Africa and the Appalachians of North America are old fold mountains of this kind. So height and sharpness mark the young, while low, worn forms mark the old.

Question 36

Look out over northern Tanzania and almost every great feature, the volcano, the rift, the lake and the highland, was raised by forces from within. Account for how the four endogenic processes together build the major landforms.

Model Answer

The four endogenic processes work together to build the major relief of the land, each contributing its own family of features. Vulcanicity pours out molten rock that builds volcanoes and lava plateaus, such as the cones of Kilimanjaro and Oldonyo Lengai. Faulting cracks and drops the crust to form rift valleys and block mountains, holding the deep lakes Tanganyika and Nyasa. Folding squeezes the crust into the ridges and troughs of fold mountains. Earthquakes, while chiefly a hazard, are the trembling sign of all this movement, accompanying the faulting and vulcanicity that shape the land. Acting together over long ages, these internal forces raise the bold framework of the landscape, the mountains, valleys and basins, which the exogenic forces of weather and water then carve into its finer detail. The scenery of northern Tanzania is their combined handiwork.

Question 37

For the people who live among Tanzania's volcanoes and faults, the forces within the Earth are both a gift and a threat. Explain the benefits and the dangers that endogenic processes bring to the people who live among them.

Model Answer

Endogenic processes bring people both rich benefits and serious dangers, because the same forces that build fertile and valuable land also shake and threaten it. On the side of benefit, volcanic activity weathers into deep, fertile soils, as on the southern slopes of Kilimanjaro where farming thrives, and it brings mineral wealth, hot springs and the geothermal heat that can generate electricity. Faulting gives the deep rift lakes that supply water and fish, and the dramatic scenery of the Rift draws tourists. On the side of danger, earthquakes destroy buildings and lives, as at Kagera in 2016, volcanic eruptions can bury farms and force people to flee, and the steep faulted slopes are prone to landslides. So the people of the Rift live with a bargain: the endogenic forces that enrich their land with soil, water and minerals are the same forces that, from time to time, endanger it.

REAL QUESTIONS

Question 38

A visitor flying over Tanzania sees snow-capped cones, a great trough lined with lakes and a high central plateau, all the handiwork of forces from within. Show how endogenic forces have shaped Tanzania's own relief.

Model Answer

Almost every bold feature of Tanzania's relief was built by endogenic forces, working through vulcanicity, faulting and uplift.

1) **The volcanoes:** vulcanicity built the great cones of the north, Kilimanjaro, Meru and the active Oldonyo Lengai, where molten rock reached the surface.
2) **The Rift Valley:** faulting tore the crust into the East African Rift, a long, steep-sided trough crossing the country from north to south.
3) **The rift lakes:** the dropped floor of the Rift holds the deep lakes Tanganyika and Nyasa and the shallow soda lakes Natron and Eyasi.
4) **The plateau and highlands:** broad epirogenic up-warping raised the high central plateau and the southern highlands on which much of the country stands.

So the cones, the trough, the lakes and the plateau are all endogenic work, the framework that the rivers and weather have since carved into detail.

Question 39

Two coastal towns the same distance from an earthquake's epicentre can suffer very different fates, one shaken to rubble, the other barely marked. Examine the six factors that decide how destructive an earthquake is in a given place.

Model Answer

How much damage an earthquake does in a place depends not on its magnitude alone but on six factors acting together.

1) **Magnitude:** the more energy the earthquake releases, the more violent the shaking and the greater the potential damage.
2) **Depth of focus:** a shallow focus delivers its energy to the surface with little weakening, so it is far more destructive than a deep one.
3) **Distance from the epicentre:** shaking is strongest at the epicentre and fades with distance, so nearer places suffer more.
4) **Local geology:** soft, loose or water-logged ground shakes and liquefies far more than solid bedrock, multiplying the damage, as the soft sediments at Kagera did in 2016.
5) **Building quality:** strong, flexible, well-built structures survive where weak, rigid or poorly built ones collapse.
6) **Population and development:** a crowded, built-up area suffers far greater loss of life and property than a sparsely settled one.

So a moderate earthquake on soft ground beneath a crowded, poorly built town can do more harm than a strong one in open country on solid rock.

False Confidence Alert
A bigger magnitude does not always mean more damage. A moderate earthquake on soft ground under a crowded, badly built town can kill more than a strong one in empty country on solid bedrock.

Question 40

For years the Kagera region in Tanzania's far north-west has been shaken by earthquakes, including the strong shock of September 2016. Account for the causes and the effects of these recurring earthquakes, using Kagera's place on the East African Rift.

Model Answer

Kagera is shaken so often because it lies on the western arm of the East African Rift, where the crust is actively splitting, and its earthquakes bring the destruction typical of shallow shocks on weak ground. The region sits on the faults of the western Rift, where the African plate is slowly tearing in two, so stress builds along the faults and is released as tectonic earthquakes. Because these shocks are shallow,

their energy reaches the surface strongly. The 2016 earthquake, of magnitude 5.9 and intensity seven, toppled buildings made of soft, un-reinforced materials, killed and injured people, cracked roads and left many families homeless, its harm worsened by the weak ground and the weak buildings. So Kagera's earthquakes are the price of living on an active rift, and much of their damage could be prevented by building more strongly.

Question 41

You are sent as a seismologist to a Tanzanian district recently struck by an earthquake, where frightened people ask how to stay safe if it happens again. Advise the community on the precautions to take before, during and after an earthquake.

Model Answer

The community can greatly cut its losses by preparing before an earthquake, acting correctly during it, and taking care afterwards.

1) **Before:** build with strong, flexible materials and fix heavy furniture to the walls; agree on safe open assembly areas; keep water, food and a first-aid kit ready; and practise a warning drill.
2) **During:** stay calm and take cover away from windows and tall furniture, or move to an open space clear of buildings, trees and power lines; if driving, slow down and stop in the open; wait until the shaking stops.
3) **After:** watch for fallen power lines and fires, expect aftershocks, use the stairs and not lifts, check and help the injured, and follow the instructions of the authorities.

Because earthquakes cannot yet be predicted exactly, it is this readiness, far more than warning, that saves lives in a Tanzanian district on the Rift.

Question 42

The Indian Ocean tsunami of December 2004 reached the East African coast and killed people as far south as Tanzania. Using that event, anticipate the effects such a tsunami would have on the East African coast, and suggest measures to reduce its impact.

Model Answer

A large Indian Ocean tsunami would strike the low, crowded East African coast with sudden flooding, heavy loss of life and lasting damage, but its toll could be cut by warning and preparation. Reaching the shore as a fast, towering wave, it would drown people on the beaches and in coastal towns such as Dar es Salaam and the islands, sweep away houses, boats and the tourist and fishing trades, spoil coastal farmland and wells with salt water, and spread disease in its aftermath, as the 2004 wave did along the coast. The impact could be reduced by joining the Indian Ocean tsunami warning system so that coasts are alerted in time, by teaching coastal people the natural warning of a sudden retreat of the sea and to flee at once to high ground, by protecting the shore with mangroves and coral reefs that break the wave, and by planning settlements and clear escape routes away from the lowest ground.

Question 43

Tanzania's volcanoes are not all the same: one still erupts in the Rift, several only sleep, and one in the south is long dead. Classify the named volcanoes of Tanzania by their state of activity, and account for each.

Model Answer

By their state of activity, Tanzania's volcanoes fall into the active, the dormant and the extinct.

Active: Oldonyo Lengai, in the northern Rift, still erupts in our own time, because magma still rises freely beneath it; it is the country's one truly active volcano.

Dormant: Kilimanjaro and Meru have not erupted for a very long time but are only sleeping, since they could erupt again, so they must still be watched.

Extinct: Rungwe, in the southern highlands, has not erupted in recorded history and is not expected to again, its activity having ceased and its cone worn down.

So a single country shows all three stages of a volcano's life, from the living Oldonyo Lengai to the dead Rungwe.

False Confidence Alert
Kilimanjaro is not an extinct volcano. It is dormant, only sleeping, and could in principle erupt again; calling a dormant volcano extinct is a common and risky mistake.

Question 44

Your teacher asks you to give a morning talk arguing that, for all their danger, volcanoes are a blessing to the people of Tanzania. With examples, explain the socio-economic value of volcanoes.

Model Answer

Volcanoes, for all their danger, give the people of Tanzania fertile land, energy, minerals, water and income.

Fertile soils: weathered volcanic rock makes deep, rich soils, as on the southern slopes of Kilimanjaro, where coffee and bananas thrive.

Geothermal energy: the heat beneath the volcanic areas of the Rift can drive geothermal power stations to generate electricity.

Minerals: volcanic activity concentrates valuable minerals, and the Rift's deposits include soda ash and the gemstone tanzanite, mined near Kilimanjaro.

Tourism: volcanic scenery draws visitors and their money, from the climbers on Kilimanjaro to the tourists at Oldonyo Lengai and the crater highlands.

Water and building stone: volcanic highlands attract rain and hold springs, and their hardened lava provides building stone.

So the same volcanic forces that threaten the land also enrich it with soil, energy, minerals and income, on balance a blessing to Tanzania.

Question 45

The Ngorongoro Crater in northern Tanzania is in truth a vast collapsed caldera, and within its walls teems some of Africa's richest wildlife. Account for the formation of the Ngorongoro caldera, and explain why such a feature becomes a haven for wildlife.

Model Answer

The Ngorongoro caldera formed when a great volcano collapsed into its own emptied magma chamber, leaving a wide, deep basin that now shelters abundant wildlife. Ngorongoro was once a large volcano. After a huge eruption drained the magma chamber beneath it, the unsupported summit collapsed inward into the void, leaving the enormous circular basin, many kilometres across and walled by steep cliffs, that we see today, a caldera rather than a mere crater. The basin became a haven for wildlife because its floor holds, in one enclosed place, everything animals need: permanent water, a soda lake, fertile volcanic grassland and patches of forest, all sheltered by the high walls. So the same collapse that ended the volcano created a self-contained refuge, which is why the Ngorongoro caldera is one of the great wildlife sites of Tanzania.

Question 46

The single greatest feature of Tanzania's landscape is the East African Rift System, which crosses the country in two great arms. With the aid of a sketch map, describe the East African Rift System through Tanzania as the work of faulting.

Model Answer

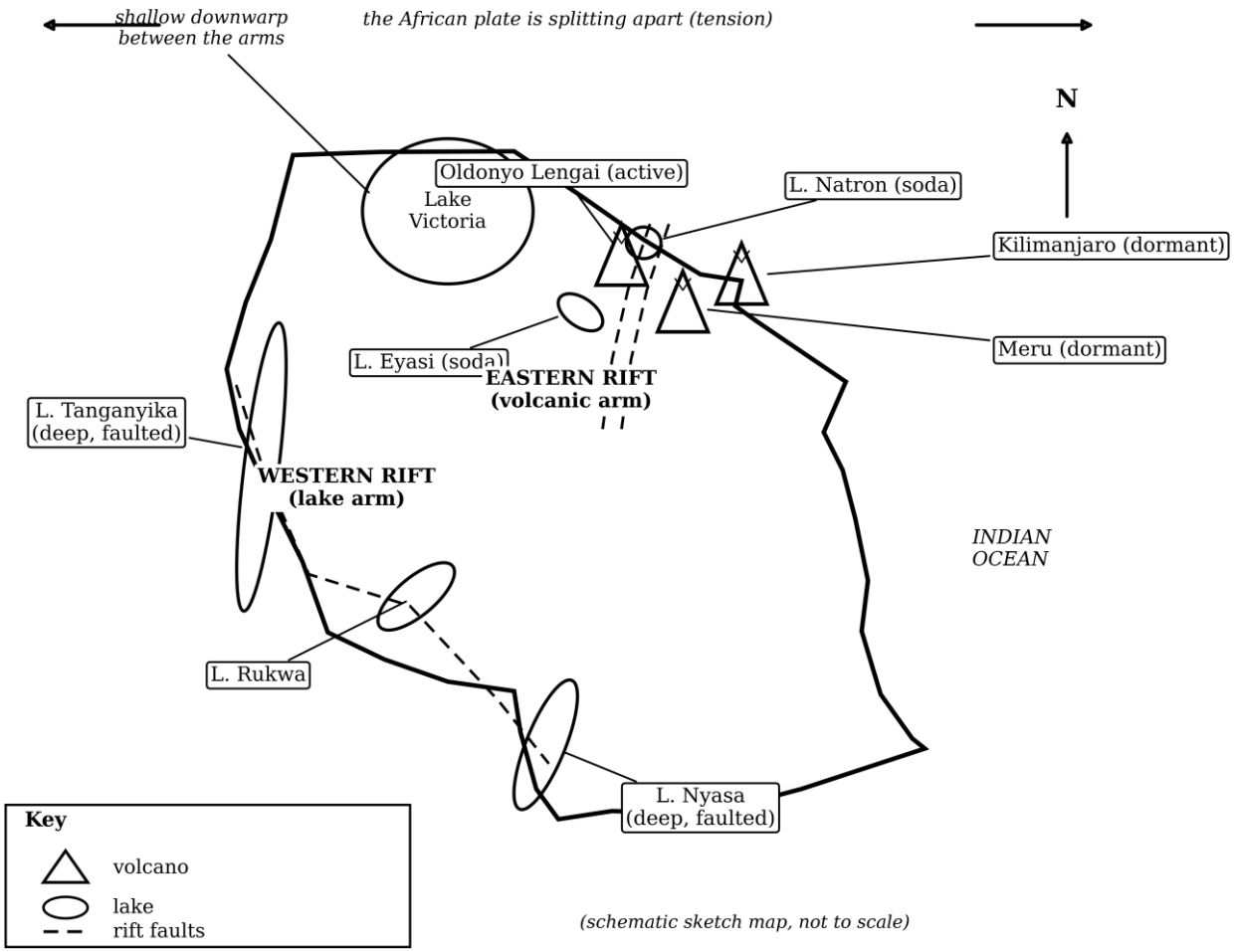


Figure 3.17: *The East African Rift System through Tanzania*

The East African Rift System is a vast set of faults along which the African plate is splitting, and through Tanzania it runs in two arms, an eastern volcanic arm and a western lake arm, around Lake Victoria. The Rift formed as tension stretched and cracked the crust into parallel normal faults, dropping long trough floors between them. The eastern arm, the Gregory Rift, runs down through northern Tanzania and is rich in volcanoes and soda lakes, carrying Oldonyo Lengai, the salt flats of Lake Natron and the shallow Lake Eyasi. The western arm curves down the country's western edge and is marked by deep faulted lakes, Tanganyika, Rukwa and Nyasa, lying on its dropped floor. Between the two arms, in a shallow downwarp rather than a rift, sits the broad basin of Lake Victoria. Together the two faulted arms, their volcanoes and their lakes are the surface signs of Tanzania being slowly pulled apart.

How to Draw It
Draw the outline of Tanzania with Lake Victoria in the north-centre. Show the eastern arm down the north-east with volcano symbols (Oldonyo Lengai, Kilimanjaro, Meru) and Lakes Natron and Eyasi, and the western arm down the west with the long lakes Tanganyika, Rukwa and Nyasa. Label the two arms and mark the faults.

False Confidence Alert
Lake Victoria is not a rift lake. It lies in a shallow downwarp between the two rift arms, which is why it is broad and shallow, quite unlike the deep, faulted Tanganyika and Nyasa.

Question 47

The lakes of the Tanzanian Rift are of two very different kinds: a few are among the deepest in the world, while others are shallow, salty pans. Account for the formation of the deep rift lakes Tanganyika and Nyasa and the shallow soda lakes Natron and Eyasi by faulting.

Model Answer

Both kinds of lake were made by faulting, but the deep lakes fill the dropped floors of the rift while the shallow soda lakes sit in smaller, sealed basins that concentrate their salts. Where faulting dropped a long, deep block of the rift floor far below its surroundings, the trough filled with water to make a deep, steep-sided lake, as with Tanganyika, one of the deepest lakes on Earth, and Nyasa; these basins are so deep that they hold huge volumes of fresh water. The soda lakes, Natron and Eyasi, also lie in fault-formed hollows on the rift floor, but their basins are shallow and have no outlet to the sea. In the hot rift more water evaporates from them than flows in, so the dissolved minerals are left behind and concentrated, turning the lakes shallow, salty and alkaline. So faulting made all of them, but depth and drainage decide whether a rift lake is deep and fresh or shallow and soda.

Question 48

Some of the rivers that feed Lake Victoria once flowed the other way, until the rising of the land turned them back. Explain how faulting and up-warping reversed the Kagera and Katonga rivers into Lake Victoria.

Model Answer

The Kagera and Katonga rivers were reversed because the up-warping of the land along the western Rift tilted their valleys backwards, forcing the water to flow the opposite way into the Lake Victoria basin. Before the Rift formed, these rivers flowed westward towards the Congo. As the western arm of the Rift developed, the crust along its shoulder was up-warped and lifted, tilting the land and raising a barrier across the rivers' old westward course. Unable to climb the rising ground, the rivers were ponded back, and their flow was gradually reversed to run eastward instead, draining into the great downwarped basin of Lake Victoria. The Kagera and Katonga thus became feeders of the lake rather than of the Congo. Their reversal shows how the vertical movements of faulting can quietly redraw the drainage of a whole region, sending rivers backwards into a new basin.

False Confidence Alert
Rivers do not always keep their original direction. Up-warping along the Rift tilted the land and reversed the Kagera and Katonga, so a river's present flow can be the very opposite of its first one.

Question 49

A farming community in one of Africa's folded valleys asks how the bends in the rock beneath their fields affect their farming. Advise them on how the folded structure affects the soil, and what farming practices would suit such a valley.

Model Answer

In a folded valley the bent rock controls where the soil is deep and where water collects, so the farmers should match their practices to the fold. Folding bends the rock into arches (anticlines) and troughs (synclines). On the arches the rock is stretched and cracked, so the soil is thinner and water drains away quickly, while in the troughs soil washed from the slopes collects deep and moist and groundwater gathers. The community should therefore farm the syncline floors and lower slopes for their deeper, moister soils and the crops that need them, while using the drier anticline crests for hardy crops or for grazing. Because the slopes are steep, they should terrace them and plough along the contour to hold the soil against erosion, and plant cover crops to keep the thin upland soils in place, just as the steep highland farms of the Usambara in Tanzania are terraced. In this way the farmers work with the folded structure rather than against it.

Question 50

While Tanzania shows little folding, the south and north of Africa carry its two great fold ranges, worn old in the south and younger in the north. Account for the formation of the Cape Fold Mountains and the Atlas Mountains.

Model Answer

Both ranges were folded by the compression of colliding plates, but the Cape Fold Mountains are old and worn while the Atlas are younger and higher. The Cape Fold Mountains of South Africa were formed very long ago, when thick layers of sediment were caught and squeezed by an ancient plate collision at the southern edge of Africa and buckled into folds. Because they were folded so long ago, they have since been worn down by erosion into low, parallel ridges, the roots of once-greater mountains. The Atlas Mountains of north-west Africa are much younger; they were folded when the African plate pushed northward against Europe, the same collision that raised the Alps, so they still stand high and rugged. Both ranges are therefore the crumpled record of plates colliding, but their difference in height and sharpness reflects the difference in their age, the Cape old and low, the Atlas young and high.

Question 51

The same slow movements that built East Africa's mountains and rifts also reshape its environment, for good and for ill. Discuss the environmental impact of diastrophic activity in East Africa, weighing the new land and resources it brings against the hazards.

Model Answer

Diastrophic activity reshapes East Africa's environment in two directions, creating valuable new land and resources on the one hand and bringing serious hazards on the other. On the side of benefit, the uplift, faulting and vulcanicity of diastrophism have built the highlands that attract rain and hold fertile soils, opened the rift basins that cradle the great lakes and their fisheries, raised the scenery that draws tourists, and concentrated minerals and geothermal energy. On the side of harm, the same forces shake the land with earthquakes that destroy life and property, as at Kagera, threaten volcanic eruptions, steepen slopes into landslides, and can disturb drainage and drown old farmland beneath new lakes. Weighing the two, diastrophism has on balance enriched East Africa with land, water and resources, but at the cost of living with real and recurring hazards. The wise course is to use its gifts while preparing for its dangers.

HOT QUESTIONS

Question 52

A student says the mountains of Tanzania are the work of forces within the Earth, while the valleys are the work of rivers and weather, as if the two never met. Assess the claim that the Earth's surface is the joint work of endogenic forces that build it up and exogenic forces that wear it down.

Model Answer

The claim is broadly correct, because the surface of the Earth is shaped by a constant contest between endogenic forces that build it up and exogenic forces that wear it down, with neither acting alone. Endogenic forces, the faulting, folding and vulcanicity driven by the Earth's internal heat, raise the bold relief: the cone of Kilimanjaro, the trough of the Rift, the highland plateaus. Exogenic forces, the weathering, rivers, wind and ice powered by the Sun, then attack these features, wearing the mountains down and filling the basins with their waste. The two work on the same land at the same time, so a mountain is being both raised from below and worn from above, and its present form is the balance between them. Kilimanjaro, lifted by vulcanicity yet gullied and lowered by ice and rivers, is one landform shaped by both. So the claim holds: the scenery is the joint and unceasing work of the builders within and the destroyers without, and a full explanation of any landform must name both.

Question 53

Before an earthquake the ground may warm, well-water may rise and animals may grow restless, yet no one can say for certain when the shock will come. Examine why earthquakes remain so hard to predict, weighing the warning signs against the limits of science.

Model Answer

Earthquakes remain hard to predict because, although several warning signs exist, none of them is reliable enough to fix the exact time and place of a shock. There are real precursors. In the days and hours before an earthquake the average temperature of a place may rise, the water in wells may suddenly rise, fall or turn muddy, the electromagnetic signals on radios and phones may be disturbed, and animals may grow restless and flee. These signs suggest that the crust is changing before it breaks. Yet science cannot use them to predict reliably, because the same signs do not appear before every earthquake, they often have other and harmless causes, and they give no precise time, place or size. An earthquake begins deep underground where it cannot be watched directly, and the moment of rupture turns on tiny details of the rock that no instrument can read in advance. So on the active Rift through Tanzania the warning signs may hint that a shock is near but cannot say when, which is why preparedness matters more than prediction.

False Confidence Alert

Warning signs are not the same as prediction. Restless animals or rising well-water may hint that a shock is near, but they cannot give its time, place or size, so they are no substitute for building well and being prepared.

Question 54

Of all the things that decide whether an earthquake becomes a disaster, geographers argue over which matters most: the strength of the shock, the ground it strikes, or the buildings upon it. Assess which single factor does most to turn an earthquake into a disaster, defending your choice against the others.

Model Answer

The quality of human building has the strongest claim to be the deciding factor, because it is collapsing buildings, far more than the shock itself, that kill people, and building is the one factor people can control. Magnitude, depth and distance certainly matter, since a strong, shallow, nearby shock delivers more energy, and local geology matters too, for soft ground multiplies the shaking. Yet the same earthquake can pass almost harmlessly where buildings are strong and flexible, and flatten a town where they are weak and rigid, as the soft-built houses of Kagera collapsed in 2016 when better construction would have stood. People cannot reduce an earthquake's magnitude or move their town off the Rift, but they can build to resist the shaking. Because it is falling buildings that cause most deaths, and because building quality is the factor within human control, it is the strongest single answer. Magnitude and geology set the challenge, but it is poor building that turns that challenge into a disaster.

Question 55

Since no scientist can yet tell a Tanzanian town the day an earthquake will strike, the question is whether the country should pin its hopes on prediction or on preparedness. Evaluate whether a country on the Rift such as Tanzania can do more through preparedness than through prediction to limit earthquake loss.

Model Answer

For a country like Tanzania, preparedness can do far more than prediction to limit earthquake loss, because prediction is still unreliable while preparedness works whatever the warning. Prediction would be valuable if it worked, but the warning signs of an earthquake are inconstant and give no exact time, place or size, so a country cannot safely evacuate or plan around them. Preparedness, by contrast, does not depend on knowing when a shock will come. By enforcing building codes so that houses and schools flex rather than collapse, by mapping the active faults of the Rift to guide where and how to build, by teaching people what to do during a shock, and by keeping emergency services ready, Tanzania can cut

its losses no matter when the next earthquake strikes. The 2016 Kagera deaths came mostly from weak buildings, exactly the thing preparedness addresses. So while research into prediction should continue, the surer investment for a Rift country is preparedness, which saves lives even when no warning comes.

Question 56

The people who farm the rich slopes of Kilimanjaro live in the shadow of the very forces that could destroy them. Assess whether vulcanicity is, on balance, more a hazard or more a resource to the people who live beside Tanzania's volcanoes.

Model Answer

On balance vulcanicity is more a resource than a hazard to the people of Tanzania's volcanic areas, because its benefits are steady and daily while its dangers are rare. The hazards are real: an eruption can bury farms and force people to flee, volcanic earthquakes shake the ground, and escaping gases can poison air and water. Yet in Tanzania these dangers are occasional, since only Oldonyo Lengai is truly active, while the benefits are constant. The weathered volcanic soils of the southern slopes of Kilimanjaro are among the most fertile in the country, feeding dense populations who grow coffee and bananas; the volcanic highlands draw rain and hold springs; the Rift's volcanic deposits yield soda ash, the gemstone tanzanite and the promise of geothermal power; and the scenery brings a steady flow of tourists. Weighing the rare catastrophe against the daily harvest, the people stay because the gains outweigh the risks. So, handled with care and watchfulness, vulcanicity is on balance a resource that sustains far more life than it threatens.

Question 57

Oldonyo Lengai often pours out its strange lava quietly, yet other volcanoes of the world blast themselves apart. Examine why some volcanoes erupt with deadly violence while others flow quietly, using the chemistry of their lava.

Model Answer

Whether a volcano erupts with violence or flows quietly is decided chiefly by the chemistry of its lava, because the amount of silica in the lava controls how thick it is and how easily its gases escape. Lava rich in silica is acidic and very viscous, or sticky. It flows slowly and tends to clog the vent, so the gases dissolved in it cannot escape freely; pressure builds until the volcano bursts in a violent, explosive eruption that throws out ash and fragments and builds steep cones. Lava poor in silica is basic and runny. It flows freely and lets its gases bubble out gently, so the eruption is quiet and the lava spreads far to build broad, low shields and plateaus. The lavas of Oldonyo Lengai and the Rift floor are of the fluid, basic kind, which is why they tend to erupt quietly rather than explosively. So the key lies in the lava: thick, silica-rich lava traps its gas and erupts with violence, while thin, silica-poor lava releases it and flows in peace.

False Confidence Alert
A volcano's violence is not a measure of its size but of its lava. Thick, silica-rich lava traps gas and explodes, while thin, silica-poor lava lets it escape and flows quietly; the chemistry, not the height, decides the danger.

Question 58

The great Rift that splits Tanzania gives it deep lakes and rich tourism, yet its scarps and tremors also stand in the way of roads and safety. Assess whether the East African Rift is, on balance, more an asset or more an obstacle to the development of Tanzania.

Model Answer

On balance the East African Rift is more an asset than an obstacle to Tanzania's development, because the resources it provides outweigh the difficulties it poses. The Rift does set obstacles: its steep fault scarps make road and railway building difficult and costly, its earthquakes threaten settlements such as Kagera, and its rugged terrain can isolate communities. Yet its assets are greater and more lasting. The

faulted basins hold the deep lakes Tanganyika and Nyasa, which supply water, fish and transport; the rift highlands and volcanic soils support farming and attract rain; the Rift concentrates minerals, soda ash and geothermal energy; and its dramatic scenery, with the volcanoes, the Ngorongoro caldera and the wildlife of the rift floor, is the foundation of Tanzania's tourist industry. Weighing the two, the Rift's lakes, soils, minerals, energy and tourism contribute far more to the country's economy than its scarps and tremors take away. So, with care taken against its hazards, the East African Rift is on balance a great asset to Tanzania.

Question 59

A confident student writes that the East African Rift Valley is simply a huge river valley widened over millions of years. Examine this mistaken belief, and correct it by explaining the true origin of each kind of valley.

Model Answer

The belief is mistaken, because a rift valley and a river valley are made by entirely different forces, the one by faulting from within and the other by erosion from without. A river valley is cut by exogenic erosion. As a river wears down its bed, it carves a valley that is usually narrow and V-shaped in its upper course, winding with the river's own path and growing wider only as its sides are slowly worn back. A rift valley is built by endogenic faulting. Tension stretches the crust until it cracks along two parallel normal faults, and the block between them drops to leave a long, straight, flat-floored trough with steep, parallel walls, as along the East African Rift. The two could hardly differ more in form, and that difference betrays their origin: the V-shape and meanders of erosion against the straight, steep, flat-floored trough of faulting. So the student has confused a structure made by the Earth's internal forces with one carved by a river; the Rift Valley was dropped between faults, not widened by a river.

False Confidence Alert
A rift valley is not a river valley made large. It is dropped between faults by tension in the crust, which is why it is wide, straight and flat-floored, whereas a river valley is cut by erosion and is narrow and V-shaped.

Question 60

Two of the great builders of relief, folding and faulting, leave very different marks on the land. Examine the impact of folding and faulting on the landscape, referring to one landform built by each.

Model Answer

Folding and faulting both build major relief, but folding bends the crust into ranges while faulting breaks and drops it into troughs and blocks, as the fold mountain and the rift valley show. Folding acts by compression. Where plates push together, thick rock layers are squeezed and buckled upward into arches and troughs, and the crumpled belt is raised into fold mountains, such as the Atlas of north-west Africa, whose long parallel ridges are the bent layers themselves. Faulting acts by tension or by sharp compression. Where the crust is stretched, it cracks along parallel faults and the block between them drops, leaving a rift valley such as the East African Rift, a long, flat-floored trough walled by fault scarps. So folding gives the land its crumpled ranges while faulting gives it its dropped troughs and uplifted blocks. The two impacts are opposite in style, the one bending the crust whole, the other breaking it, and between them they raise much of the world's boldest scenery.

Question 61

While other continents owe their mountains to folding, Tanzania's boldest features are its rifts and volcanoes, with scarcely a fold range to be seen. Assess why Tanzania's relief is dominated by rifting and vulcanicity rather than by the folding that built other continents' mountains.

Model Answer

Tanzania's relief is dominated by rifting and vulcanicity because the country sits where the African plate is being pulled apart by tension, not pushed together by compression, and folding needs

compression. Fold mountains form only where plates collide and squeeze thick sediments together, as the Alps and the Atlas were built where Africa pushed against Europe. Tanzania lies far from such a collision zone. Instead it sits astride the East African Rift, where the African plate is slowly splitting into two, so the dominant force on its crust is tension, the pulling-apart that cracks and drops the land rather than the squeezing that folds it. This tension has faulted the crust into the great rift troughs and their lakes, and the thinning of the crust has let magma rise to build the volcanoes such as Kilimanjaro and Oldonyo Lengai. With compression absent, folding has had no chance to act, so the country's scenery is written in faults and volcanoes. Tanzania's relief is therefore the signature of a continent being torn apart, not pressed together.

False Confidence Alert
Rifting and folding are not just two ways of making the same mountains. Tanzania has rifts and volcanoes, not fold ranges, because its plate is being pulled apart by tension, not driven together by compression.

Question 62

The forces within the Earth that gave Tanzania its mountains, lakes and fertile soils are the same forces that shake its towns and threaten its people. Evaluate the view that endogenic processes are both the builders of the Earth's relief and a standing threat to those who live on it.

Model Answer

The view is sound, because the endogenic processes are at once the makers of the land's most valuable features and the source of its gravest natural hazards, the two being inseparable. As builders, the endogenic forces have raised the relief on which life depends: the volcanic soils and highlands that feed and water the people, the rift basins that hold the great lakes and their fisheries, and the minerals and energy locked in the crust. As a threat, the very same forces shake the ground with earthquakes that flatten towns like Kagera, build volcanoes that may erupt, and steepen slopes that fail in landslides. The point is that these are not two different sets of forces but one: the faulting that drops a fertile rift basin is the faulting that quakes, and the vulcanicity that makes rich soil is the vulcanicity that erupts. People settle exactly where the building has been richest, and so are exposed where the threat is greatest. The view therefore holds: to live on the land the endogenic forces have built is to live with the danger they still pose, and wisdom lies in taking the gift while guarding against the hazard.

Question 63

Tanzania's landscape owes its boldest lines to two endogenic forces above all, the faulting that split the Rift and the vulcanicity that raised the cones. Assess which of the two, faulting or vulcanicity, has done more to shape the relief of Tanzania.

Model Answer

Faulting has the stronger claim to have shaped Tanzania's relief, because it created the great framework of the land, the Rift with its lakes and highlands, within which the volcanoes are only the most striking details. Vulcanicity has certainly built Tanzania's most famous features, the towering cones of Kilimanjaro, Meru and Oldonyo Lengai, and spread the fertile volcanic soils, but these are local, however grand. Faulting has shaped the country on a far larger scale: it tore the East African Rift across the whole land in two great arms, dropped the basins that hold Tanganyika, Nyasa, Natron and the other lakes, raised the rift-shoulder highlands, and even reversed the rivers into Lake Victoria. Moreover the vulcanicity itself is a child of the faulting, for it was the thinning and cracking of the crust along the Rift that let the magma rise to build the volcanoes. So while the volcanoes catch the eye, it is faulting that drew the master plan of Tanzania's relief, and vulcanicity that decorated it. Faulting has therefore done more.

Question 64

The snows of Kilimanjaro are shrinking, the Rift is still widening, and the rivers still carry the highlands grain by grain to the sea. Examine the statement that no landform is ever finished, because endogenic building and exogenic wearing never stop.

Model Answer

The statement is true, because every landform is caught between endogenic forces still building it and exogenic forces still wearing it down, so it is always changing and never complete. Endogenic forces have not finished their work: the East African Rift is still splitting and widening by a few millimetres a year, Oldonyo Lengai still erupts, and the crust is still being faulted and warped. At the same time the exogenic forces never rest: weathering, rivers, wind and the shrinking ice on Kilimanjaro are wearing the high ground down and carrying it grain by grain towards the lakes and the sea. So a landform such as Kilimanjaro is at every moment being both raised or held up from below and lowered from above, and its present shape is only a passing balance between the two. Were the building to stop, erosion would in time wear the mountain flat; were the wearing to stop, the building would pile it ever higher. Because neither ever stops, the surface of the Earth is a work always in progress.

False Confidence Alert
Landforms are not finished products. Even Kilimanjaro is still being raised from below and worn from above, so the shape we see is a passing stage in an endless making and unmaking, not a final form.

Chapter 4

EXOGENIC PROCESSES OF THE EARTH

This chapter turns from the forces that build the land from within to those that wear it down from without. Powered by the Sun and by the pull of gravity, the exogenic processes break rock where it lies, carry it downslope, and set running water, wind, waves and ice to carve the surface of the Earth and lay its debris down again. Its hundred and two questions run in three tiers and are best worked in order.

BINDER questions build the core explanation of each process: weathering and mass wasting, the work of wind and water in the deserts, the karst of the limestone country, the rivers from their youthful torrents to their old-age deltas, and the waves, tides and coral coasts of the sea, many with the help of a labelled diagram. REAL questions carry that understanding into real Tanzanian settings, the Hanang and Lushoto mudflows, the Amboni caves, the Rufiji delta, the beaches of Bagamoyo and the reefs of the Indian Ocean. HOT questions ask you to weigh these processes against one another and to judge their work on the land and on human life.

BINDER QUESTIONS

Question 1

A traveller flying from the snows of Kilimanjaro to the flat Rufiji delta crosses a land that the inner forces raised but the weather is steadily wearing down. Explain what the exogenic processes of the Earth are and account for the energy that drives them.

Model Answer

Exogenic processes are the external forces that wear down, move and redeposit the materials of the land surface, in contrast to the endogenic forces that raise it from within.

They are powered mainly by energy from outside the solid Earth. Solar heating sets the air and water in motion and drives the water cycle, so that running water, waves and wind all gain their energy from the Sun. Gravity then pulls loosened material downslope, while the rocks are first prepared by weathering. Working together these processes carry out denudation, the general lowering of the land. Because they never stop, even a high block like the Kilimanjaro massif is slowly being stripped and carried towards the Indian Ocean.

The exogenic family therefore has four linked members: weathering, which breaks rock in place; mass wasting, which moves it downslope under gravity; erosion, which wears and picks it up; and deposition, which lays it down again.

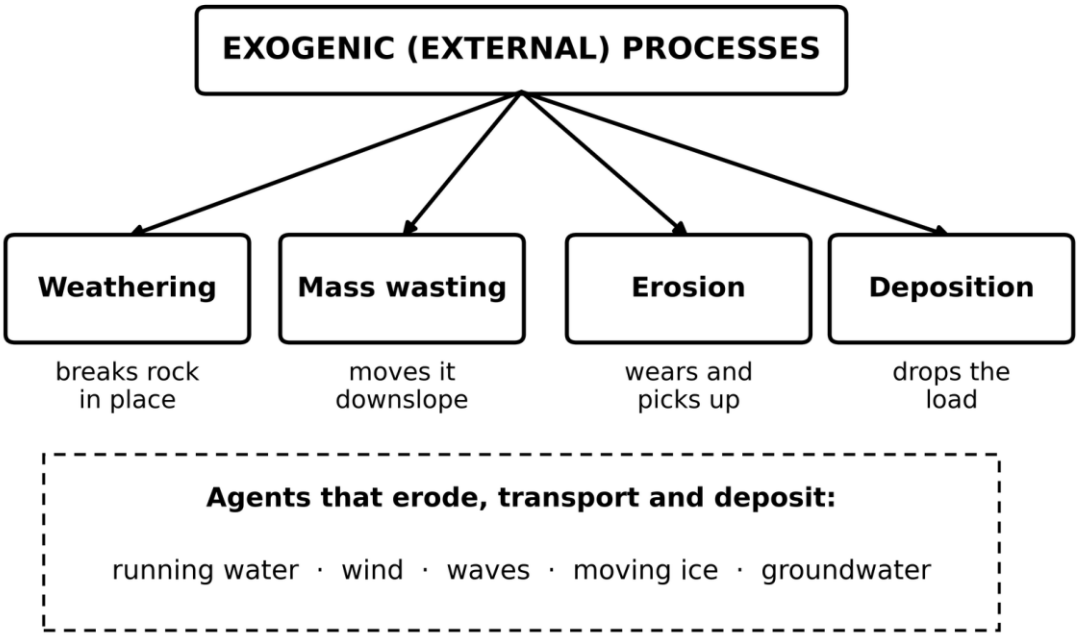


Figure 4.1: *The exogenic processes of the Earth*

Question 2

A student writes that *'denudation and erosion mean the same thing'*. Using the Tanzanian landscape, explain why this is wrong by distinguishing denudation from its parts.

Model Answer

Denudation is the whole work of wearing down and laying bare the land surface, and erosion is only one stage within it, so the two are not the same.

1) **Weathering:** the breakdown of rock in place by physical, chemical or biological action, as when the granite tors of the central plateau crumble where they stand, without yet being carried away.
2) **Mass wasting:** the downslope movement of the loosened material under gravity, such as the landslides that scar the steep Uluguru slopes after heavy rain.
3) **Erosion:** the wearing away and picking up of material by a moving agent, as the Pangani river scours its bed and banks.
4) **Transport and deposition:** the carrying of the load and its dropping when energy falls, as silt is laid down on the Rufiji floodplain.

So denudation is the sum of all four, while erosion is the single step that lifts and carries; weathering and mass wasting must usually prepare the material before erosion can act.

Question 3

On the bare granite hills of Dodoma the rock is flaking and crumbling although nothing has carried it away. Explain what weathering is and why exposed rock breaks down.

Model Answer

Weathering is the breakdown and decay of rock in place, at or near the surface, without the broken material being removed.

It happens because rock formed at depth meets very different conditions once it is exposed. Underground it formed under high pressure, steady temperature and little water, whereas at the surface it faces daily heating and cooling, rainfall, gases such as oxygen and carbon dioxide, and living things. Since the minerals are no longer stable in these new conditions, they are attacked physically and chemically and slowly weaken. The Dodoma granite flakes because its surface expands and contracts and its feldspar rots to clay. Weathering does not itself carry the debris away; it only prepares loose material that erosion and mass wasting can later remove, which is why it is called the preparation stage of denudation.

False Confidence Alert
Weathering is not erosion. Weathering breaks rock where it lies; erosion picks the pieces up and moves them. A question that says material was 'worn away and carried off' is testing erosion, not weathering.

Question 4

In the cold nights of the Kilimanjaro highlands and the hot days of the Sahara, rock shatters without any change to its chemistry. Explain mechanical weathering and account for why it dominates in deserts and cold highlands.

Model Answer

Mechanical (physical) weathering is the breaking of rock into smaller fragments without any change in its chemical make-up.

It works by setting up physical stresses that crack the rock apart, through heating and cooling, the freezing of water, the growth of salt crystals, the release of pressure and the prising action of roots. It dominates in deserts and cold highlands because these environments have the large temperature swings and the freezing conditions that drive such stresses, while their dryness slows the chemical reactions that would otherwise dominate. On the bare slopes of Kilimanjaro above the forest, repeated freezing and thawing shatters the

rock into angular scree, since there is little vegetation or moisture to encourage chemical decay. The end product is broken but chemically unchanged rock.

Question 5

The great rounded granite domes of central Tanzania shed curved shells of rock like the skins of an onion. Explain how thermal expansion produces exfoliation domes.

Model Answer

Exfoliation is the peeling away of curved outer shells of rock, and it results from the repeated thermal expansion and contraction of the rock surface.

By day the intense sun heats the outer skin of the rock, which expands; by night the surface cools and contracts. Because rock is a poor conductor of heat, this swelling and shrinking is concentrated in the outer layer while the inside stays unmoved. The strain set up between the heated shell and the cool interior eventually cracks the rock parallel to its surface, so that shells peel off one after another. As the shells fall away a rounded mass is left, forming an exfoliation dome with scree gathered at its foot. The bare granite domes of the central plateau show this well, since the daily temperature range there is large.

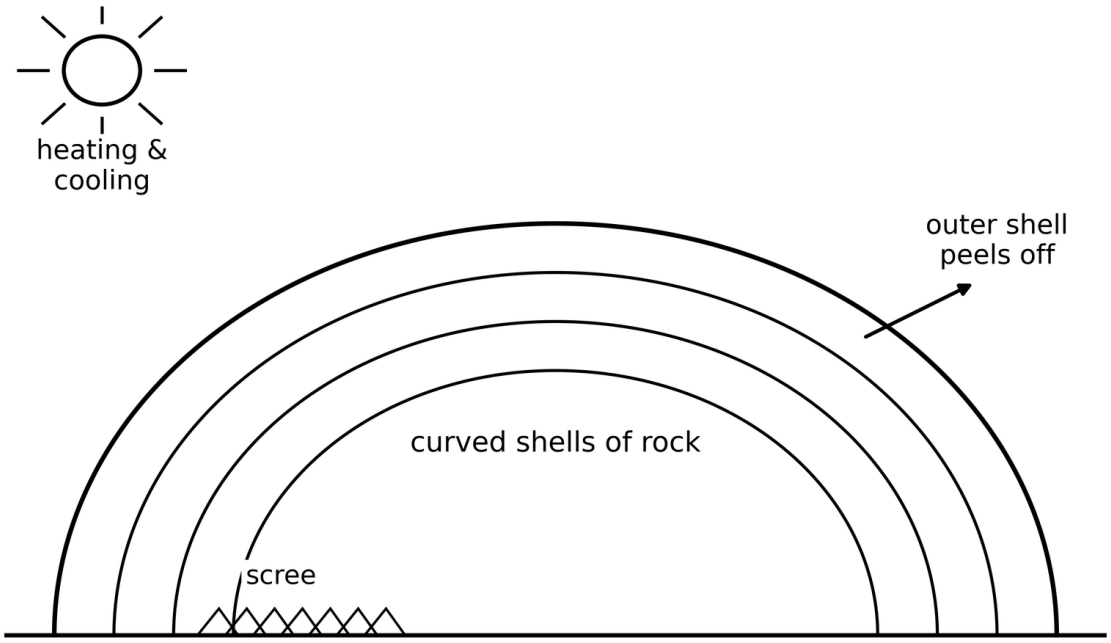


Figure 4.2: *An exfoliation dome formed by thermal expansion*

Question 6

On the freezing peaks of Kilimanjaro and along the salty shore at Pangani, water and salt prise rock apart by sheer pressure. Explain frost action and salt crystallization as forms of mechanical weathering.

Model Answer

Both frost action and salt crystallization break rock by the pressure of a substance growing inside its cracks and pores.

Frost action: water collects in joints and freezes, and since water expands by about a tenth as it turns to ice, it pushes hard on the walls of the crack. Repeated freezing and thawing, common on the high slopes of Kilimanjaro, widens the joints until the rock splits into angular blocks.

Salt crystallization: salty water soaks into pores in rock near the coast or in the desert, and when it evaporates the salt crystals grow. As they grow and take up water they expand and press on the pore walls, prising the grains apart, which is why coastal sandstone near Pangani crumbles grain by grain.

In both cases no chemistry changes the rock; it is simply forced apart by pressure from within.

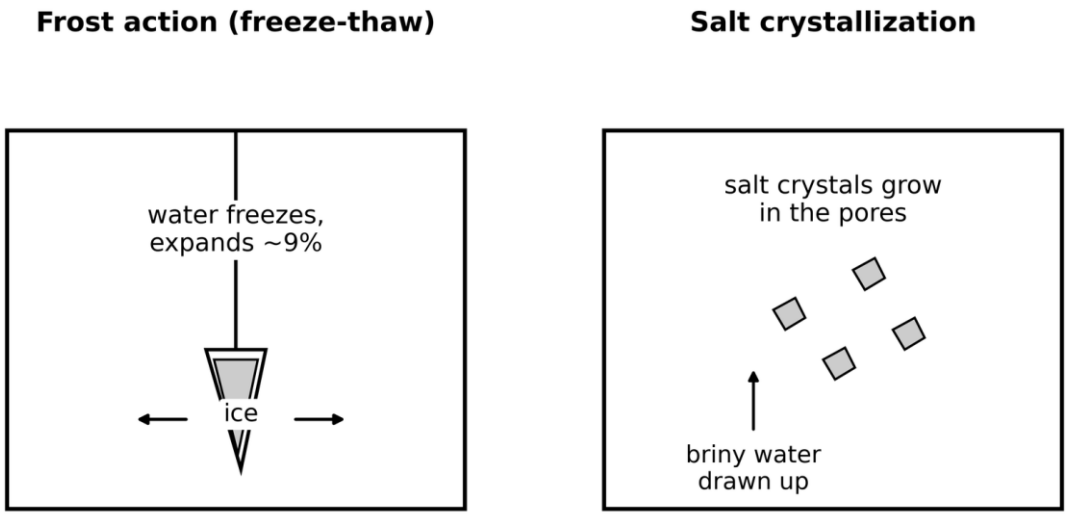


Figure 4.3: *Mechanical weathering by frost action and salt crystallization*

Question 7

Where deep granite is exposed on the central plateau, sheets of rock spring off the surface, and where clay-rich ground in central Tanzania dries between rains it cracks and crumbles. Account for pressure release and alternate wetting and drying as mechanical weathering.

Model Answer

Both processes break rock by stresses set up as conditions at the surface change, the first by removing load and the second by repeated swelling and shrinking.

Pressure release (unloading): rocks such as granite form deep down under great pressure. When erosion strips away the overlying material the confining pressure is removed, so the rock expands upward and cracks form parallel to the surface. Sheets then peel off, a process called sheeting, well seen on the exposed granite of the central plateau.

Alternate wetting and drying: some rocks and clays absorb water and swell, then shrink and crack as they dry. Repeated through the wet and dry seasons, this weakens the rock and breaks it into fragments, and it is why clay-rich ground crumbles and cracks as it dries.

Neither process alters the chemistry of the rock; each simply works it loose by physical strain.

Question 8

In the warm, wet miombo country of western Tanzania the rock does not just crack, it rots into soft red clay. Explain chemical weathering and why it deepens in the hot, wet tropics.

Model Answer

Chemical weathering is the decay of rock through chemical reactions that change its minerals into new, weaker substances.

It works when water, helped by dissolved gases such as carbon dioxide and oxygen, reacts with the minerals in the rock. The original minerals are changed into new ones, often soft and soluble, so the rock loses strength and crumbles. It deepens in the hot, wet tropics because warmth speeds up chemical reactions and abundant rainfall keeps the rock supplied with water, so the two main conditions for reaction are met all year. This is why the rock under the miombo woodland is rotted to deep red clay, while the same rock in a cold or dry place would barely be touched. The main chemical processes are carbonation, hydration, oxidation, hydrolysis and solution.

False Confidence Alert
Chemical weathering does not need a living thing or a hammer blow; it is the water and air themselves attacking the minerals. Heat and moisture speed it up, so the tropics weather chemically far faster than deserts.

Question 9

At Amboni near Tanga, rain has dissolved whole caverns out of solid limestone. Explain carbonation as a process of chemical weathering.

Model Answer

Carbonation is the chemical weathering of limestone by weak carbonic acid, which changes the rock into a soluble form that water can carry away.

As rain falls it dissolves a little carbon dioxide from the air to form a weak carbonic acid. When this acid meets limestone, which is calcium carbonate, it reacts to form calcium bicarbonate, a salt that dissolves readily in water. The dissolved rock is then carried off in solution, leaving hollows, widened joints and, underground, the caverns seen at Amboni in Tanga. The reaction can be written as calcium carbonate plus carbonic acid giving calcium bicarbonate. Because it depends on slightly acid water meeting carbonate rock, carbonation is most active in limestone country and is the master process that creates karst scenery.

Question 10

Where iron-rich rocks are exposed in Tanzania they turn rusty red, and certain minerals swell and flake as they take up water. Explain hydration and oxidation as forms of chemical weathering.

Model Answer

Hydration and oxidation are chemical weathering processes in which minerals are changed by taking up water or by reacting with oxygen.

Hydration: certain minerals absorb water into their structure and swell as they do so. The swelling sets up strain that weakens and flakes the rock, and it can change a mineral such as anhydrite into gypsum. Because the mineral takes in water without fully dissolving, hydration both expands and chemically alters the rock.

Oxidation: oxygen in air and water reacts with metallic minerals, especially those bearing iron, to form oxides. The new rusty iron oxides occupy more space and are easily broken down, so iron-rich rock crumbles and stains red. This is why exposed iron-bearing rocks in Tanzania weather to a reddish, rotted crust.

Both processes leave new minerals that are softer and more easily removed than the originals.

Question 11

In the deeply rotted soils of the western highlands, hard feldspar in the granite has turned to soft white clay. Explain hydrolysis and solution as processes of chemical weathering.

Model Answer

Hydrolysis and solution are chemical weathering processes in which water either reacts with minerals to form new ones or simply dissolves them away.

Hydrolysis: slightly acid water reacts with minerals such as the feldspar in granite, breaking them down into clay minerals plus soluble salts that are carried off. Because feldspar is common in granite, hydrolysis is the chief way the granite of the western highlands rots to deep clay soils.

Solution: some minerals, such as rock salt and gypsum, dissolve directly in water without being chemically changed, and simply disappear into the water. This is most important where soluble rocks are present.

Hydrolysis is the more powerful of the two for ordinary rocks, since feldspar makes up so much of the crust, and it explains the deep, clay-rich tropical soils.

Question 12

On a rocky Kilimanjaro slope, fig roots split the boulders they grow over, while termites and farmers loosen the same ground. Explain biological weathering and its three forms.

Model Answer

Biological weathering is the breakdown of rock by the action of living things, working either mechanically or chemically.

1) **Flora (plants):** roots grow into joints and cracks and, as they thicken, prise the rock apart, while decaying plants release organic acids that rot the minerals. Tree roots splitting boulders on a hillside show this clearly.
2) **Fauna (animals):** burrowing animals such as termites, worms and rodents loosen and mix the soil and rock, bringing fresh material to the surface and speeding its decay.
3) **Anthropogenic (human):** people break rock directly through quarrying, mining, road building and cultivation, exposing fresh surfaces to further weathering.

Biological weathering therefore bridges the physical and the chemical, since roots both wedge the rock open and feed acids into it.

The fig roots that split the boulders on the rocky slopes of Kilimanjaro show this prising action at work.

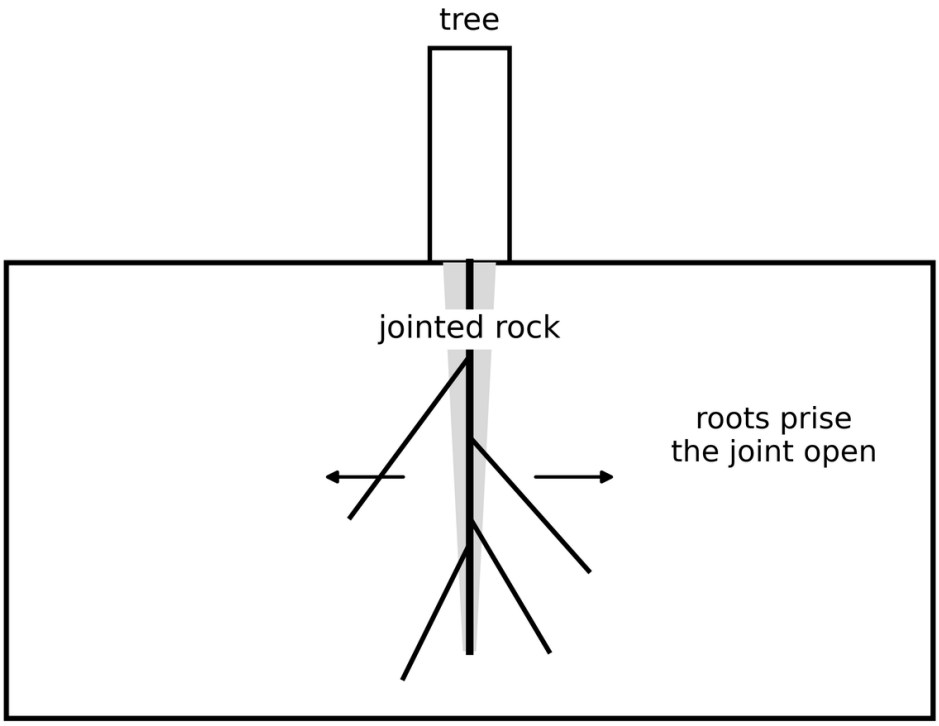


Figure 4.4: *Biological weathering: roots prising open a rock joint*

How to Draw It
Draw a block of jointed rock with a tree on top and a thick root pushing down into a widening joint, with small side roots. Add arrows showing the joint being forced apart and label the roots, the joint and the rock.

Question 13

On the steep Uluguru slopes above Morogoro, soil and rock slide downhill after heavy rain even though no river carries them. Explain what mass wasting is and why water matters even though it does not transport the material.

Model Answer

Mass wasting is the movement of rock and soil down a slope under the direct pull of gravity, rather than by being carried in a moving agent such as a river.

It includes the creeping, flowing, sliding and falling of weathered material downhill. Gravity is the driving force, so the steeper the slope the more readily material moves. Water matters greatly even though it does not carry the debris away itself, because it adds weight to the material and lubricates the grains, reducing the friction that holds them in place. So after heavy rain the saturated soil of the Uluguru slopes becomes heavy and slippery and slides under gravity. The amount of movement depends on slope angle, the weight and nature of the material, the water present and the vegetation cover.

False Confidence Alert
In mass wasting it is gravity, not running water, that moves the material. Water only adds weight and lubrication. Do not confuse mass wasting with river erosion, where the water itself does the carrying.

Question 14

Two hillsides in Lushoto face the same rain, yet one slips and the other holds firm. Account for the factors that trigger mass wasting.

Model Answer

Mass wasting is triggered by a set of factors that work together to overcome the friction holding material on a slope.

1) **Slope angle:** the steeper the slope, the stronger the pull of gravity along it, so steep Lushoto hillsides slip more readily than gentle ones.
2) **Water:** heavy rain saturates the material, adding weight and lubricating the grains, so saturated ground moves far more easily than dry ground.
3) **Nature and weight of material:** loose, heavy or clay-rich material on weak bedding planes slides more easily than firm, light material.
4) **Vegetation cover:** roots bind the soil and hold it in place, so a bare slope is far more likely to fail than a well-wooded one.
5) **Human action and earth tremors:** cultivation, road cutting and quarrying weaken slopes, while earthquakes shake material loose.

Where several of these combine, as on a steep, bare, rain-soaked and over-cultivated slope, failure becomes almost certain.

Question 15

On a gentle Iringa hillside the fences lean, the poles tilt and the tree trunks curve, yet no one has seen the ground move. Explain the slow forms of mass movement and how creep is recognised.

Model Answer

Slow mass movements shift material downhill so gradually that the eye cannot follow them, and they are known mainly by their after-effects.

1) **Soil creep:** the slowest movement, less than a centimetre a year, as soil particles swell when wet and shrink when dry and edge downslope. It is recognised by tilted poles, leaning fences, curved tree trunks and small terracettes on the hillside.

2) **Talus creep:** the slow downslope shifting of loose angular rock fragments piled at the foot of a cliff.
3) **Solifluction:** the flow of waterlogged soil over frozen subsoil in cold regions, faster than creep but still slow.
4) **Soil flow:** the steady movement of soil in a plastic, water-soaked state down a gentle slope.

All are gentle and persistent, so the leaning poles and bent trunks of an Iringa hillside are the surest sign that the soil beneath is slowly creeping.

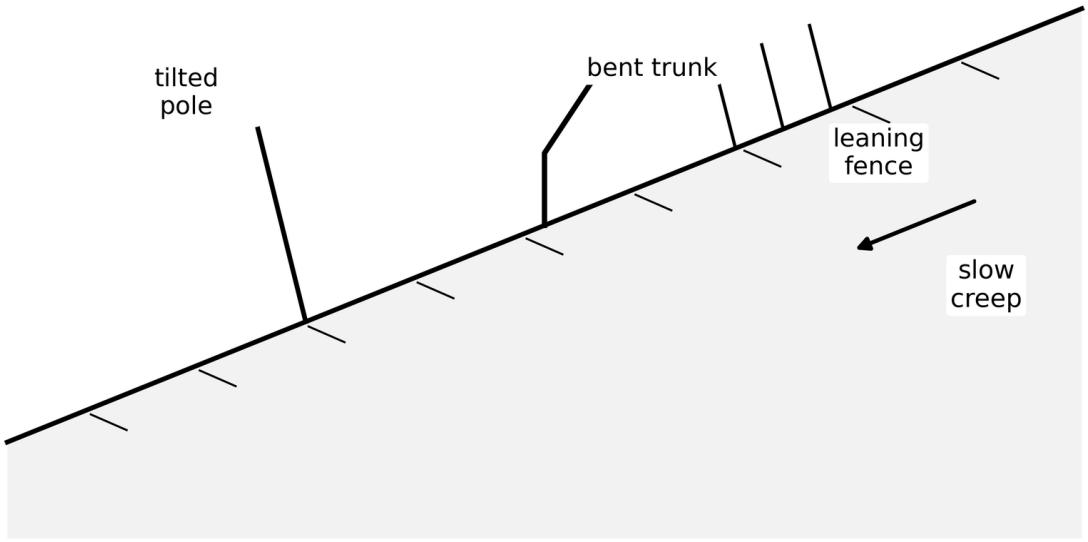


Figure 4.5: *Soil creep shown by its surface signs*

How to Draw It
Draw a gentle slope and on it place a tilted telephone pole, a curved tree trunk, a leaning fence and small step-like terracettes, with a downslope arrow labelled creep. The leaning objects are the key labels.

Question 16

In December 2023 a wall of mud buried homes around Hanang within minutes, while elsewhere boulders crash from cliffs without warning. Explain the rapid forms of mass movement.

Model Answer

Rapid mass movements shift large amounts of material suddenly and dangerously, and they are grouped by their water content, speed and the kind of material involved.

1) **Mudflow:** saturated soil and debris pour down a slope faster than walking pace after heavy rain, as in the Hanang disaster of 2023, burying everything in their path.
2) **Slump:** a block of weak material slips down a curved, concave surface and rotates as it goes, common where rain has soaked a steep bank.
3) **Rock fall:** individual boulders break free from a cliff and fall or bounce to its foot, gathering as scree or talus.
4) **Rock slide:** a mass of solid rock slides rapidly down a slope along a joint or bedding plane that lies parallel to the hillside.

In all of these the steeper the slope and the wetter the material, the faster and more destructive the movement.

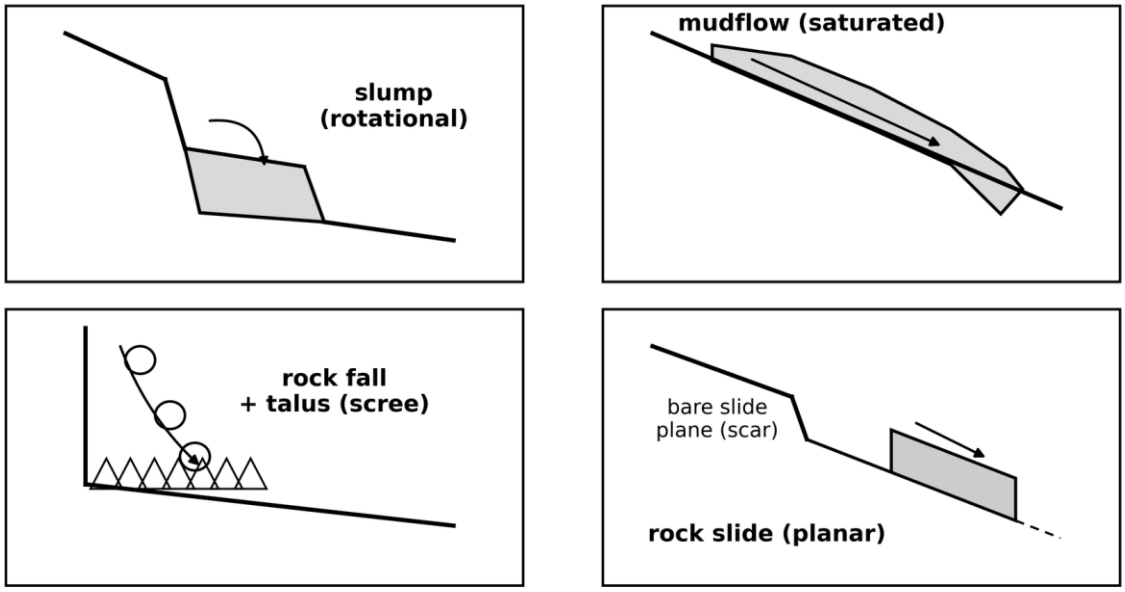


Figure 4.6: *Types of rapid mass movement on a hillslope*

How to Draw It
Draw a single hillslope and place the four rapid movements on it: a curved slump scar near the top, a mudflow tongue, a rock fall with boulders and talus at a cliff, and a planar rock slide. Label each by name.

False Confidence Alert
A landslide is not just a fast soil creep. Creep is imperceptible and harmless; rapid movements like mudflow and rockfall happen in minutes and can bury settlements, so the two must never be lumped together.

Question 17

After repeated landslides on the steep slopes above their village, a Lushoto community asks how the danger can be reduced. Account for the measures that reduce mass wasting.

Model Answer

Mass wasting is reduced by measures that strengthen slopes, remove excess water and control how the land is used.

1) **Afforestation:** planting trees and grasses so that their roots bind the soil and hold it together against movement.
2) **Slope drainage:** digging trenches and drains to remove the excess water that adds weight and lubricates the soil.
3) **Terracing and retaining walls:** cutting the slope into steps and building walls to reduce its angle and hold material back.
4) **Controlling land use:** limiting settlement, cultivation and quarrying on dangerous steep slopes so that they are not weakened further.
5) **Laws and education:** enacting and enforcing conservation rules and teaching communities to recognise and avoid the danger.

For a place like Lushoto a combination works best, since reforesting and draining the slope while keeping heavy building off it attacks several triggers at once.

Question 18

The Sahara and the Namib stretch for thousands of kilometres almost without rain. Account for why deserts form.

Model Answer

Deserts form wherever air is kept too dry to give rain, and several causes can produce this dryness.

1) **Sub-tropical high pressure:** around 15 to 30 degrees north and south of the equator, air descends, warms and dries, giving the clear skies and rainlessness of the Sahara and Kalahari.
2) **Rain shadow:** where moist air is forced over a mountain it sheds its rain on the windward side and descends dry on the leeward side, leaving a rain shadow desert.
3) **Cold ocean currents:** cold currents offshore chill the air above them so that it brings little rain to coasts such as the Namib.
4) **Continentality:** land far from the sea, deep in a continent, receives little moisture-bearing wind and so stays dry.
5) **Human action:** overgrazing, deforestation and poor farming strip the cover and spread desert conditions, a process called desertification.

Most great deserts owe their dryness mainly to descending sub-tropical air, with the other causes reinforcing it.

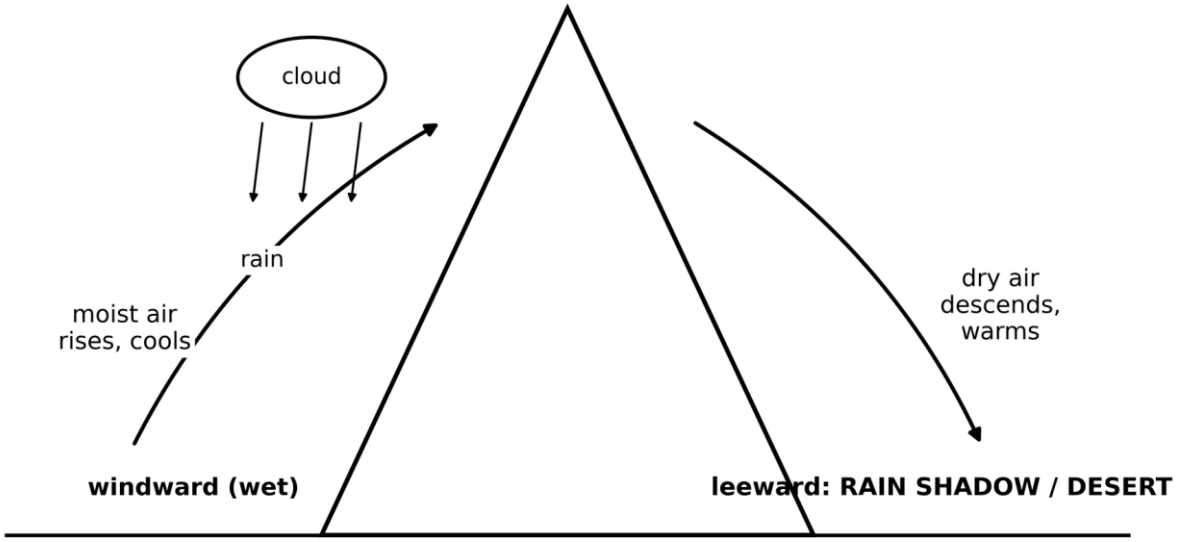


Figure 4.7: Rain shadow as a cause of deserts

How to Draw It
Draw a mountain with moist air rising and raining on the windward side and dry air descending on the leeward side into a desert. Label windward (wet), leeward (rain shadow / desert) and the direction of the wind.

Question 19

As the wind sweeps the Sahara it both sweeps the surface bare and sandblasts the standing rock. Explain how wind erodes the desert by deflation and abrasion.

Model Answer

Wind erodes the desert in two ways, by deflation, which lifts and removes loose material, and by abrasion, which sandblasts solid rock.

Deflation: the wind lifts and blows away fine, dry sand and dust, lowering the surface and leaving behind a pavement of pebbles too heavy to move. Where it scoops out the ground, hollows and depressions form.

Abrasion: sand grains carried by the wind are hurled against standing rock, grinding, scratching and polishing it. Because the sand is carried mostly near the ground, abrasion bites hardest close to the base, undercutting the rock.

Wind erosion is powerful because a small rise in wind speed produces a large rise in erosive force, so a fast desert wind can carry and fling far more sand than a slow one. Together deflation and abrasion shape the whole erosional landscape of the desert.

All of this can be seen across the Sahara, the greatest of the world's deserts.

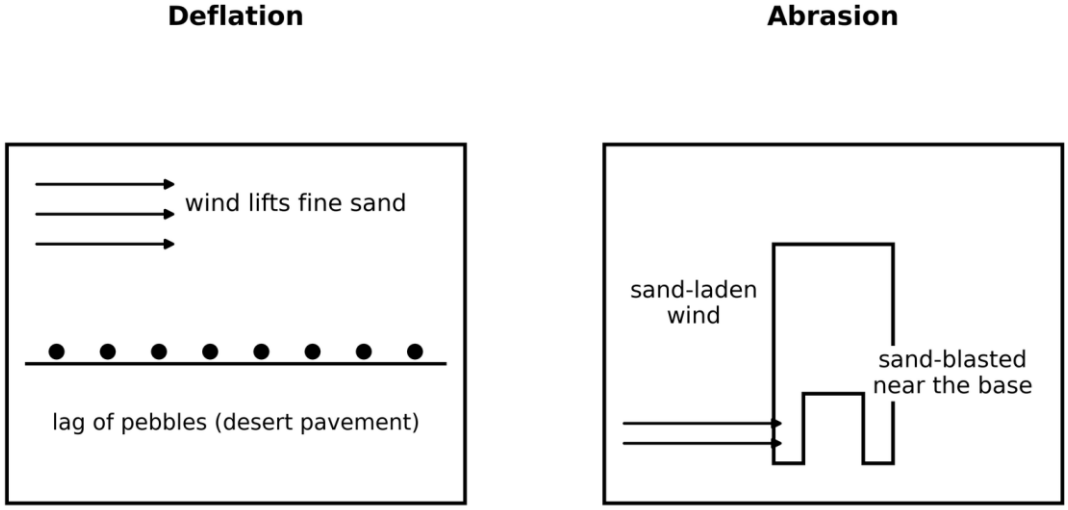


Figure 4.8: *Wind erosion by deflation and abrasion*

How to Draw It
Use two boxes. In the first show wind lifting fine sand and leaving a pebble pavement (deflation); in the second show sand-laden wind sand-blasting and undercutting a rock near its base (abrasion). Label deflation and abrasion.

False Confidence Alert
Deflation and abrasion are not the same. Deflation removes loose material and lowers the surface; abrasion uses wind-carried sand to wear away solid rock. A hollow is deflation; a sand-blasted, undercut rock is abrasion.

Question 20

In the heart of the Sahara, palm-fringed pools of water lie in deep hollows far below the surrounding plain. Explain the landforms produced by wind deflation.

Model Answer

Deflation produces hollows and depressions where the wind has scooped fine material out of the desert surface.

Where the ground is made of soft, loose material, the wind blows the fine sand away and lowers the surface, leaving an enclosed deflation hollow. These hollows range from small basins to very large depressions; the

Qattara Depression in Egypt has been lowered to about 134 metres below sea level in this way. Where a hollow is deepened until it reaches the water table, groundwater seeps in and collects to form an oasis, a patch of permanent water and vegetation in the dry desert. Deflation works fastest where the rock is soft, since hard rock resists removal, so it is the soft-floored areas that are hollowed out while the resistant ground stands above.

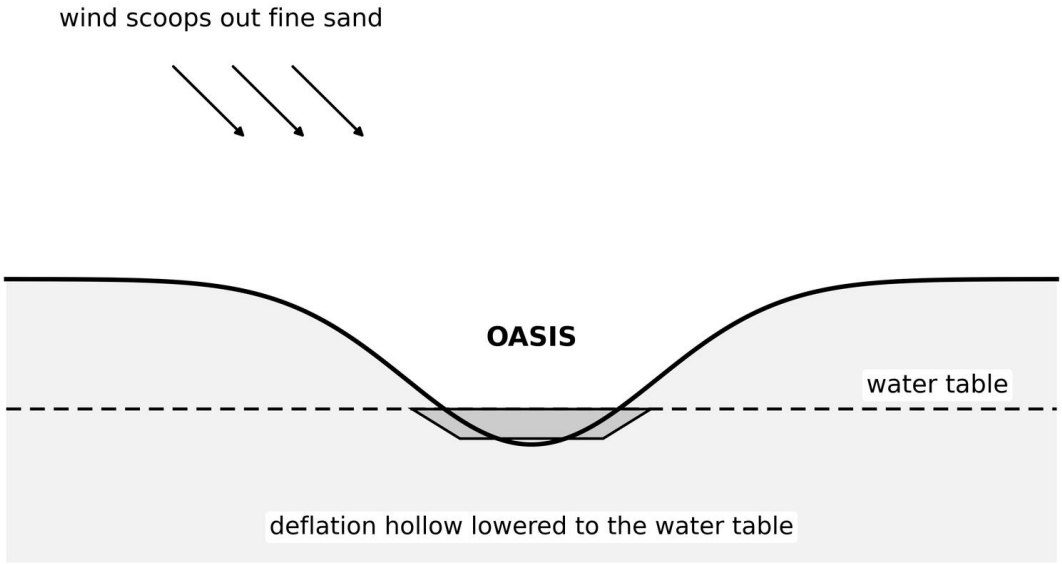


Figure 4.9: *A deflation hollow lowered to the water table to form an oasis*

How to Draw It
Draw a cross-section of the desert surface with a wide hollow scooped in it, a dashed water-table line, and water collecting where the hollow dips below that line. Label the deflation hollow, the water table and the oasis.

Question 21

Across the Sahara the wind has carved rocks into mushrooms, ridges and isolated hills. Explain the landforms produced by wind abrasion.

Model Answer

Wind abrasion sculpts standing rock into a family of landforms by sandblasting it unequally, hardest near the ground.

1) **Ventifacts:** loose stones worn smooth and faceted on the side facing the wind.
2) **Rock pedestals (mushroom rocks):** rocks undercut near the base, where sand-blasting is strongest, leaving a narrow stalk under a broader top.
3) **Zeugen:** flat-topped ridges of hard rock separated by furrows cut along the joints in softer rock beneath.
4) **Yardangs:** streamlined ridges carved parallel to the wind where hard and soft rock lie in vertical bands.
5) **Inselbergs:** steep-sided isolated hills of resistant rock left standing above the worn-down plain, seen in Maasai country in northern Tanzania.

Each form reflects the same rule: soft rock is cut away while resistant rock stands out, and the wind bites hardest near the surface.

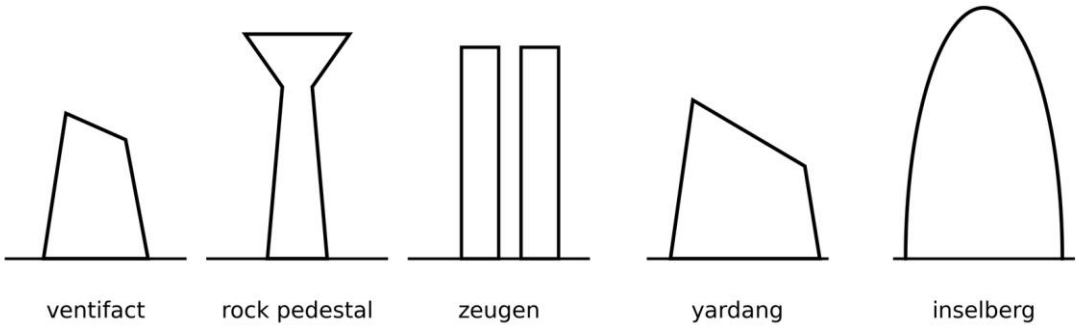


Figure 4.10: *Landforms of wind abrasion*

Question 22

A dust storm darkens the sky over the Sahara while sand grains bounce and roll along the ground below. Explain how the wind transports its load.

Model Answer

The wind carries its load in three ways, sorted by the size and weight of the particles.

1) **Suspension:** the finest dust is lifted high into the air and carried great distances, sometimes for thousands of kilometres, producing dust storms.
2) **Saltation:** sand grains too heavy to stay aloft are bounced along the ground in a series of low hops, knocking other grains into motion as they land.
3) **Surface creep:** the largest grains, too heavy to be lifted at all, are rolled and pushed along the surface by the wind and by the impact of saltating grains.

Transport is most effective where the wind is strong and steady, the ground is dry and loose, and there is no vegetation to bind the grains or absorb the wind's energy. The wind therefore sorts its load, dropping the coarse near the source and carrying the fine far away.

It is this sorting that lets a Sahara dust storm lift fine dust into the skies over West Africa while the coarse sand creeps along behind.

Question 23

Where the wind drops its sand, the Sahara is ridged with dunes of crescent, ridge and star shapes. Explain how dunes form and distinguish their main types.

Model Answer

Sand dunes are hills of wind-deposited sand, and their shape depends on the wind direction, the wind strength and the supply of sand.

1) **Barchan:** a crescent-shaped dune whose horns point downwind, formed by a wind blowing steadily from one direction with limited sand.
2) **Seif (longitudinal):** a long ridge of sand lying parallel to the prevailing wind, sometimes many kilometres long.
3) **Transverse:** wave-like ridges lying across the wind, built by gentle winds where sand is plentiful.
4) **Star:** a dune with arms radiating from a central peak, formed where the wind blows from several directions.
5) **Parabolic:** a U-shaped dune whose horns point upwind, often anchored by vegetation.

The same wind that erodes elsewhere builds these forms wherever its speed falls and it can no longer hold its sand.

The barchans of the Sahara and the long seifs of the Namib show these forms on a grand scale.

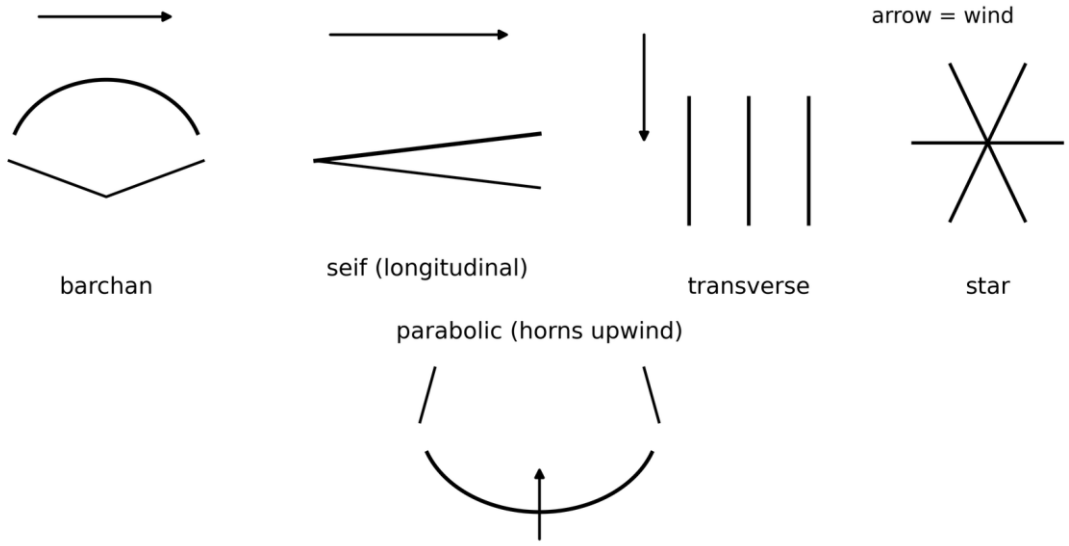


Figure 4.11: *The main types of sand dune*

How to Draw It
Draw the main dunes in plan view with a wind arrow above each: a crescent barchan with horns downwind, a long seif parallel to the wind, transverse ridges across the wind, a star dune, and a parabolic dune with horns upwind. Label each and the wind direction.

False Confidence Alert
Barchan and parabolic dunes look alike but face opposite ways. A barchan's horns point downwind; a parabolic dune's horns point upwind. Getting the horns the wrong way round is a common and costly slip.

Question 24

Rain is rare in the Sahara, yet when a storm breaks it tears channels into the bare ground within hours. Explain the erosional features cut by water in the desert.

Model Answer

Although rain is rare in deserts, when it falls it runs off the bare, hard ground at once and cuts a sharp set of erosional features.

1) **Rills:** small, shallow channels scored into the surface by the first runoff of a storm.
2) **Gullies:** deeper, steep-sided channels formed where the runoff concentrates and deepens the rills.
3) **Wadis:** deep, steep-sided dry valleys cut by occasional flash floods, holding water only briefly during a storm and dry for most of the year.
4) **Badlands:** intricately dissected slopes where countless rills and gullies have cut up soft rock into a maze of ridges and channels.

All of these form quickly because the desert surface is bare and baked hard, so rain cannot soak in and instead rushes over the surface, concentrating its erosive power into channels.

These channels are cut afresh by every rare storm that breaks over the Sahara.

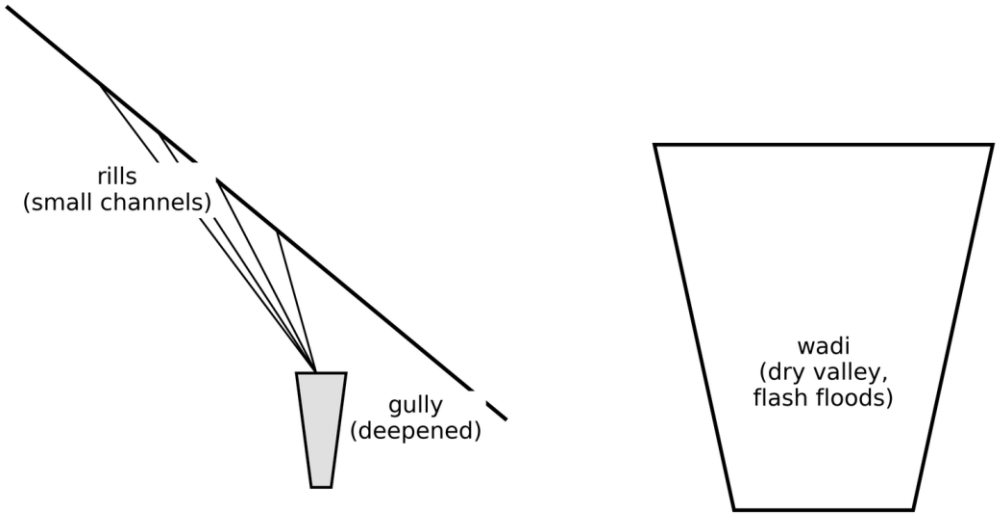


Figure 4.12: *Erosion by desert storm water*

How to Draw It
Draw a slope with several small rills running into a deeper gully, and beside it a steep-sided dry wadi with a flat floor. Label rills, gully and wadi, and show the direction of water flow.

Question 25

Across the dry north of Kenya, flat-topped tablelands and isolated towers stand above the plain. Explain the residual landforms left as desert highlands are worn back.

Model Answer

Residual landforms are the remnants left standing as a desert highland is worn back by weathering and slope retreat, protected by a cap of resistant rock.

1) **Mesas:** extensive flat-topped tablelands capped by a layer of hard, resistant rock that shields the softer rock beneath.
2) **Buttes:** smaller flat-topped hills, the further-worn remnants of a mesa, still capped with resistant rock.
3) **Pediments:** gently sloping rock platforms left at the foot of a highland as its edge is pushed back by erosion, thinly veiled with debris.

They form because the resistant cap rock protects the column beneath it while the surrounding softer rock is stripped away, so a mesa is slowly reduced to a butte and finally to nothing, leaving the pediment as the worn-down surface. Such tablelands are seen in the dry lands of northern Kenya.

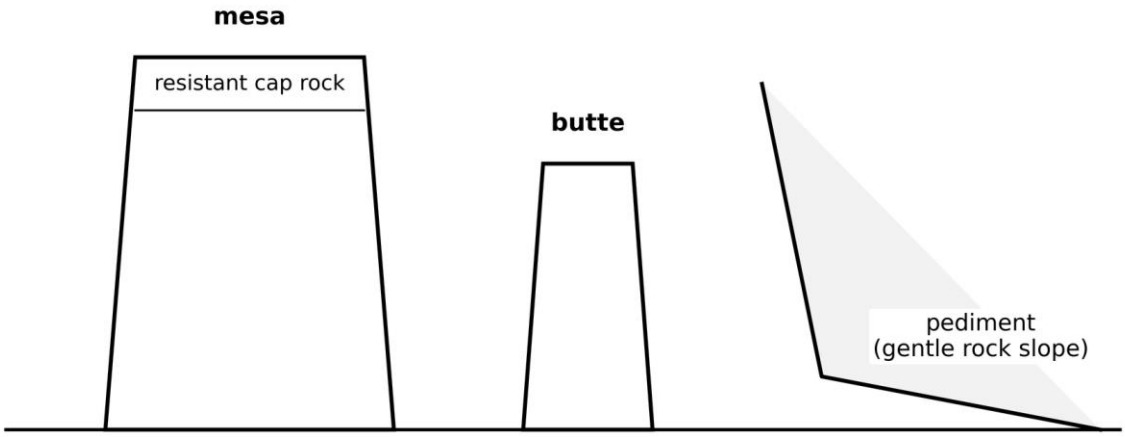


Figure 4.13: *Residual desert landforms*

How to Draw It
Draw a flat-topped mesa with a marked cap rock, a smaller butte beside it, and a gentle pediment sloping from the foot of a highland. Label the resistant cap rock on the mesa and butte.

Question 26

Where a desert stream bursts from the mountains onto the plain, it dumps its load in fans and salt flats. Explain the features laid down by water deposition in the desert.

Model Answer

When a desert stream leaves the mountains and loses energy on the plain, it drops its load to build a set of depositional features.

1) **Alluvial fans:** fan-shaped spreads of sediment laid down where a stream emerges from a steep valley onto the flat desert floor and suddenly slows.
2) **Bajada:** a continuous apron formed where several alluvial fans grow and merge along the foot of a highland.
3) **Playa or sebka:** a flat salt-crusted floor in an enclosed basin, left when a temporary lake dries up and its dissolved salts are deposited.

Each forms as the water loses the energy to carry its load: the coarse material drops first at the mountain front to build the fans, while the finest material and dissolved salt are carried into the basin and left as a salt flat when the water evaporates.

Such fans, bajadas and salt flats are common along the mountain fronts of the Sahara.

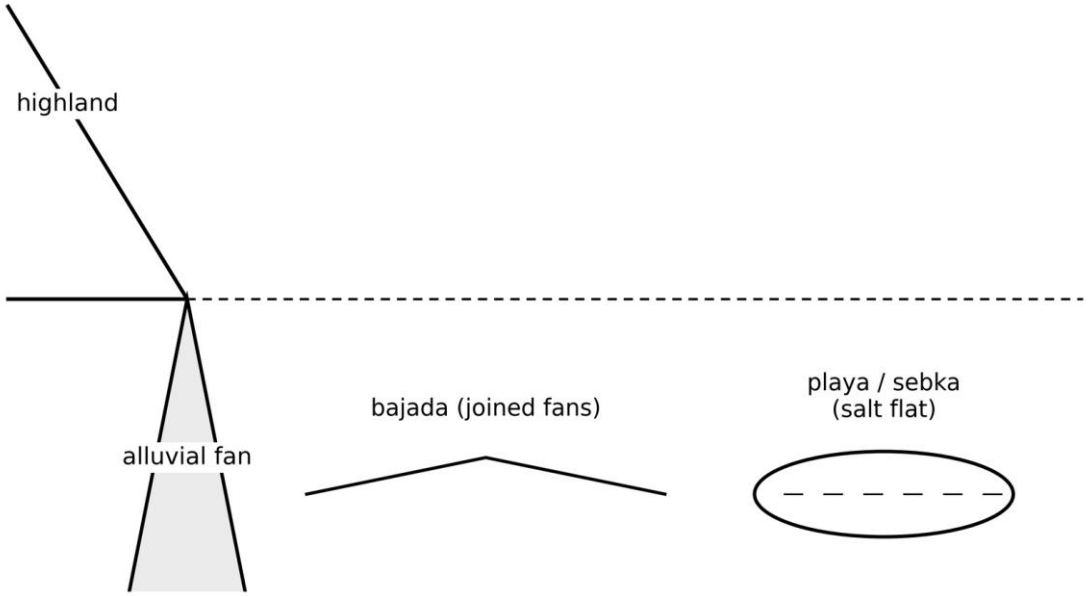


Figure 4.14: *Deposition by desert water*

How to Draw It
Draw a mountain front with a fan-shaped spread of sediment at its foot, several fans merging into a bajada, and a flat salt-crusted playa in the basin beyond. Label the alluvial fan, bajada and playa (sebka).

Question 27

In the limestone country around Amboni in Tanga, rain disappears underground through cracks and carves caves out of solid rock. Explain how karst landscapes form.

Model Answer

Karst is the distinctive scenery that develops on limestone, formed chiefly by the chemical solution of the rock by slightly acid water.

Rain dissolves a little carbon dioxide from the air to form a weak carbonic acid. Where this acid falls on well-jointed limestone it reacts with the calcium carbonate through carbonation, changing it into soluble calcium bicarbonate that is carried away in solution. Because the rock is full of joints, the water sinks quickly along them, widening the cracks and dissolving passages both at the surface and underground. Over time this etches the surface into a maze of grooves and hollows and hollows out caverns below, as at Amboni in Tanga. Karst therefore depends on two things together: a soluble, well-jointed rock such as limestone, and rainwater made slightly acid.

Question 28

A visitor to the karst country of Songwe is surprised to find thin soil, little surface water and scrubby grass on land made of solid rock. Account for the characteristics of karst regions.

Model Answer

Karst regions have a recognisable set of characteristics that all follow from their soluble, porous, well-jointed limestone.

1) **Scant vegetation and thin soil:** because solution removes the rock in solution rather than leaving a deep weathered mantle, the soil is thin and patchy and supports only scrub and grass, useful mainly for grazing.
2) **Little surface drainage:** because water sinks at once down the joints and swallow holes, rivers run underground and the surface stays dry, with few streams.

3) **Bare, jointed rock outcrops:** the limestone is exposed in blocky, well-jointed pavements that let rainwater percolate freely, a property called secondary permeability.

So at Songwe the same solubility that makes the caves also strips the soil and drains the surface, giving land that is dry and rocky yet useful for keeping livestock.

Question 29

On a limestone pavement the rock is cut into blocks and slots, and streams vanish into holes in the ground. Explain the surface features of a karst region.

Model Answer

The surface of a karst region is etched by solution into a set of distinctive features as rainwater attacks the joints of the limestone.

1) **Clints and grikes:** clints are the flat-topped blocks of a limestone pavement, separated by grikes, the deep slots dissolved out along the joints between them.
2) **Swallow holes (sinkholes):** vertical openings where a surface stream disappears underground down an enlarged joint.
3) **Dolines:** shallow, roughly circular surface depressions formed as swallow holes widen or several merge.
4) **Uvalas and poljes:** larger depressions formed where several dolines join (uvala) or where collapse and solution make a very large flat-floored basin (polje).

All of these grow as slightly acid water exploits the joints, widening them downward and carrying the dissolved rock away underground.

These surface forms are well shown on the limestone country around Amboni in Tanga.

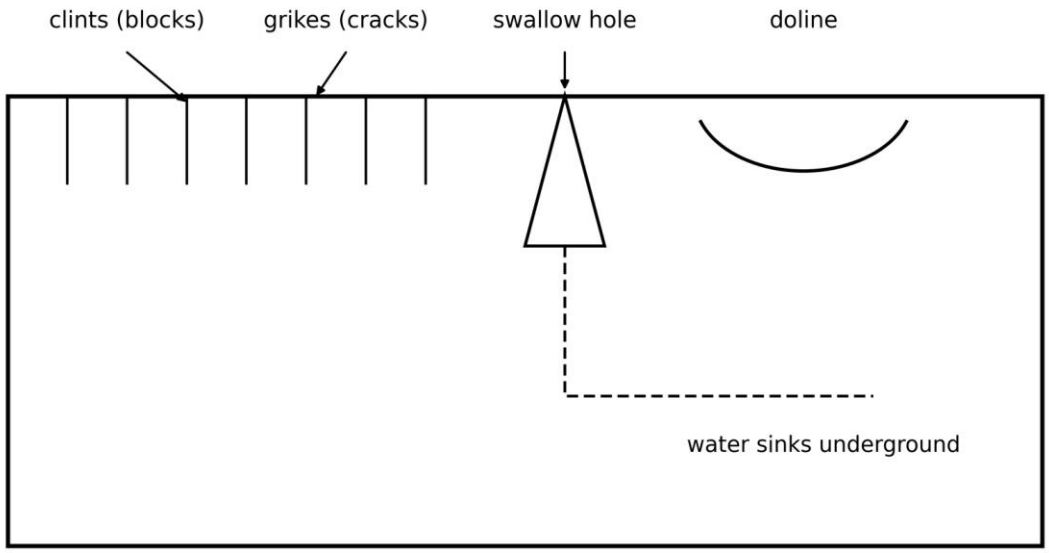


Figure 4.15: *Surface features of a karst landscape*

How to Draw It
Draw a block of limestone with a pavement of clints and grikes on top, a stream disappearing down a swallow hole, and a shallow doline depression. Show the water sinking underground and label each feature.

Question 30

Deep in the Amboni caves, stone icicles hang from the roof and rise from the floor while a hidden river flows through the dark. Explain the sub-surface features of a karst region.

Model Answer

Below the surface of a karst region, solution hollows out chambers while the slow deposition of calcium carbonate builds delicate features inside them.

1) **Caves and caverns:** underground chambers dissolved out of the limestone where water has flowed along joints and bedding planes.
2) **Stalactites:** finger-like growths of calcium carbonate that hang from the cave roof, built up as drips lose carbon dioxide and deposit their dissolved lime.
3) **Stalagmites:** matching growths that rise from the cave floor where the drips land.
4) **Pillars:** columns formed where a stalactite and a stalagmite meet and join.
5) **Underground rivers:** streams that flow through the cave system after sinking at a swallow hole.

So the same water both dissolves the chambers and, by losing its carbon dioxide as it drips, slowly rebuilds the lime as the cave ornaments seen at Amboni.

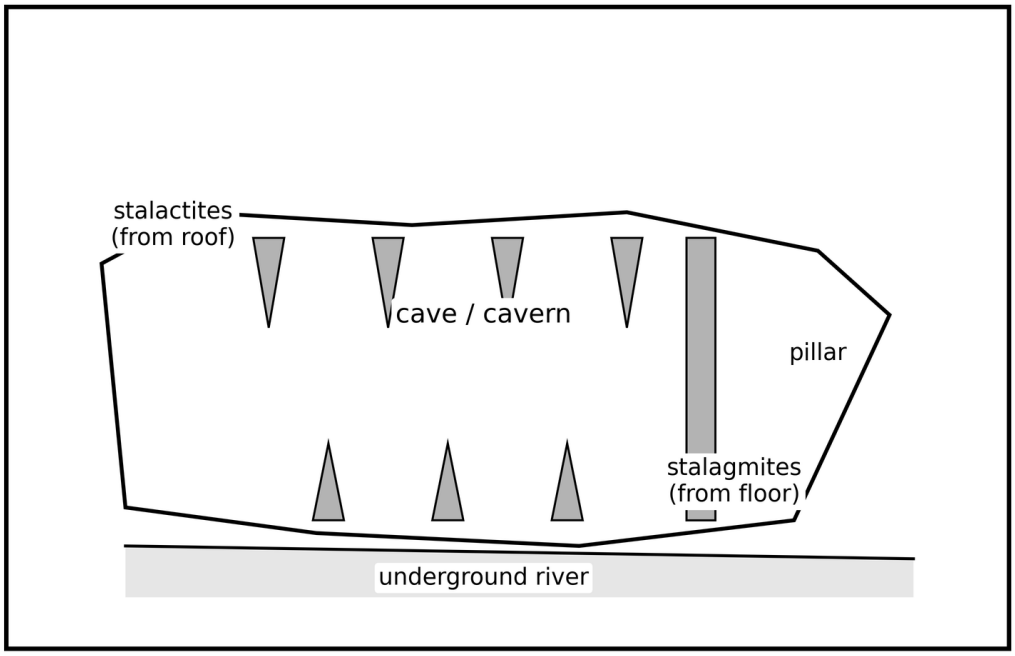


Figure 4.16: *Sub-surface features of a karst region*

How to Draw It
Draw a cave cross-section with stalactites hanging from the roof, stalagmites rising from the floor, a pillar where they join, and an underground river along the base. Label each, and show that stalactites hang while stalagmites stand.

Question 31

From its source on the Kipengere highlands to its mouth at the coast, the Great Ruaha shapes the land it crosses. Explain the work of a river as an agent of denudation.

Model Answer

A river is one of the chief agents of denudation, lowering the land as it carries its load from source to mouth through erosion, transport and deposition.

As it flows, a river erodes its bed and banks, picking up rock and soil; it transports this load downstream; and where it loses energy it deposits the load again. The material it carries, known as its load, may be mud, silt, sand, gravel or dissolved matter, and it can travel hundreds of kilometres from source to the plain. The river is most powerful where its volume and speed are greatest, so in flood the Great Ruaha can shift far more material than in the dry season. Erosion by running water is called fluvial erosion, and through these three linked actions a river slowly carves valleys, builds plains and reshapes the whole landscape it crosses.

Question 32

As the Pangani tumbles over its rocky bed it wears the rock in several different ways at once. Explain the four processes by which a river erodes.

Model Answer

A river erodes its bed and banks by four processes working together: hydraulic action, abrasion, attrition and solution.

1) **Hydraulic action:** the sheer force of the moving water alone, which pushes into cracks, compresses the air there and prises the rock loose.
2) **Abrasion (corrasion):** the wearing away of the bed and banks by the rock and pebbles the river carries, which grind against them like sandpaper; this is most effective in the upper and middle course.
3) **Attrition:** the load itself being worn down, as the carried fragments knock against one another and break into smaller, rounder pieces.
4) **Solution (corrosion):** the dissolving of soluble rock such as limestone by the slightly acid river water.

Hydraulic action and abrasion do most of the cutting, while attrition reduces the load and solution removes the soluble rock, so together they let the Pangani deepen and widen its channel.

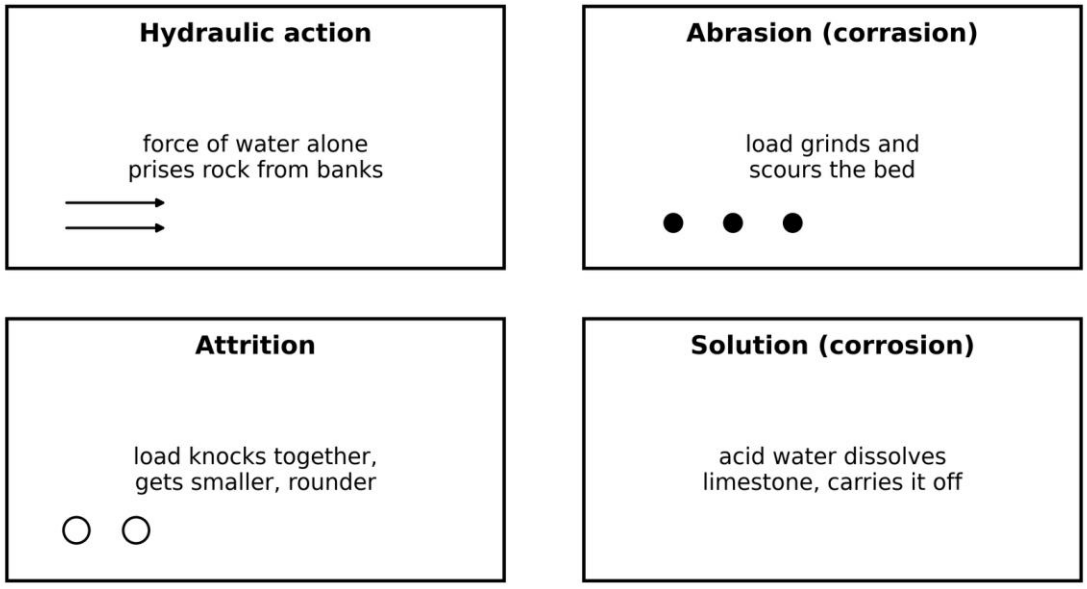


Figure 4.17: *The four processes of river erosion*

How to Draw It
Draw four small boxes for hydraulic action, abrasion, attrition and solution. In each show the idea simply (water forcing a crack; pebbles scouring the bed; pebbles knocking together; rock dissolving). Label each process.

False Confidence Alert
Abrasion and attrition are easy to confuse. Abrasion is the load wearing away the channel; attrition is the load wearing away itself. One shapes the river bed, the other rounds the pebbles.

Question 33

In its youth the Kihansi cuts straight down, in its middle course it swings sideways, and at its source it eats backwards into the hills. Explain how a river erodes its channel in three directions.

Model Answer

The four erosion processes let a river cut its channel in three directions: vertically, laterally and headward.

1) **Vertical erosion:** the deepening of the channel as the river cuts downward into its bed. It is strongest in the steep upper course, where it carves deep V-shaped valleys.
2) **Lateral erosion:** the widening of the channel as the river wears sideways into its banks, especially on the outside of bends. It dominates in the middle and lower course, opening out the valley.
3) **Headward erosion:** the lengthening of the channel as the river cuts back at its source, extending the valley uphill away from the direction of flow.

A young river such as the Kihansi in its steep upper reach is dominated by vertical erosion, but as the gradient eases downstream lateral erosion takes over and the valley grows wide.

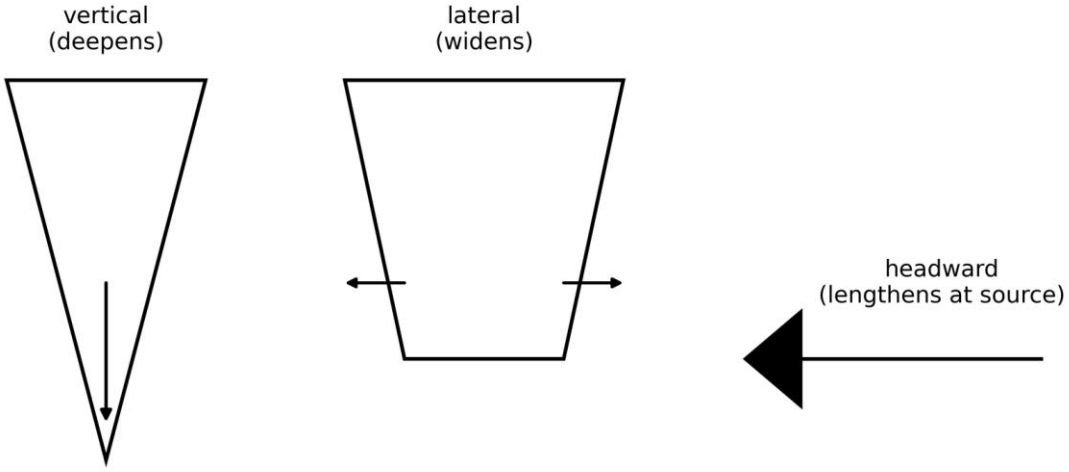


Figure 4.18: *Vertical, lateral and headward erosion*

How to Draw It
Draw three small sketches: a deep V being cut downward (vertical), a channel being widened sideways by arrows (lateral), and a channel head cutting back at the source (headward). Label the direction of erosion in each.

Question 34

The Rufiji in flood rolls boulders along its bed, bounces sand, and carries silt and dissolved salts to the sea. Explain how a river transports its load and what controls the amount it can carry.

Model Answer

A river transports its load in four ways, and the amount it can carry depends mainly on its volume and speed.

1) **Traction:** large boulders and stones are rolled and dragged along the bed.
2) **Saltation:** smaller stones and coarse sand are bounced along the bed in a series of hops.
3) **Suspension:** fine particles of silt and clay are held up in the body of the water and carried along, giving a river in flood its muddy colour.
4) **Solution:** dissolved minerals are carried along invisibly in solution.

The load a river can move depends on the volume of water, the velocity, the gradient and the size of the load relative to the flow. So in flood, with high volume and speed, the Rufiji can roll boulders it could never move in the dry season, while its everyday work is to carry silt in suspension to its delta.

Question 35

Where the Rufiji slows on its floodplain it drops its boulders first and carries its silt furthest. Explain why and how a river deposits its load.

Model Answer

A river deposits its load whenever it no longer has the energy to carry it, so deposition is essentially the failure of transport.

A river loses energy when its volume falls, its velocity drops, its gradient flattens, or it meets an obstacle such as a lake or the sea. As the energy falls it can no longer hold the heaviest particles, so they are dropped first, while the finer material is carried further. This sorts the load by size: coarse boulders and gravel are laid down first, then sand, and finally the fine silt is carried furthest, often to the river mouth. Deposition is greatest in the lower course, on the floodplain and at the mouth, where the gradient is gentle and the river slow. So the Rufiji drops its gravel upstream and spreads its fine silt across the floodplain and delta, building fertile land.

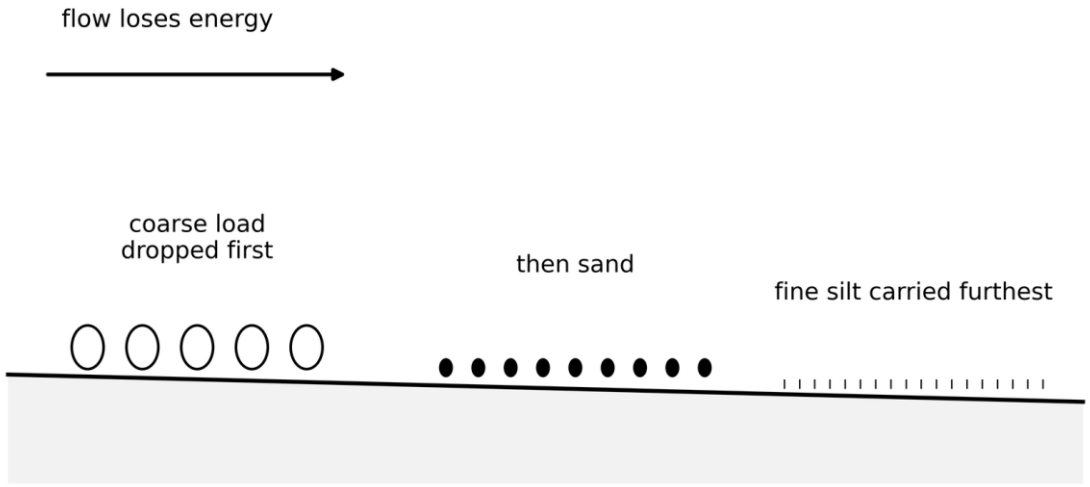


Figure 4.19: *River deposition and the sorting of the load*

How to Draw It
Draw a river losing energy as it reaches a lake or sea, dropping coarse boulders first, then sand, then carrying fine silt furthest. Use an arrow for falling energy and label the coarse-to-fine sorting of the load.

Question 36

Drawn from source to mouth, a mature river's bed forms a smooth concave curve that geographers call graded. Explain the long profile and the idea of a graded profile.

Model Answer

The long profile is the slope of a river's bed from source to mouth, and a graded profile is the smooth concave curve it tends towards when erosion and deposition are in balance.

The long profile is steep near the source and gentle near the mouth, giving a concave shape, because erosion is more active in the middle reaches than at the head or the mouth. The cross profile, the shape across the valley, changes too, from a narrow V in the youthful upper course to a wide, flat-floored valley in the old lower course. A graded profile is reached when the river has adjusted its slope so that, on average, the rate of erosion equals the rate of deposition, a state of dynamic equilibrium. Even then the grade is easily upset by changes in climate, rock type, sea level or river volume, so a real river is never perfectly and permanently graded.

The Great Ruaha shows such a smooth, concave graded profile as it nears its mouth.

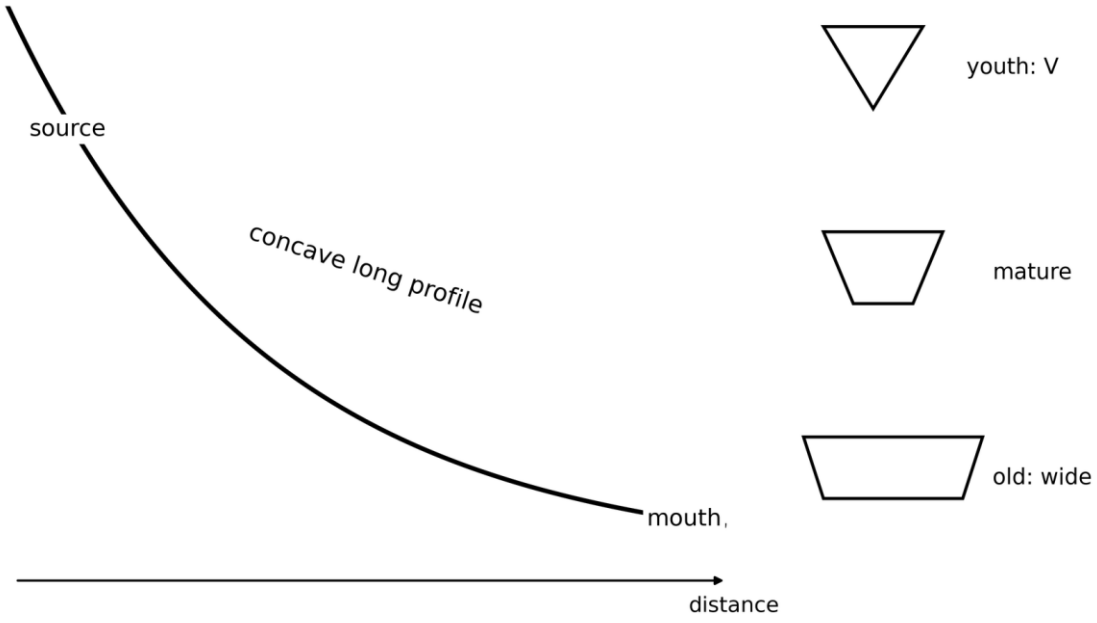


Figure 4.20: *The long profile and cross profiles of a river*

How to Draw It
Draw a concave long profile from a high source to a low mouth, labelling source and mouth, and beside it three cross-profiles (a narrow V, an open valley and a wide flat valley) for youth, maturity and old age.

False Confidence Alert
A graded profile is not a straight line, and it is not fixed. It is a smooth concave curve in a moving balance; any change in sea level, climate or rock can upset the grade and set erosion going again.

Question 37

The Pangani changes from a steep mountain torrent to a slow, broad river crossing the coastal plain. Explain the stages of a river valley and the changing work at each.

Model Answer

A river valley passes through three stages from source to mouth, youth, maturity and old age, each with its own dominant process and valley shape.

1) **Youth (upper course):** the river is steep and fast and cuts downward by vertical erosion, carving a narrow, steep-sided V-shaped valley with waterfalls and rapids.
2) **Maturity (middle course):** the gradient eases, lateral erosion grows, and the valley opens out, with meanders beginning to swing across a widening floor.
3) **Old age (lower course):** the river is slow and broad on a gentle gradient, deposition dominates, and it winds across a wide, flat floodplain to its mouth, often building a delta.

So the Pangani is a downcutting torrent in its youthful highland reach but a depositing, meandering river by the time it crosses the coastal plain.

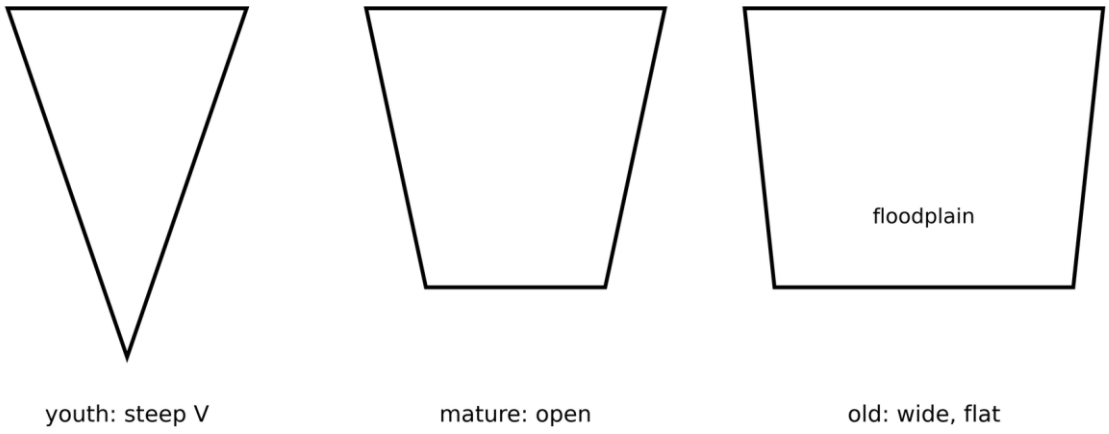


Figure 4.21: *The youth, mature and old stages of a river valley*

How to Draw It
Draw three valley cross-sections side by side: a narrow steep V (youth), an open V with a small floor (mature), and a very wide flat-floored valley with a floodplain (old). Label the stage and the dominant process under each.

Question 38

In its steep upper course the Kihansi spins pebbles into the bedrock and winds between projecting ridges. Explain the erosional features of the upper course of a river.

Model Answer

In its steep upper course a river cuts downward strongly, producing a set of erosional features dominated by vertical erosion.

1) **Pot holes:** circular hollows ground into the bedrock where pebbles caught in eddies are swirled round and round, deepening and widening the bed.
2) **V-shaped valleys:** narrow, steep-sided valleys cut as the river deepens its bed faster than the sides are worn back.
3) **Interlocking spurs:** ridges that project alternately from each side of the valley, around which the young river winds because it cannot yet cut them away.
4) **Gorges:** narrow, deep, steep-walled valleys cut where the river follows a line of weakness or where downcutting is very strong.

All of these reflect the same youthful condition: a steep gradient and fast flow that make the river cut down hard while doing little sideways work, so the valley stays narrow and the spurs interlock.

The youthful Kihansi in the southern highlands cuts just such a narrow valley between interlocking spurs.

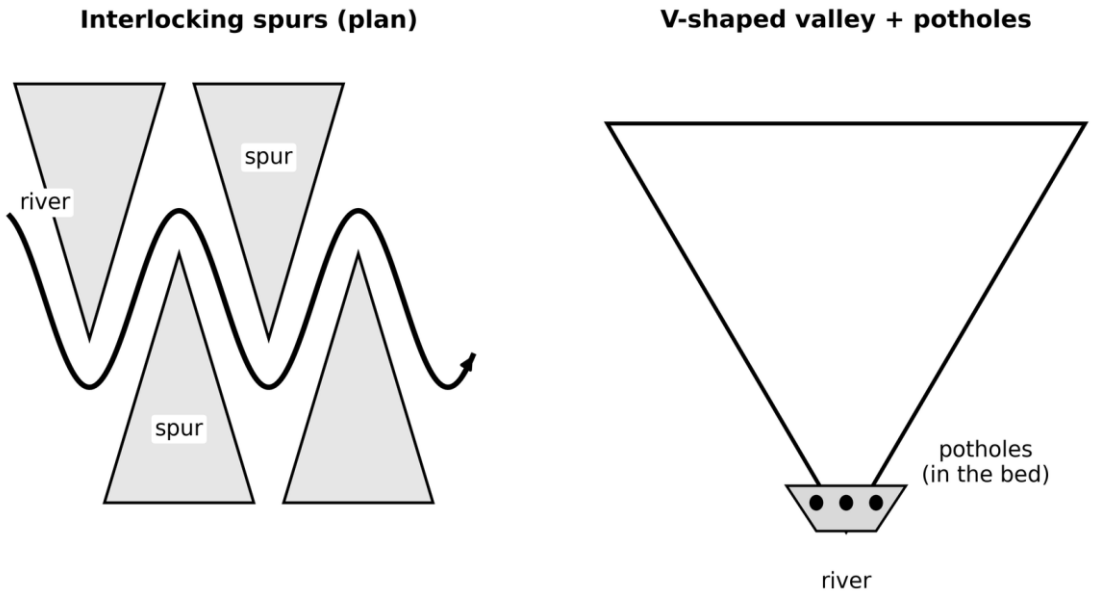


Figure 4.22: *Erosional features of the upper course*

How to Draw It
Draw a plan view of a winding river between interlocking spurs on one side, and a cross-section of a steep V-shaped valley with pot holes in the bed on the other. Label spurs, the V-valley and the pot holes.

Question 39

At Kalambo near Lake Tanganyika, water plunges over a great drop and a deep pool churns at its foot. Explain how waterfalls and rapids form.

Model Answer

A waterfall is a vertical drop in a river's course, formed most often where a band of hard rock lies across the channel above softer rock.

Where hard rock overlies soft rock, the river wears away the soft rock downstream faster than the hard, leaving a step over which the water plunges. At the foot the falling water and its load swirl and erode a deep plunge pool. The falling water then undercuts the soft rock behind the fall, so the hard cap is undermined and collapses, and in this way the waterfall slowly retreats upstream, often leaving a gorge below it. The break of slope at the lip is called a knick point. Rapids form in a similar way where the rock is less sharply stepped, giving a stretch of broken, tumbling water rather than a single clean drop, as on many of Tanzania's highland rivers.

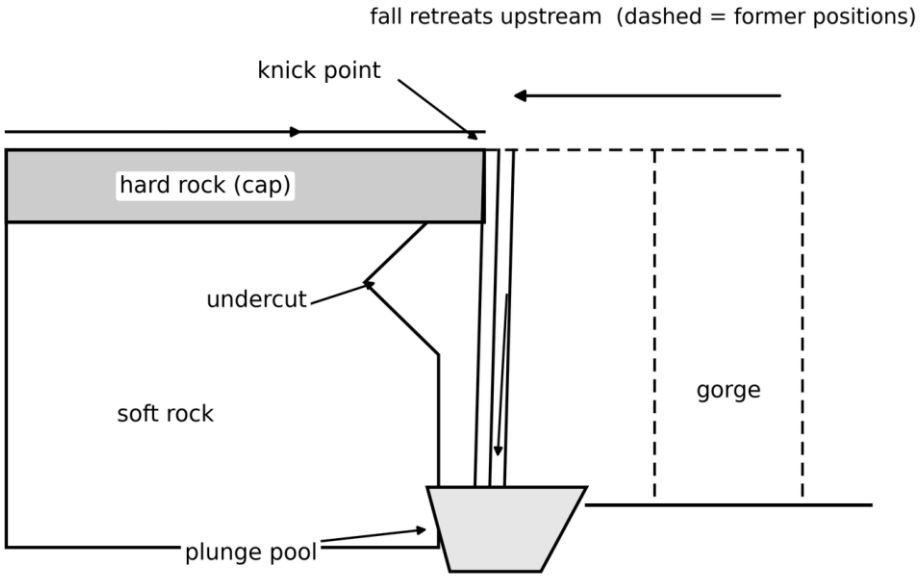


Figure 4.23: *How a waterfall forms and retreats*

How to Draw It

Draw a band of hard rock over soft rock with water plunging over the step into a plunge pool, and a dashed line showing the fall retreating upstream. Label the hard and soft rock, the plunge pool and the knick point.

False Confidence Alert

A waterfall is not fixed in place. By undercutting the soft rock behind it, the fall eats its way upstream over time, leaving a gorge. A question about how a waterfall 'changes' is testing this retreat.

Question 40

In its middle course the river swings in broad curves, and along its bed deeper pools alternate with gravelly shallows. Explain the features of the middle course of a river.

Model Answer

In the middle course the gradient eases and lateral erosion grows, so the valley widens and a set of new features appears as the river begins to swing.

1) **Bluffs:** steep banks left where the spurs of the upper valley have been cut back by the widening river, marking the edge of the valley floor.
2) **Riffles and pools:** an alternation along the bed of deeper pools, scoured on the bends, and shallow gravel riffles between them, giving the channel an undulating bed.
3) **Developing meanders:** the river begins to swing in broad curves, eroding the outer banks and depositing on the inner ones.

These appear because the gradient is gentler than in the youthful reach, so vertical erosion weakens and the river turns its energy sideways, widening the valley and starting the great bends that will dominate its lower course.

The middle course of the Pangani shows these widening bends and gravelly riffles well.

Question 41

Across the flat floor of the lower Kilombero the river swings in great loops, biting one bank and building the other. Explain how meanders and a floodplain develop.

Model Answer

Meanders are the sweeping bends a river develops on its gentle lower course, and the floodplain is the wide flat valley floor they build.

As the river swings, the fast water on the outside of each bend erodes the bank, cutting a steep river cliff, while the slow water on the inside deposits its load to build a gentle slip-off slope. In this way the bends grow and shift across the valley. When the river floods, it spills over its banks and lays silt across the valley floor, and as the meanders migrate they sweep this floor flat. The result is a broad, fertile floodplain of alluvium, like that of the Kilombero, with the river winding across it in great loops. Meanders are most pronounced where the gradient is gentle and the river slow.

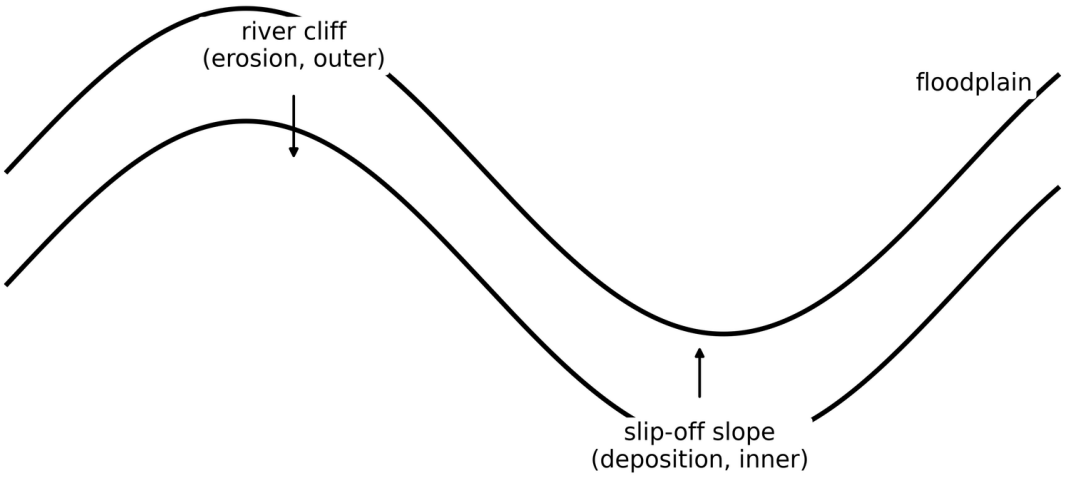


Figure 4.24: *A meander, with erosion and deposition*

Question 42

On the Kilombero floodplain a curved lake lies cut off from the river that once flowed through it. Explain how an oxbow lake forms and how a channel becomes braided.

Model Answer

An oxbow lake is a curved lake left when a meander loop is cut off from the main river, and braiding is the splitting of a channel into several threads.

Oxbow lake: as a meander grows, erosion narrows the neck of land between the two arms of the loop. In a flood the river breaks straight through the neck, taking the shorter course. Deposition then seals off the old loop, leaving a curved oxbow lake separated from the river.

Braided channel: where a river is overloaded with sediment and its banks are weak, it deposits bars of sand and gravel in mid-channel that split the flow into several threads which divide and rejoin.

Both features mark a river that is depositing heavily on a gentle gradient, so the meandering Kilombero leaves oxbows while a sediment-choked channel braids.

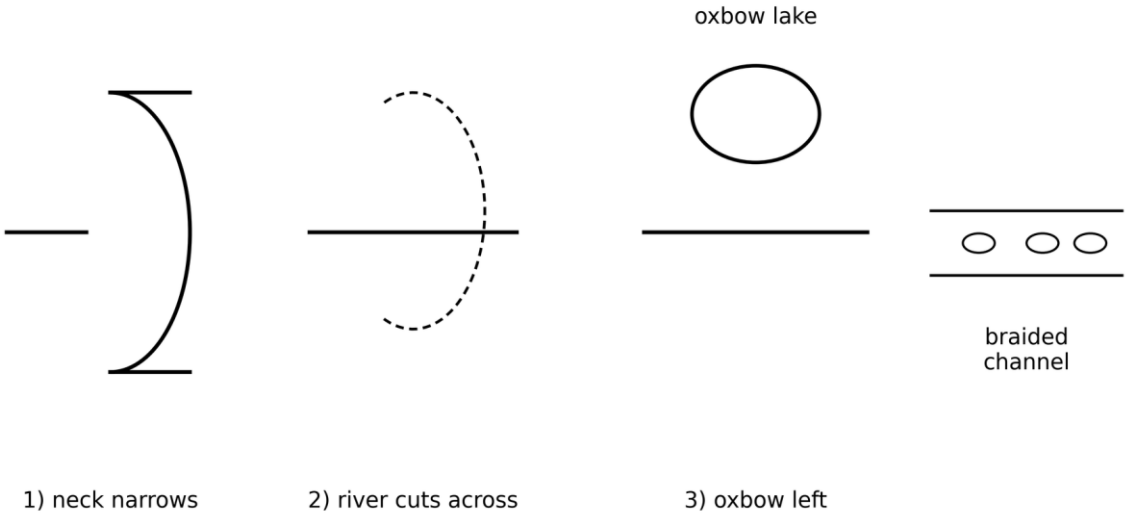


Figure 4.25: *Formation of an oxbow lake and a braided channel*

How to Draw It
Draw three stages of a meander: a tight loop with a narrow neck, the river cutting straight across the neck, and the loop sealed off as an oxbow lake. Add a small braided reach split by bars. Label each stage.

Question 43

Along the lower Rufiji the banks stand raised above the floodplain, and a tributary is forced to run for miles beside the main river before joining it. Explain how levees and deferred tributaries form.

Model Answer

Levees are raised banks built along a river by repeated flooding, and a deferred tributary is one forced to run alongside the main river by those banks.

Levees: when a river floods, it slows as it leaves the channel and drops its coarsest load first, right at the channel edge. Repeated floods build these deposits up into raised banks, or levees, standing above the floodplain.

Deferred (yazoo) tributaries: because the levees of the main river stand higher than the floodplain behind them, a tributary cannot cross to join the main river at once and is forced to flow alongside it, sometimes for many kilometres, until it finds a gap.

Both are features of a heavily depositing lower course, where flooding repeatedly spreads and drops sediment, as along the lower Rufiji.

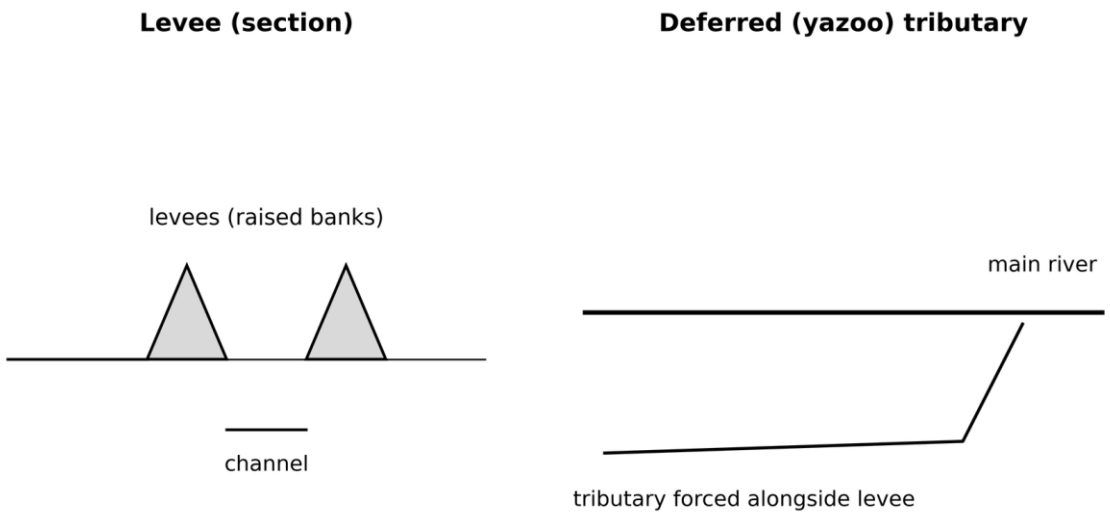


Figure 4.26: *Levees and a deferred (yazoo) tributary*

How to Draw It

Draw a channel cross-section with raised levees on each bank standing above the floodplain, and a plan view of a tributary running alongside the main river before joining it. Label the levees and the deferred tributary.

Question 44

Where the Rufiji meets the Indian Ocean it splits into many channels across a great triangle of fertile land. Explain how deltas form and distinguish their main types.

Model Answer

A delta is a low, flat plain of sediment built where a river enters a sea or lake and drops its load faster than it can be removed.

As the river meets the still water its velocity falls, so it deposits its load and splits into many smaller channels called distributaries that spread the sediment into a triangular plain. A delta forms only where the river carries a large load, the sea is shallow and sheltered, and waves and currents are too weak to sweep the sediment away. The main types are the arcuate, a fan-shaped delta of coarse and fine sediment crossed by many distributaries, such as the Rufiji; the digitate or bird's-foot, with a few long fingers of silt; the estuarine, formed in a drowned river mouth; and the cuspate, a tooth-shaped delta where waves spread the sediment evenly. The Rufiji delta is Tanzania's finest example.

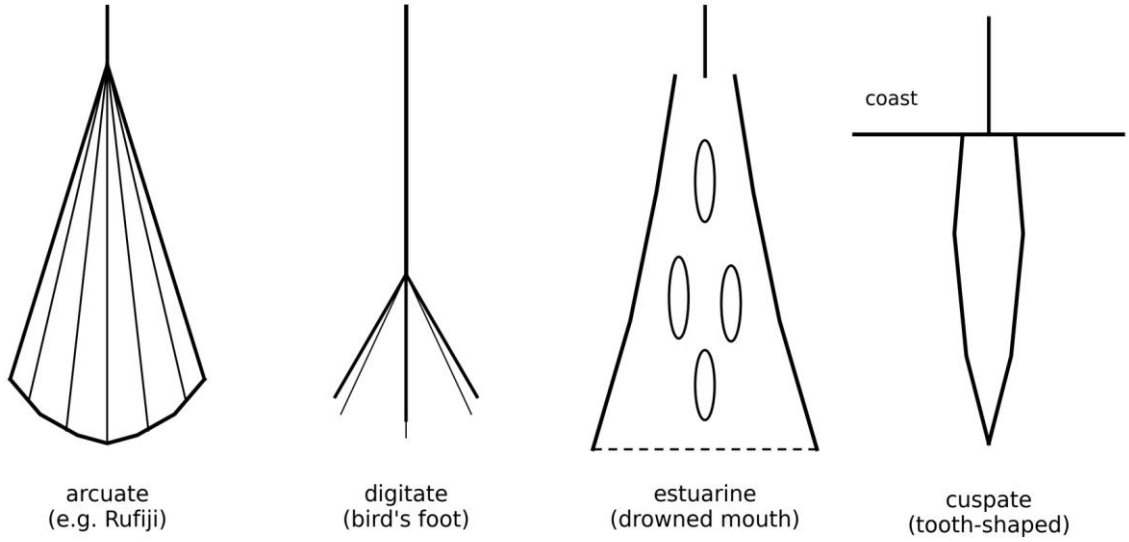


Figure 4.27: *The main types of delta*

How to Draw It
Draw the four delta shapes in plan view: a fan-shaped arcuate (label Rufiji), a bird's-foot digitate, an estuarine delta in a drowned mouth, and a tooth-shaped cuspate. Label each type and show the distributaries.

False Confidence Alert
Not every river mouth makes a delta. A delta forms only where the load is large and the sea is shallow and calm; where waves and currents are strong they sweep the sediment away and no delta builds.

Question 45

Where the land of the southern highlands was uplifted, old, gently flowing rivers began once more to cut deep into their beds. Explain river rejuvenation and its types.

Model Answer

River rejuvenation is the renewal of a river's erosive power, which sets it cutting downward again after it had reached a gentle, graded course.

It happens when the river's base level is lowered or its energy is increased, usually by a fall in sea level or an uplift of the land, which steepens the gradient and revives downcutting. There are three types. Dynamic rejuvenation follows the tilting or uplift of the land by earth movements, which steepens the slope. Static rejuvenation follows an increase in the river's volume, from heavy rain or river capture, without a change of slope. Eustatic rejuvenation follows a fall in sea or lake level, which lowers the base level. In the uplifted southern highlands, dynamic rejuvenation has set old rivers cutting fresh, deep valleys into their former gentle floors.

Question 46

In the Usambara mountains the Mkomazi has cut a steep new gorge inside its older, wider valley, with stepped benches along its sides. Explain the landforms produced by river rejuvenation.

Model Answer

A rejuvenated river, cutting down into its own valley floor, leaves a set of landforms that record its renewed downcutting.

1) **Knick point:** a sharp break of slope in the long profile, often marked by a waterfall or rapid, where the new steeper grade meets the old.

2) **River terraces:** step-like benches left along the valley sides, the remnants of the former floodplain into which the river has since cut; they are paired if equal on both sides.

3) **Incised meanders:** old meanders cut deep into the rock as the river renewed its downcutting while keeping its winding course, as on the Mkomazi between Mlalo and Lushoto.

4) **Valley within a valley:** a steep new gorge cut inside the wider old valley, recording the fresh phase of erosion.

Together these show a river given new energy, carving down into the floor it had earlier built.

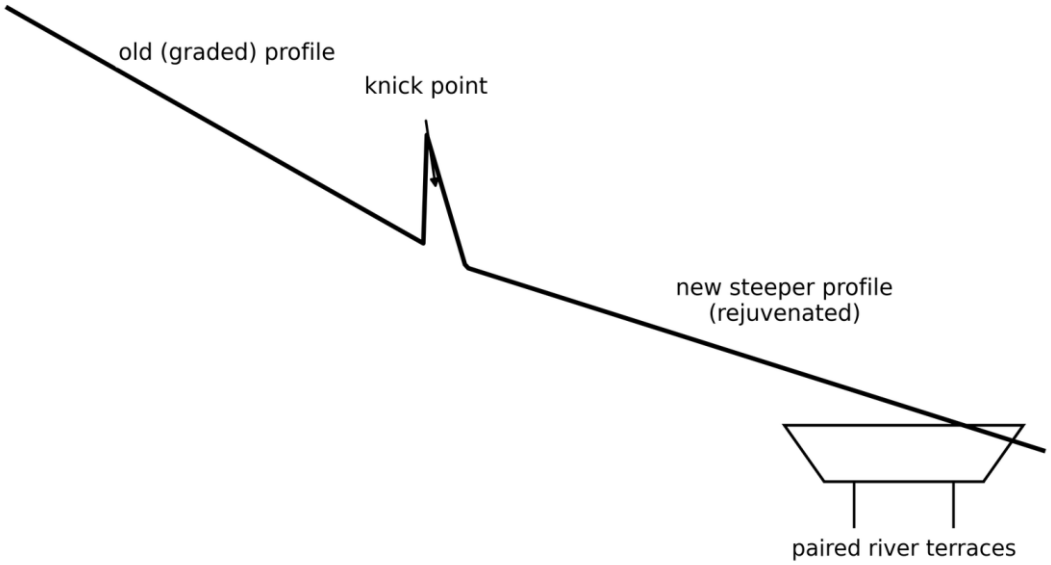


Figure 4.28: *Landforms produced by river rejuvenation*

How to Draw It
Draw a long profile with a clear knick point where a gentle old grade meets a steep new one, and a valley cross-section with paired terraces stepping down to a deep new channel. Label the knick point and terraces.

Question 47

In some highland areas a vigorous river has eaten back into the headwaters of a weaker neighbour and stolen its flow. Explain how river capture happens and the features it leaves.

Model Answer

River capture, or piracy, is the diversion of part of one river's course into that of a stronger, more vigorous neighbour.

It happens when a powerful river, with a steeper gradient and greater energy, cuts back vigorously by headward erosion until it breaks into the valley of a weaker river. The weaker river's headwaters are then diverted into the stronger one. The capture leaves several features: an elbow of capture, the sharp bend where the diverted water turns into its new course; a wind gap, the now-dry valley below the point of capture; and a misfit or beheaded stream, the weakened river left below the capture, too small for its valley. Capture is favoured where a strong river works along a band of weak rock that lets it erode headward quickly, as in parts of the East African highlands.

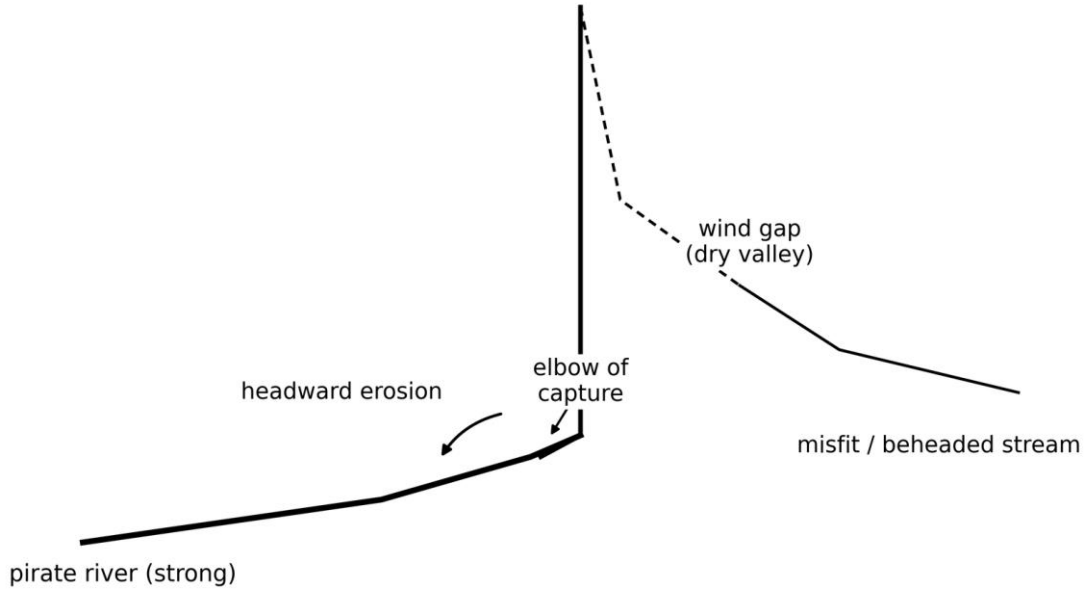


Figure 4.29: *River capture (piracy) in plan view*

How to Draw It
Draw two streams in plan view: a strong pirate river cutting back by headward erosion until it captures a weaker stream. Mark the elbow of capture, the dry wind gap and the beheaded misfit stream.

Question 48

Along the Bagamoyo shore the sea rolls in as a steady train of waves born far out over the open water. Explain what a wave is and name its main elements.

Model Answer

A wave is the movement of energy through the surface water of the sea, created by the wind blowing across it; the water itself moves only in a circle while the energy travels on.

As wind blows over the sea its friction sets the surface rising and falling, and this energy travels forward as waves until they break on the shore. The main elements are the crest, the highest part of the wave; the trough, the lowest part; the wave height, the vertical distance from trough to crest; the wavelength, the horizontal distance between one crest and the next; and the wave period, the time for two crests to pass a point. The size of the waves depends on the strength of the wind, how long it blows, and the fetch, the stretch of open water over which it blows. So the long fetch of the Indian Ocean lets large, powerful waves reach the Bagamoyo coast.

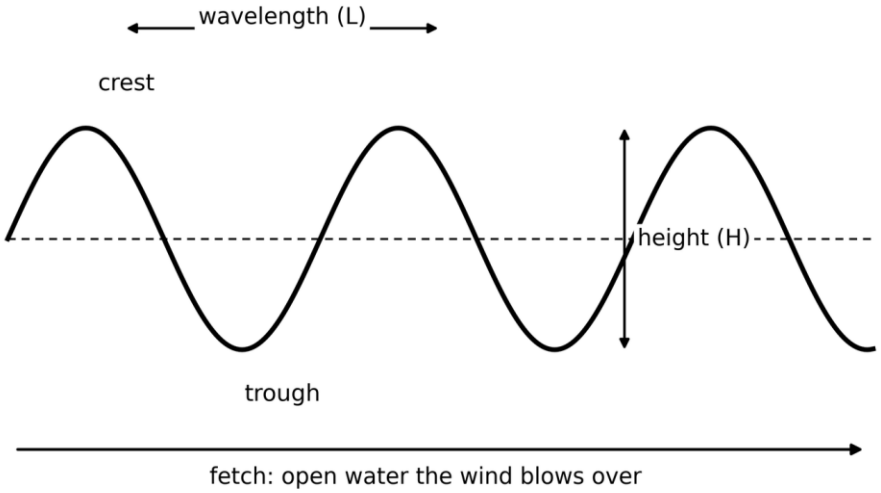


Figure 4.30: *The elements of a wave*

How to Draw It
Draw a smooth wave profile of two or three waves with a dashed still-water line. Label the crest, trough, wave height (vertical) and wavelength (crest to crest), and add an arrow for the fetch of open water.

Question 49

Some waves nudge sand up the beach and build it, while others drag it away and strip it. Distinguish constructive from destructive waves.

Model Answer

Waves are grouped into constructive and destructive types according to whether the swash or the backwash is the stronger, and therefore whether they build the shore or wear it away.

Constructive waves: the swash, the rush of water up the beach, is stronger than the backwash, the return flow. So the waves carry material up and leave it, building beaches and other depositional features. They are typically low, gentle waves with a long wavelength.

Destructive waves: the backwash is stronger than the swash, so the waves drag material back down and erode the shore, forming cliffs and other erosional features. They are typically tall, steep, frequent storm waves.

So whether a stretch of the Tanzanian coast is being built up or worn back depends largely on which type of wave dominates there.

False Confidence Alert
A destructive wave is not simply a 'bigger' wave. What makes it destructive is that its backwash is stronger than its swash, so it pulls material away. The swash-backwash balance, not size alone, decides the work it does.

Question 50

At Bagamoyo the same wind that raises a gentle swell one day drives a battering surf the next. Account for swash and backwash and the factors that decide a wave's height and power.

Model Answer

Swash and backwash are the two movements of a breaking wave, and the height and power of waves depend mainly on the wind and the fetch.

When a wave breaks, the water thrown up the beach is the swash, and the water draining back to the sea is the backwash. Their balance decides whether the wave builds or erodes the shore. The height and power of waves are decided by several factors: the strength of the wind, since a stronger wind raises larger waves; the length of time the wind blows, since waves grow as long as it lasts; the fetch, the stretch of open water the wind crosses, since a longer fetch gives larger waves; and the depth of water near the shore. So at Bagamoyo a strong wind blowing steadily over the long Indian Ocean fetch raises tall, powerful waves, while a light, short-lived wind gives only a gentle swell.

Question 51

As the surf pounds the rocky headlands near Tanga it attacks the rock in several ways at once. Explain the four processes by which waves erode the coast.

Model Answer

Waves erode the coast by four processes, the same kinds that work in a river but driven by the power of the surf: hydraulic action, abrasion, attrition and solution.

1) **Hydraulic action:** the force of the breaking wave compresses air trapped in cracks in the rock, and the sudden expansion as the wave retreats shatters and prises the rock apart.
2) **Abrasion (corrasion):** the waves hurl sand and pebbles against the cliff, grinding and wearing it away; this is the most effective process on coasts exposed to storm waves.
3) **Attrition:** the rock fragments carried by the waves knock against one another and are worn down into smaller, rounder pebbles and sand.
4) **Solution:** soluble rocks such as limestone are dissolved by the sea water and carried away.

On a hard, well-jointed headland near Tanga, hydraulic action and abrasion do most of the cutting, exploiting every crack the rock offers.

Question 52

Along parts of the Tanga coast a steep rock face rises straight from the sea, fronted by a flat rocky shelf uncovered at low tide. Explain how a cliff and a wave-cut platform form.

Model Answer

A cliff is a steep coastal rock face cut back by wave erosion, and a wave-cut platform is the flat rocky shelf left in front of it as it retreats.

Waves attack the foot of the rock most strongly at the high-tide line, cutting a notch there by hydraulic action and abrasion. As the notch deepens, the rock above is undermined and collapses, leaving a steep cliff. Repeated again and again, this drives the cliff steadily landward. As the cliff retreats it leaves behind a gently sloping shelf of rock at its foot, planed flat by the waves, called the wave-cut platform, which is exposed at low tide. The wider the platform grows, the more it makes the waves break further out and lose energy, so cliff retreat slows over time. This is well seen along the rocky stretches of the Tanga coast.

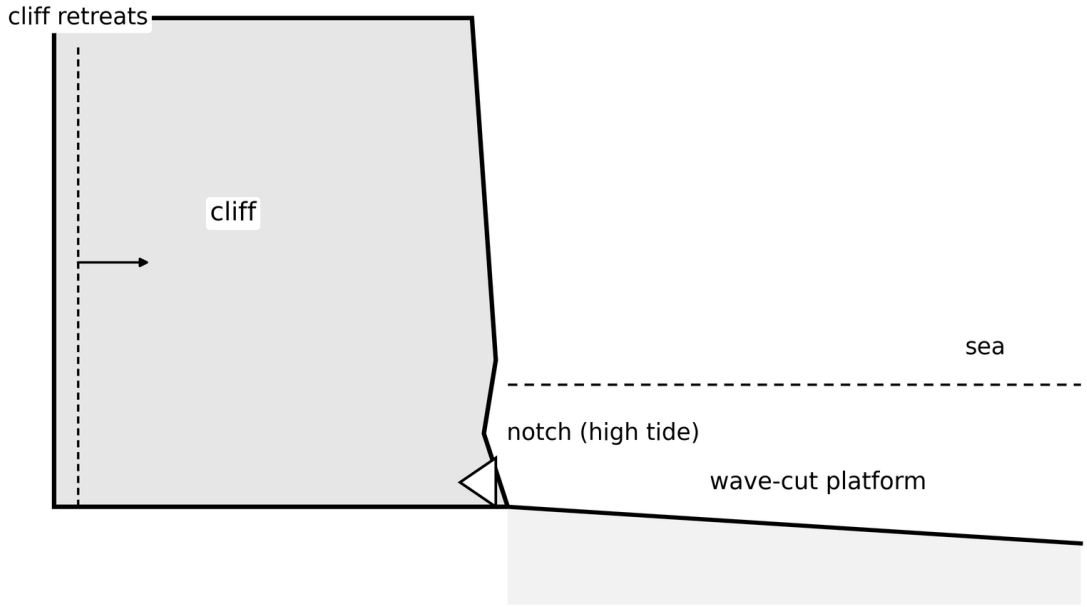


Figure 4.31: *Cliff retreat and the wave-cut platform*

How to Draw It
Draw a cliff with a notch cut at its base, a dashed line showing the former cliff position to mark retreat, and a flat wave-cut platform sloping seaward in front of it. Label the cliff, the notch and the wave-cut platform.

Question 53

On a rocky headland the sea opens a cave, pierces it into an arch, and at last leaves a lone pillar of rock standing in the water. Explain the sequence of features formed as waves erode a headland.

Model Answer

Where waves attack a headland of resistant rock they exploit its weaknesses in a clear sequence, from cave to arch to stack to stump.

1) **Cave:** waves enlarge a line of weakness such as a joint or fault in the headland, hollowing out a cave by hydraulic action and abrasion.
2) **Arch:** where caves are cut from both sides of a narrow headland and meet through it, an arch is left spanning the gap.
3) **Stack:** when the roof of the arch is undermined and collapses, an isolated pillar of rock, a stack, is left standing offshore.
4) **Stump:** continued wave attack undercuts the stack until it too collapses, leaving a low stump visible mainly at low tide.

The whole sequence shows the headland being eaten back, with each feature the worn-down form of the one before, as on the rocky headlands of the Tanzanian coast.

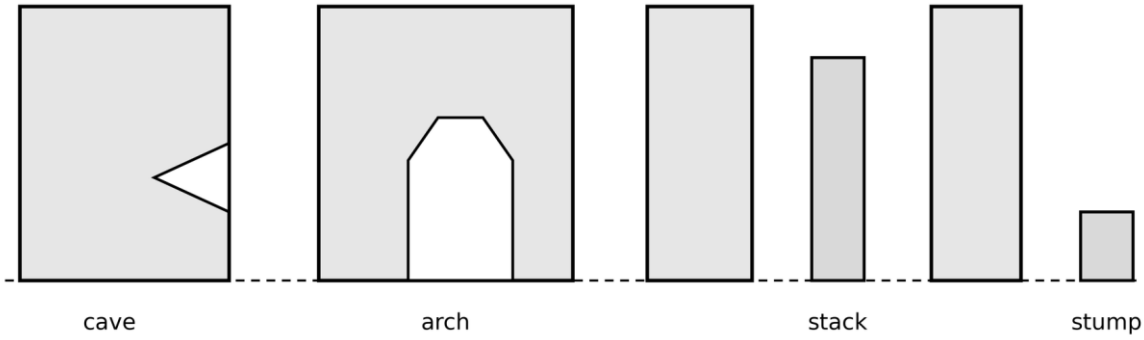


Figure 4.32: *The sequence cave, arch, stack, stump on a headland*

How to Draw It
Draw four sketches in a row of a headland: a cave cut into it, an arch pierced through it, a separated stack, and a low stump, all on a dashed sea line. Label each stage in order.

Question 54

Where the waves lose their force along the Bagamoyo shore they build broad beaches and long sand ridges. Explain the features formed by wave deposition.

Model Answer

Where constructive waves and longshore drift drop their load, they build a family of depositional features along the coast.

1) **Beach:** a strip of sand or shingle laid down between the high and low tide marks, like the beaches at Bagamoyo and Nungwi.
2) **Spit:** a long ridge of sand or shingle joined to the land at one end, built where the coast turns and longshore drift carries material out across the gap, often curving at its free end.
3) **Bar:** a ridge of sand built across a bay; where it seals off the water behind it, a lagoon is enclosed.
4) **Tombolo:** a bar that links an offshore island to the mainland.

All are built by longshore drift, the zig-zag movement of material along the shore as waves strike the coast at an angle, so wherever the waves weaken and drop their load these forms appear.

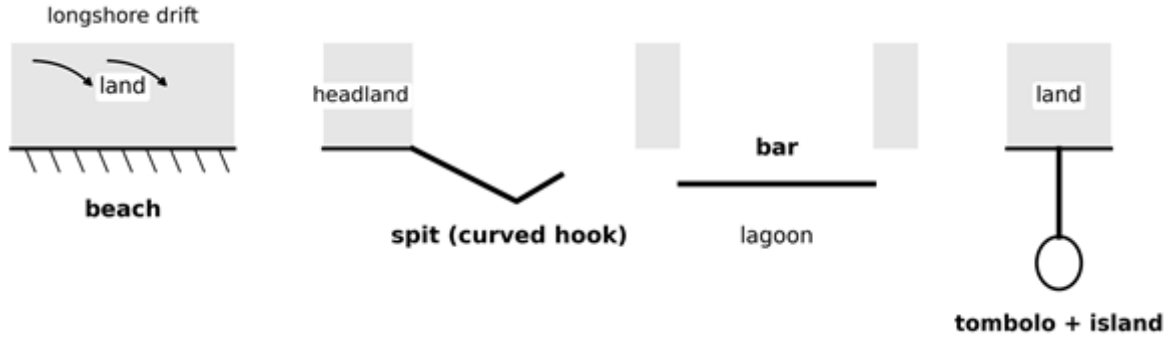


Figure 4.33: *Features built by wave deposition*

How to Draw It
Draw a coast with a hatched beach, a spit growing across a bay with a curved end, a bar sealing a bay to make a lagoon, and a tombolo linking the shore to an island. Add longshore-drift arrows and label each feature.

Question 55

Twice a day the sea at Dar es Salaam climbs up the shore and falls back again with great regularity. Explain what tides are and what causes them.

Model Answer

Tides are the regular rise and fall of the sea, caused mainly by the gravitational pull of the Moon, and to a lesser extent the Sun, on the waters of the Earth.

The Moon's gravity pulls the ocean water towards it, raising a bulge of high water on the side of the Earth facing the Moon. At the same time a second bulge forms on the opposite side, because there the pull is weakest and the water is, in effect, left behind as the Earth is pulled away from it; this balancing is helped by the centrifugal force of the Earth-Moon system. As the Earth turns daily through these two bulges, each coast passes through high and low water, giving the regular tides seen at Dar es Salaam. The Sun adds a smaller pull. Tidal energy therefore comes from gravity, unlike ordinary waves, which draw their energy from the wind.

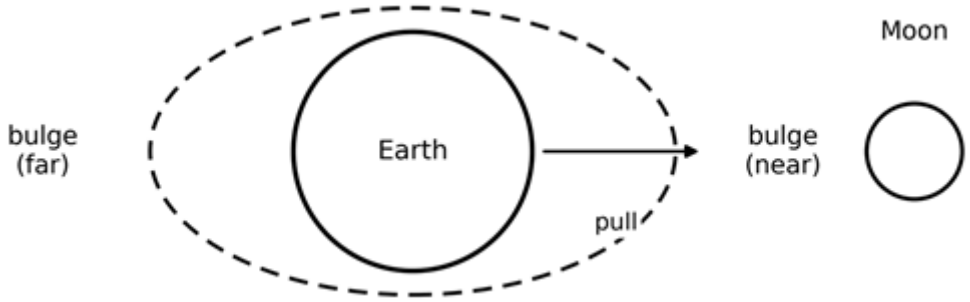


Figure 4.34: *The cause of tides: the Moon's pull and two bulges*

How to Draw It
Draw the Earth as a circle with the Moon to one side, and an oval of water around the Earth showing a bulge facing the Moon and another on the far side. Label the two bulges, the Moon and the direction of its pull.

Question 56

Twice a month the tides at the coast rise especially high, and twice a month their range is feeble. Distinguish the types of tide.

Model Answer

Tides are classified by how often they occur and by their height, which changes with the alignment of the Sun and Moon.

1) **By frequency:** most coasts, including Tanzania's, have a semi-diurnal pattern of two high and two low tides each day; some have a diurnal pattern of one of each; and some have a mixed pattern of differing heights.
2) **Spring tides:** when the Sun, Moon and Earth are in a straight line, at new and full moon, their pulls combine to give the highest high tides and lowest low tides, so the tidal range is greatest.
3) **Neap tides:** when the Sun and Moon are at right angles to the Earth, their pulls partly cancel, giving the smallest tidal range.

So spring and neap tides alternate roughly weekly as the Moon moves round the Earth, changing how high the sea climbs at the coast.

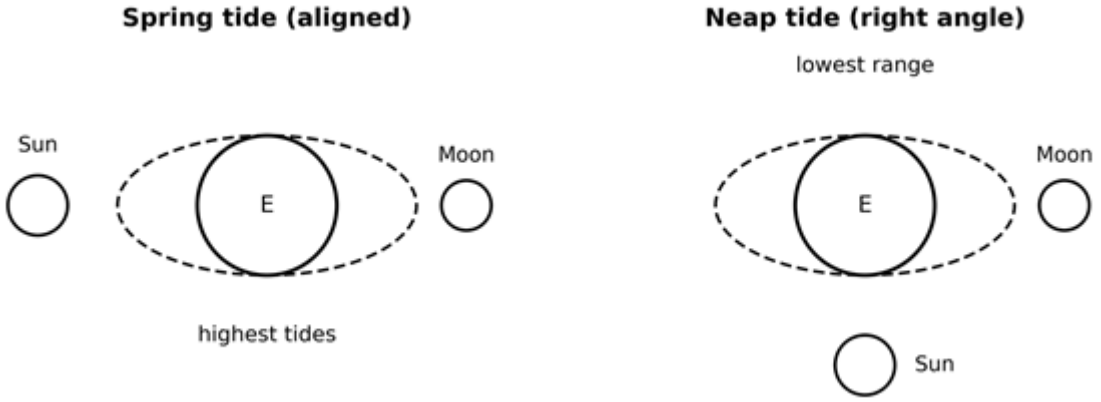


Figure 4.35: *Spring and neap tides*

How to Draw It
Draw two small diagrams. In the first, the Sun, Earth and Moon lie in a straight line for spring tide; in the second, the Moon is at a right angle to the Sun for neap tide. Label spring (aligned, highest) and neap (right angle, lowest).

Question 57

Geographers find old beaches stranded above today's sea and drowned valleys below it, proof that the level of the sea has shifted. Account for the causes of sea-level change.

Model Answer

The level of the sea relative to the land changes for two broad reasons, a change in the amount of water in the oceans and a change in the height of the land.

Eustatic change: a worldwide change in the volume of ocean water. When ice ages lock water up as ice, sea level falls everywhere; when the ice melts, as with present global warming, sea level rises everywhere.

Isostatic change: a local change in the height of the land. When land is loaded with ice it sinks, and when the ice melts it slowly rises, so the sea appears to fall against it.

Other causes: tectonic uplift or subsidence of the coast, and the warming and expansion of sea water as the climate warms.

Today the chief cause of rising sea level is global warming, which both melts ice and expands the warming ocean, threatening low coasts such as those of the Indian Ocean.

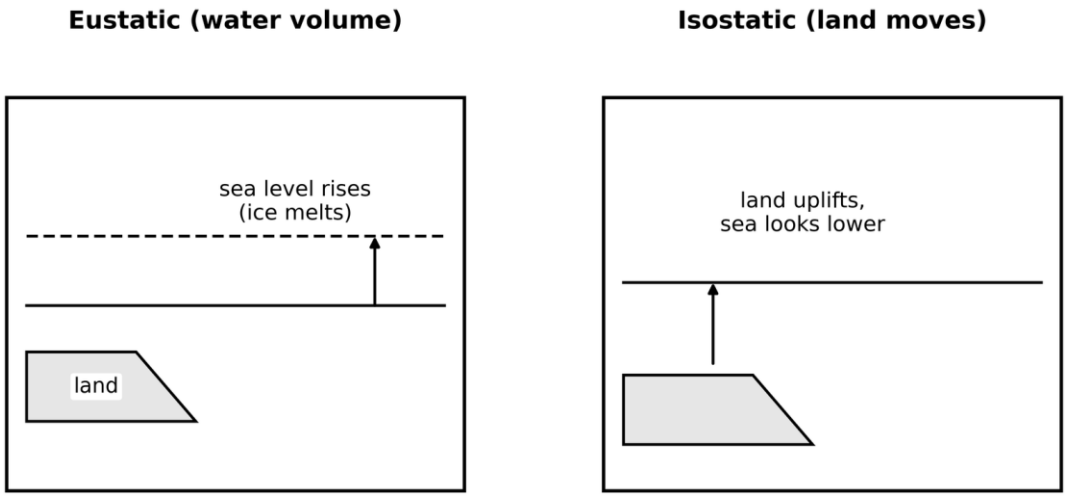


Figure 4.36: *Eustatic and isostatic sea-level change*

How to Draw It
Use two boxes. In the first show ocean water rising worldwide as ice melts (eustatic); in the second show land uplifting so the sea seems to fall against it (isostatic). Label each clearly.

False Confidence Alert
Eustatic and isostatic change are different. Eustatic is a worldwide change in the volume of ocean water; isostatic is a local rise or fall of the land. One moves the sea everywhere; the other only seems to, against a moving coast.

Question 58

Scientists warn that the sea off Dar es Salaam stands higher now than a century ago, and the evidence of past change is written all along the coast. Explain present sea-level rise and the evidence for past sea-level change.

Model Answer

Sea level is rising today mainly because of global warming, and the evidence for past rises and falls is preserved in the coastal landforms.

Global warming raises sea level in two ways: it melts ice on land, adding water to the oceans, and it warms the sea water, which expands as it heats. Together these are lifting the global sea level by a small amount each year, a serious threat to low-lying coasts and islands. The evidence that sea level has changed in the past is read from the coast itself. A fall in sea level, or a rise of the land, leaves raised beaches, old cliffs and wave-cut platforms stranded above the present shore. A rise in sea level, or a sinking of the land, leaves drowned valleys such as rias and fiords, and submerged forests and mudflats. These stranded and drowned features along the East African coast record the shifting level of the sea.

Question 59

Some coasts stand stranded above the sea while others are drowned beneath it, and geographers sort them accordingly. Explain how coasts are classified.

Model Answer

Coasts are classified mainly by how they have responded to changes in sea level, into emergent, submergent, stable and compound types.

1) **Emergent coasts:** coasts that have risen relative to the sea, through a fall in sea level or an uplift of the land, leaving former sea-floor and beaches exposed above the shore.

2) **Submergent coasts:** coasts that have sunk relative to the sea, through a rise in sea level or a sinking of the land, so that valleys and lowlands are drowned.
3) **Stable (neutral) coasts:** coasts showing no clear sign of a change in level, shaped by ordinary erosion and deposition.
4) **Compound coasts:** coasts that show a mixture of emergence and submergence, having undergone both at different times.

This classification matters because the type of coast decides which landforms are present and how useful the coast is, for example for harbours.

Tanzania's own Indian Ocean coast is mainly submergent, with the drowned harbour of Kilindini lying just across the border at Mombasa.

Question 60

At the entrance to Kilindini harbour in Mombasa an old notch and a raised beach stand above the reach of today's waves. Explain the features of an emerged coast.

Model Answer

An emerged coast is one that has risen relative to the sea, so that features cut or built by the sea are now stranded above the present shoreline.

1) **Raised beach:** a former beach left standing above the present sea level, often still bearing old shells and pebbles.
2) **Old cliff:** a former sea cliff now standing back from and above the sea, no longer reached by the waves.
3) **Notch and wave-cut platform:** a former notch and rock shelf, cut by waves at the old sea level, now raised above it, as seen at the entrance to Kilindini harbour in Mombasa.

All of these record a sea that once stood higher against the land, or a land that has since risen, so that the old shoreline now lies above the new one. A fresh cliff may be cut at the present sea level below the old features.

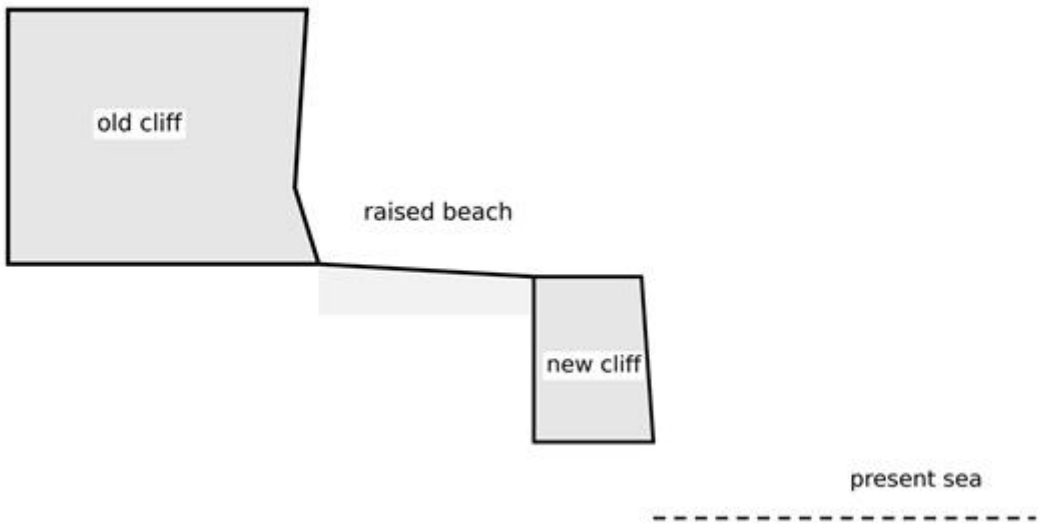


Figure 4.37: *Features of an emerged coastline*

How to Draw It
Draw a coastal cross-section with an old cliff and a raised beach standing above the present sea, and a new cliff being cut at the present sea level below. Label the raised beach, old cliff and present sea level.

Question 61

In some lands the sea reaches far inland up branching, drowned valleys that make fine natural harbours. Explain the features of a submerged coast.

Model Answer

A submerged coast is one that has sunk relative to the sea, through a rise in sea level or a sinking of the land, so that former valleys are drowned by the sea.

1) **Ria:** a drowned river valley, formed where the sea floods the lower part of a winding river valley, giving a branching inlet that deepens seaward and makes a good harbour.
2) **Fiord:** a drowned glacial valley, a long, deep, steep-sided inlet formed where the sea floods a U-shaped valley cut by ice, as in Norway.
3) **Estuary and dalmatian coast:** an estuary is the drowned funnel-shaped mouth of a river, while a dalmatian coast forms where the sea floods valleys lying parallel to the shore, leaving lines of islands.

Because the sea reaches far inland up these drowned valleys, submerged coasts often provide deep, sheltered natural harbours, such as Kilindini in Mombasa.

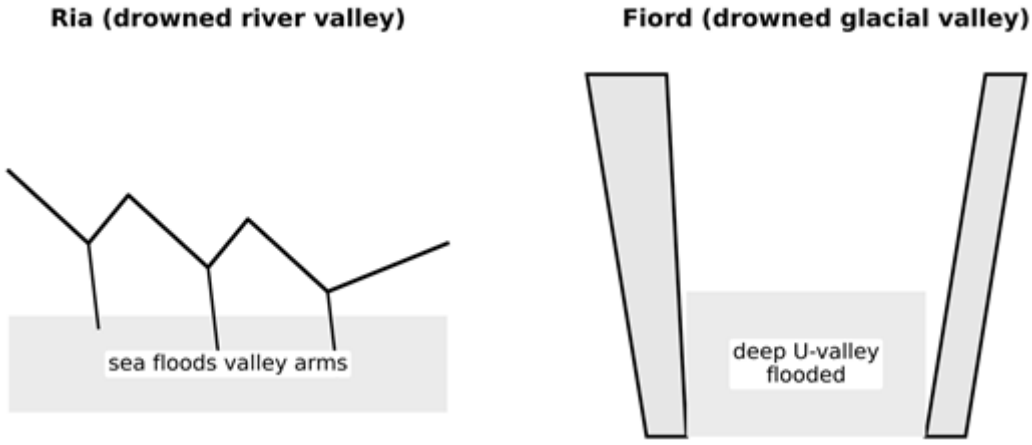


Figure 4.38: *Submerged coasts: ria and fiord*

How to Draw It
Draw two sketches: a ria as a branching, drowned river valley with the sea reaching inland, and a fiord as a deep, steep-sided drowned glacial valley. Label the drowned valley arms and the sea in each.

Question 62

Off Mafia and Zanzibar, banks of limestone built by tiny living animals fringe the warm, clear sea. Explain how coral coasts build and the conditions the coral polyps need.

Model Answer

A coral coast is one built of coral reef, a limestone rock made from the skeletons of tiny marine animals called coral polyps.

Coral polyps are small sea animals that build hard skeletons of calcium carbonate. When they die, their skeletons accumulate and cement together with other remains into coral limestone, and over long periods these build up into great banks of rock called reefs along the coast. Because they are living creatures, the polyps can only build where conditions suit them: warm sea water between about 20 and 30 degrees Celsius; clear, shallow, sunlit water no more than about 50 metres deep; salty, well-oxygenated water kept free of mud; and a firm base to grow on. The warm, clear, shallow waters off Mafia and Zanzibar meet these conditions, which is why coral reefs flourish along the Tanzanian coast.

False Confidence Alert
Coral is built by living animals, not by waves or chemical deposition, and the reef is limestone made of their skeletons. Because the polyps are alive, muddy, cold or deep water kills them, so reefs only grow where conditions are exactly right.

Question 63

Around the islands of the Indian Ocean, coral grows tight against some shores, offshore behind a lagoon at others, and in great rings around none. Distinguish the types of coral reef.

Model Answer

Coral reefs are grouped into three types according to their position relative to the land and the lagoon between.

1) **Fringing reef:** a reef that grows directly against the shore, with little or no lagoon between it and the land, the commonest type along the East African coast.
2) **Barrier reef:** a reef lying offshore, separated from the land by a wide, deep lagoon, such as the reef around Mayotte near the Mozambique Channel.
3) **Atoll:** a roughly circular reef enclosing a lagoon with no land in the centre, like the Aldabra atoll between Zanzibar and Madagascar.

The three are often seen as stages in one story, in which a fringing reef becomes a barrier reef and finally an atoll as the land it grew around slowly sinks beneath the sea.

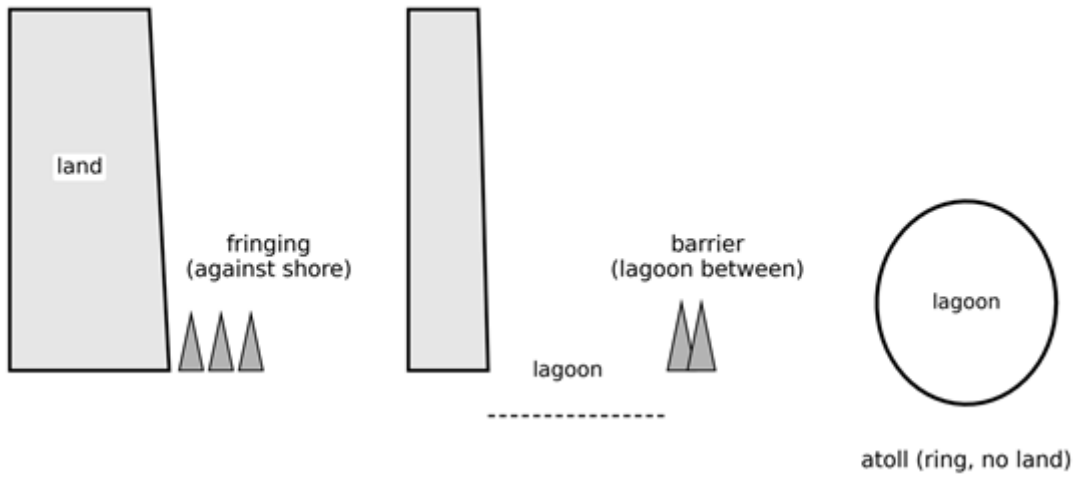


Figure 4.39: *The three types of coral reef*

How to Draw It
Draw three cross-sections: a fringing reef against the shore, a barrier reef separated from land by a lagoon, and a ring-shaped atoll enclosing a lagoon with no land. Label the land, lagoon and reef in each.

Question 64

For over a century geographers have argued how the great barrier reefs and atolls of the oceans came to be. Explain the main theories of how coral reefs form.

Model Answer

The origin of barrier reefs and atolls has long been debated, and three main theories have been put forward to explain them.

1) **Darwin's subsidence theory:** Darwin held that a reef begins as a fringing reef around an island. As the island slowly sinks, the coral grows upward to stay in the sunlit shallows, becoming a barrier reef separated by a widening lagoon, and finally, when the island is wholly submerged, an atoll.
2) **Daly's glacial-control theory:** Daly linked reefs to the rise of sea level after the ice age, arguing that melting ice raised the sea and the coral grew up to keep pace, forming barrier reefs and atolls.
3) **Murray's standstill theory:** Murray held that reefs grew outward on platforms of their own debris without any sinking of the land.

No single theory explains every reef, which is why the origin of coral reefs is still considered debatable; Darwin's subsidence theory remains the most widely accepted.

The theories are tested against real reefs such as the Aldabra atoll between Zanzibar and Madagascar.

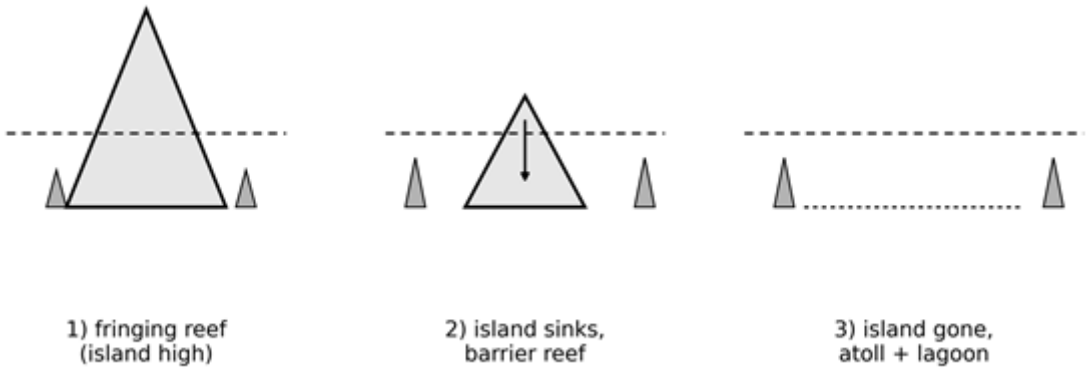


Figure 4.40: *Darwin's subsidence theory of reef formation*

How to Draw It
Draw Darwin's three stages: a fringing reef around a high island, a barrier reef with a lagoon as the island sinks, and an atoll ring once the island is submerged. Add a downward arrow for subsidence and label the three stages.

REAL QUESTIONS

Question 65

On the central plateau two outcrops stand side by side under the same sun and the same rain, yet one has crumbled to loose grus while the other still rises as a bare, solid dome. Examine the factors that decide a rock's resistance to weathering and erosion.

Model Answer

A rock's resistance to weathering and erosion is set by its mineral make-up and its physical structure, which together decide how easily water and air can get in and attack it.

1) **Mineral composition:** rocks of stable, insoluble minerals such as quartz resist decay, while those rich in feldspar or calcite rot or dissolve quickly.
2) **Grain size and cementation:** coarse, well-cemented and well-crystallised rock resists, so a hard granite outlasts a weak, loosely-bound shale.
3) **Jointing and porosity:** closely jointed or porous rock lets water seep in and weathers fast, whereas massive, impermeable rock keeps it out.
4) **Colour of minerals:** dark minerals such as olivine heat and expand faster than pale quartz, so dark rock disintegrates sooner under the tropical sun.

5) **Bedding and structure:** horizontally bedded or strongly foliated rock is prised apart along its planes, while massive unbedded rock resists.

So on the central plateau the massive, quartz-rich granite stands as a dome while the jointed, clay-rich rock beside it has crumbled to grus.

Question 66

Road engineers prospecting for a quarry on untouched land near Dodoma were puzzled to find clean, freshly broken sheets of rock on the bare surface, although no one had ever worked the ground. Account for what had split the rock.

Model Answer

The fresh, clean breaks were made by pressure release, also called unloading, which needs no tool or human action at all.

The granite formed deep underground under enormous confining pressure. Over a very long time, erosion stripped away the overlying rock, so the pressure that had held the granite tightly compressed was slowly removed. As the load came off, the rock expanded upward and cracks opened parallel to the surface. Sheets of rock then sprang and peeled away along these cracks, a process called sheeting, leaving the clean, freshly broken surfaces the engineers found. Because the breaks come from the rock relaxing as its overburden is removed, they appear fresh even on virgin land, as on the exposed granite of the central plateau.

False Confidence Alert
Fresh, clean breaks in rock do not prove recent human or mechanical disturbance. Pressure release splits exposed granite naturally as erosion unloads it, so do not read newly broken rock on virgin land as a sign that someone has been working there.

Question 67

In December 2023 a wall of mud buried homes around Mount Hanang within minutes, and back in 1955 a single night of torrential rain set the slopes of Tukuyu-Kandete sliding. Account for the causes and the effects of these two Tanzanian mass-wasting disasters.

Model Answer

Both were rapid mass movements set off when heavy rain saturated steep, deeply weathered slopes, so that gravity pulled the loosened material down at speed.

1) **Steep slopes:** both Hanang and the Tukuyu highlands have steep slopes on which gravity acts strongly once the material is loosened.
2) **Heavy rain:** prolonged downpours, about 425 millimetres in one night at Tukuyu in 1955, soaked the soil, adding weight and lubricating the grains until the slope failed.
3) **Deep, loose regolith:** a thick mantle of weathered rock and soil, stripped of binding vegetation, gave a large mass ready to move.

The effects were severe: at Hanang the mudflow buried houses and killed people in minutes, while both events destroyed cropland, blocked roads and cut off communities, showing how mass wasting turns a wet hillside into a sudden hazard.

Question 68

The people of Lwandai in the Lushoto highlands ask why, after every spell of heavy rain, mud pours off the mountains above and onto their homes. As a geographer, explain the causes of the mudflows to them.

Model Answer

Mud flows onto Lwandai because the steep Lushoto slopes, soaked by heavy rain and stripped of their cover, can no longer hold their soil against gravity.

1) **Steep slopes:** the Usambara mountains rise in steep slopes down which saturated material moves quickly and far.
2) **Heavy, prolonged rain:** long downpours soak the soil, add weight and act as a lubricant between the grains.
3) **Deep weathered soil:** a thick layer of loose, weathered regolith sits ready to move once it is wet enough.
4) **Loss of vegetation:** clearing forest for farms removes the roots that bind the soil, so bare slopes fail far more readily.
5) **Gravity on a wet mass:** once saturated, the heavy, slippery soil flows downhill under gravity as a mudflow.

So the remedy points the same way as the cause: replanting the slopes and draining the water would hold the soil of Lwandai in place.

Question 69

A village clinging to a steep Uluguru hillside above Morogoro has lost homes to repeated landslides. Advise the community on the practical steps that would cut the risk.

Model Answer

The village can cut its landslide risk by strengthening the slope, taking the water off it, and controlling how the land above is used.

1) **Afforestation:** planting trees and grasses so their roots bind the soil and hold it together against movement.
2) **Terracing:** cutting the slope into steps to reduce its angle and slow the run-off.
3) **Drainage:** digging trenches and drains to carry away the rainwater that adds weight and lubricates the soil.
4) **Retaining walls:** building walls at the slope foot to hold material back.
5) **Land-use control:** keeping heavy building, cultivation and quarrying off the steepest ground so it is not weakened or undercut.

Used together on the Uluguru slope, replanting and draining while keeping the steepest land clear would attack several triggers of mass wasting at once.

Question 70

Leading tourists across the Sahara, you are asked how the strange wind-carved rocks and ridges all around them came to be. Explain the origin of the desert's wind scenery.

Model Answer

The desert's wind scenery is carved by two erosional processes, deflation, which lifts and removes loose sand, and abrasion, which sand-blasts the standing rock, with resistant rock left and soft rock cut away.

Deflation blows the fine, dry sand away, lowering the surface, leaving stony pavements and scooping out hollows. Abrasion drives wind-borne sand against the rock, grinding and polishing it, and because the sand is carried mostly near the ground, it bites hardest at the base.

Rock pedestals (mushroom rocks): rocks undercut near the base, leaving a narrow stalk under a broader cap.

Zeugen and yardangs: ridges and furrows cut where bands of hard and soft rock lie side by side.

Inselbergs: steep, isolated hills of resistant rock standing above the worn plain.

So the scenery the tourists admire, seen across the Sahara from the Tibesti to the Devil's Rock of Agadez, records the same rule: the wind sweeps away the weak and leaves the strong standing.

Question 71

Travelling into the Sahara with his uncle, Ahmed is astonished to hear that water, not wind, cut many of the features around him. With the aid of a diagram, demonstrate six water-erosion features of the desert and how each forms.

Model Answer

Although rain is rare in the desert, when a storm breaks it runs off the bare, baked ground at once and cuts a sharp set of erosional features.

1) **Rills:** tiny, shallow channels scored into the surface by the first runoff of a storm.
2) **Gullies:** deeper, steep-sided channels formed where the runoff concentrates and deepens the rills.
3) **Ravines:** narrow, steep gorges cut where gullies are deepened further into the slope.
4) **Wadis:** deep, flat-floored dry valleys cut by occasional flash floods, holding water only briefly during a storm.
5) **Canyons:** very deep, steep-walled valleys cut where a river slices down through resistant rock over a long time.
6) **Badlands:** slopes cut into a maze of ridges and channels where countless rills and gullies have dissected soft rock.

All form quickly because the desert surface is bare and hard, so rain cannot soak in and instead rushes over it, concentrating its power into channels, as in the wadis of the Sahara such as the Hamra.

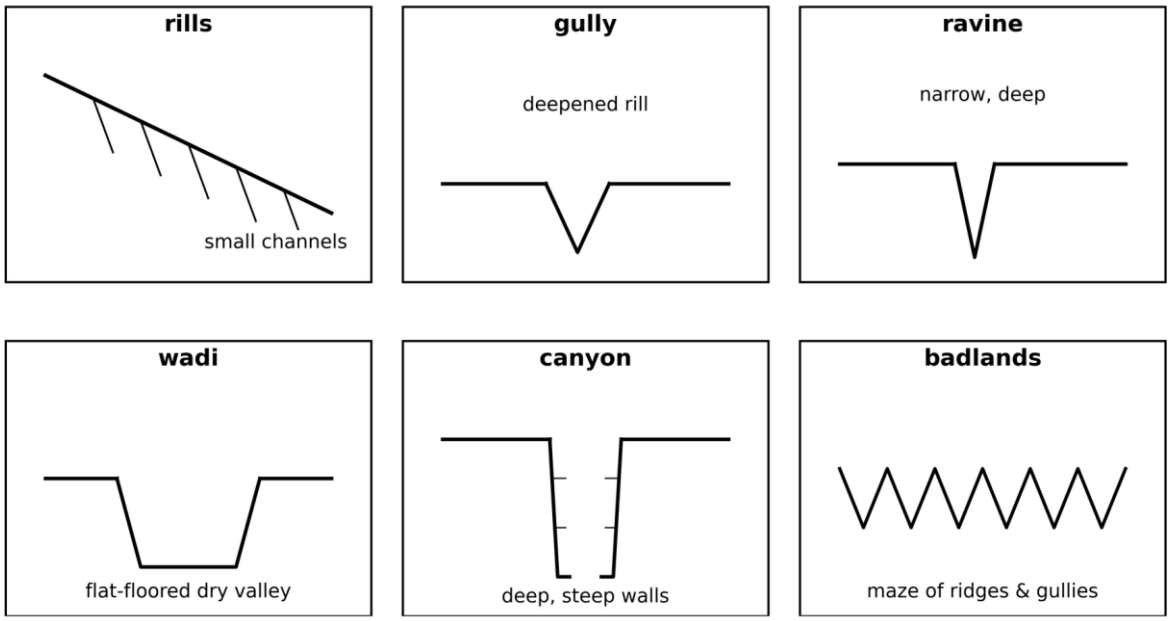


Figure 4.41: *Erosional features cut by water in the desert*

How to Draw It
Draw a desert slope with small rills running into a deeper gully and a steep ravine, then a flat-floored wadi and a deep steep-sided canyon, with a dissected badland slope alongside. Label all six and show the direction of water flow.

Question 72

Despite its thin soil and scrubby cover, the karst country around Amboni in Tanga and Nanyala in Songwe supports real livelihoods. Appraise the socio-economic value of Tanzania's karst regions.

Model Answer

Tanzania's karst country is worth far more than its thin soil suggests, since its caves, limestone and underground water all support livelihoods.

1) **Tourism:** the underground caverns, with their stalactites, stalagmites and pillars, draw visitors, as at the Amboni caves near Tanga, earning income and foreign currency.
2) **Cement and lime:** the limestone is the essential raw material for cement and lime, supplying industry and construction.
3) **Livestock keeping:** the grasses on the thin karst soils provide grazing for goats, sheep and cattle.
4) **Water supply:** underground rivers and springs in the limestone give water for people and stock.
5) **Fertile pockets and stone:** patches of rich terra rossa soil grow crops, and the rock itself is quarried for building stone.

So even at Amboni and Nanyala, where the surface looks poor, the karst earns its keep through caves, cement, grazing and water.

Question 73

Across Tanzania rivers trace very different patterns, from the branching streams of an even plain to the angular courses of faulted highland and the streams that pour off Kilimanjaro on every side. Justify, with diagrams, how the nature of the rock and the relief of the land shape the pattern a river develops.

Model Answer

The pattern a river system develops is set by the rock it crosses and the relief of the land, because water always takes the line of least resistance.

1) **Dendritic:** on uniform rock of even resistance, streams branch freely like a tree, the commonest pattern on gently sloping plains.
2) **Trellis:** where hard and soft beds lie in parallel bands, the main rivers follow the soft bands and tributaries join at right angles.
3) **Rectangular:** on strongly jointed or faulted rock, rivers bend sharply at right angles along the lines of weakness.
4) **Radial:** on a volcanic cone or dome, streams run outward in all directions down the slopes, as on Kilimanjaro.

So the same rainfall makes a tree-like, an angular, or a radiating network depending on the structure and slope beneath it, which is why Kilimanjaro carries a radial pattern while a faulted block carries a rectangular one.

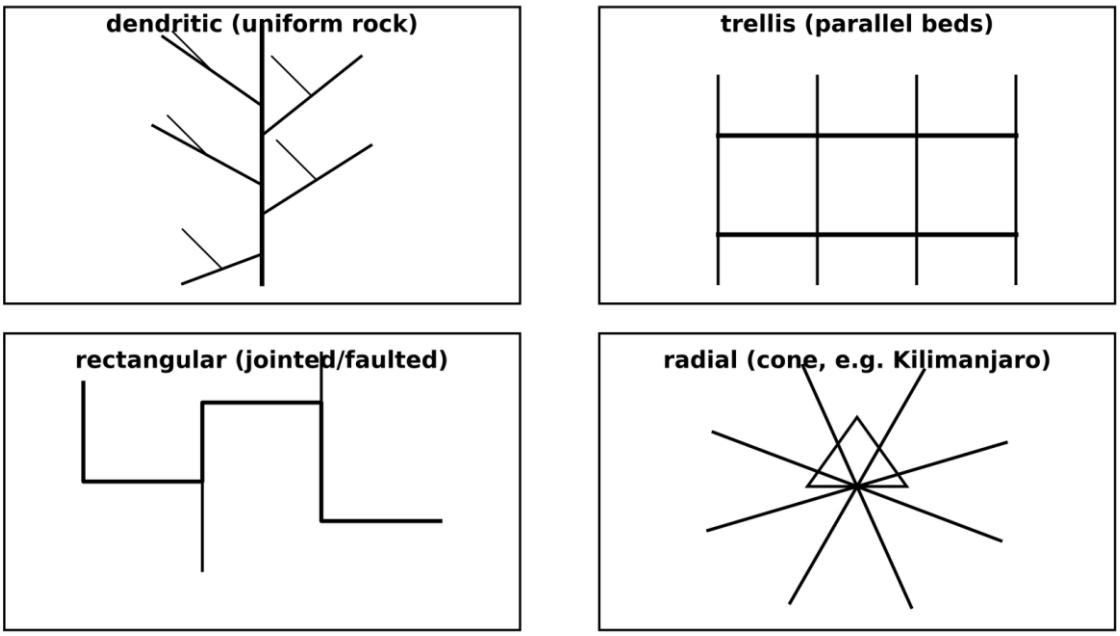


Figure 4.42: *Drainage patterns controlled by rock and relief*

How to Draw It
Draw four small plan-view sketches: a tree-like dendritic network, a trellis with right-angled tributaries along parallel bands, a rectangular pattern bending along joints, and a radial pattern running off a cone. Label each and the rock or relief that controls it.

Question 74

Where the Rufiji meets the Indian Ocean it has built Tanzania's largest delta, a broad arcuate fan of fertile islands, channels and mangrove. Account for the formation of the Rufiji delta.

Model Answer

The Rufiji delta has formed because the river deposits its huge load faster than the sea can carry it away, building a fan of sediment across its mouth.

The Rufiji drains a very large basin and reaches the coast carrying a heavy load of silt and sand. As it enters the shallow, sheltered sea its velocity falls, so it can no longer hold its load and drops it at the mouth. Because the waves and tides here are too weak to sweep the sediment away, the load builds up and forces the river to break into several distributaries that spread it into a broad, low, triangular plain with a gently curved, arcuate seaward margin. The conditions are all met at the Rufiji: a large load, a gentle gradient, and a shallow, calm sea, which is why it is Tanzania's finest delta and a rich farming and fishing ground.

False Confidence Alert
Not every river mouth builds a delta. A delta forms only where the load is large and the sea is shallow and calm; where strong waves or tides remove the sediment, as on many exposed coasts, no delta grows however big the river.

Question 75

On the Kilombero floodplain an oxbow lake lies cut off from the river that once flowed through it, while upstream the planners argue over where to place a hydroelectric dam. Describe the value of an oxbow lake, and explain why a dam is poorly sited near a river's mouth.

Model Answer

An oxbow lake is a useful resource on the floodplain, but a river's mouth is a poor place for a hydroelectric dam because the river there has little energy to drive it.

1) **Value of an oxbow lake:** it provides fishing, water for livestock and irrigation, fertile silt around its edge, a habitat for wildlife, and a site for recreation, as on the Kilombero floodplain.
2) **Low gradient at the mouth:** near the mouth the river runs on an almost flat gradient, so there is little fall, or head, to spin the turbines that generate power.
3) **Heavy siltation:** the lower course carries and drops a heavy load of silt, which would quickly fill the reservoir.
4) **Wide flat valley:** damming the broad lower valley would flood a vast area of farmland for little gain.

This is why Tanzania sites its hydropower on the steep upper and middle courses, as at Kidatu and Kihansi, where a gorge gives the head and the firm rock the river needs.

Question 76

In the Usambara mountains the Mkomazi winds in deep, steep-sided loops cut into solid rock, while across the border in Kenya the Tiva was robbed of its headwaters by a stronger neighbour. Account for these two effects of river rejuvenation and river capture.

Model Answer

Both features record a river given new cutting power, the Mkomazi by rejuvenation and the Tiva by capture into a more vigorous stream.

Incised meanders of the Mkomazi: when the Usambara land was uplifted, the base level fell and the Mkomazi was rejuvenated, so it cut downward again while keeping its old winding course, carving its meanders deep into the rock as incised meanders.

Capture of the Tiva: a stronger river, with a steeper gradient and greater energy, eroded headward until it broke into the Tiva's valley and diverted its headwaters into its own system.

Features left by capture: the capture left an elbow of capture where the diverted water turns, a dry wind gap below it, and a shrunken misfit stream too small for its valley.

So uplift and unequal erosion explain both: the renewed downcutting of the Mkomazi in the Usambara and the beheading of the Tiva in Kenya.

Question 77

Form Six students visiting the Bagamoyo coast watch a shore being torn back by powerful waves whose backwash outruns their swash. With the aid of a labelled diagram, identify the erosional features that such destructive waves form.

Model Answer

Where the backwash is stronger than the swash, the waves wear the coast back, and they carve a recognisable family of erosional features by attacking its lines of weakness.

1) **Headlands and bays:** waves cut back the soft rock into bays while the hard rock juts out as headlands.
2) **Cliff and wave-cut platform:** the waves cut a notch at the cliff foot, undermine it so it retreats, and leave a flat wave-cut platform in front.
3) **Cave, arch, stack, stump:** on a headland the waves open a cave, pierce it into an arch, leave a stack when the arch collapses, and reduce the stack to a low stump.
4) **Blowhole and geo:** spray forced up a cave roof bursts out as a blowhole, and a collapsed cave leaves a narrow inlet called a geo.

All of these can be read along the rocky stretches of the Tanzanian coast near Bagamoyo and Tanga, where destructive storm waves attack the headlands.

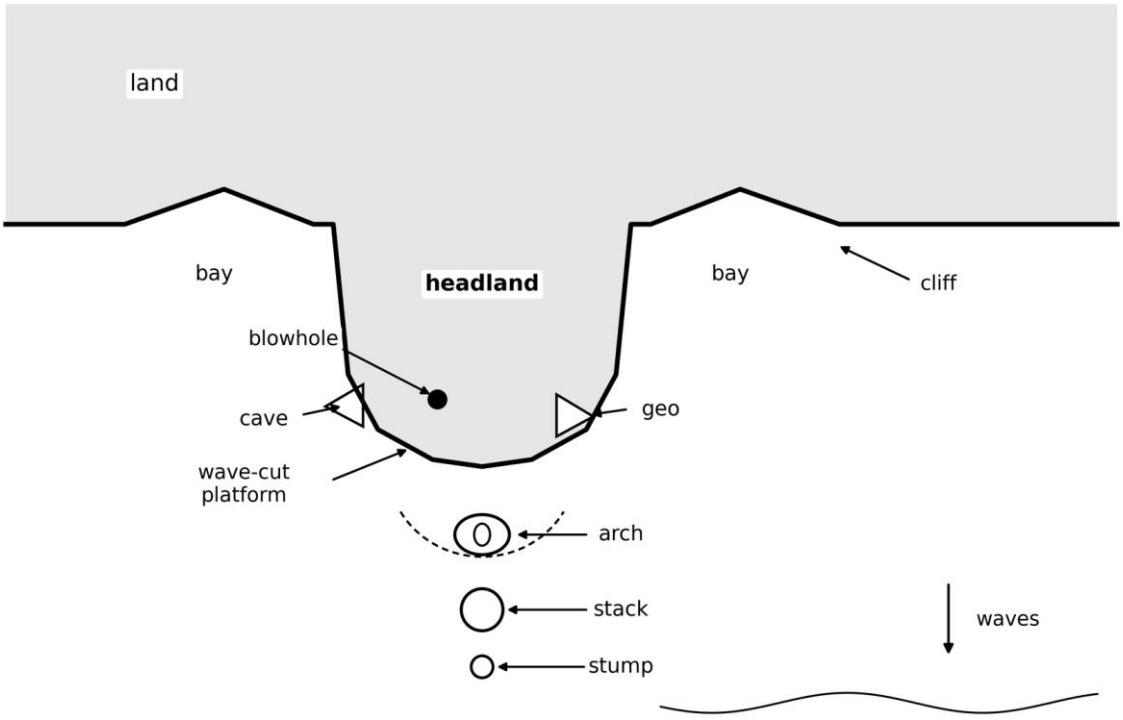


Figure 4.43: *Erosional features of a destructive (backwash-dominated) coast*

How to Draw It
Draw a stretch of coast in plan and section: a hard headland with a soft bay on each side, a cliff with a wave-cut platform, and on the headland the sequence cave, arch, stack, stump, with a blowhole on top. Label every feature.

Question 78

From the deep natural harbour at Kilindini to the white beaches of Zanzibar and the fishing grounds of the reefs, the coast shapes how people live. Justify the claim that coastal landforms are significant to human lives.

Model Answer

Coastal landforms are significant to human lives because they provide the harbours, beaches, fishing grounds and fertile land on which coastal economies depend.

1) **Natural harbours:** drowned, submerged coasts give deep, sheltered harbours for ports and trade, as at Kilindini in Mombasa and Dar es Salaam.
2) **Tourism:** beaches, cliffs, caves and reefs draw visitors and earn foreign currency, as at Zanzibar and Bagamoyo.
3) **Fishing:** lagoons, reefs and estuaries are rich breeding grounds that support fisheries and food supply.
4) **Farming and salt:** deltaic and mudflat soils give fertile farmland, as on the Rufiji, and coastal flats yield salt.
5) **Protection:** reefs and offshore bars break the force of the waves and shelter the coast behind them.

So from Kilindini's harbour to Zanzibar's beaches and the Rufiji's flats, coastal landforms underpin trade, tourism, fishing and farming alike.

Question 79

The shape of the East African coast is not fixed; the sea has stood both higher and lower than it does today. Prove, with named coastal evidence, that the sea level has changed through time.

Model Answer

The coast itself carries the proof: features cut or built at one sea level now lie stranded above or drowned below the present shore.

1) **Raised beaches:** old beaches with their shells and pebbles now stand above the present shore, proving the sea once stood higher or the land has since risen.
2) **Old cliffs and notches:** cliffs, notches and wave-cut platforms cut by past waves now lie above the reach of the sea, as the raised notch at the entrance to Kilindini harbour in Mombasa.
3) **Drowned river valleys:** rias and estuaries, the flooded lower courses of rivers, prove a rise in sea level or a sinking of the land.
4) **Submerged forests and mudflats:** tree stumps and flats now below the tide level show that the sea has risen over former land.

Taken together, the raised beaches and notches and the drowned valleys of the East African coast prove that its sea level has both fallen and risen through time.

False Confidence Alert
A raised beach does not mean the sea simply 'went down' on its own. It records a change in the level of the sea relative to the land, which can come either from a worldwide fall in the sea or from an uplift of the coast; the evidence shows the relative change, not which one moved.

Question 80

Guiding tourists along the East African coast, rich in coral from Mafia to Zanzibar, you are asked why the reefs thrive here and what they are worth to the people. Explain the conditions that let coral reefs flourish and their significance.

Model Answer

Coral reefs flourish along the East African coast because the warm, clear, shallow tropical sea gives the coral polyps exactly the conditions they need, and the reefs they build are of great value to the people.

1) **Warm, clear, shallow water:** the polyps need water between about 20 and 30 degrees Celsius, clear and shallow enough, under 50 metres, for sunlight to reach them.
2) **Salty, clean, firm water:** they need salty, well-oxygenated water free of mud, and a firm base to grow on, all met off Mafia and Zanzibar.
3) **Fishing:** the reefs are rich breeding grounds that support coastal fisheries and food supply.
4) **Tourism:** their beauty draws divers and tourists, earning income and foreign currency.
5) **Protection and lime:** the reefs break the force of the waves and shelter the coast, and supply lime and building material.

So the same warm, clear waters that build the reefs of Mafia, Zanzibar and the Aldabra atoll also make them a mainstay of fishing, tourism and coastal defence.

Question 81

"Coastal landforms can induce economic prosperity along the coast." Using the Tanzanian coast, justify this statement.

Model Answer

Tanzania's coastal landforms induce prosperity by providing the harbours, beaches, fishing grounds and fertile flats that drive trade, tourism, fishing and farming.

1) **Ports and trade:** deep natural harbours on submerged coasts carry the country's trade, as at Dar es Salaam, bringing revenue and employment.
2) **Tourism:** beaches, cliffs, caves and coral draw visitors and earn foreign currency, as at Zanzibar and Bagamoyo.
3) **Fishing:** reefs, lagoons and estuaries are breeding grounds that support a coastal fishing industry.
4) **Farming:** fertile deltaic and mudflat soils grow crops, as the rice and other produce of the Rufiji delta.
5) **Salt and mangroves:** coastal salt flats yield salt, and mangroves supply timber and shelter fish nurseries.

So from the port of Dar es Salaam to the beaches of Zanzibar and the flats of the Rufiji, the landforms of the coast turn the shore into an engine of the economy.

HOT QUESTIONS

Question 82

From the rising cone of Kilimanjaro to the worn plains of the central plateau, Tanzania's relief is shaped by two opposing sets of forces. Assess the view that its landscape is a standing contest between the forces that build it and those that wear it down.

Model Answer

Tanzania's landscape is indeed a contest between the endogenic forces that build the land from within and the exogenic forces that wear it down from without, but it is a contest whose balance shifts from place to place and time to time.

The endogenic side has raised the land: vulcanicity built Kilimanjaro and Meru, faulting opened the Rift and its lakes, and broad uplift lifted the central plateau. Against this, the exogenic side never rests: weathering rots the granite, mass wasting strips the steep slopes, and rivers such as the Rufiji carry the worn material steadily to the Indian Ocean.

Where building has been recent and rapid, relief is high and rugged, as on the young cone of Kilimanjaro; where wearing has long had the upper hand, relief is subdued, as on the old, low plateau. So the relief seen today records which side is currently winning. The view holds: the landscape is a genuine and unending contest, and its present shape is simply the score at this moment.

Question 83

A student claims that chemical and mechanical weathering work quite separately, each in its own places. Substantiate the view that, in reality, each depends on the other.

Model Answer

Chemical and mechanical weathering do not act in isolation; each prepares the way for the other, so that in nature they form one combined attack.

Mechanical weathering breaks rock into ever smaller fragments, and in doing so it greatly increases the surface area exposed to the air and water. Since chemical weathering acts on exposed surfaces, this shattering speeds the chemical decay enormously, a small block rotting far faster once it is broken into many pieces.

Chemical weathering returns the favour. By rotting and softening the rock along its joints and grain boundaries, it weakens the rock so that frost, heating and salt can break it apart far more easily. On a Kilimanjaro slope, frost first shatters the rock, the fresh surfaces then rot, and the rotted rock shatters again.

So the claim is wrong: the two are partners, each opening fresh work for the other, which is why TIE describes weathering as a combination of processes acting together.

False Confidence Alert
Chemical and mechanical weathering are not rivals working in separate places. They reinforce one another: breaking rock exposes more surface for chemical decay, and chemical decay weakens rock for further breaking. Treat them as one combined attack, not two.

Question 84

Imagine a Tanzanian landscape from which all biological and chemical weathering were removed, leaving only physical weathering at work. Evaluate how the breakdown of rock would then proceed.

Model Answer

With only physical weathering at work, rock would still break down, but far more slowly and into a quite different landscape of bare, angular, thin-soiled slopes.

Physical processes such as frost shattering, exfoliation and salt crystallization would continue to split rock into angular fragments, scree and grus. But there would be no rotting of minerals, so no clay and no deep, mature soils would form. The deep red soils of the miombo, which are the work of chemical hydrolysis, would never appear.

The breakdown would also be confined to where temperature swings and freezing operate, the high slopes and the deserts, and would be slow without the prising of roots and the bite of organic acids. The result would be a cold-desert kind of landscape: bare rock, angular debris and thin stony soils. So rock would still break, but the fertile, deeply weathered tropics of Tanzania could not exist without the chemical and biological work that physical weathering alone cannot do.

Question 85

Two outcrops in the same wet highland weather very differently, one rotted to deep clay, the other barely touched. Assess why the depth of weathering can differ so sharply under a single climate.

Model Answer

Under one climate the depth of weathering is decided not by the weather but by the rock, the time and the site, which together control how deeply water can work.

The rock: feldspar-rich rock such as granite rots deep through hydrolysis, while quartz-rich or massive rock resists; well-jointed rock lets water reach far down, while impermeable rock keeps it near the surface.

The time: rock that has lain exposed for longer is weathered more deeply, so an older surface rots deeper than a freshly exposed one nearby.

The site and drainage: on flat, poorly drained ground water lingers and weathers the rock deeply, whereas on a steep slope it runs off before it can penetrate.

So the climate sets the kind of weathering, but the rock, the length of exposure and the position decide its depth, which is why one outcrop rots to clay while its neighbour, under the same rain, stands almost fresh.

So in Tanzania's western highlands the feldspar-rich granite rots to deep red clay while a quartz-rich ridge beside it, under the very same rain, stays almost bare.

Question 86

It is sometimes said that the danger of mass wasting lies almost entirely on the steep slopes and hardly at all on the lowlands. Argue the case for this statement.

Model Answer

The case is strong: mass wasting is overwhelmingly a danger of steep slopes, because it is the slope angle that gives gravity the downhill pull it needs to move material at all.

On a steep slope a large part of gravity acts down the slope, so loosened material moves readily and, once moving, accelerates; the steeper the slope, the faster and more frequent the movement. The steep slopes of Lushoto and the Uluguru mountains slide and slump after heavy rain, while the flat plains beside them do not. On level ground gravity acts almost straight down, with little downslope component, so material simply stays where it is, and water pools instead of rushing off.

It must be granted that the lowland at the foot of a slope is not wholly safe, since mudflows and rockfalls run out onto it and bury settlements, as at Hanang. But this danger is imported from the slopes above; the lowland itself does not generate mass wasting. So the statement holds: the trigger and the home of mass wasting are the steep slopes, even if the lowland sometimes bears the consequences.

Question 87

Mass wasting is usually cast as pure disaster, yet its record for the people is more mixed than that. Appraise the contribution of mass wasting to the socio-economic life of the people.

Model Answer

Mass wasting is on balance a hazard to be managed, yet it also does quiet good, so its contribution to socio-economic life is genuinely mixed.

On the cost side, its rapid forms are destructive and deadly: the Hanang mudflow of 2023 buried homes and killed people, and such events destroy cropland, block roads, displace communities and demand costly relief and rebuilding. On steep, settled slopes like those of Lushoto this is a constant threat to life and property.

On the benefit side, the slow forms of mass wasting, creep and wash, carry weathered material down to the footslopes and valley floors, where it builds the deep, fertile soils that farmers depend on, and the talus at a cliff foot supplies stone. Weighing the two, the short-term cost of the sudden disasters is severe and visible, while the long-term benefit of soil-building is real but quiet. The fair appraisal is that mass wasting is mainly a danger to be guarded against, but one that also slowly builds the fertile lowlands on which people live.

Question 88

Although rare storms send water rushing across the desert, it is the wind that is usually named its master sculptor. Justify, with the aid of a diagram, why wind is the major agent of erosion in the desert.

Model Answer

Wind is the major agent of erosion in the desert because the desert surface is exactly suited to it: dry, bare and loose, with the wind blowing constantly while water comes only rarely.

Because there is little rain and almost no vegetation, the sand lies dry and unbound, with no roots to hold it and no plants to absorb the wind's energy, so the wind can lift and hurl it freely. It erodes in two ways, by deflation, lifting the fine sand and lowering the surface to leave pavements and hollows, and by abrasion, sand-blasting the standing rock near its base. A small rise in wind speed produces a large rise in erosive force, so a strong desert wind does great work.

The proof is in the landforms: ventifacts, rock pedestals, yardangs, zeugen and the great dune fields are all the wind's work. It must be admitted that where a rare storm strikes, water cuts wadis and canyons quickly, so water is locally decisive. But over most of the surface and most of the time it is the constant wind, working on a dry and defenceless surface, that is the master sculptor of the Sahara.

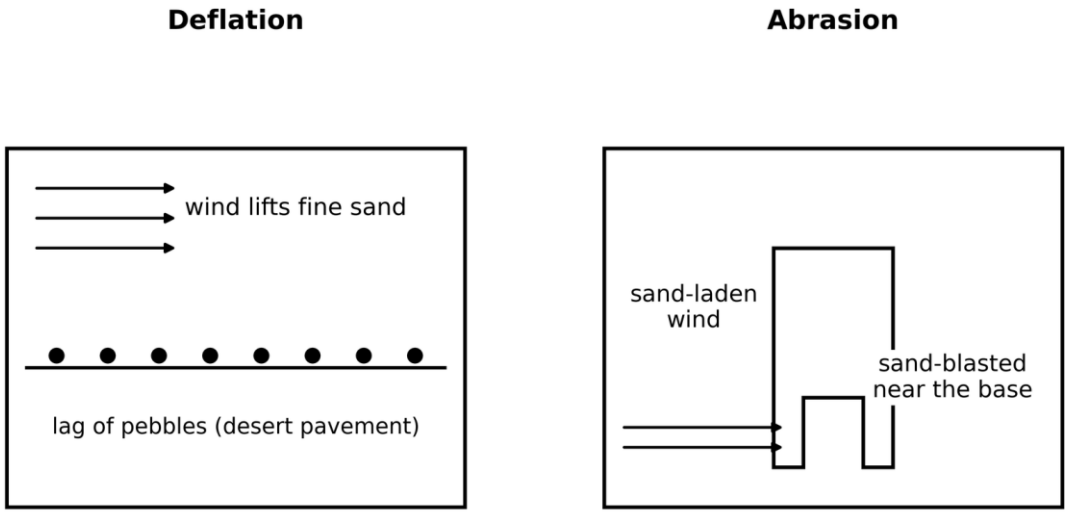


Figure 4.44: *Wind erosion in the desert: deflation and abrasion*

Question 89

From the crescent barchan to the long seif and the many-armed star, dunes take strikingly different forms. Examine the factors that decide the type and morphology of a sand dune.

Model Answer

The form a dune takes is chiefly a record of the wind that built it, modified by the supply of sand and the presence of vegetation.

1) **Wind direction:** a wind from one steady direction builds crescent barchans and transverse ridges; two dominant directions build long seif ridges; winds from many directions build star dunes.
2) **Wind strength:** light to moderate winds build broad transverse dunes, while strong winds draw the sand out into long seifs.
3) **Sand supply:** a limited supply gives scattered barchans, while an abundant supply gives continuous transverse dunes and sand seas.
4) **Vegetation and obstacles:** plants anchor the arms of a parabolic dune, and a rock or bush can fix the nucleus of a barchan or an attached dune.

So the same sand can be shaped into a crescent, a ridge or a star, depending mainly on the wind regime and how much sand is available, which is why the barchans of the Sahara differ so from the long seifs of the Namib.

Question 90

It seems a paradox that in the driest places on Earth water can still be the dominant agent of erosion and deposition. Discuss this claim.

Model Answer

The paradox is real but resolvable: rain is rare in the desert, yet when it falls it does so violently on a defenceless surface, so it accomplishes a disproportionate amount of erosion and deposition.

In favour of the claim, desert rain comes as sudden torrents, and on bare, baked, vegetation-free ground it cannot soak in, so it runs off at once with great force. In hours it cuts rills, gullies, wadis and deep canyons, and where it slows it lays down alluvial fans and salt-crusted playas. The very dryness of the desert, with no soil or plants to slow the runoff, makes that runoff far more erosive than the same rain in a humid land.

Against the claim, water works only on the rare occasions it appears, whereas the wind works every day and reshapes most of the surface. The resolution is that the two divide the labour: water does the sudden, large-scale cutting, so the deepest valleys and canyons are water-cut, while wind does the constant everyday reworking. So the paradox holds, because rare water, striking a surface with no defence against it, does work out of all proportion to its scarcity, as in the great wadis of the Sahara.

Question 91

A visitor dismisses the karst country of Songwe as worthless, seeing only thin soil and bare grey rock. Explain how such a region can in fact hold real significance.

Model Answer

The visitor sees only the surface; in fact the very solution that strips the karst of its soil also creates a hidden wealth that makes the region genuinely significant.

The same dissolving of the limestone that leaves the surface thin and bare hollows out caves below, and these, with their stalactites, stalagmites and pillars, draw tourists and earn income, as at the Amboni caves near Tanga. The limestone itself is the essential raw material for cement and lime, feeding industry and construction, and it is quarried for building stone. Underground rivers and springs in the rock supply water for people and stock.

On the surface, the thin grasses still provide grazing for livestock, and pockets of fertile terra rossa soil grow crops. So the poverty the visitor sees is only skin deep: the karst of Songwe and Amboni is poor on top but rich beneath and in its rock, and is therefore far from worthless.

Question 92

Deposition is often listed as one of a river's active powers, yet it may be better understood as a failure. Justify the view that river deposition is simply the failure of transport.

Model Answer

River deposition is best understood not as an active power but as the failure of transport, since a river lays down its load only when it can no longer carry it.

A river transports its load only as long as it has the energy to do so. When that energy falls, because its volume drops, its gradient flattens, its velocity slows, or it meets the still water of a lake or sea, it can no longer hold its load and is forced to drop it. The dropping is therefore the direct consequence of losing the power to carry, not a separate ability.

The way the load is dropped confirms this. The coarsest material, which the river fails to carry first, is deposited first, then sand, then the finest silt, sorting the load by the order in which transport fails. And where energy is restored, in a flood or a steeper reach, the same material is picked up and carried again. So deposition is the negative image of transport: wherever transport fails, deposition follows, which is exactly why it is called the failure of transport, as seen where the Rufiji drops its load at its quiet mouth.

False Confidence Alert
Deposition is not a separate 'power' the river switches on. It is what happens when the river loses the energy to transport, so the coarse load drops first and the fine is carried furthest. Read deposition as failed transport, not as an active force.

Question 93

Hydraulic action and abrasion are the obvious ways a river wears its bed, but solution is easily overlooked. Explain how solution, or chemical erosion, ranks among the genuine processes of river erosion.

Model Answer

Solution ranks as a genuine process of river erosion because it truly removes rock; it simply does so chemically, by dissolving the rock, rather than mechanically, by breaking it.

Where a river flows over soluble rock such as limestone, its water, made slightly acid by dissolved carbon dioxide, reacts with the calcium carbonate through carbonation and changes it into soluble calcium bicarbonate, which is then carried away invisibly in solution. Material is therefore taken from the bed and banks, which is exactly what erosion means.

Solution differs from the other processes in useful ways: it needs no load to act, unlike abrasion, and it works in all stages of the river and on any gradient, since it depends on the chemistry of the water and the rock, not on the river's speed. It is decisive where the rock is soluble, lowering and widening the channel in limestone country. So although it is quiet and unseen, solution is true erosion, and it must be counted alongside hydraulic action, abrasion and attrition.

This is why a river crossing the limestone country around Amboni in Tanga is eroded as much by quiet solution as by open force.

Question 94

A river wears its channel not in one way but in four, and they work together. With the aid of diagrams, illustrate the four processes that combine to let a river erode its channel.

Model Answer

A river erodes its channel by four processes that work together: hydraulic action, abrasion, attrition and solution.

1) **Hydraulic action:** the sheer force of the moving water, which pushes into cracks, compresses the air there and prises the rock loose.
2) **Abrasion (corrasion):** the rock and pebbles the river carries grind against the bed and banks like sandpaper, wearing them away, most strongly in the upper and middle course.
3) **Attrition:** the load itself is worn down, as the carried fragments knock against one another and break into smaller, rounder pieces.
4) **Solution (corrosion):** the slightly acid water dissolves soluble rock such as limestone and carries it away.

Working together, hydraulic action and abrasion do most of the cutting while attrition reduces the load and solution removes the soluble rock, and it is this combined attack that lets a river such as the Pangani deepen, widen and lengthen its channel.

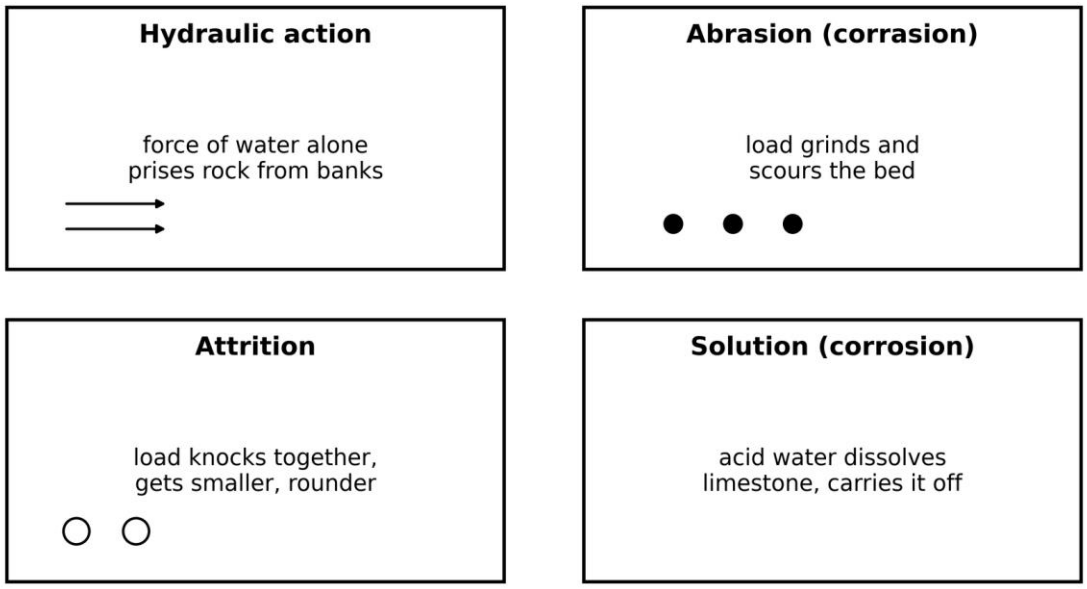


Figure 4.45: *The four processes of river erosion*

Question 95

Follow a single river from its mountain source to its delta, and the land it crosses is utterly transformed. Evaluate how the changing work of one river reshapes the landscape along its course.

Model Answer

A single river is the most powerful agent reshaping the landscape it crosses, because its work changes completely from source to mouth, destroying in the highlands and building in the lowlands.

In its youthful upper course the river cuts downward, carving steep V-shaped valleys, gorges, waterfalls and potholes, as in the highland reaches of the Pangani. In its middle course the gradient eases, lateral erosion takes over, and the valley opens out as meanders begin to swing. In its old lower course the river deposits, building floodplains, levees and oxbow lakes, and at its mouth a delta, as the Rufiji has built across its coast.

So one river is destructive upstream and constructive downstream: it lowers the highlands, carries the material across the land, and builds the lowlands and coast with it, all in one continuous, graded system. Evaluated as a whole, the river is the single greatest sculptor of Tanzania's interior landscape, wearing down the mountains and building out the coast at the same time.

Question 96

One river can rob another of its headwaters entirely. With the aid of a diagram, describe the mechanism by which river capture, or piracy, takes place.

Model Answer

River capture takes place when a stronger, more vigorous river erodes backward until it cuts into the valley of a weaker neighbour and diverts its headwaters into its own system.

The capturing river must have the greater energy, with a steeper gradient and a lower base level, so that it can cut down and, above all, erode headward, eating back at its source. It is helped where it works along a band of weak rock that lets it cut back quickly. As it erodes headward it advances toward the divide separating it from the weaker river.

Eventually it cuts through the divide and breaks into the valley of the weaker river, tapping its channel. The weaker river's upper water is then diverted down the steeper course of the captor, and the weaker river is beheaded. The capture leaves a clear set of features: an elbow of capture where the diverted water makes a sharp turn, a dry wind gap below it, and a shrunken misfit stream too small for its valley. So the mechanism is one of unequal headward erosion, the stronger river literally eating back until it steals the weaker one's water, as the Tiva was robbed in Kenya.

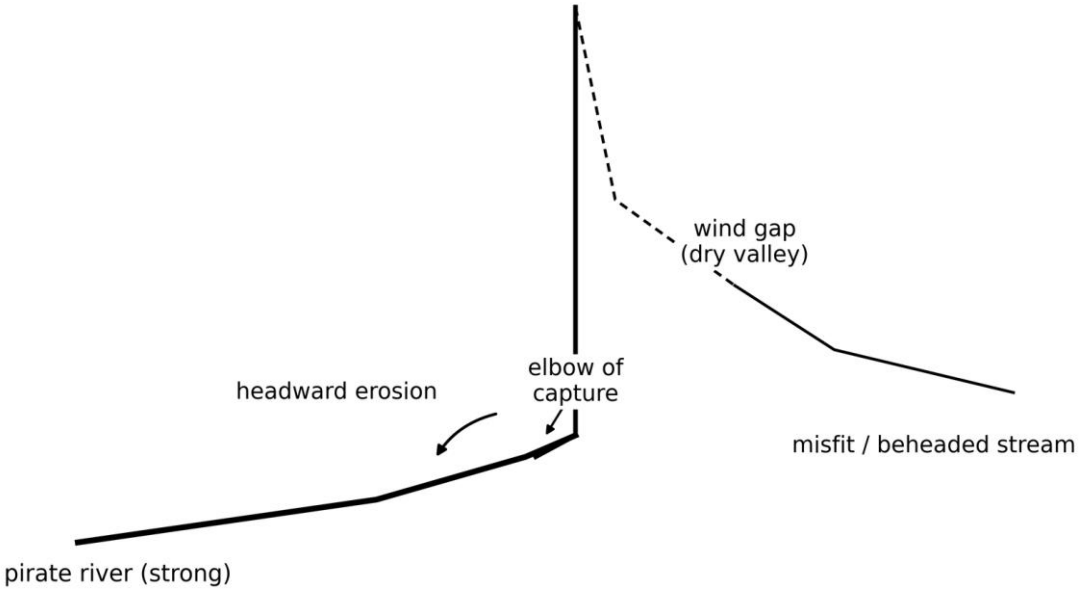


Figure 4.46: *River: capture (piracy)*

Question 97

As a geographer, explain how the action of the waves modifies the geomorphology of a coastal region over time.

Model Answer

Waves modify the geomorphology of a coast by eroding, transporting and depositing material, so that over time they both wear the coast back and build it out, and steadily reshape its outline.

Where destructive waves attack, they erode the headlands, cutting cliffs, caves, arches, stacks and stumps, and wearing platforms at their feet, as on the rocky stretches near Tanga. The eroded material is then carried along the shore by longshore drift. Where constructive waves dominate, they deposit this material as beaches, spits, bars and tombolos, as along the Bagamoyo coast.

Over time these actions tend to straighten the coast, cutting back the headlands and filling the bays, while tides and changes in sea level add their own effects. The result is a coastline that is never fixed but is continually being re-carved and rebuilt. So the waves are the chief sculptors of the coast, and its geomorphology at any moment is simply the current balance of their wearing and building.

Question 98

"The coastal zone is undergoing constant change." Justify this statement with vivid evidence.

Model Answer

The statement is fully justified, because the coast changes at every scale of time, from the hourly tide to the age-long shift of sea level, and the evidence is written all along the shore.

1) **By the hour and the day:** the tides rise and fall and the waves erode and deposit, never leaving the shore still.
2) **By the season:** storm waves strip the beaches in the rough season and gentle waves rebuild them in the calm, so a beach is never the same from month to month.
3) **By the year and the century:** cliffs retreat, spits grow, deltas advance as the Rufiji delta does, and reefs build outward.
4) **By the age:** changes in sea level drown or strand the coast, leaving raised beaches and notches, as at Kilindini, and drowned valleys such as rias.

To this natural change human action now adds its own, through groynes, sea walls, sand mining and building. With raised beaches recording past change, cliffs visibly retreating and the Rufiji delta visibly advancing, the evidence at every scale proves that the coastal zone is indeed never at rest.

Question 99

Appraise the contribution of the rise and fall of the sea level and of the land surface to the formation of coasts.

Model Answer

The rise and fall of the sea level and the land surface is the master control on the formation of coasts, because it decides the whole type of coast, within which the waves then carve the detail.

Where the sea falls or the land rises, the coast emerges, leaving raised beaches, old cliffs, notches and exposed coastal plains stranded above the present shore. Where the sea rises or the land sinks, the coast is submerged, and the drowned valleys give rias, fiords and estuaries. These submerged coasts provide the deepest and best natural harbours, as at Kilindini in Mombasa.

So the relative movement of sea and land is what makes a coast emergent or submergent in the first place, and therefore what kind of landforms and harbours it will have. The waves, tides and rock structure shape the detail, but they work within the frame that the change of level has set. Appraised fairly, the rise and fall of sea and land is the principal architect of coastal form, with the waves doing the carving inside the outline it draws.

Question 100

Sea level changes both because the oceans themselves rise and fall and because the land moves up and down. Assess whether eustatic or isostatic change has done more to set the present shoreline.

Model Answer

Both have shaped the present shoreline, but eustatic change, the worldwide rise and fall of the oceans, has done more overall, while isostatic change dominates only in particular regions.

Eustatic change acts everywhere at once. The great rise of about 120 metres since the last glacial maximum drowned coasts across the world, creating the rias and estuaries that mark so many shores, and the present warming-driven rise threatens low coasts and islands today. Because it changes the volume of the whole ocean, its effect is global.

Isostatic change, the rise or fall of the land itself, is more local. It is decisive in lands once loaded by ice, such as Scandinavia, which is still rising and leaving raised beaches, but it matters far less in tropical Tanzania, which carried no ice. So for the world as a whole, and for the East African coast in particular, eustatic change has been the greater architect of the present shoreline; isostatic change is the master only where the land has been heavily loaded and is still recovering.

False Confidence Alert
Eustatic and isostatic change are not the same. Eustatic is a worldwide change in the volume of ocean water; isostatic is a local rise or fall of the land. One moves the sea everywhere; the other only seems to, against a moving coast. Name the right one for the evidence.

Question 101

For more than a century the origin of barrier reefs and atolls has divided geographers. Discuss why the origin of coral reefs has remained debatable.

Model Answer

The origin of coral reefs has remained debatable because reefs form in different settings, so that each of the rival theories fits some reefs but none fits them all.

1) **Darwin's subsidence theory:** holds that a reef begins as a fringing reef round an island, and as the island slowly sinks the coral grows upward, becoming a barrier reef and finally an atoll. This fits the subsiding volcanic islands of the deep ocean, such as the Aldabra atoll, but not reefs that sit on stable shelves.
2) **Daly's glacial-control theory:** links reefs to the post-glacial rise of the sea, the coral growing up to keep pace with the rising water. This fits the timing of the last rise but cannot explain reefs of every depth.
3) **Murray's standstill theory:** holds that reefs grow outward on platforms of their own debris with no sinking at all, which fits shallow platforms but not deep atolls.

Because deep borings into reefs have given mixed evidence, and because reefs genuinely occur in these different settings, no single theory has won universal acceptance. So the origin is debatable simply because different reefs were formed in different ways; Darwin's subsidence theory remains the most widely accepted, but not the only one needed.

False Confidence Alert
No single theory explains every coral reef. Darwin's subsidence theory fits sinking ocean islands, Daly's fits the post-glacial rise, Murray's fits shallow platforms. The honest answer names all three and shows why each fits some reefs but not all.

Question 102

The coral coast of the Indian Ocean faces a growing human threat. Evaluate how human activity endangers the growth and survival of coral reefs.

Model Answer

Human activity has become the chief threat to the coral reefs, endangering them both directly, through destructive use of the coast, and indirectly, through the global warming that human emissions drive.

Directly, destructive fishing with dynamite and chemicals shatters and poisons the reefs; sediment and mud washed from coastal deforestation and farming smother the polyps, which need clear water; sewage and oil pollution poison them; and the mining of coral and sand removes the reef outright. Careless tourism and trampling add further damage. Off the Tanzanian coast it is destructive fishing and siltation that do the most immediate harm.

Indirectly, the warming of the sea caused by human emissions bleaches the coral, and the rising sea and acidifying water threaten its long-term survival; this is the gravest danger of all because it is global and hard to reverse. Yet not all is lost: good management, through laws and marine parks such as that at Mafia, can curb the local damage. Evaluated overall, human activity is now the principal threat to the reefs, but firm protection of the coast can still save much of what remains.

Chapter 5

ROCKS

This chapter turns from the forces that shape the land to the solid material on which they work, the rock itself. It asks what a rock is, how the three great families of rock, igneous, sedimentary and metamorphic, are formed and told apart, how the rock cycle binds them into one endless round, how the age of a rock is read both relatively and in years, and how, at the last, rock is broken down into the soil that feeds the nation.

BINDER questions build the core explanation of each idea: what each rock family is and how it forms, the textures and chemistry that classify igneous rock, the three modes of sedimentary rock, the agents and types of metamorphism, the rock cycle, the dating of rocks and the geological time scale, and the making of soil, many with the help of a labelled diagram. REAL questions carry that understanding into real Tanzanian settings, the Tanzanite of Simanjiro, the building granites of Dodoma, the coalfields of Kiwira, the limestone of Tanga and the ash soils of Rungwe and Kilimanjaro. HOT questions ask you to weigh these ideas against one another and to judge them, from whether parent rock or climate rules the soil to whether rock formation is truly without end.

BINDER QUESTIONS

Question 1

A mason in Dodoma splits a block of grey granite and sees within it glassy, white and dark specks locked tightly together. Explain what a rock is, and account for the chemical elements from which almost every rock is built.

Model Answer

A rock is a naturally occurring solid aggregate of one or more minerals, held together as a coherent natural mass.

Some rocks are made of a single mineral, whereas most, like the granite of Dodoma, combine several, since the grey block is built from quartz, feldspar and mica grown together. Because the minerals differ, the rocks they build differ too in hardness, coherence and permeability, which is why this granite stands firm as a building stone while a clay rock crumbles in the hand.

Almost every rock is built from only eight chemical elements. Oxygen and silicon are by far the commonest, and they join with aluminium, iron, calcium, sodium, potassium and magnesium to form the silicate minerals that make up the bulk of the crust. Thus the whole variety of Tanzanian rock, from the plateau granite to the coastal limestone, is the work of a small handful of elements arranged into different minerals.

Question 2

A well driller near Singida finds that water seeps freely through one rock yet is held back completely by another close by. Explain how the mineral make-up of a rock decides its hardness, coherence and permeability.

Model Answer

The properties of a rock follow directly from the minerals that compose it and from the way those minerals are packed together.

Hardness: this depends on the minerals present, so a quartz-rich rock such as granite is very hard and resists wear, whereas a rock rich in soft clay minerals is easily scratched and worn.

Coherence: this is how firmly the grains are bound, so a crystalline rock with interlocking crystals holds together strongly, while a poorly cemented sandstone falls apart grain by grain.

Permeability: this is whether water can pass through, so a rock with connected pores or open joints lets the driller's water seep, whereas a dense crystalline rock holds it back.

Near Singida it is exactly this contrast that the driller meets, since the porous sandstone passes water freely while the neighbouring crystalline rock stays impermeable.

Question 3

A geology student at the University of Dar es Salaam is handed a tray of mixed rock samples and asked to sort them in an orderly way. Account for the three bases on which rocks are classified, and explain why one rock may be named under all three.

Model Answer

Rocks are classified on three bases: their mode of formation, their chemical composition and their age.

1) **Mode of formation:** the chief basis, which divides all rock into igneous, formed from cooled magma, sedimentary, formed from settled sediment, and metamorphic, formed from altered rock.
2) **Chemical composition:** which groups rock by its dominant minerals, for example acidic rock rich in silica against basic rock rich in iron and magnesium.
3) **Age:** which orders rock by the time it formed, whether dated relatively against its neighbours or absolutely in years.

These bases do not compete but describe different aspects of one rock, so that a single Tanzanian basalt may be named at once as igneous by origin, basic by chemistry and Cenozoic by age.

Question 4

The dark basalt that floors much of the land around Mount Meru began as red-hot lava that cooled and set. Explain what igneous rock is, and why it is called the primary or mother rock of the others.

Model Answer

Igneous rock is rock formed by the cooling and solidification, that is the crystallisation, of molten rock material, whether magma below ground or lava at the surface.

The name comes from the Latin ignis, meaning fire. As the molten material loses heat, its minerals crystallise and lock together into a solid mass, so the basalt around Meru is simply lava that has set.

It is called the primary or mother rock because the other two families owe their origin to it: when igneous rock is weathered and its debris settles it becomes sedimentary rock, and when either is heated and pressed it becomes metamorphic rock. Since igneous rock also forms the basis of soil and makes up almost the whole crust, the basalt of Meru stands as a parent from which Tanzania's other rocks descend.

False Confidence Alert
It is a mistake to call only volcanic rock igneous. Igneous rock includes the intrusive granites that cooled deep underground just as much as the lava erupted at the surface, since both solidified from molten material.

Question 5

Beneath Oldoinyo Lengai in the northern Rift, solid rock at depth turns to liquid magma that the volcano then erupts. Account for the formation of magma, and for the three conditions that cause solid rock to melt.

Model Answer

Magma forms when rock deep within the Earth melts, in part or wholly, into a hot mobile liquid.

1) **A rise in temperature:** added heat, as from radioactive decay or from rising hot material, lifts the rock above its melting point so that it turns to liquid.
2) **A fall in pressure:** when the overlying pressure is released, as where the Rift is stretching and thinning the crust, rock that was solid under pressure melts even without added heat.

3) **A change in composition:** the addition of water or other volatiles lowers the melting point of the rock, so that it melts at a temperature it would otherwise have withstood.

At Oldoinyo Lengai the thinning, stretching crust of the Rift offers exactly the fall in pressure that frees magma to rise and erupt.

Question 6

Asked to tell a granite tor on the Dodoma plateau from a layered cliff of sandstone, a student looks for tell-tale features. Explain the diagnostic characteristics of igneous rocks, and why they can hold no fossils.

Model Answer

Igneous rocks share a set of characteristics that set them apart from the sedimentary and metamorphic families.

1) **Crystalline and granular:** they are made of interlocking crystals grown as the magma cooled, which gives a hard, compact rock.
2) **Without strata:** they lack the layers or bedding of sedimentary rock, since they set from a molten mass and not from settled sediment.
3) **Hard and impermeable:** water enters only with difficulty, along joints rather than through pores.
4) **Without fossils:** because magma is intensely hot, it destroys any organic remains it touches, so igneous rock can preserve no fossil.
5) **Acidic or basic in chemistry:** they are classed by their silica content rather than by any layering.

The grey granite of Dodoma shows all of these, so its crystals, its lack of bedding and its absence of fossils mark it at once as igneous.

Question 7

The granite now exposed across the Dodoma plateau cooled kilometres underground, while the basalt of the northern volcanoes set at the surface. Distinguish intrusive from extrusive igneous rocks, and explain how intrusive rock is further divided.

Model Answer

Igneous rock is divided, by where its magma solidified, into intrusive rock formed within the crust and extrusive rock formed at the surface.

Intrusive (plutonic) rock: this cools and crystallises slowly within the crust, as with granite; because the cooling is slow, large crystals have time to grow. It is divided by depth into plutonic rock, formed very deep as in the great batholiths, and hypabyssal rock, formed just below the surface as dykes and sills.

Extrusive (volcanic) rock: this forms when magma reaches the surface as lava or fragments and cools quickly, as with basalt and pumice; because the cooling is fast, the crystals are small or absent.

So the deep-cooled granite of the Dodoma plateau is intrusive, whereas the surface-cooled basalt of the northern volcanoes is extrusive.

Question 8

Granite shows large crystals easily seen by the eye, yet basalt from the very same family looks almost smooth. Account for the coarse crystals of intrusive rock by the way it cools, and contrast it with extrusive rock.

Model Answer

The size of the crystals in an igneous rock is set by the rate at which its magma cooled, which in turn depends on where it solidified.

Intrusive rock cools slowly, deep underground, so the minerals have a long time to gather into large, well-formed crystals, giving the coarse, sparkling texture of granite. Extrusive rock, by contrast, cools quickly

at the surface, so the minerals have little time to grow and the crystals are tiny or even absent, as in fine basalt or glassy obsidian.

Thus the deep, slow cooling of the central-plateau granite explains its coarse crystals, whereas the quick-chilled basalt of the northern volcanoes is fine-grained.

False Confidence Alert
It is wrong to think large crystals mean a rock cooled for a longer number of years in total. What matters is the rate of cooling, not the length of geological time since; slow cooling at depth grows big crystals, fast cooling at the surface grows small ones, whatever their later age.

Question 9

A museum tray in Dar es Salaam holds a coarse granite, a glassy black obsidian and a frothy pumice, all igneous yet utterly unlike to the touch. Explain how the texture of an igneous rock records its cooling history.

Model Answer

Texture, the size and arrangement of the mineral grains, records how fast and where an igneous rock cooled.

1) **Phaneritic:** large crystals visible to the eye, grown by slow, deep cooling, as in granite.
2) **Aphanitic:** crystals too small to see, formed by rapid cooling near the surface, as in basalt.
3) **Porphyritic:** large crystals set in a fine matrix, recording two stages of cooling, slow at depth and then fast near the surface.
4) **Glassy:** no crystals at all, formed by cooling so fast that none could grow, as in obsidian.
5) **Vesicular:** full of gas-bubble holes left as escaping gas frothed the lava, as in pumice and scoria.

So the obsidian and pumice on the tray are both quick-chilled lava, while the coarse granite beside them cooled slowly at depth.

Tanzania's own Rift volcanoes, around Oldoinyo Lengai, throw out exactly such glassy and frothy lava.

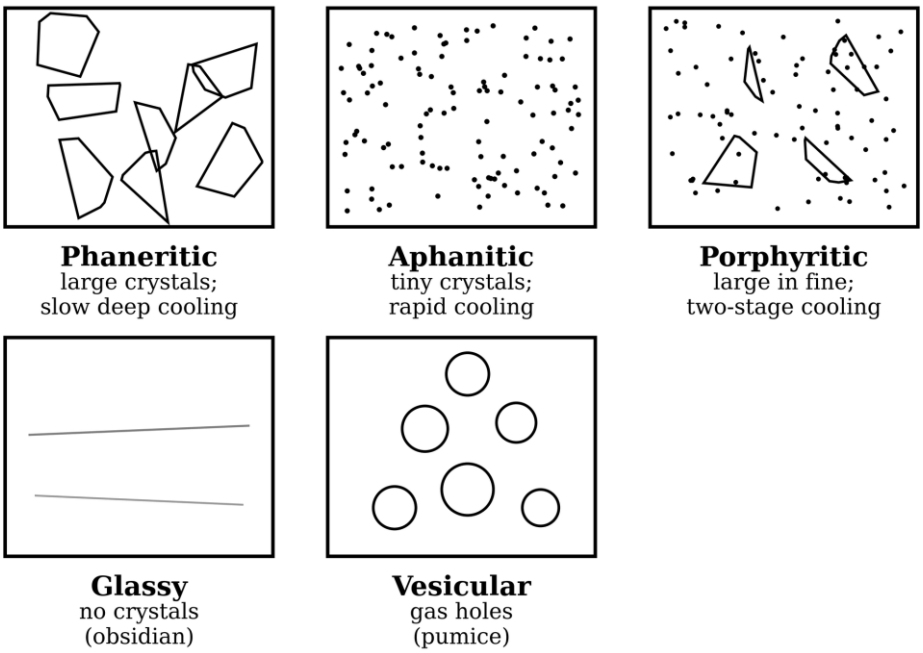


Figure 5.1: *The main textures of igneous rocks*

Question 10

A pale, light block of granite and a dark, heavy block of basalt sit side by side, and the difference in colour and weight is plain to see. Explain how the silica content of igneous rock separates it into acidic, basic and ultrabasic types.

Model Answer

Igneous rocks are grouped by their chemical composition, and above all by how much silica they contain.

Acidic (felsic) rocks: these are rich in silica, over fifty per cent, with much quartz and feldspar and little iron, so they are pale and of low density, as in granite at about 2.7 grams per cubic centimetre.

Basic (mafic) rocks: these are poorer in silica but rich in iron and magnesium, so they are dark and denser, as in basalt and gabbro at about 3.0 grams per cubic centimetre.

Ultrabasic rocks: these are very low in silica, under forty-five per cent, and very rich in heavy metallic minerals, so they are the darkest and densest, as in peridotite at about 3.3 grams per cubic centimetre, and are rare at the surface.

So as silica falls the colour darkens and the density rises, which is exactly why the basic basalt outweighs the acidic granite beside it.

The dark basalt of the northern volcanoes and the pale granite of the Dodoma plateau stand at the two ends of this scale.

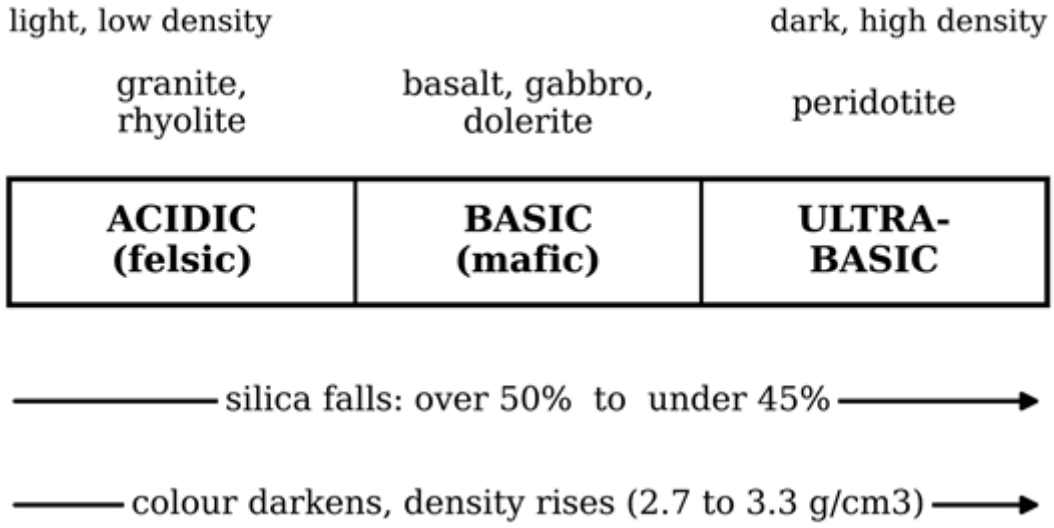


Figure 5.2: *The chemical classification of igneous rocks by silica content*

Question 11

The flat-lying limestone around Tanga formed grain by grain on an ancient sea floor and was only later raised into low cliffs. Explain how sedimentary rock forms, and why its name fits the way it is made.

Model Answer

Sedimentary rock is rock formed at or near the Earth's surface by the accumulation and lithification of sediment, or by precipitation from solution.

The name comes from the Latin sedere, meaning to settle. Sediment derived from weathered older rock, or from the remains of living things, is carried by wind, water or ice and deposited in layers; the loose layers are then compacted and cemented, a process called lithification, into solid rock.

So the Tanga limestone settled as lime mud and shell on a sea bed and hardened in place, exactly as the word settle implies.

False Confidence Alert
Do not assume every sedimentary rock is built from broken fragments of older rock. Many form instead from chemical solution, such as rock salt and gypsum, or from living remains, such as limestone and coal, with no rock fragments at all.

Question 12

Where the Rufiji enters the sea it lays down mud, dissolved minerals and the remains of swamp plants all together. Distinguish the three types of sediment from which sedimentary rocks are built.

Model Answer

Sediment is of three kinds according to its origin: detrital, chemical and organic.

1) **Detrital (clastic) sediment:** solid fragments mechanically eroded from older rock, such as the mud and sand the Rufiji carries down to its delta.
2) **Chemical sediment:** mineral matter precipitated or evaporated from solution, such as the salts left behind when mineral-rich water dries out.
3) **Organic sediment:** the remains of once-living things, such as shells, coral and the buried plant matter of a swamp.

In the Rufiji delta all three arrive together, so that detrital mud, dissolved minerals and plant remains are laid down side by side.

Question 13

A water well sunk into sandstone near Kilwa yields both fresh water and the fossil shells of sea creatures. Explain the characteristics of sedimentary rocks that account for both finds.

Model Answer

Sedimentary rocks carry a set of characteristics that follow from their formation out of settled sediment.

1) **Layering (strata):** they are built up in successive layers, so they show clear bedding one above another.
2) **Fossils:** because they form gently at the surface, they preserve the remains of plants and animals, unlike the fossil-free igneous rock.
3) **Soft, porous and permeable:** most are only loosely cemented, so they hold and pass water, though a few are dense and impermeable.
4) **Wide cover:** they form only a thin skin of the crust yet spread over about three-quarters of the land surface.

So the pores of the Kilwa sandstone give up the fresh water, while its gentle, layered deposition preserved the sea shells.

Question 14

On a beach near Bagamoyo the waves sort the loose debris from fine mud through sand to coarse pebbles. Explain how mechanically formed, or clastic, sedimentary rocks are classified by the size of their grains.

Model Answer

Mechanically formed, or clastic, sedimentary rocks are built from fragments of older rock cemented together, and are graded by the size of those fragments.

1) **Argillaceous rocks:** the finest, made of clay and silt under about 0.02 millimetres, forming mudstone and shale.
2) **Arenaceous rocks:** medium, made of sand from about 0.06 to 2 millimetres, forming sandstone.

3) **Rudaceous rocks:** the coarsest, made of gravel and pebbles over 2 millimetres, forming conglomerate where the fragments are rounded and breccia where they are angular.

So the Bagamoyo waves sort their debris into exactly these size classes, fine mud at one end and coarse shingle at the other.

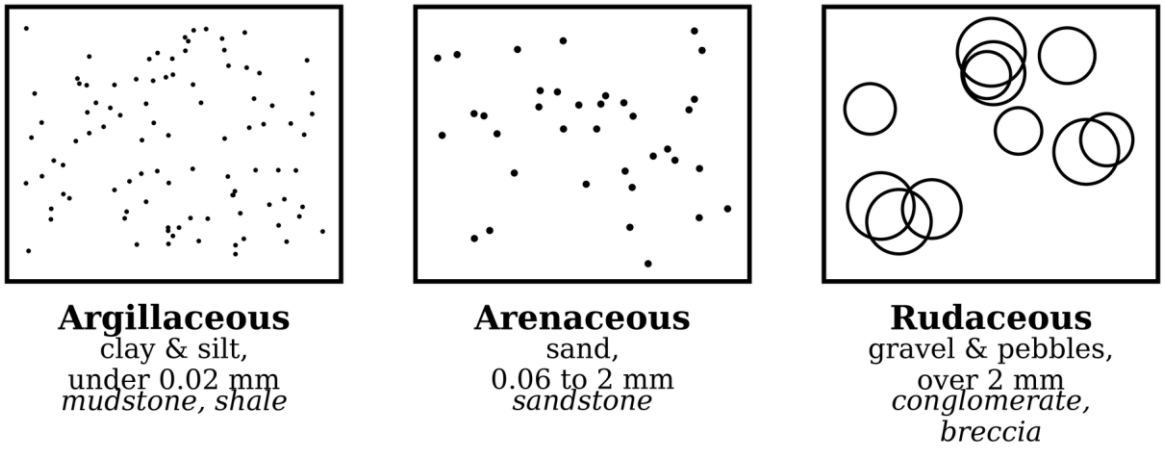


Figure 5.3: *Clastic sedimentary rocks graded by grain size*

How to Draw It
Draw three boxed panels side by side. In the first scatter many very fine dots and label it argillaceous, under 0.02 millimetres, mudstone and shale. In the second draw larger evenly spread dots and label it arenaceous, sand of 0.06 to 2 millimetres, sandstone. In the third draw a few large pebble circles and label it rudaceous, over 2 millimetres, conglomerate and breccia. Let the grain symbols grow plainly larger from left to right.

Question 15

The coral rag that builds the old stone town of Zanzibar and the coal mined at Kiwira both began as living matter. Explain how organically formed sedimentary rocks arise, naming the main kinds.

Model Answer

Organically formed sedimentary rocks are built from the accumulated remains of once-living organisms.

1) **Calcareous rocks:** from the lime shells and skeletons of sea animals and coral, forming limestone, chalk and coral rag.
2) **Siliceous rocks:** from the silica skeletons of tiny organisms such as diatoms, forming diatomite.
3) **Carbonaceous rocks:** from plant matter buried and compressed over ages under heat and pressure, forming the coals such as lignite, bituminous coal and anthracite.
4) **Ferruginous rocks:** from iron-rich organic remains, forming ironstone.

So the coral rag of Zanzibar is a calcareous rock built from reef lime, while the Kiwira coal is a carbonaceous rock built from ancient plants.

Question 16

Around Lake Natron in the north, white crusts of mineral salt are left behind as the shallow water evaporates under the strong sun. Explain how chemically formed sedimentary rocks are produced, with examples.

Model Answer

Chemically formed sedimentary rocks are produced when minerals dissolved in water are laid down as solids by evaporation or precipitation.

Evaporites: where mineral-rich water dries up, the dissolved matter is left behind, so calcium sulphate forms gypsum and sodium chloride forms rock salt, as the salt crusts of Lake Natron show.

Carbonate rocks: where weak carbonic acid in rainwater dissolves limestone, the calcium carbonate is carried in solution and may later be precipitated again, building carbonate rock and the features of limestone country.

So the shimmering salt flats of Lake Natron are chemically formed sedimentary rock in the very act of being made.

Question 17

In parts of the Usambara mountains, ordinary limestone has been turned into hard, crystalline marble without ever having melted. Explain what metamorphic rock is, and how metamorphism changes a rock.

Model Answer

Metamorphic rock is rock formed when an existing igneous or sedimentary rock is changed in the solid state, without melting, by heat, pressure or chemically active fluids.

Metamorphism is the change of the minerals and the texture of a pre-existing rock into a new form, taking place below the zone where the rock would melt to magma. Any earlier rock, even a metamorphic one, can be altered again, and the change is one of mineral composition and texture rather than a melting.

So the Usambara limestone recrystallised into marble while remaining solid throughout, its calcite reformed into a harder, interlocking rock.

False Confidence Alert
A common error is to say metamorphic rock is rock that has melted. It is not; metamorphism changes a rock in the solid state, by heat and pressure, without melting. Once a rock actually melts to magma it leaves the metamorphic field and will set as igneous rock.

Question 18

Where the rocks of an old mountain belt were squeezed and baked at depth, they came back to the surface completely made over. Account for the three agents that bring about metamorphism, and say which matters most.

Model Answer

Metamorphism is brought about by three agents: heat, pressure and chemically active fluids.

1) **Heat:** the most important agent, supplied by deep burial or by contact with magma, since it lets the minerals of the parent rock recrystallise into new ones.
2) **Pressure (compression):** from the weight of overlying rock or from the squeezing of earth movements, which changes the rock's form and packs its minerals tightly together.
3) **Chemically active fluids:** hot water and gases that pass through the rock and alter its chemical make-up by adding or removing material.

Of the three, heat is taken as the master agent, because it drives the recrystallisation that defines metamorphic change, as in the baked roots of the old Mozambique Belt that runs through eastern Tanzania.

Question 19

Rock baked beside a hot intrusion and rock crushed in a mountain belt are both made over, yet by different means. Distinguish the main types of metamorphism by the force that drives each.

Model Answer

Metamorphism is of several types according to whether heat, pressure, or both, drives the change.

1) **Dynamic metamorphism:** driven by pressure from compressional earth movements acting over wide areas, as in the building of great fold mountains, which is why it is also called regional metamorphism.
2) **Thermal (contact) metamorphism:** driven by heat alone, where rock is deeply buried or lies next to an intruding body of magma, in the contact zone called the aureole.
3) **Thermo-dynamic metamorphism:** driven by heat and pressure together over wide areas during major earth movements.
4) **Metasomatic metamorphism:** driven by the introduction of ions carried in fluids from an outside source, which changes the chemistry of the rock.

The regional, dynamic type built the metamorphic cores of Africa's old fold belts, including the gneisses and schists of the Mozambique Belt in eastern Tanzania.

Question 20

Roofing slate splits cleanly into flat sheets, yet marble of the same metamorphic family breaks in no particular direction at all. Explain the difference between foliated and non-foliated textures.

Model Answer

Metamorphic rocks are described by their texture as foliated or non-foliated, according to whether their minerals are arranged in parallel layers.

1) **Foliated rocks:** their minerals are flattened and aligned into parallel bands under directed pressure, so the rock splits readily along these layers, as in slate and schist.
2) **Non-foliated rocks:** their minerals have no banded arrangement, so the rock shows no layering and will not split into sheets, as in marble and quartzite.

So the foliation of slate lets it be split to roof a house, while the unfoliated marble, having no such layering, is carved instead as ornament.

Tanzania's old metamorphic basement supplies both, the foliated schists of its ancient belts and the unfoliated marble cut for building.

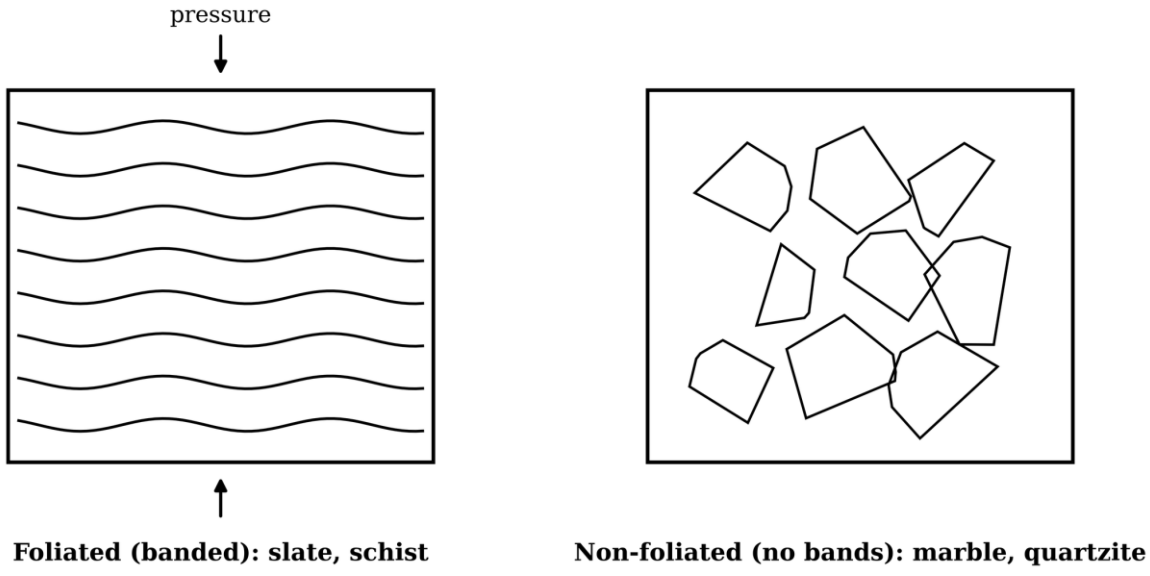


Figure 5.4: *Foliated and non-foliated metamorphic textures*

How to Draw It
Draw two boxed panels. In the left panel draw several parallel wavy bands across the box and add arrows pressing in from top and bottom, labelling it foliated, slate and schist. In the right panel draw randomly arranged interlocking crystals with no banding, labelling it non-foliated, marble and quartzite. The contrast between aligned bands and random grains is the whole point.

Question 21

Heated and pressed at depth, a soft shale becomes hard slate and a porous sandstone becomes glassy quartzite. Account for the common changes by which familiar rocks are turned into metamorphic ones.

Model Answer

Metamorphism transforms each parent rock into a characteristic, harder product.

1) **Limestone becomes marble:** its calcium carbonate recrystallises into an interlocking crystalline rock that is prized for building and carving.
2) **Sandstone becomes quartzite:** its sand grains and their cement fuse into an extremely hard, non-porous rock.
3) **Shale becomes slate, then schist:** its clay minerals realign under pressure into a foliated rock that splits into sheets, and under stronger metamorphism into the coarser, glittering schist.

These very changes built the marble and quartzite found in the ancient basement rocks of the Usambara and the wider Tanzanian shield.

Question 22

The minerals in a single grain of Rufiji sand may once have been part of a mountain of solid rock, and may one day be locked inside rock again. Explain what the rock cycle is, and the forces that drive it.

Model Answer

The rock cycle is the continual transformation of rock from one of the three families into another, in an endless and reversible round.

Igneous, sedimentary and metamorphic rock change into one another over time, so that no rock type is a final state. The cycle is driven by two engines working together: the Earth's internal heat, which moves material in the mantle and core and melts and raises rock, and the hydrological cycle, the movement of water, ice and air at the surface, which weathers, erodes and deposits.

So the minerals of a Rufiji sand grain are merely between rounds of this cycle, once part of solid rock and bound for solid rock again.

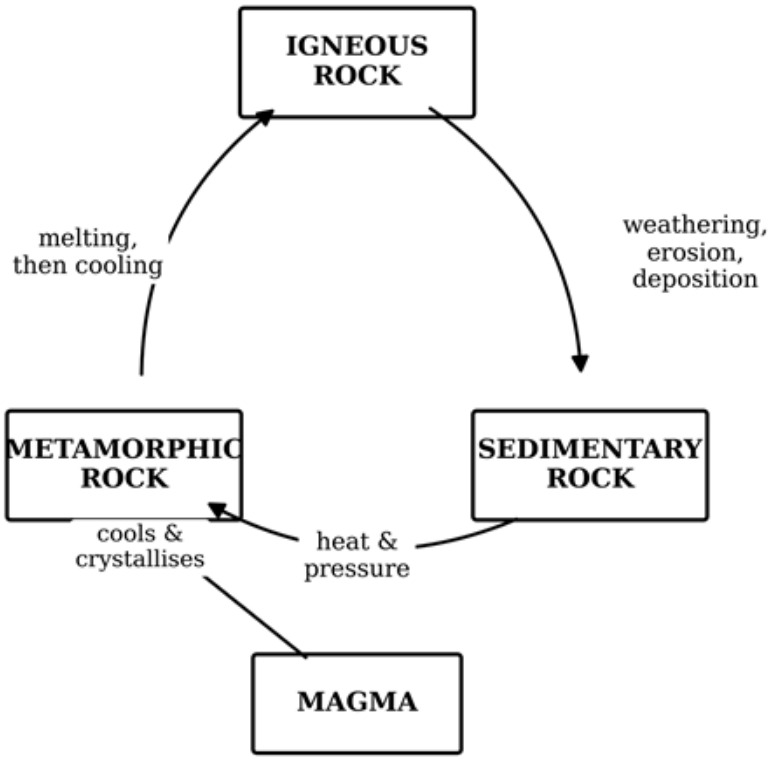


Figure 5.5: *The rock cycle*

False Confidence Alert
Do not picture the rock cycle as a one-way line from igneous to sedimentary to metamorphic. It is reversible and may skip stages, so an igneous rock can be metamorphosed directly, and a metamorphic rock can be weathered straight back into sediment.

Question 23

Follow a single mass of magma as it cools, is worn down, is buried deep, and is melted once more. Account for the five stages through which the rock cycle passes.

Model Answer

The rock cycle can be traced through five linked stages, beginning and ending with magma.

1) **Magma:** the cycle begins with molten material rising through vents, fissures and cracks towards the surface.
2) **Igneous rock:** the magma cools and solidifies, below ground or at the surface, into intrusive or extrusive igneous rock.
3) **Sedimentary rock:** the exposed igneous rock is weathered and eroded, its debris is deposited, and the deposits are compacted and cemented, that is lithified, into sedimentary rock.
4) **Metamorphic rock:** deeply buried sedimentary rock, or rock caught at a plate collision, is changed by great heat and pressure into metamorphic rock.
5) **Back to magma:** with still greater heat the metamorphic rock melts to magma, and the whole round begins again.

The cycle is not strictly linear, since a rock may skip a stage, yet the full round runs from magma back to magma, as a grain of the Tanzanian basement could one day prove.

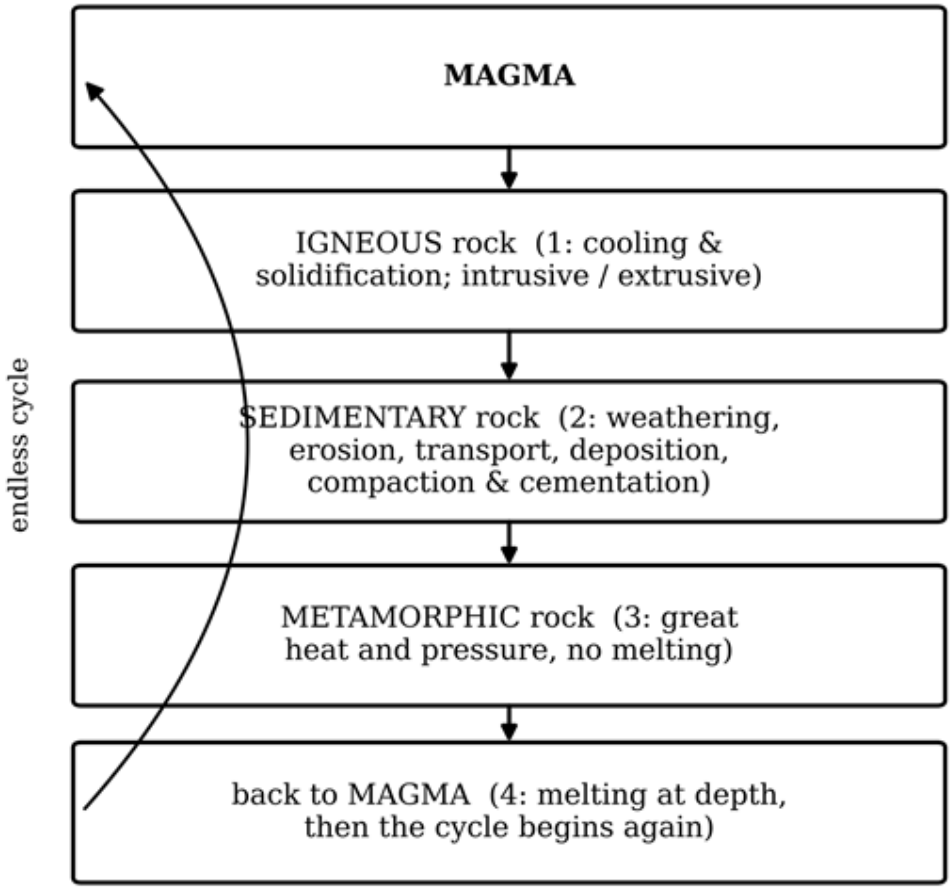


Figure 5.6: *The five stages of the rock cycle*

How to Draw It
Draw five boxes in a vertical column, joined by downward arrows: magma at the top, then igneous rock, then sedimentary rock, then metamorphic rock, then back to magma at the foot. Beside each arrow write the process that drives that stage (cooling, weathering and deposition, heat and pressure, melting). Add one long curved arrow from the foot back to the top to show the cycle repeats.

Question 24

Geologists hold that whichever rock you pick up, its ultimate ancestor was igneous. Explain why the igneous rock is taken as the first rock of the cycle.

Model Answer

The igneous rock is regarded as the first or primary rock because the Earth's crust was once wholly molten.

When that early molten crust first cooled and solidified, it could only form igneous rock, since there was as yet no older rock to weather and no sediment to bury. Only after igneous rock existed could its weathering supply the sediment for sedimentary rock, and only later still could heat and pressure make metamorphic rock. So every other rock traces the material it is made of back to an igneous beginning.

The ancient igneous basement granites that underlie much of Tanzania are just such first rock, from which the younger rocks above were ultimately derived.

Question 25

A teacher tells her class that the rock cycle is the single most useful idea in the whole chapter. Examine why the rock cycle is valued, both for understanding rocks and for what follows from it.

Model Answer

The rock cycle is valued because it explains, in one model, the origin and the kinship of all rocks.

1) **It shows origin:** it makes plain the source of each rock and how one type becomes another, so that no rock is studied in isolation.
2) **It shows unity:** it reveals the three families as stages in a single continuing process rather than as separate, unrelated kinds.
3) **It opens the way to soil:** the weathering that turns rock into sediment also turns rock into soil, so the cycle links the hard geology of rock to the living surface.

So the cycle explains, for example, how the hard granite of the central plateau can end its days as the fertile sediment and soil of a valley floor, feeding the people who farm it.

Question 26

Standing before a cliff of stacked rock layers near Amboni, a student is asked which layer is the oldest and how old it is. Explain what is meant by the age of a rock, and distinguish relative from absolute age.

Model Answer

The age of a rock is the time since it formed, and it may be expressed in two ways, relative and absolute.

Relative age: the age of a rock compared with its neighbours, telling only which is older or younger and not how old in years, and resting on the order of the layers.

Absolute age: the actual age of a rock in years, found by measuring the radioactive elements that the rock contains.

So at the Amboni cliff relative age names the lowest layer the oldest, while absolute dating would put a figure, in millions of years, on just how old it is.

Question 27

In an undisturbed cliff the rock layers lie one above another like the pages of a closed book. Account for the laws of original horizontality and superposition, by which such layers are ordered in age.

Model Answer

Two basic laws order the layers of an undisturbed sedimentary sequence in age: original horizontality and superposition.

1) **Original horizontality:** sediment settles under gravity in nearly horizontal layers, so beds that now lie flat were laid down flat, and beds that now lie tilted must have been disturbed after they formed.
2) **Superposition:** in an undisturbed sequence each layer is younger than the one beneath it, so the oldest bed lies at the bottom and the youngest at the top.

So reading the cliff from the bottom upward reads it from oldest to youngest, which is why the lowest layer is named the oldest.

So at the Amboni cliffs near Tanga the lowest bed is read as the oldest of all.

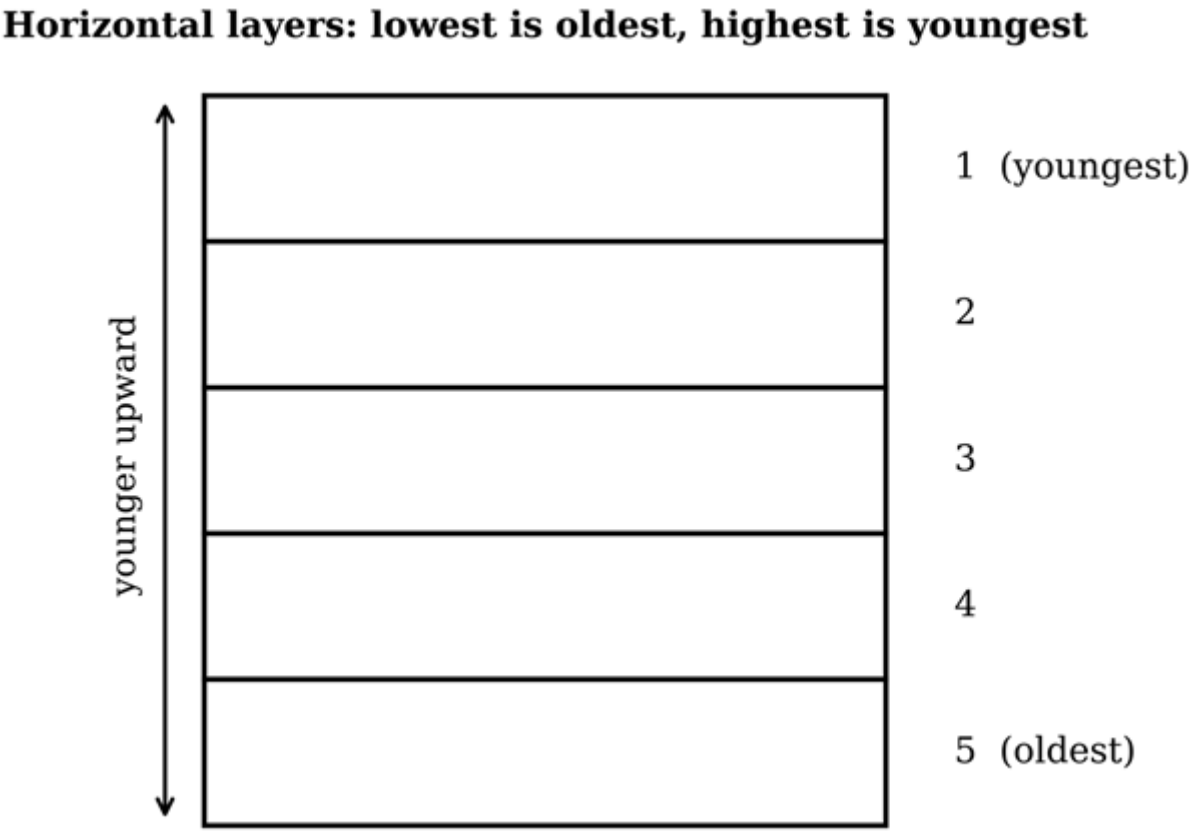


Figure 5.7: *Original horizontality and superposition*

Question 28

A dark dyke of igneous rock cuts straight across a set of sedimentary layers, and within the dyke sits a fragment torn from another rock. Explain how the laws of cross-cutting and inclusions extend relative dating.

Model Answer

Beyond simple superposition, further principles allow even rocks that have been cut, or that enclose fragments of others, to be placed in age.

1) **Cross-cutting relationships:** any feature that cuts across another must be younger than the rock it cuts, so a dyke or a fault that slices through layers must have formed after those layers.

2) **Inclusions:** a fragment enclosed within a rock must be older than the rock that surrounds it, and such a fragment caught in igneous rock is called a xenolith.

3) **Lateral continuity:** a layer extends sideways until it thins out or meets an obstacle, so matching beds on opposite sides of a valley were once one continuous layer.

So the dyke is younger than the layers it cuts across, while the fragment it holds is older than the dyke itself.

Such relations are read in the igneous dykes that cut across the ancient basement rocks of central Tanzania.

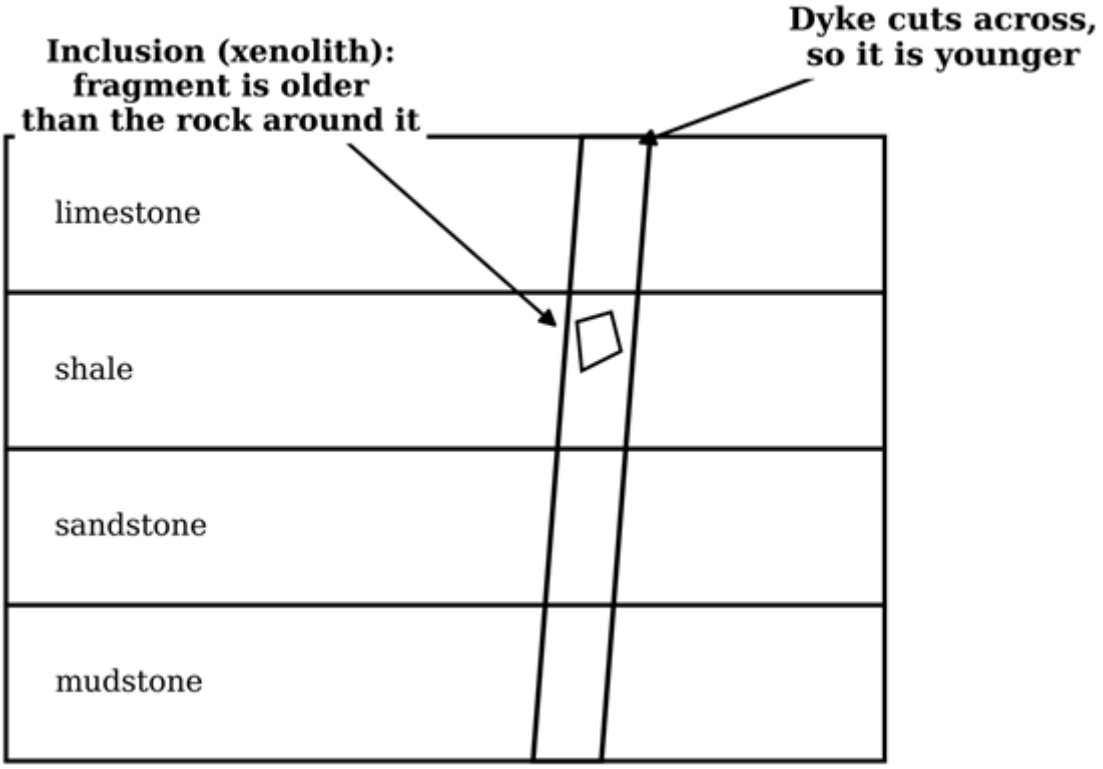


Figure 5.8: *Cross-cutting relationships and inclusions*

How to Draw It
Draw several horizontal sedimentary layers, then a vertical dyke cutting up through all of them. Label the dyke younger because it cuts across. Inside the dyke draw a small angular fragment and label it an inclusion or xenolith, older than the rock around it. Two arrows to these labels make the principles clear.

Question 29

Two distant outcrops, one near Tanga and one far inland, are found to carry the very same fossil shells. Explain how the principles of fossil succession and lithology let rocks of the same age be matched across wide distances.

Model Answer

Rocks lying far apart can be matched in age by the fossils they contain and by their physical character.

Fossil succession: life has evolved a known order of unique fossils, so a bed containing a particular fossil belongs to the time that fossil lived, and beds carrying the same fossil are of the same age wherever they are found.

Lithology: the physical character of a bed, its colour, grain and composition, lets it be identified and traced from place to place for the purpose of mapping and correlation.

So the shared fossil shells show the Tanga and the inland beds to be of one and the same age, even though they lie far apart.

Question 30

Between two sets of rock layers a geologist finds a buried, worn surface that stands for millions of lost years. Distinguish the three types of unconformity, and the break that each one represents.

Model Answer

An unconformity is a buried surface of erosion or non-deposition that marks a long gap in the rock record, and it is of three main types.

1) **Non-conformity:** sedimentary layers rest directly on an eroded surface of older igneous or metamorphic rock.
2) **Disconformity:** younger and older sedimentary layers lie parallel, but an eroded surface between them shows that some beds were removed or never laid down.
3) **Angular unconformity:** horizontal layers rest on older layers that were first tilted and eroded, so the two sets meet at an angle.

Each marks a break in the record, sometimes of hundreds of millions of years, during which rock was worn away rather than laid down.

An unconformity of this kind lies beneath the coastal sedimentary rocks of Tanzania, where they rest on the worn old basement.

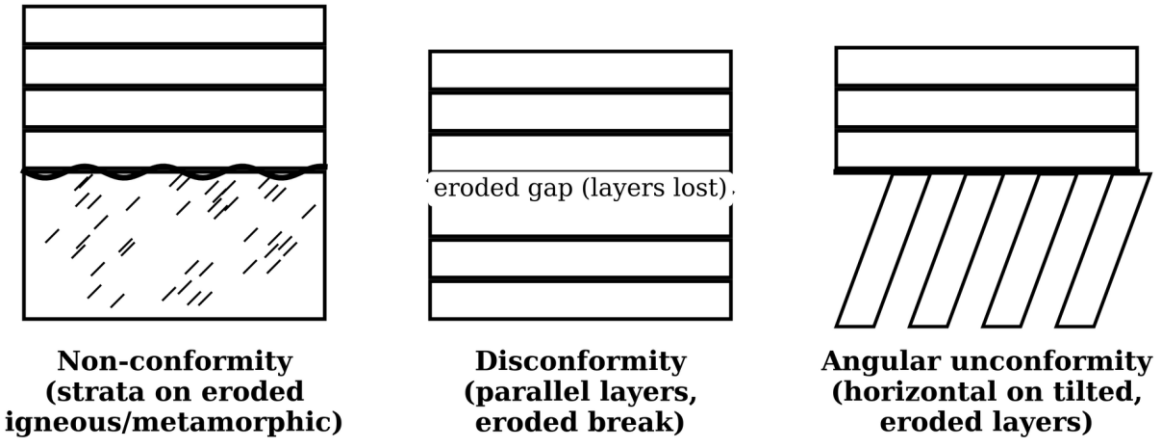


Figure 5.9: *The three types of unconformity*

How to Draw It
Draw three boxed panels. In the first, flat layers over a wavy line above an area of random crystals (non-conformity, strata on eroded igneous or metamorphic rock). In the second, flat layers, a wavy eroded line, then more flat layers (disconformity). In the third, flat layers resting on steeply tilted, truncated layers (angular unconformity). Label each panel and mark the eroded surface in each.

Question 31

A slab of dark shale holds the clear outline of a trilobite, a creature that vanished from the seas long ago. Explain how index fossils such as trilobites and graptolites fix the age of the rock that holds them.

Model Answer

Certain fossils, called index fossils, fix the age of the rock that contains them because they lived only during a known span of time.

An organism that flourished in a definite period and then died out marks any rock holding its remains as belonging to that period. Trilobites, the earliest abundant marine animals, lived about 500 to 600 million years ago, while graptolites lived later, about 350 to 450 million years ago. So a rock bearing trilobites is older than one bearing graptolites, and each fossil dates its rock to the creature's own span.

So the trilobite preserved in the shale stamps that rock as very ancient indeed, formed in the early seas.

Fossils like these date the old Palaeozoic rocks of Africa, far older than the young lavas of the Rift.

Question 32

Locked inside some Tanzanian rocks are atoms of uranium that have been turning steadily into lead ever since the rock first formed. Explain how radioactive dating measures the absolute age of a rock.

Model Answer

Radioactive dating measures the absolute age of a rock from the steady decay of a radioactive element it contains.

A radioactive element breaks down into a stable product at a fixed rate, measured by its half-life, the time taken for half of it to decay. Uranium-238 decays to lead-206 with a half-life of 4.5 billion years, so after one half-life half the uranium remains and the amount of lead has doubled. By comparing the amounts of the parent uranium and the daughter lead in the rock, its age is read off; the very long half-life of uranium makes it suited to dating the oldest rocks.

Applied to meteorites, made of the same material as the early Earth, this same method gives the age of the Earth itself as about 4.5 billion years.

The same method dates the ancient rocks of the Tanzania Craton among the oldest in all Africa.

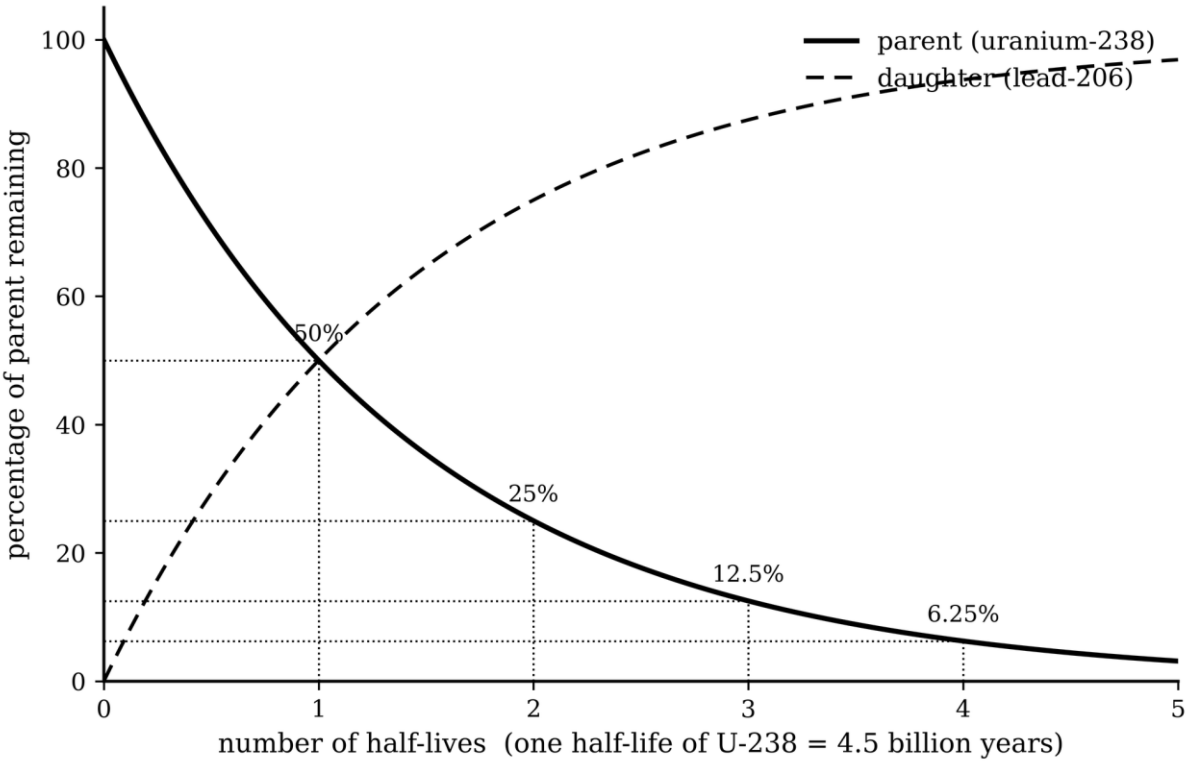


Figure 5.10: *Radioactive decay and half-life*

Question 33

An archaeologist at a recent coastal dig wants the age of a charred piece of ancient wood, not of the rock around it. Account for radiocarbon dating, and explain why it works only on young material.

Model Answer

Radiocarbon dating finds the age of once-living material from the decay of the carbon-14 it contains.

All living things take in radioactive carbon-14 from the air while they are alive, so its amount stays steady. At death the intake stops and the carbon-14 begins to decay at a known rate, with a half-life of 5,730 years. By measuring how much carbon-14 is left in the sample compared with a living thing, the time since death is found.

Because its half-life is short, the carbon-14 is almost all gone after a few tens of thousands of years, so the method serves only for young material, up to about 70,000 years, and not for ancient rock. So the coastal charcoal is well within its reach, while the rock around it is not.

So a charred sample from a coastal site such as Kilwa can be dated this way, while the rock beneath it cannot.

False Confidence Alert
Do not treat carbon-14 as a way to date rocks or the Earth itself. It dates only once-living material such as wood, charcoal, bone and shell, and only up to about 70,000 years; the great age of rocks is found instead from long-lived elements such as uranium.

Question 34

To make sense of an Earth over four billion years old, geologists divide its history into named blocks of time. Explain how the geological time scale is organised, and characterise its four great eras.

Model Answer

The geological time scale divides the Earth's history into ordered units of time, from the longest eons down through eras, periods and epochs.

1) **Pre-Cambrian:** from the Earth's formation to about 600 million years ago, the longest span by far, holding only the earliest and simplest life and few preserved rocks.
2) **Palaeozoic (ancient life):** about 600 to 230 million years ago, the age of invertebrates, when the first fish, land plants and amphibians appeared and much of the world's coal was formed.
3) **Mesozoic (middle life):** about 230 to 70 million years ago, the age of reptiles, dominated by the dinosaurs until their disappearance at its close.
4) **Cenozoic (recent life):** from about 70 million years ago to the present, the age of mammals, the era in which human beings at last appeared.

Each era is named for the life that dominated it, so the scale serves at once as a calendar of the Earth and as a record of the history of life.

Tanzania itself preserves rock from across this scale, from its Pre-Cambrian craton to the young Cenozoic lavas of the Rift.

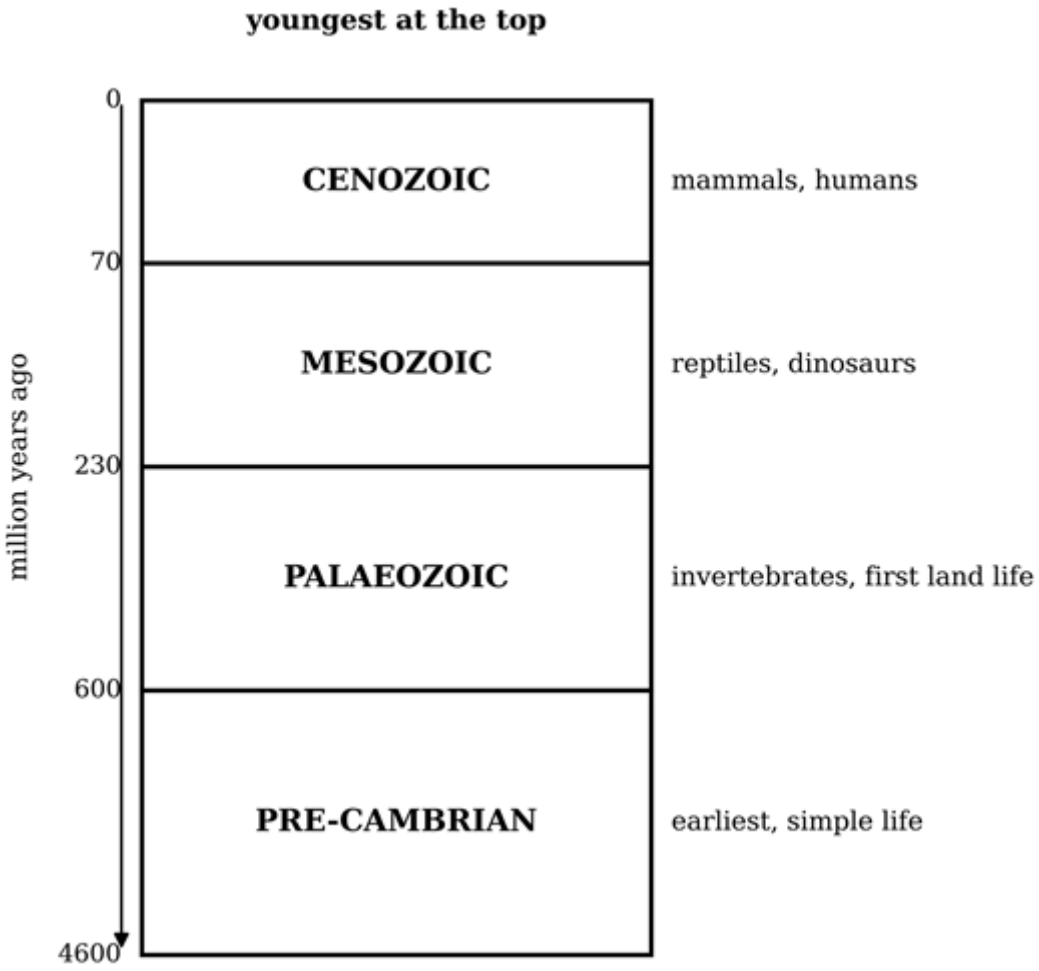


Figure 5.11: *The geological time scale*

How to Draw It
Draw a vertical column divided into four stacked bands. Put the youngest era, Cenozoic, at the top and the oldest, Pre-Cambrian, at the foot, with Mesozoic and Palaeozoic between. Beside each band write its dominant life (mammals and humans, reptiles, invertebrates, earliest simple life) and mark the boundary ages down the side (about 70, 230, 600 and 4600 million years).

Question 35

A farmer in the Southern Highlands digs through dark topsoil into broken rock and finally into solid bedrock, all in a single pit. Explain how soil formation begins with the weathering of parent rock into regolith.

Model Answer

Soil formation, or pedogenesis, begins with the weathering of the parent rock from which the soil's mineral matter is drawn.

The parent rock is the source of the rock fragments that make up the soil. It is broken down, both physically and chemically, by weathering into a loose mantle of broken, unconsolidated material called regolith, and from this regolith true soil then develops. The rock supplies all the mineral matter and plant nutrients of the soil except nitrogen, hydrogen and carbon, and the regolith may be added to by deposited alluvium, drift, loess or volcanic ash.

So the farmer's pit shows the whole passage in one face, from solid bedrock through broken regolith to the dark soil at the top.

This is just what a soil pit dug in the Southern Highlands reveals in a single face.

Question 36

Farmers know that the dark soils over old lava grow heavier crops than the pale soils over granite. Account for the greater fertility of soils formed on basic rock than on acidic rock, and for the poverty of soils on quartzite.

Model Answer

The fertility of a soil depends strongly on the chemistry of the parent rock from which it forms.

Basic, or mafic, rocks such as basalt are rich in calcium, magnesium and iron, so the soils they yield are more fertile. Acidic, or felsic, rocks such as granite are richer in quartz, so their soils carry more clay, take a reddish-brown colour and are less fertile. Quartzite, being almost pure quartz, weathers very little and yields hardly any soil, so soils on it are shallow and poor.

So the basalt-derived soils of the northern volcanic highlands are far richer than the granitic soils of the central plateau, which is why the one is densely farmed and the other only thinly.

Question 37

The southern slopes of Kilimanjaro and the hills of Rungwe carry some of the densest farming populations in Tanzania. Explain why the volcanic-ash soils of these areas are so fertile.

Model Answer

The volcanic-ash soils of Kilimanjaro and Rungwe are exceptionally fertile because fresh ash renews them again and again.

Volcanic ash falls as periodic deposits on the existing soil, and because the ash weathers quickly it constantly adds fresh, mineral-rich material to the surface. Where temperature and rainfall are favourable, as on these well-watered mountain slopes, this gives deep, fertile soils, known as andisols, that support the intensive growing of bananas, coffee and food crops.

So these renewed ash soils carry dense populations, as among the people of Kilimanjaro and Rungwe, who farm their slopes closely.

Question 38

Two farms on the very same rock, one in a cool wet highland and one in a hot dry plain, are found to carry quite different soils. Explain why soil is the product of five factors working together, and not of parent rock alone.

Model Answer

Soil is the joint product of five factors working together, so that one and the same rock can yield different soils in different settings.

1) **Parent rock material:** which supplies the mineral matter and influences the soil's fertility and texture.
2) **Climate:** which, through temperature and rainfall, drives the weathering and the leaching that shape the soil, and is the dominant factor.
3) **Topography (relief):** which, through the angle of slope, governs soil depth, drainage and erosion.
4) **Organisms (biota):** the plants, animals and humans that add humus and mix the soil.
5) **Time:** which allows the other factors to act and a full soil profile to develop.

So one rock gives two soils, because the cool wet highland and the hot dry plain differ in every other factor, and soil may be written as a function of parent rock, climate, topography, organisms and time together.

So one Tanzanian rock may carry a thin soil on a cool, wet highland and quite a different soil on a hot, dry plain.

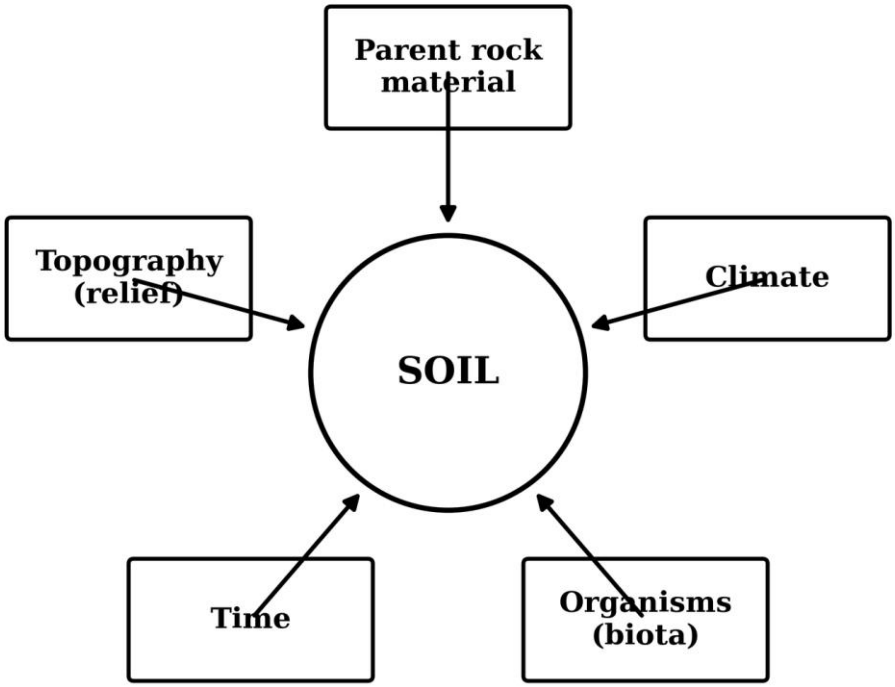


Figure 5.12: *The five factors of soil formation*

False Confidence Alert
Soil is not simply crushed parent rock. The rock supplies the minerals, but the soil that finally forms is shaped just as much by climate, relief, organisms and time, which is why one rock yields different soils in different places.

Question 39

Geographers single out one of the five soil factors as the leading one, the same factor that explains why tropical and temperate soils differ so sharply. Account for climate as the dominant factor in soil formation.

Model Answer

Climate is the dominant factor in soil formation because, through temperature and rainfall, it controls the very processes that build the soil.

Temperature and moisture set the rates of the chemical, physical and biological reactions that form soil, and they govern the balance between plant growth and decay that makes humus. Where rainfall exceeds evaporation, water passing down through the soil carries dissolved and fine material from the upper layers to the lower, the process called leaching, which strongly shapes the soil. Temperature also drives the breakdown of rock into ever finer particles.

So the hot, wet south of Tanzania develops deep, heavily leached soils, while the dry centre, lacking the same rainfall, does not, which is climate ruling the outcome.

Question 40

On a steep slope of the Uluguru mountains the soil is thin and stony, yet in the valley below it is deep and dark. Explain how topography controls the depth of soil.

Model Answer

Topography, or relief, controls the depth of soil chiefly through the angle of the slope.

On steep slopes: rapid runoff and erosion strip the loose material away, and little rainwater soaks in before running off, so the soils are thin, poorly developed and dry.

On gentle slopes and valley floors: material moved downhill collects, and water soaks in, so the soils are deep; but on very flat, poorly drained ground the soil may become waterlogged and form peat.

So the Uluguru hillside carries only thin, stony soil while its valley floor, gathering the material washed down from above, holds soil that is deep and dark.

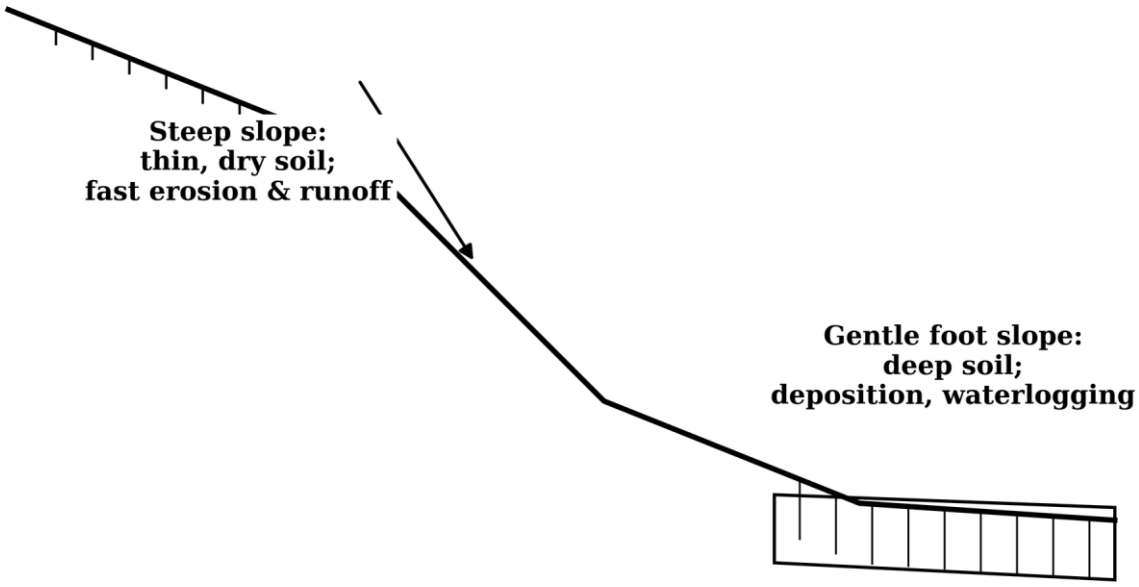


Figure 5.13: *Slope and the depth of soil*

How to Draw It
Draw a hill in profile, steep on one side and flattening to a valley floor. On the steep part draw only a very thin soil layer and add arrows for runoff and erosion. At the gentle foot draw a thick, deep soil layer and label it as the place of deposition and possible waterlogging. Label the steep slope thin and dry, the gentle foot deep.

Question 41

From the earthworms that burrow to the farmer who ploughs and manures, living things are at work in every Tanzanian field. Explain the part played by organisms and human activity in soil formation.

Model Answer

Living organisms, from plants and animals to humans, give the soil its life and help to build it.

Plants: their fallen leaves are decomposed by micro-organisms into humus, which binds the soil particles into crumbs and enriches the soil with nutrients.

Animals: burrowing creatures such as earthworms and termites mix the upper and lower layers and open the soil to air and water.

Humans: by manuring, liming, ploughing, draining and irrigating, and by controlling erosion, people deliberately improve the soil, though careless use can also degrade it.

So the manuring and careful ridging of farms in the Southern Highlands show human soil-building at work alongside that of the worms and the plants.

Question 42

A fresh road cut exposes raw rock that will not become farm soil within any human lifetime. Account for the role of time in soil formation, and how long a mature soil may take to form.

Model Answer

Time is the factor through which all the others act, since a soil develops its features only gradually.

A soil needs time to weather its parent rock, to gather humus and to develop the layered horizons of a mature profile, and the longer the soil-forming factors act, the more developed the profile becomes. The rate depends on climate and rock, being faster in warm, moist conditions and on soft sediment, and slower in cold, dry conditions and on hard bedrock.

It may take several hundred years to form even an inch of soil, and from about 3,000 to 12,000 years to build a depth of mature soil fit for farming, so the raw rock of the road cut will need many centuries before it carries true soil.

So the raw rock of a fresh road cut in the Tanzanian highlands will carry no true soil for many centuries yet.

Question 43

Within a single soil profile, material is steadily added at the top, washed downward through the layers, and changed in place. Explain the processes that form soil, grouping them as simple and complex.

Model Answer

Soil-forming processes can be grouped into the simple processes and the complex processes that combine them.

The four basic movements: addition of material from above or below, loss by erosion or solution, translocation or movement within the soil as eluviation washes material down and illuviation lays it down lower, and transformation or change in place, as when leaves rot into humus.

Simple processes: these include leaching, the removal of material in solution, eluviation and illuviation, the washing down and redeposition of material, humification, the rotting of matter into humus, and mineralisation.

Complex processes: these combine the simple ones into whole soil types, such as podsolisation in cool wet lands, laterisation in the humid tropics, calcification in dry lands, salinisation in deserts, and gleying in waterlogged ground.

So laterisation, which leaves the iron-rich red laterite soils, is the typical complex process of the humid tropical parts of Tanzania.

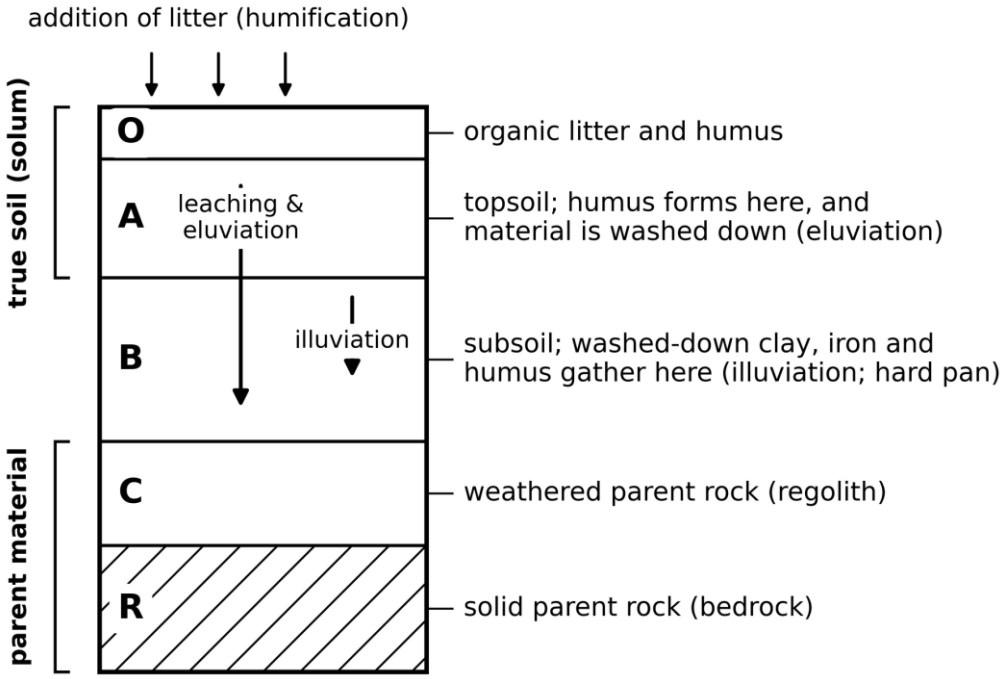


Figure 5.14: *The soil profile and its forming processes*

How to Draw It
Draw a soil profile as a vertical column of labelled horizons: O for surface litter and humus, A for topsoil, B for subsoil, C for weathered parent rock and R for solid bedrock at the base. Add downward arrows from A through to B labelled leaching and eluviation, and an arrow showing illuviation depositing material in the B horizon. Speckle the bedrock to show solid rock.

REAL QUESTIONS

Question 44

Tanzanite, a blue-violet gemstone found nowhere on Earth but the Mererani hills of Simanjiro, has carried Tanzania's name into the jewellery houses of the world. Discuss the contributions of rocks and their minerals to the economy of Tanzania, in eight points.

Model Answer

Rocks and the minerals they hold are a foundation of Tanzania's economy, earning income, building the country and employing its people.

Foreign exchange: the export of gemstones and metals, from the Tanzanite of Mererani to the gold of the Lake Victoria belt and diamonds of Mwadui, earns the hard currency that funds national development.

Employment: mining and quarrying give work to great numbers, from the gemstone diggers of Simanjiro to the quarry and cement workers near the towns.

Government revenue: royalties, levies and taxes on minerals and quarried stone swell the national budget and pay for public services.

Building and construction: rock supplies the cement from limestone, the crushed stone, the sand and the building blocks that raise the country's houses, roads, bridges and dams.

Industrial raw materials: limestone for cement, gypsum, kaolin, iron ore and the soda ash of Lake Natron feed local industry.

Energy: the coal of Kiwira and Ngaka and the gas formed in sedimentary basins provide fuel for power and industry.

Infrastructure and rural development: mining areas draw roads, electricity, water and new towns, carrying development into once-remote districts.

Trade, tourism and skills: the gemstone trade supports cutting, polishing and selling, and rare stones like Tanzanite draw buyers and visitors who spend in the wider economy.

So from the gem pits of Mererani to the cement works at Wazo Hill near Dar es Salaam, the nation's rocks underwrite both its wealth and its growth.

Question 45

In many Tanzanian districts the rush to dig sand, cut building stone and mine gemstones has scarred farmland and silted the rivers. Drawing on your own community, assess how a region can win wealth from its rocks without exhausting or ruining them.

Model Answer

Because rocks are a finite, non-renewable resource, their economic use must be weighed against the lasting damage that careless extraction can do.

Licensed, controlled extraction: quarrying and mining under permits and to agreed limits stops pits being dug recklessly across farmland and settlement.

Rehabilitation of worked ground: refilling and replanting exhausted pits and quarries heals the land, as is badly needed where sand mining along rivers such as the Ruvu has left raw gullies.

Adding value at home: cutting and polishing Tanzanite within the country, rather than exporting raw stone, keeps more wealth and wastes less rock.

Protecting soil and water: keeping sand and stone extraction back from riverbeds and steep slopes prevents the siltation and erosion that follow careless digging.

Sharing benefits and planning ahead: returning part of the mineral revenue to the community and planning extraction so that future generations also inherit the resource.

So a district can prosper from its rock, as Simanjiro does from Tanzanite, only by treating that rock as a finite inheritance to be used with care, not stripped in haste.

Question 46

On a geography field walk across your home area you pick up a hard, speckled, crystalline stone and must decide whether it is igneous, sedimentary or metamorphic. Explain how you would tell an igneous rock from the other two in the field.

Model Answer

An igneous rock can be told from sedimentary and metamorphic rock by a few clear field characteristics.

1) **Interlocking crystals, no layers:** igneous rock is built of interlocking crystals and shows no strata, unlike the plain bedding layers of sedimentary rock.
2) **No fossils:** it holds no fossils, since the heat of the magma destroyed any remains, whereas sedimentary rock often carries shells and plant traces.
3) **No foliation or banding:** it is hard and lacks the parallel bands that split a metamorphic rock such as slate or schist.
4) **A cooling texture:** it may be coarse like granite, fine or glassy like basalt and obsidian, or full of gas holes like pumice, all signs of cooled magma.

So the speckled, layer-free, crystalline stone in your hand, like the granite that litters the Dodoma plateau, is an igneous rock.

False Confidence Alert
Do not judge a rock by its colour alone, for a dark stone could be basalt (igneous), shale (sedimentary) or slate (metamorphic). Weigh texture, layering and fossils together, never a single feature.

Question 47

In a form five classroom a geography teacher states that sedimentary rocks are both an industrial raw material and a source of energy. Supporting the teacher in eight points, show how Tanzania's sedimentary rocks serve both industry and power.

Model Answer

Sedimentary rocks are at once an industrial raw material and a source of energy, as Tanzania's own deposits prove.

1) **Limestone for cement:** burned and ground at works such as Wazo Hill and Tanga, limestone makes the cement that builds the nation, and it also yields lime and neutralises acid.
2) **Clay and shale:** shaped and fired into the bricks, tiles and pottery of everyday construction.
3) **Sandstone and sand:** quarried for building stone, for glass-making and for concrete.
4) **Gypsum:** used in cement, in plaster and in wallboard.
5) **Salt and soda ash:** rock salt yields common salt, and the soda ash of Lake Natron feeds the chemical and glass industries.
6) **Iron-rich and phosphate rock:** supply raw material for iron and for fertiliser.
7) **Coal for power:** the carbonaceous coal of Kiwira and Ngaka is burned for electricity and industry.
8) **Oil and natural gas:** form in sedimentary basins, so that Tanzania's offshore gas at Songo-Songo and Mnazi Bay, sedimentary in origin, now generates power.

So from the cement of Wazo Hill to the gas of Songo-Songo, sedimentary rock both builds and powers the country, and the teacher is right.

Question 48

Mr Chapakazi tells his class that igneous and metamorphic rocks, though both hard and crystalline, have quite distinct characteristics. Explain the key differences by which his students could tell the two apart.

Model Answer

Igneous and metamorphic rocks differ in how they form, in their texture and in the features they show.

1) **Origin:** igneous rock forms by the cooling of molten magma, whereas metamorphic rock forms by the alteration of an existing rock in the solid state, without any melting.
2) **Layering:** many metamorphic rocks are foliated, showing parallel bands that split, as in slate and schist, while igneous rock shows no such banding.
3) **Texture:** igneous rock has interlocking crystals grown from a melt, while metamorphic rock has recrystallised or aligned minerals formed under heat and pressure.
4) **Parentage:** igneous rock is a primary rock straight from magma, while metamorphic rock is a made-over rock derived from an earlier igneous or sedimentary rock.
5) **Resistance:** metamorphic rock is often even harder and more resistant than the igneous rock, having been compressed and recrystallised.

So a banded, foliated slate is plainly metamorphic while a speckled, unlayered granite is igneous, the two lying side by side in the old basement rocks of the Usambara.

False Confidence Alert
It is a mistake to think that any hard, crystalline rock must be igneous. Metamorphic rock is just as hard and crystalline; what separates them is foliation and origin, not hardness.

Question 49

The Geological Survey of Tanzania sends a team to map an area and report where valuable minerals might lie. Analyse six criteria the team would use to identify mineral deposits.

Model Answer

A geologist identifies likely mineral deposits by reading the rocks, structures and surface signs of an area against what is known of how minerals occur.

1) **Host rock type:** since particular minerals occur in particular rocks, igneous and metamorphic rocks point to metals and gems (the Tanzanite of Mererani sits in metamorphic rock near intrusions), while sedimentary rocks point to coal, limestone, gypsum and salt.
2) **Geological structure:** faults, folds, dykes and veins channel the mineral-bearing fluids, so these structures are searched for the ores they may carry.
3) **Surface indications:** stained, rusty or altered rock and mineral veins laid bare by erosion betray ore lying beneath.
4) **Associated (pathfinder) minerals:** because one mineral often keeps company with another, the presence of an indicator mineral guides the search to the target.
5) **Rock age from the time scale:** knowing the age of the rocks shows which mineral-forming events they could have shared, and so narrows the ground worth testing.
6) **Geophysical and geochemical surveys:** magnetic, gravity and stream-sediment tests detect dense ores and the trace elements washed downstream from a hidden deposit.

So by reading rock type, structure and surface clues together, the Survey can mark where the gold of the Lake Victoria greenstone belt or the Tanzanite of Mererani is likely to lie.

False Confidence Alert
Minerals are not scattered at random through the ground. They follow particular host rocks and structures, so any search that ignores rock type and faulting is likely to miss them.

Question 50

A geologist dating Tanzania's rocks reaches constantly for the geological time scale, calling it the most useful tool of all. Examine the usefulness of the geological time scale.

Model Answer

The geological time scale is valued because it orders the whole history of the Earth and lets rocks and events be placed and compared in time.

1) **Dating and ordering rocks:** it gives each rock its place in time, so that rocks across the country can be matched and ranked from oldest to youngest.
2) **Understanding mountain building:** it records when the great mountain-building events, the Caledonian, Hercynian and Alpine, and the older African ones, occurred, helping explain when relief rose.
3) **Reading the history of life:** it ties the rocks to the fossils and life of each era, showing how plants and animals appeared and changed.

4) **Guiding the search for resources and hazards:** knowing the age of rocks helps predict where mineral deposits formed and where old, fault-prone rocks may still move.

5) **Correlation across regions:** it lets rocks of the same age be matched between distant areas and even between continents.

Yet the scale rests partly on estimation, so a careful geologist uses it together with the absolute dates that refine it, as when dating the ancient Tanzania Craton among the oldest rock in Africa.

Question 51

A farmer moving across Tanzania finds the soil changing with the rock beneath it, the climate around it and the plants upon it. Explain how parent rock, climate and living organisms each influence soil formation, giving three points for each.

Model Answer

Parent rock, climate and living organisms each shape the soil that forms, and together they make one soil differ from another.

Parent rock material:

1) **Mineral supply:** it provides the mineral matter of the soil, so basic rock like basalt gives a richer soil than acidic granite.

2) **Texture:** it sets the texture, so sandstone yields a sandy soil and shale a heavy clay soil.

3) **Depth:** it governs depth, since hard quartzite weathers slowly to a thin soil while soft rock weathers deep.

Climate:

1) **Weathering:** temperature and rainfall drive the weathering of rock, so the hot, wet south weathers rock fast and deep.

2) **Leaching:** heavy rain washes nutrients downward, leaving leached, acidic soils where rainfall is high.

3) **Humus balance:** warmth speeds the decay of plant matter while cold preserves it, so climate sets how much humus the soil holds.

Living organisms:

1) **Plants:** their fallen leaves rot into humus, which enriches the soil and binds it into crumbs.

2) **Animals:** earthworms and termites mix and aerate the soil and open it to air and water.

3) **Humans:** by manuring, ploughing, draining and irrigating, people build the soil, though careless use can also degrade it.

So the volcanic-ash soils of Rungwe owe their richness to all three at once, a fertile parent ash, a warm wet climate and a dense cover of plants.

HOT QUESTIONS

Question 52

From the gold of Geita to the Tanzanite of Mererani and the cement of Wazo Hill, every shilling Tanzania digs from the ground is sometimes called a gift of the rocks. Assess the view that the nation's mineral wealth is, in the end, a product of the rock-forming processes themselves.

Model Answer

The view is largely sound, since every mineral resource is made and concentrated by a rock-forming process, yet it must be weighed against the human effort that turns rock into wealth.

In its favour, minerals are produced by the very processes that make rocks. Cooling magma concentrates metals and gems, the Tanzanite of Mererani was formed by metamorphism beside intrusions, sedimentary processes laid down the coal of Kiwira and the gas offshore, and weathering gathered some ores. So without the rock cycle there would be no deposit to mine in the first place, and geology decides where wealth can be found.

Yet rock alone is not wealth, since it becomes valuable only through exploration, extraction, processing and trade. The Tanzanite of Mererani lay unknown and worthless for ages until it was found, mined and cut, so human skill and capital convert the geological gift into an economic resource.

So the rocks supply the raw possibility and fix where wealth can be won, but it is the marriage of geology with human effort that turns a mineral into money, which is the truer account.

Question 53

Two geologists argue over a slab of igneous rock: one reads its history from the size of its crystals, the other from its chemistry. Assess the view that an igneous rock's texture is a more reliable record of how it formed than its chemical composition.

Model Answer

The view holds only for the question of cooling history, since texture is the better record of how a rock cooled while chemistry is the better record of what it is made of.

For reading the cooling history, texture is decisive. Coarse phaneritic granite records slow, deep cooling; fine aphanitic basalt and glassy obsidian record fast surface cooling; a porphyritic rock records two stages of cooling. So if the question is how and where the rock solidified, the crystals answer it directly.

Yet chemistry tells what texture cannot, namely the family and source of the rock. Silica content sorts the rock into acidic, basic or ultrabasic and points to the magma it came from, so that a granite and a fine rhyolite, alike in chemistry but unlike in texture, are shown to share a parent melt.

So texture is the more reliable record of cooling history in particular, while chemistry reveals the nature of the magma, and the sound geologist reads both, as on the basic basalts of the northern volcanoes.

Question 54

An old geologist tells his students that an igneous rock is the mother rock of all the others. Examine this statement, weighing how far every sedimentary and metamorphic rock can be traced back to igneous rock.

Model Answer

The statement is largely true, since igneous rock was the first rock and the ultimate source of the material in the others, though the rock cycle complicates a strictly one-way descent.

In its favour, the early crust solidified from molten material as igneous rock, so it came first. The weathering of igneous rock then supplied the sediment for sedimentary rock, and heat and pressure on either made metamorphic rock, so all rock material traces back to an igneous beginning, and igneous rock still makes up most of the crust.

Yet the rock cycle is reversible and not strictly linear. A sedimentary rock may form from the debris of an older sedimentary or metamorphic rock with no fresh igneous parent between, and a metamorphic rock may come straight from a sedimentary one, so a rock's immediate parent is not always igneous.

So igneous rock is rightly the mother rock in the ultimate sense, as the ancient basement granites of Tanzania are ancestral to the rocks above them, even where any single rock's nearest parent is some other family.

False Confidence Alert
Do not read 'mother rock' as meaning every rock's immediate parent is igneous. In the rock cycle a sedimentary rock can come from another sedimentary rock, and a metamorphic rock straight from a sedimentary one; igneous rock is the ultimate ancestor, not always the nearest parent.

Question 55

Of the three rock families, only sedimentary rock carries both the fossils of past life and the coal, limestone and gas that industry needs. Assess why sedimentary rock, and not the others, preserves the record on which both geology and industry depend.

Model Answer

Sedimentary rock preserves the record because of how and where it forms, gently and in layers at the surface from the remains of life, unlike the hot or crushed origins of the other families.

Because sedimentary rock forms by quiet deposition at surface temperatures, the remains of plants and animals are buried and kept as fossils, whereas the heat of igneous rock and the heat and pressure of metamorphism destroy them. So only sedimentary rock holds the fossil record that dates and orders the rocks, and only its strata record the very order of events that relative dating reads.

The same surface, life-derived origin also concentrates the economic materials, since coal comes from buried plants, limestone from shells, oil and gas from organic matter, and gypsum and salt from evaporated water. These are the fuels and raw materials industry depends on.

So sedimentary rock is the archive of the Earth, which is why the world's fossils and the coal of Kiwira lie in sedimentary and never in igneous rock.

Question 56

Quartzite shrugs off the weather that crumbles softer rock, and the old metamorphic belts of Tanzania stand as rugged highlands. Assess the claim that metamorphic rocks are the hardest and most resistant of the three families, and what this means for the land.

Model Answer

The claim is broadly true, since metamorphism makes rock harder and more compact, yet resistance also depends on the particular rock and the climate, so it is not absolute.

In its favour, metamorphism recrystallises and compacts rock under heat and pressure, fusing the grains and closing the pores, so quartzite and gneiss become very hard and resist erosion strongly. This is why metamorphic belts often stand up as highlands and ridges, as the Usambara and Uluguru of the Eastern Arc do.

Yet not every metamorphic rock is equally resistant. Marble, though hard, dissolves in rainwater as limestone does, and slate splits along its foliation; meanwhile igneous rocks like granite are also highly resistant, and in the hot, wet tropics chemical weathering attacks even the hardest rock. So resistance is relative to the rock and the climate it faces.

So metamorphic rock is generally among the most resistant, which is why it holds up the Eastern Arc highlands, but the claim must be qualified by the kind of rock and the climate around it.

Question 57

A physical geography teacher tells the class that rock formation is an endless process that has neither beginning nor end. Assess this statement.

Model Answer

The statement is largely true, since the rock cycle has run without pause since the Earth formed and shows no sign of stopping, yet strictly it had a beginning and depends on engines that will not last forever.

In its favour, the three families change endlessly into one another, driven by the Earth's internal heat and the water cycle, and no rock is ever a final state, since even the hardest will in time weather, be buried, melt and form again. In every human and historical sense, therefore, the process is ceaseless.

Yet strictly the cycle did have a beginning, when the molten early Earth first solidified into igneous rock, and it runs only while the planet keeps its internal heat and its surface water; should these fail in the far future, the cycle would slow and halt.

So for all practical purposes rock formation is indeed endless and reversible, as the rocks of Tanzania from the ancient craton to the young Rift lavas show, even though it began with the first crust and must one day cease.

False Confidence Alert

Take 'endless' to mean ceaseless in practice, not literally without beginning. The cycle began when the first molten crust solidified, and it runs only while the Earth keeps its internal heat and its water.

Question 58

Imagine a world holding only one kind of rock. Assess the view that no single rock family could exist for long without the other two, so that the cycle, and not the rock, is the true unit of study.

Model Answer

The view is sound, since each family forms from and decays into the others, so that none could persist alone, and the cycle is therefore the proper unit of study.

Each family depends on the rest. Sedimentary rock needs the weathering of pre-existing rock for its sediment, metamorphic rock needs an igneous or sedimentary parent to alter, and igneous rock, in the full cycle, is renewed by the melting of buried metamorphic and sedimentary rock. Remove any one family and the others lose either a source or a destination.

A single rock, moreover, is only a stage, a passing form of material moving through the cycle, and its meaning lies in where it came from and where it is bound. So it is the study of the cycle that explains the rock, and not the study of one rock that explains the cycle.

So the three families are interdependent and the cycle is the true unit, which is why a grain of Rufiji sand is best read not as a fixed thing but as a single moment in an endless round.

Question 59

Now that radioactive clocks can date a rock in millions of years, some say the old stratigraphic laws are obsolete. Assess the view that absolute dating has made relative dating unnecessary.

Model Answer

The view is mistaken, since absolute and relative dating answer different questions and work best together, so neither makes the other obsolete.

Absolute dating has real strengths, for it gives the actual age in years through the decay of uranium or carbon, which relative methods cannot, and it fixes the boundaries of the time scale and dates the oldest rocks, such as the Tanzania Craton.

Yet relative dating is still indispensable, since it is quick, cheap and works in the field on any layered rock by superposition, cross-cutting, fossils and unconformities, even where no datable mineral is present. Absolute methods need suitable radioactive elements and costly laboratories, and carbon-14 reaches back only about seventy thousand years, so most field mapping still rests on relative order.

So absolute dating has refined and not replaced relative dating; it pins numbers to the order that the stratigraphic laws establish, and the working geologist in Tanzania uses the two together.

False Confidence Alert
A newer method is not automatically a replacement. Absolute dating needs suitable radioactive minerals and laboratories, and carbon-14 reaches back only about seventy thousand years, so relative dating still does most of the work in the field.

Question 60

It is often said that the geological time scale gives a clear picture of the geomorphological and biological history of the Earth. Examine this statement.

Model Answer

The statement is largely true, since the time scale records both the great earth movements and the succession of life, though the picture it gives is far clearer for recent ages than for the deep past.

For biological history, the eras are named for the life that dominated each, the Palaeozoic of invertebrates, the Mesozoic of reptiles and the Cenozoic of mammals, and the fossils in each record the appearance, spread and extinction of living things, so the scale traces the history of life.

For geomorphological history, the scale dates the great mountain-building events, the Caledonian, Hercynian and Alpine, and records glaciations, eruptions and changes of sea level, so it traces the shaping of the land as well.

Yet the record thins in the Pre-Cambrian, where few fossils survive and few rocks remain, so the early picture is much dimmer than the recent one, and the scale rests partly on estimation. So it gives a broadly clear picture of both histories, sharp for the last six hundred million years but faint for the vast age before.

Question 61

A soil scientist tells a farming community that the very soil they till was once solid rock. Substantiate the view that soils were once rocks, tracing the path from rock to soil.

Model Answer

The view is fully substantiated, since soil forms directly from the breakdown of rock, and the path from solid rock to fertile soil can be traced step by step.

First, the parent rock is broken down, both physically and chemically, by weathering into a loose mantle of fragments called regolith. Then plants colonise the regolith, and as they die their decay adds humus, which gives the young soil both life and fertility.

Next, water washes material down through the soil by leaching and eluviation and lays it down lower by illuviation, so that distinct layers develop, the dark O and A horizons over the B, above the C of weathered rock and the R of bedrock. Over centuries the five factors of parent rock, climate, relief, organisms and time mature this profile.

The proof stands in any soil pit, where solid bedrock passes upward through broken regolith into true soil, and in the volcanic-ash soils of Rungwe, which are simply weathered volcanic rock enriched by life. So the farmer's soil is indeed rock made over.

Question 62

On the same granite, the soils of a cool wet highland and a hot dry plain are utterly different, while on different rocks under one climate the soils may be alike. Assess whether parent rock or climate is the master control on the soil that finally forms.

Model Answer

Climate is usually the master control over the long run, since it can override the parent rock, yet parent rock dominates in the early stages and in harsh climates, so neither rules entirely alone.

The case for climate is strong, for the same rock yields different soils under different climates, since temperature and rainfall drive the weathering, leaching and humus formation that shape the soil. Over long periods climate so reworks the rock that soils on quite different parent rocks come to resemble one another, as the deep red laterites of the humid tropics do.

Yet parent rock dominates at the start, and wherever weathering is slow, as in cold or dry climates or on very hard rock like quartzite, since it fixes the texture, the fertility and the depth of the young soil, so that basalt gives a rich soil and granite a poor one even under one climate.

So climate is generally the master factor over the long run, as the contrast between tropical and temperate soils shows, but parent rock rules at the beginning and in extreme settings, and the truth is that the two govern the soil together.

False Confidence Alert
Do not force a single winner between parent rock and climate. Soil is a function of both, together with relief, organisms and time; which one appears to dominate depends on the stage of development and the setting.

Chapter 6

HYDROLOGY

BINDER QUESTIONS

Water is the one resource a country can neither manufacture nor do without, and Chapter 6 is the study of how it moves. Having traced in Chapter 5 how the rocks and soils of Tanzania were made, we now follow the water that runs over them, soaks into them and is stored beneath them. Hydrology and its central idea, the hydrological cycle, explain why the Pangani and the Rufiji keep flowing, why boreholes on the central plateau reach water at all, why Lake Victoria does not overflow while Lake Natron never runs fresh, and why a wetland such as the Kilombero floods and dries with the seasons. This is the final chapter of the Physical book, and it gathers the rain, the rivers, the groundwater, the lakes, the wetlands and the oceans into one working system.

The questions run in three tiers, best worked in order. BINDER is the core, explanation-first tier: it builds each idea from the ground up, from the meaning of hydrology to the movement of groundwater, and it carries the diagrams. REAL is the Tanzanian-application tier, where the science is set to work in real catchments, aquifers, lakes and wetlands. HOT is the higher-order tier of evaluation, where claims such as the one that the cycle has neither a beginning nor an end are weighed and judged. Each question stands on its own, like an examination item, and every model answer names a Tanzanian or African example so that a process is always tied to a real place.

Question 1

A water engineer drilling boreholes near Dodoma says she must first understand the whole behaviour of water before she can promise a village a reliable supply. Using her remark as a starting point, explain what hydrology is and what it covers.

Model Answer

Hydrology is the science that deals with the occurrence, distribution and circulation of water on the Earth, together with its physical and chemical properties and its interaction with the environment, including the activities of people.

The name is built from the Greek hydro, meaning water, and logos, meaning study, so at its root it is simply the study of water. In practice it is wider than that, because it follows water through every stage of its movement, as it falls as rain, runs over the land, soaks into the soil, is stored in rivers, lakes and rocks, and returns to the air by evaporation. It also asks how clean the water is and how living things and human actions change it. For the engineer near Dodoma this matters because a borehole succeeds only where she has read correctly how rainfall on the central plateau recharges the rock beneath, so the science of hydrology stands behind the practical promise of water.

Question 2

Rain that falls on the slopes of Kilimanjaro does not simply disappear, since some sinks in, some runs to the Pangani, some is stored and some returns to the sky. Account for the occurrence and distribution of water on the Earth using the ideas of input, process, storage and output.

Model Answer

Water on the Earth is best understood as a system with an input, a set of processes, storage and an output, all kept turning by the Sun.

Input as precipitation: the water entering the land arrives mainly as precipitation, such as the rain that feeds the Pangani on the southern slopes of Kilimanjaro.

Process of movement: the water then moves, running over the surface as runoff and soaking in by infiltration and percolation through the soil and rock.

Storage on and below the land: some water is held for a time on the land, in rivers, lakes, the soil and the rocks, as in Lake Jipe and the aquifers below the plateau.

Output to the atmosphere: water leaves the land by evaporation from open surfaces and by transpiration from plants, returning to the air as vapour.

Because the output of vapour feeds the next round of rainfall, the four parts form a closed loop, so the water that leaves Kilimanjaro today helps to make the rain that falls on it tomorrow.

Question 3

A research institute studying water in Tanzania advertises posts for a surface-water specialist, a groundwater specialist and a water-isotope specialist. Explain the branches of hydrology that these job titles reflect.

Model Answer

Hydrology has grown several branches, each dealing with water in a different part of its journey.

1) **Surface hydrology:** studies water on the surface, in streams, rivers, dams, lakes and wetlands, and measures how much is available, as on the Rufiji and Lake Victoria.
2) **Groundwater hydrology:** also called hydrogeology, studies water in aquifers and the pore spaces of rock below the surface, and guides its exploration and extraction, as in the boreholes of the central plateau.
3) **Isotope hydrology:** uses the isotopic signatures of water to date it and to trace its origin and age as it circulates.
4) **Hydrometeorology:** studies the transfer of water and energy between the land, the water bodies and the lower atmosphere, and supports flood and drought forecasting.
5) **Ecohydrology:** studies the hydrological processes in the soil and plant foliage and their effect on plant life and distribution.

Question 4

When the Julius Nyerere Hydropower plant on the Rufiji was planned, hydrologists were consulted long before the engineers arrived. Account for the importance of hydrology to a country like Tanzania.

Model Answer

Hydrology matters to Tanzania because almost every use of water depends on knowing how much there is, where it is and when it comes.

1) **Domestic water supply:** it guides the planning of town and village supplies, as when Dar es Salaam draws its water from the Ruvu.
2) **Agriculture and irrigation:** it schedules water for crops in schemes such as the Usangu and Mbarali rice fields.
3) **Hydropower:** it estimates river flow so that dams can be sized and run, as at the Julius Nyerere plant on the Rufiji and the Mtera dam.
4) **Flood and drought management:** it forecasts high and low flows, which matters in the seasonally flooded Kilombero Valley.
5) **Water quality and health:** it monitors pollution so that water stays safe to use.
6) **Planning and sustainability:** it helps share a limited resource fairly between farms, towns and power, now and in the future.

Question 5

Water that evaporates from the Indian Ocean off Tanga may fall weeks later as rain over the Usambara, run down to the sea and rise again. With the aid of a diagram, explain the hydrological cycle and the processes that keep it going.

Model Answer

The hydrological cycle is the continuous movement of water between the sea, the air, the land surface and the rocks beneath, driven by the Sun and by gravity, and it has neither a true beginning nor an end.

Heat from the Sun evaporates water from the ocean, the lakes and the wet ground, and plants add to it by transpiration, so water vapour rises into the air. As the vapour cools it condenses into clouds, and when the droplets grow heavy they fall as precipitation. Part of the rain is caught on leaves by interception, part soaks into the ground by infiltration and percolation to recharge the groundwater, and the rest runs over the surface as runoff into streams, rivers and lakes and back to the sea. From every wet surface evaporation begins the journey again, which is why the total amount of water stays the same while its distribution keeps changing. The rain over the Usambara that returns to the sea off Tanga is one full turn of this wheel.

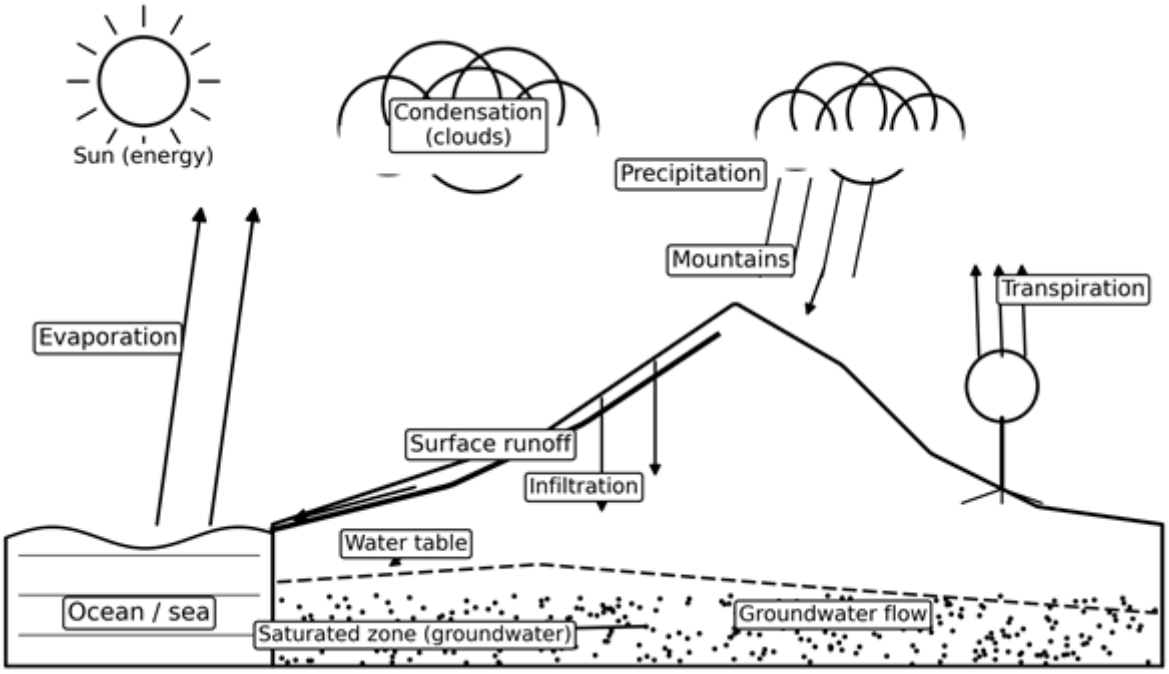


Figure 6.1: *The hydrological cycle*

Question 6

Without the Sun, a geography teacher tells her class, every river in Tanzania would eventually stand still. Explain why the Sun and gravity are together the driving force of the hydrological cycle.

Model Answer

The hydrological cycle is driven from above by the Sun and from within by gravity, and neither force alone would keep it turning.

The Sun supplies the energy that does the lifting, because its heat evaporates water from the ocean, from Lake Victoria and from wet ground, changing liquid into vapour that rises into the atmosphere. Gravity then supplies the force that brings the water back, since condensed droplets fall as rain and the fallen water runs downhill as runoff and sinks as infiltration on its way to the sea. So the Sun raises the water and gravity returns it, and because the teacher's rivers depend on rain that began as solar evaporation, the flow of the Pangani is ultimately powered by the Sun.

Question 7

On a single Tanzanian mountain, Kilimanjaro, water exists as ice at the summit, as streams on the slopes and as vapour in the air above. Explain the three physical states in which water occurs in the hydrological cycle.

Model Answer

Water occurs in the cycle in three physical states, namely solid, liquid and gas, and all three can be seen on one mountain.

1) **Solid:** water frozen as ice and snow in glaciers and ice sheets, as in the shrinking ice cap on the summit of Kilimanjaro.
2) **Liquid:** water flowing or standing in ponds, streams, rivers, lakes and oceans, as in the streams draining the mountain and in nearby Lake Chala.
3) **Gas:** water as invisible vapour in the atmosphere, as in the moisture rising from the forest belt on the slopes.

Because water can pass directly between these states, even the summit ice contributes to the cycle, since it can turn straight to vapour by sublimation.

Question 8

Asked to list the processes of the hydrological cycle, a student names only evaporation and rainfall and stops. Distinguish the major processes of the cycle from the complementary ones that go with them.

Model Answer

The hydrological cycle has five major processes, supported by several complementary ones, so the student's two are only a small part of the whole.

The five major processes are evaporation, precipitation, infiltration, runoff and groundwater flow, because these carry the bulk of the water between the air, the surface and the rocks. Working alongside them are the complementary processes, which are condensation that forms the clouds, interception that catches rain on leaves, transpiration that releases water from plants, depression and moisture storage that hold water for a time, and percolation that moves it down through the rock. A full account of rain falling over the Uluguru and draining to the Ruvu must therefore include both groups, since the complementary processes are exactly what link the major ones together.

False Confidence Alert
Do not treat the five major processes as the only ones. They are called major because they move the most water, not because the rest are optional; condensation and transpiration are essential links, and without them the cycle would break.

Question 9

On a hot afternoon the shallow water of Lake Natron seems to shrink before the eye as it turns to vapour. Explain the process of evaporation and the surfaces from which it takes place.

Model Answer

Evaporation is the process by which liquid water is changed into water vapour and removed from a wet surface, using heat energy from the Sun.

When radiant energy from the Sun strikes water it excites the water molecules until the fastest of them break free of the surface and rise into the air as vapour, a change also called vaporization. It happens not only from open water but from many surfaces, from rivers and lakes, from wet soil and rock, from pavements after rain, and from the wet leaves of plants. At Lake Natron the strong sunshine, the high temperature and the wide shallow surface together make evaporation rapid, which is why the lake concentrates into soda and shrinks as the dry season advances.

Question 10

Two open reservoirs of the same size, one in the hot lowlands near Dodoma and one in the cool Southern Highlands, lose water to the air at very different rates. Account for the factors that control the rate of evaporation.

Model Answer

The rate of evaporation rises or falls with several factors that together decide how fast a surface dries.

1) **Solar radiation:** the main source of the energy that vaporizes water, so the sunnier the site the faster the loss.
2) **Temperature:** warmer air and water give the molecules more energy to escape, raising evaporation.
3) **Humidity:** dry air absorbs vapour readily, while air already near saturation slows the loss.
4) **Wind speed:** turbulent wind sweeps the moist layer away and replaces it with drier air, so stronger wind speeds evaporation.
5) **Water characteristics:** salinity, depth and size matter, since salty and deep water evaporate more slowly than fresh and shallow water.
6) **Soil and surface characteristics:** the moisture, colour and exposure of the surface change how much it warms and dries.
7) **Vegetation cover:** plants shade the surface and alter how much of it is exposed to the Sun and wind.

The hot, dry and often windy reservoir near Dodoma therefore loses far more water than the cool, humid one in the Southern Highlands.

False Confidence Alert
Do not assume temperature alone decides evaporation. A hot but very humid day can evaporate less than a warm, dry and windy one, because saturated air can accept little more vapour however warm it is.

Question 11

Over a maize field near Iringa, water is lost to the air both from the damp soil and from the leaves of the plants, and the two losses cannot easily be separated. With the aid of a diagram, explain evapotranspiration and the process of transpiration within it.

Model Answer

Evapotranspiration is the combined loss of water to the atmosphere from two processes acting at once, namely evaporation from the land surface and transpiration from plants.

Evaporation removes water from open and wet surfaces such as the damp soil between the maize, while transpiration removes it through the plants themselves. In transpiration, water is drawn up from the soil through the roots and stem to tiny pores on the underside of the leaves, called stomata, where it escapes into the air as vapour. Because the two go on together and at the same time over a cropped field near Iringa, and there is no easy way to measure one apart from the other, geographers combine them into the single term evapotranspiration.

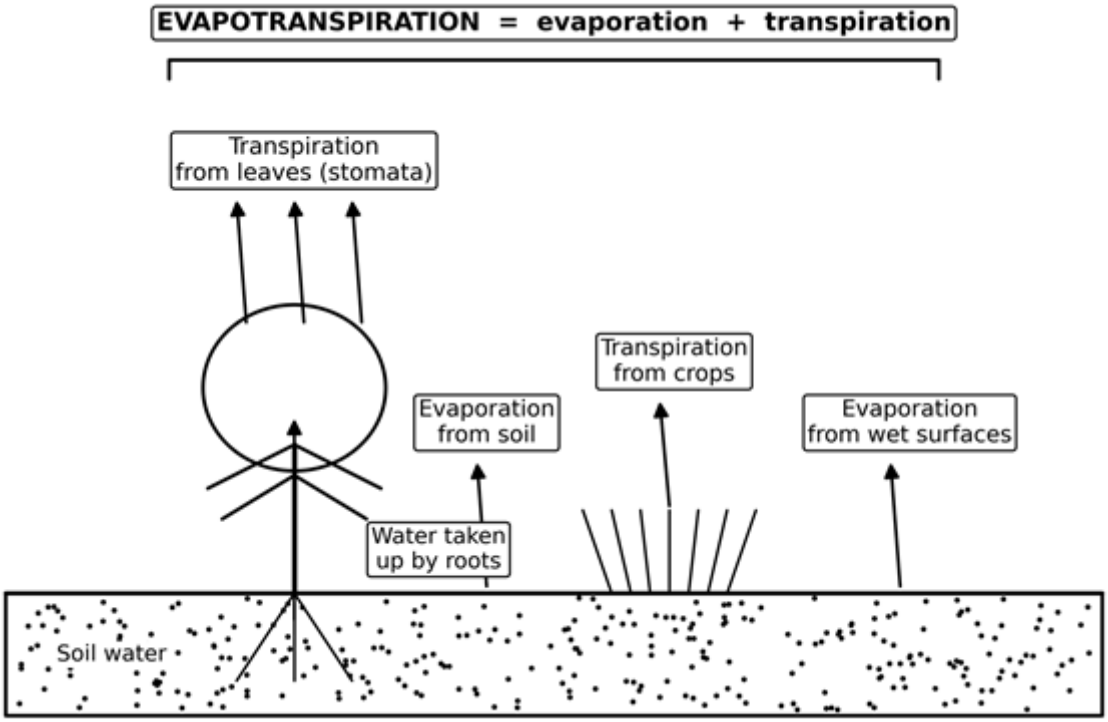


Figure 6.2: *The process of evapotranspiration*

How to Draw It
Draw a soil layer with a tree on one side and a grass or crop tuft on the other, both resting on the soil line. Show roots reaching down and one arrow rising up the stem for the water taken up by the roots. Put upward arrows from the leaves labelled transpiration, and separate upward arrows from the bare soil and wet surfaces labelled evaporation. Finally bracket the whole picture and label it evapotranspiration equals evaporation plus transpiration.

Question 12

An irrigation officer in the Usangu plains separates the water a crop would use if water were unlimited from the water it actually uses once the soil runs dry. Examine the difference between potential and actual evapotranspiration.

Model Answer

Potential and actual evapotranspiration differ in one decisive thing, which is whether water is freely available or not.

Potential evapotranspiration is the maximum amount that would be lost from the soil and the crop if water were supplied without limit under the prevailing weather, so it is set only by the demand of the atmosphere. Actual evapotranspiration is the amount that really takes place under field conditions, when the supply of soil water may fall short, the stomata partly close, and less water is lost. In the Usangu plains during a good wet season the two are almost equal, but as the dry season advances and the soil dries, the actual loss drops well below the potential, and that widening gap is exactly what the irrigation officer must make up with water.

False Confidence Alert
Do not read potential evapotranspiration as the water a crop really loses. It is the demand set by the weather, an upper limit; the actual loss is usually smaller because the soil cannot always meet that demand.

Question 13

Two rice schemes in the Kilombero Valley, one flood-irrigated and one under drip lines and mulch, return very different amounts of water to the air. Account for the factors that control the rate of evapotranspiration.

Model Answer

Evapotranspiration is controlled by the weather, by the plants and by how the land is managed.

1) **Air temperature:** warm, sunny weather raises the loss, while cool, cloudy weather lowers it.
2) **Humidity:** the humid air of the valley sits close to saturation, which reduces the demand for water.
3) **Wind speed:** turbulent wind sweeps the saturated air off the canopy and replaces it with drier air, raising the loss.
4) **Vegetation characteristics:** the crop type, the rooting depth, the leaf area, the number of stomata and the stage of growth all change how much water the plants release.
5) **Land management:** the method of irrigation matters most here, since flood irrigation loses much, sprinkler less and drip least, while mulching lowers the loss and heavy fertiliser raises it by making the plants more vigorous.

For this reason the flood-irrigated scheme in the Kilombero Valley returns far more water to the air than the mulched, drip-fed one beside it.

Question 14

On a clear night in the Southern Highlands the grass is dry at dusk but soaked with dew by dawn, although no rain has fallen. Explain the process of condensation and the meaning of dew point.

Model Answer

Condensation is the process by which water vapour in the air changes back into liquid water after it has been cooled to and below its dew point.

It takes place when three conditions are met, namely that there is water vapour in the air, that there are tiny hygroscopic particles such as dust or salt on which the vapour can gather, and that the air is cooled. As air cools its capacity to hold vapour falls, and the dew point is the temperature at which the air becomes saturated, so that any further cooling forces the vapour to condense into liquid. On a clear night in the Southern Highlands the ground loses heat rapidly, the air just above it cools past its dew point, and the vapour condenses onto the cold grass as the dew found at dawn.

Question 15

Condensation can be brought about in several ways, from the still air of a calm night to the moist wind forced up the side of Kilimanjaro. Explain the main ways in which air is cooled so that condensation takes place.

Model Answer

Air is cooled to condensation in several ways, all of which lower its temperature to the dew point.

1) **Radiation cooling:** the ground loses heat at night and chills the air resting on it, forming dew, fog or frost.
2) **Advection cooling:** warm moist air is cooled as it moves horizontally over a cooler land or sea surface.
3) **Orographic uplift:** moist air is forced to rise over a mountain barrier such as Kilimanjaro, cooling as it climbs.
4) **Convective or adiabatic cooling:** air heated by day rises in thermals and cools as the pressure on it falls with height.
5) **Frontal cooling:** a warm air mass meets a cold one and is forced to rise over it, cooling as it goes.

Question 16

The single process of condensation shows itself as the dew on a Mufindi lawn, the frost on a cold highland morning, the fog in a valley and the clouds overhead. Explain the forms in which condensation appears.

Model Answer

Condensation appears in four main forms, depending on where it happens and how cold the air becomes.

1) **Dew:** droplets of water that form on cool surfaces at night when the vapour condenses, as on the grass of a Mufindi lawn at dawn.
2) **Frost:** small white ice crystals that form when condensation takes place below freezing point on a cold highland morning.
3) **Fog and mist:** water droplets suspended in the air at or near the ground, which reduce visibility.
4) **Clouds:** water droplets condensed high in the atmosphere around tiny nuclei, from which precipitation may fall.

Question 17

A driver on the Mufindi escarpment meets thick fog where visibility drops below a kilometre, while lower down only a thin mist hangs in the air. Classify the main types of fog and distinguish fog from mist.

Model Answer

Fog is a cloud of water droplets lying at the ground, and it is grouped by the way it forms.

1) **Radiation fog:** forms at night when the ground cools below the dew point and chills the air above it.
2) **Advection fog:** forms when warm moist air is cooled as it drifts over a cold land or sea surface.
3) **Steam or sea fog:** forms when cold air blows over much warmer water, which appears to steam.
4) **Frontal or precipitation fog:** forms where two air masses of contrasting temperature and humidity meet.
5) **Hill fog:** is simply cloud lying against high ground, as on the Mufindi escarpment.

Fog and mist are the same suspension of droplets, and they are told apart only by visibility, which is below one kilometre in fog and between one and two kilometres in mist.

False Confidence Alert
Do not treat fog and mist as different things. They are the same cloud of water droplets at ground level; the names mark only how far you can see, fog below one kilometre and mist between one and two.

Question 18

Precipitation reaches the ground as the fine drizzle of the coast, the heavy rain of the Lake Victoria basin, the hail of the highlands and even the snow on the summit of Kilimanjaro. Explain the forms precipitation takes and how rain itself is formed.

Model Answer

Precipitation is water that falls from clouds to the ground, and it takes several forms set by the temperature in the cloud and at the surface.

1) **Drizzle:** very fine droplets that fall from shallow layer cloud.
2) **Rain:** liquid drops larger than half a millimetre, the common form in Tanzania.
3) **Hail:** pellets of ice formed when drops are carried up to great height and frozen.
4) **Snow:** ice crystals formed when vapour freezes and unites into flakes, as on the summit of Kilimanjaro.
5) **Sleet:** a mixture of rain and partly melted snow.

Rain itself forms when vapour condenses around tiny nuclei of dust and salt into droplets, which then collide and coalesce into drops heavy enough to overcome the rising air and fall, as in the downpours over the Lake Victoria basin.

Question 19

On many afternoons over the Lake Victoria basin the morning is clear, towering clouds build by midday, and a violent thunderstorm breaks by evening. With the aid of a diagram, explain how convectional rainfall is formed.

Model Answer

Convectional rainfall forms where strong surface heating lifts warm moist air, which cools and condenses into tall clouds that give heavy, thundery rain.

By day the Sun heats the ground strongly, and the ground heats the air resting on it. This warm moist air becomes less dense and rises in powerful currents, expanding and cooling as it climbs until it reaches its dew point and condenses into towering cumulonimbus clouds. The uplift goes on until the drops are too heavy to be held, and they fall as a sudden, heavy downpour, often with thunder and lightning. Around the Lake Victoria basin the constant high temperatures and abundant moisture make this the usual afternoon pattern.

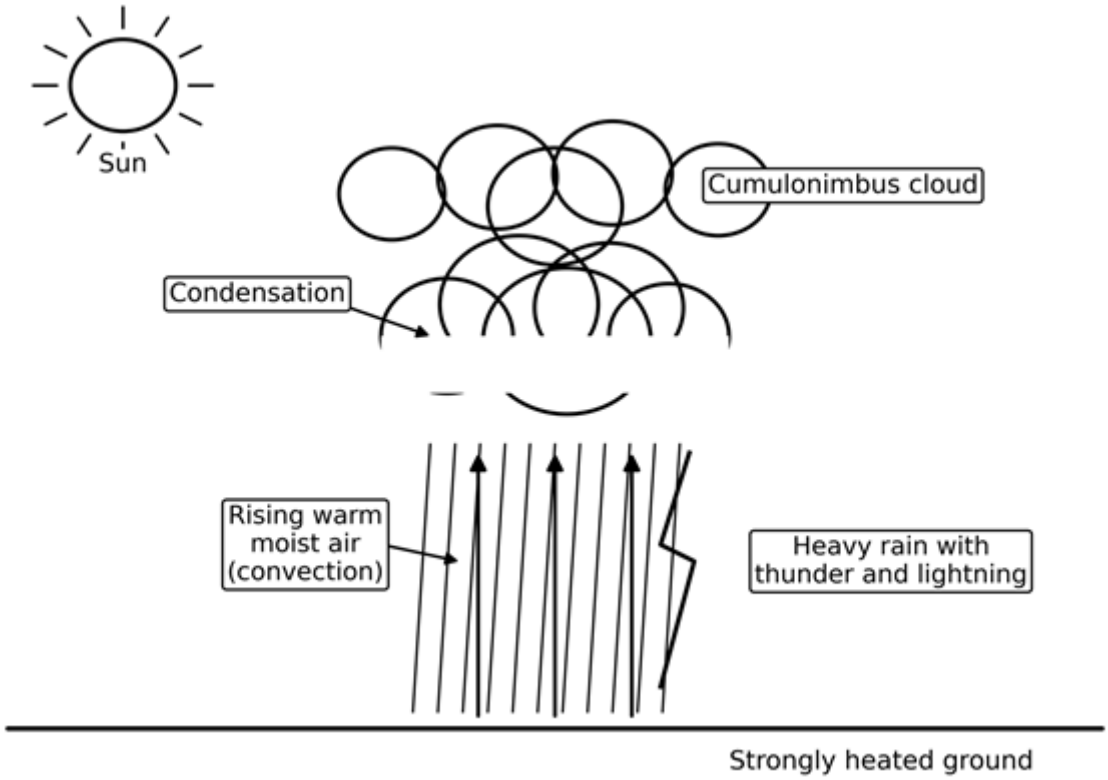


Figure 6.3: *Convectional rainfall*

How to Draw It
Draw a flat, strongly heated ground with the Sun above it. Put upward arrows rising from the ground for convection, and a tall cumulonimbus cloud with a spreading anvil top above them. Show heavy vertical rain from the base of the cloud, add a lightning streak, and label the heated ground, the rising warm moist air, the condensation, the cloud and the heavy rain.

Question 20

The southern slopes of Kilimanjaro that face the moist wind are green and well watered, while the land in the mountain's shelter to the north is dry. With the aid of a diagram, explain how orographic rainfall produces this contrast.

Model Answer

Orographic or relief rainfall forms when a mountain forces moist air to rise, so the windward side is wet while the sheltered leeward side lies in a dry rain shadow.

When a moist wind from the sea meets a mountain barrier it is forced to rise up the windward slope. As it rises it expands and cools to its dew point, condenses into cloud, and drops its moisture as rain on that side. Having lost much of its water, the air then descends the far slope, where it warms and dries, so the leeward side receives little rain and forms a rain shadow. On Kilimanjaro the moist southern slopes are green and heavily farmed, while the sheltered country to the north is markedly drier.

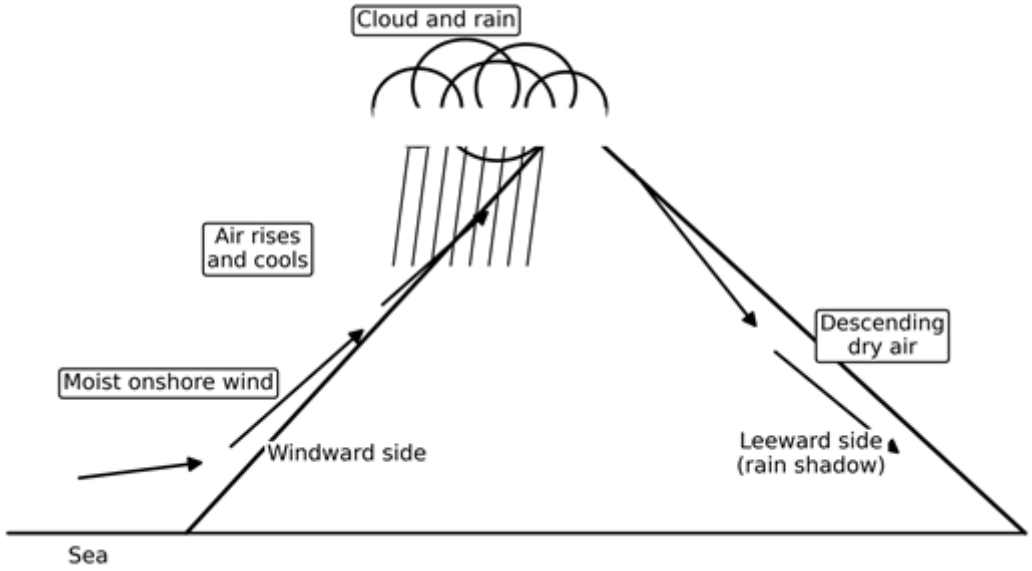


Figure 6.4: *Orographic (relief) rainfall*

How to Draw It
Draw a mountain with the sea on the windward side. Use arrows to carry a moist wind up the windward slope, place a cloud with rain near the top of that slope, and label the windward side. On the far slope draw arrows for descending dry air and label the leeward side as the rain shadow.

False Confidence Alert
Do not read the rain shadow as a place with no rain at all. The leeward side simply gets much less, because the air has already shed its moisture on the windward slope and is now warming and drying as it descends.

Question 21

Where a warm, moist air mass meets a cold, dense one, the lighter warm air is forced to climb over the cold wedge and rain falls along the boundary between them. With the aid of a diagram, explain how cyclonic rainfall is formed.

Model Answer

Cyclonic or frontal rainfall forms when two air masses of different temperature meet, and the warm, lighter air is forced to rise over the cold, denser air along a front.

Where the masses meet, the warm moist air cannot push the cold dense air aside, so it is forced to rise up over it along the sloping boundary called a front. As the warm air rises it cools to its dew point and condenses into clouds, which give steady rain along the line of the front, usually lighter than convectional rain but lasting far longer. This rainfall belongs mainly to the temperate latitudes, although the same lifting along the Inter-Tropical Convergence Zone brings much of the converging rain that crosses Tanzania.

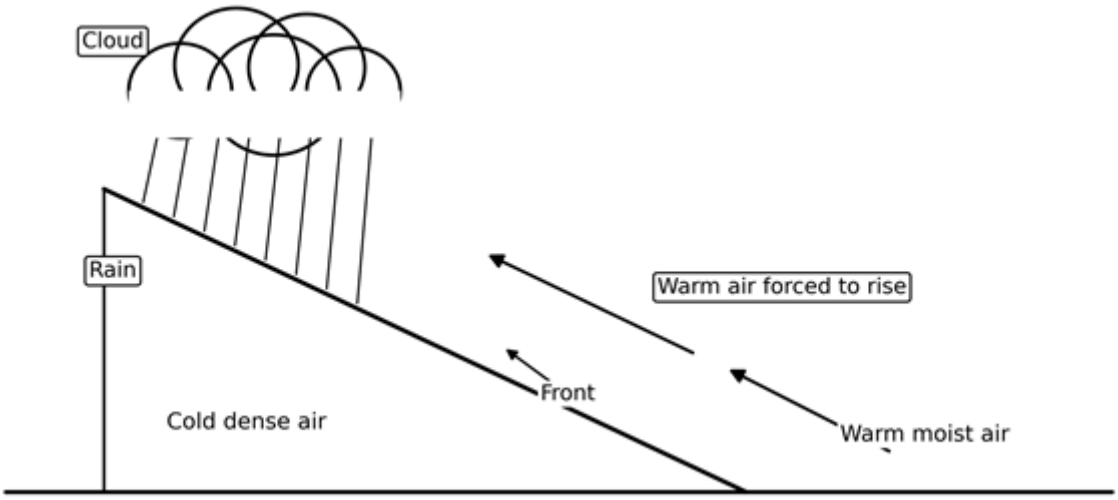


Figure 6.5: *Cyclonic (frontal) rainfall*

How to Draw It
Draw a low wedge of cold dense air with its thin edge pointing toward the warm air, and label it. Draw the sloping boundary as the front. Use arrows to show the warm moist air rising up over the wedge, place a cloud at the top of the slope, and show rain falling onto the wedge along the front.

Question 22

In a patch of miombo woodland near Morogoro much of a shower never reaches the soil, because it is caught on the leaves, drips from them or runs down the trunks. With the aid of a diagram, explain interception and its three components.

Model Answer

Interception is the catching and storing of precipitation by vegetation, so that part of the rain never reaches the ground directly, and it has three components.

1) **Interception loss:** the water held on the leaves and branches that later evaporates back into the air.
2) **Throughfall:** the water that drips from the leaves, twigs and needles down to the ground.
3) **Stemflow:** the water that runs down the twigs, branches and trunk to the base of the plant.

In the dense miombo canopy near Morogoro a large share of a light shower is held and lost again by evaporation, so only the throughfall and the stemflow reach the soil.

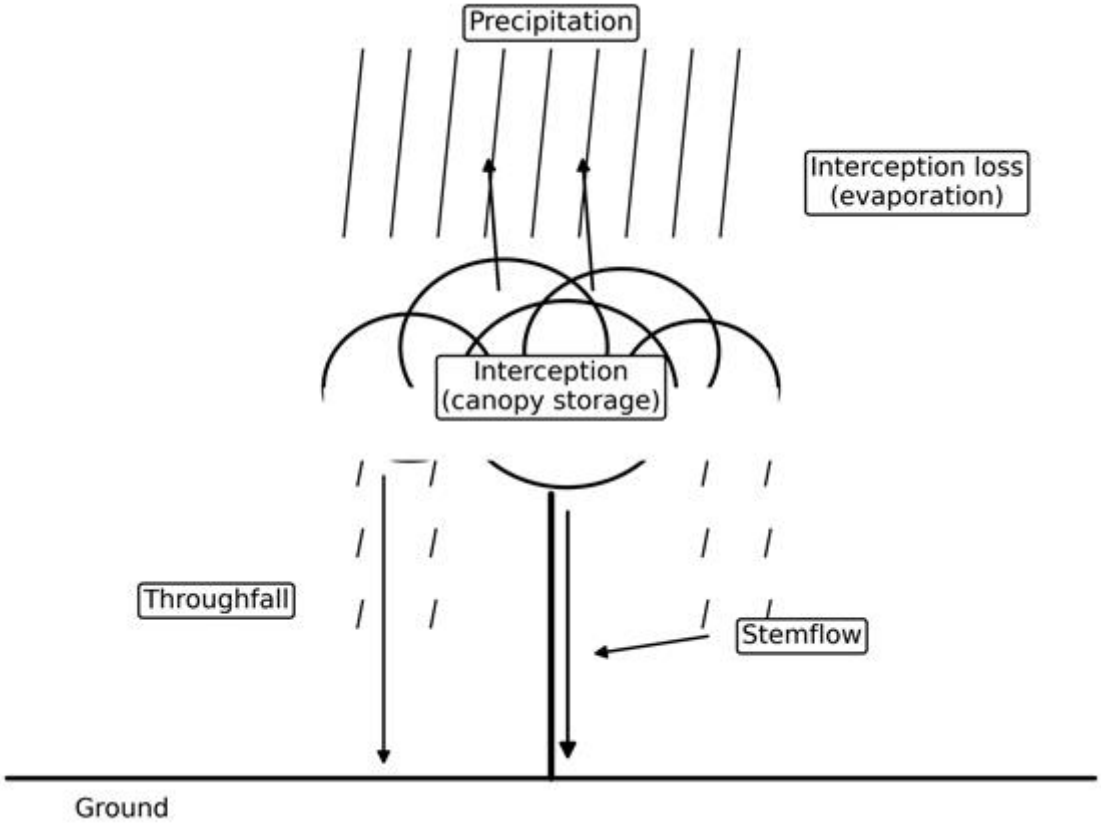


Figure 6.6: *The interception process*

How to Draw It
Draw a tree on the ground with rain falling onto its canopy. Show one or two arrows rising from the canopy for interception loss by evaporation, drops falling from the canopy for throughfall, and an arrow running down the trunk for stemflow, and label each of the three.

Question 23

A bare cassava plot and a dense stand of mature trees beside it intercept very different amounts of the same shower. Account for the factors that control how much precipitation is intercepted.

Model Answer

The amount of precipitation intercepted depends on the rain, the plants and the wind.

1) **Amount of precipitation:** a light shower is largely intercepted, while a long, heavy fall soon overwhelms the canopy and reaches the ground.
2) **Type of vegetation:** dense, tall and mature plants intercept far more than low or sparse ones, and needle-leaved trees more than broadleaves.
3) **Wind velocity:** strong wind shakes the leaves and speeds evaporation, changing how much water the canopy can hold.
4) **Precipitation characteristics:** the duration, intensity and form of the rain matter, since gentle drizzle is held far more than a beating downpour.

So a dense stand of mature trees on the Uluguru holds much of the shower, while a bare cassava plot on the coastal lowland near Mtwara lets nearly all of it strike the soil.

Question 24

When the first rain of the season falls on dry ground near Singida it soaks in at once, but as the storm goes on the same ground takes the water in more and more slowly. With the aid of a diagram, explain infiltration and distinguish the infiltration rate from the infiltration capacity.

Model Answer

Infiltration is the process by which water on the surface enters the soil, and it is described by the infiltration rate and limited by the infiltration capacity.

The infiltration rate is the speed at which water actually enters the soil at a given moment, while the infiltration capacity is the maximum rate at which a particular soil can absorb water under given conditions. Within the soil the water moves by transmission, flowing steadily down through the large connected pores, and by diffusion, spreading from pore to pore. On the dry ground near Singida the capacity is high at first, so the early rain soaks straight in, but as the soil fills the rate falls toward the capacity, and water begins to pond and run off.

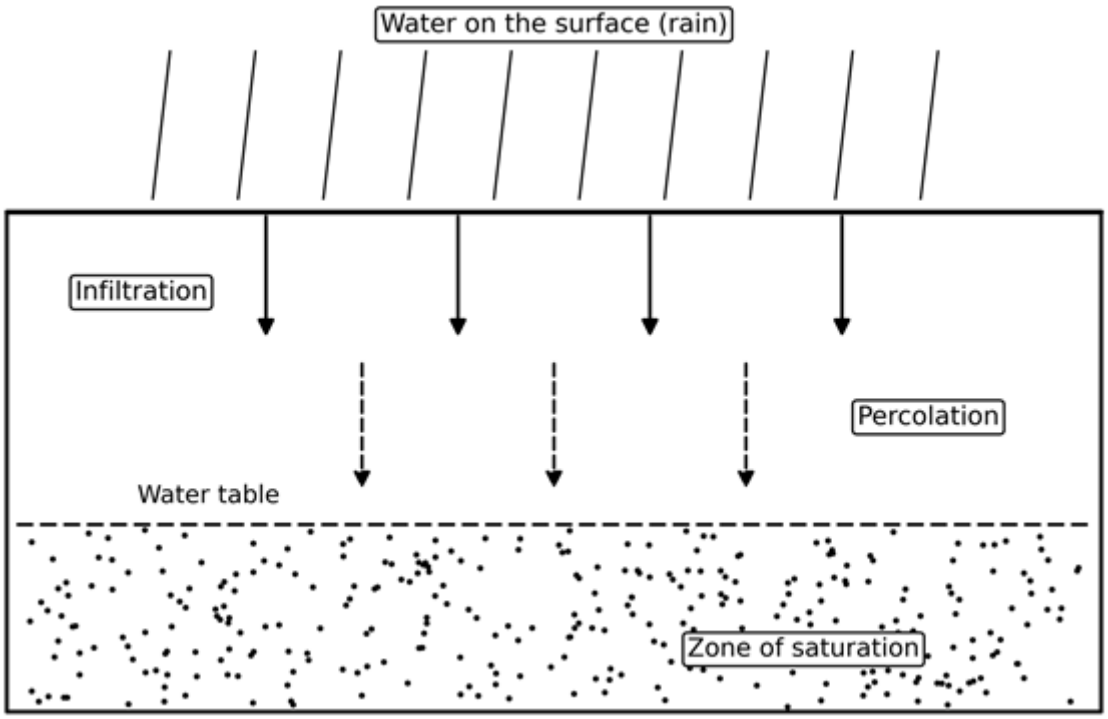


Figure 6.7: *The infiltration process*

How to Draw It
Draw a block of soil with water lying on the surface. Use short downward arrows at the surface for infiltration and longer dashed arrows below for percolation. Add a dashed water table near the base with a stippled saturated zone beneath it, and label the surface water, infiltration, percolation, water table and zone of saturation.

False Confidence Alert
Do not confuse the infiltration rate with the infiltration capacity. The capacity is the most a soil can ever take in; the rate is what is actually soaking in at the time, and it falls toward the capacity as the soil wets up.

Question 25

Rain soaks readily into the sandy, root-bound soil of a wooded slope but runs off the bare, trampled ground of a cattle track beside it. Account for the factors that control the rate of infiltration.

Model Answer

Infiltration is controlled by the rain, the soil, and the way the land is used and covered.

1) **Precipitation:** the form, amount and duration of the rain, since gentle rain on dry soil soaks in while a brief downpour runs off.
2) **Soil characteristics:** the porosity, texture and moisture of the soil, so that sandy soils with large pores take water far faster than clays.
3) **Soil compaction:** trampling by cattle and traffic seals the surface pores and lowers infiltration.
4) **Organic material:** litter and humus open the soil and raise its capacity to absorb water.
5) **Land cover and management:** vegetation and roots open the soil and slow the water, while tarmac, roofs and heavy tillage reduce infiltration.

So a wooded slope in the Usambara drinks in the rain through its open, root-bound soil, while a compacted cattle track on the Maasai steppe sheds it.

Question 26

An agronomist comparing the sandy soils of the coast with the heavy clays of a floodplain finds water sinking many times faster into the sand. Account for the way the infiltration rate changes with soil type.

Model Answer

Infiltration rate depends strongly on soil texture, because the size of the pores between the particles decides how fast water can move in.

1) **Sand:** very high infiltration, since its large pores let water pass freely.
2) **Sandy loam:** high infiltration.
3) **Loam:** moderate infiltration.
4) **Clay loam:** low infiltration.
5) **Clay:** very low infiltration, since its tiny pores hold the water back.

So water sinks quickly into the sandy soils of the coast but slowly into the heavy clays of a floodplain such as the Kilombero.

False Confidence Alert
Do not assume clay always infiltrates slowly. When a clay soil dries it cracks, and those cracks act as open channels that let water rush in quickly, until the clay swells and seals them again.

Question 27

Water that has soaked into the ground on the Makonde Plateau does not stop at the surface soil, but works its way down through the rock until it reaches the saturated zone. Explain the process of percolation and how it links infiltration to the groundwater.

Model Answer

Percolation is the downward movement of water through the soil and rock under gravity, after it has infiltrated the surface, until it reaches the water table.

Once water has entered the soil by infiltration, gravity draws it on downward through the pores of porous rocks such as sandstone and the joints of pervious rocks such as jointed limestone. It passes through the unsaturated zone, where some is held for plants, and continues until it reaches the zone of saturation, recharging the groundwater. On the Makonde Plateau this slow percolation through the rock is what keeps the deep water table supplied, so that the wells and springs go on flowing into the dry season.

Question 28

Not all the rain that falls on a catchment near Babati reaches its streams, because much is lost to the air and the soil before any water flows. Explain what runoff is and the initial losses that come before it.

Model Answer

Runoff is the portion of precipitation that flows over the land into streams, rivers, lakes and the sea after the initial losses have been satisfied.

When rain reaches the ground it does not all run away. Part is caught on leaves by interception, part is held in hollows as depression storage, part evaporates back into the air, and part soaks in by infiltration. Only once these initial losses are met, and the rain keeps falling faster than the soil can absorb it, does the surplus water begin to flow overland as runoff. In a catchment near Babati a light shower may be lost entirely to these stores, so that no runoff reaches the streams, while a heavy storm fills them quickly.

Question 29

Water reaches a stream near Mbeya by three different paths: straight over the surface, sideways through the topsoil, and slowly through the rock beneath. With the aid of a diagram, explain the three types of runoff.

Model Answer

Runoff reaches a stream by three paths, namely surface runoff, sub-surface runoff and baseflow, which differ in depth and in speed.

1) **Surface runoff:** also called overland flow, the water that travels over the ground surface and reaches the stream quickly.
2) **Sub-surface runoff:** also called interflow or throughflow, the water that moves sideways through the upper soil before joining the stream.
3) **Baseflow:** the delayed water that infiltrates and percolates to the water table and seeps slowly to the stream, keeping it flowing in the dry season.

Near Mbeya the surface runoff gives the quick flood after a storm, while the baseflow is what keeps the stream alive long after the rain has stopped.

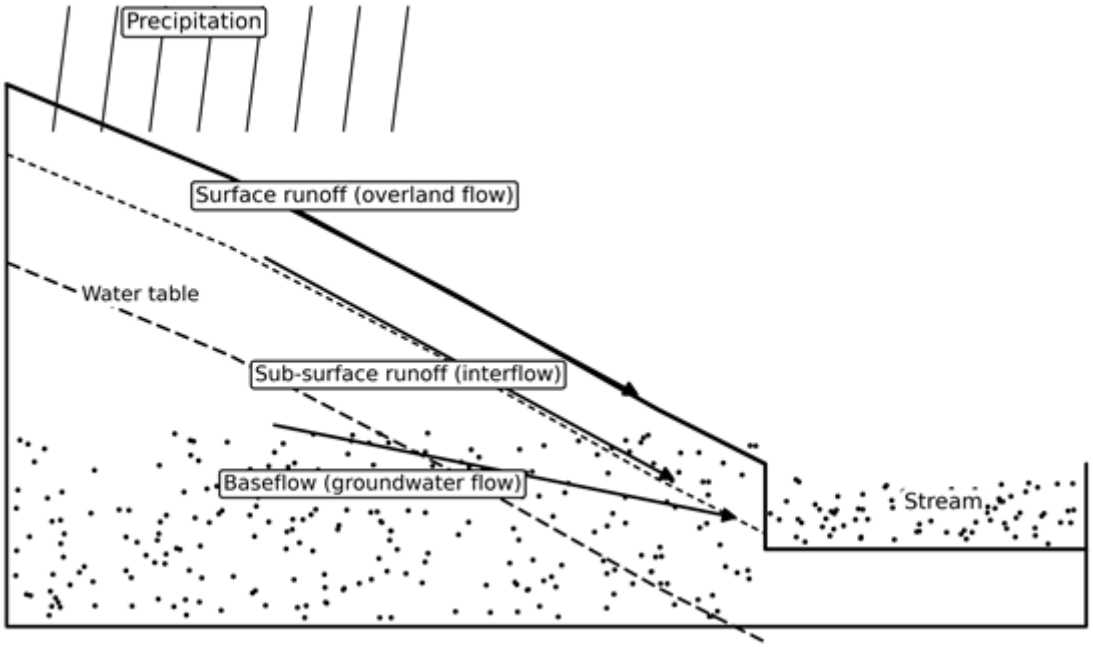


Figure 6.8: *The three types of runoff*

How to Draw It
Draw a hillslope running down to a stream channel on one side. Show precipitation on the slope, then three arrows toward the stream: one along the surface for surface runoff, one just below the surface for sub-surface runoff, and one deep below a dashed water table for baseflow. Label each path and the stream.

Question 30

Two neighbouring catchments above the Pangani, one steep and bare and one gentle and wooded, send very different amounts of storm water down to the river. Account for the factors that control the amount of runoff.

Model Answer

The amount of runoff depends on the rain, the slope, the rocks, the soil and the plant cover of a catchment.

1) **Precipitation:** heavy, prolonged rain produces far more runoff than light, brief showers.
2) **Slope:** steep ground sheds water quickly, while gentle ground lets it collect and soak in.
3) **Geology:** pervious and porous rocks lose water to seepage and yield little runoff, while impermeable rocks shed it.
4) **Soil type and moisture:** dry sandy soils absorb water and cut runoff, while clay or already saturated soils shed it.
5) **Vegetation:** a plant cover intercepts the rain and slows the flow, while bare ground lets it run freely.

So the steep, bare catchment above the Pangani sends a sudden flood to the river, while the gentle, wooded one releases its water slowly.

Question 31

In the dry months around Tabora, when the streams have vanished, the people still draw water from wells sunk into the rock. Explain what groundwater is, where it comes from and why it matters.

Model Answer

Groundwater is the water held below the ground surface in the cracks, joints and pore spaces of the soil and rock, in the zone where these spaces are saturated.

It is also called phreatic or subterranean water. Its main sources are rainwater and melt water, which infiltrate the surface and percolate downward until they collect in the saturated rock. Groundwater matters greatly because it is the most reliable freshwater resource, holding far more than all the rivers and lakes together and carrying little salt. Around Tabora, where the surface water fails in the dry season, the wells and boreholes that tap this groundwater are what keep homes, livestock and gardens supplied through the year.

Question 32

Two boreholes a few kilometres apart near Dodoma yield water of noticeably different taste and hardness, although both draw from the same depth. Account for the properties of groundwater and what gives it its composition.

Model Answer

The properties of groundwater are set mainly by the rock it passes through, so its composition reflects the local geology.

Because the water is in constant contact with the rock in which it stagnates or circulates, an equilibrium develops between the two, and the rock slowly dissolves into the water. Water moving through sandy or granitic rock stays acidic and carries few minerals, while water passing through limestone takes up bicarbonates and becomes alkaline and hard. Beyond this, groundwater is usually low in turbidity, holds a

fairly constant temperature, is poor in oxygen and is microbiologically pure. So the two boreholes near Dodoma differ in taste and hardness because the rock along their separate paths is not the same.

Question 33

Not all the water below the ground arrived there as recent rain, since some was trapped in the rock long ago and some rose from deep within the Earth. Classify groundwater according to its origin.

Model Answer

Groundwater is grouped into four types according to where it came from.

1) **Meteoric water:** water derived directly from rainfall and snowmelt that infiltrates the ground, by far the most common type.
2) **Connate water:** water trapped in sedimentary rock at the time of its formation, often salty and found in arid areas.
3) **Juvenile or magmatic water:** water brought up from deep within the Earth by volcanic activity, usually rich in minerals.
4) **Oceanic water:** sea water that has seeped sideways through the rock into the ground, as in the salty water of some coastal boreholes near Dar es Salaam.

Question 34

Water that enters the rock on a Kondoa hillside does not stay where it fell, but creeps slowly through the rock toward the valley. Explain how groundwater moves and what controls its movement.

Model Answer

Groundwater is in constant but slow motion, moving both vertically and horizontally under gravity and pressure.

It moves vertically downward under the pull of gravity, and upward where it is pushed from a zone of higher pressure to one of lower pressure. It also moves horizontally, either down a gradient or from a wetter soil toward a drier one. The movement is far slower than a stream, because the water must thread its way through the narrow spaces in the rock, and its speed is governed by two properties of the rock, namely porosity, which is how much space there is, and permeability, which is how well those spaces connect. So the water entering the rock on a Kondoa hillside seeps quietly toward the valley over months and years rather than hours.

Question 35

The wells of the Makonde Plateau fill again in the rains and are drawn down in the dry season, in a slow rhythm of replenishment and release. Explain the recharge and discharge of groundwater.

Model Answer

Groundwater is replenished by recharge and released by discharge, and the balance between them sets the level of the water table.

Recharge happens when surface water, whether from direct rain, from rivers or from melting snow, percolates downward through the soil and rock and enters a saturated, water-bearing formation called an aquifer. Discharge is the outflow of that stored water, which leaves the ground naturally through springs, rivers and lakes, or is drawn out through wells. Both depend on the permeability of the rock and on the hydraulic gradient. On the Makonde Plateau the heavy rains recharge the aquifer and raise the water table, while steady discharge to springs and wells draws it down again through the dry season.

Question 36

A villager is puzzled that a thick bed of clay, which clearly soaks up water, will not let any pass through to his well below. Explain rock permeability and the difference between primary and secondary permeability.

Model Answer

Permeability is the ability of a rock to let water pass through it, and a rock may be either permeable or impermeable.

Permeable rocks allow water to move through them freely, either because they are porous, with connected pore spaces as in sandstone, or because they are pervious, with cracks and joints as in jointed limestone. Impermeable rocks do not let water through, because they lack cracks and their pores are too small or unconnected, as in shale and unfractured granite. Permeability is further divided into primary permeability, which comes from the original open texture of the rock such as sand and gravel, and secondary permeability, which comes from later joints, cracks and fissures, as in crystalline limestone and jointed granite. The villager's clay, like the clay of the Kilombero floodplain, holds water in its tiny pores but those pores do not connect, so although it absorbs water it will not transmit it.

False Confidence Alert
Do not confuse holding water with letting it through. Clay is porous and can hold a great deal of water, yet it is impermeable because its pores are too small and unconnected to transmit it, so porosity and permeability are not the same thing.

Question 37

When the Geological Survey looks for a rock that will both store and yield water, it tests whether the rock has spaces and whether those spaces connect. With the aid of a diagram, explain rock porosity and its main states.

Model Answer

Porosity is the presence of spaces within a rock that can hold water, and rocks fall into four states according to their spaces.

1) **Porous:** rocks with small pores or holes in which water may be held, such as the sandstones around Tanga.
2) **Non-porous:** rocks with interlocking grains and no spaces, so water cannot enter, such as the granite of the central plateau, slate and marble.
3) **Pervious:** rocks through which water may pass along cracks or large pores, such as jointed sandstone or jointed granite.
4) **Impervious:** rocks through which water cannot pass, because there are no cracks and the pores are too small, such as clay.

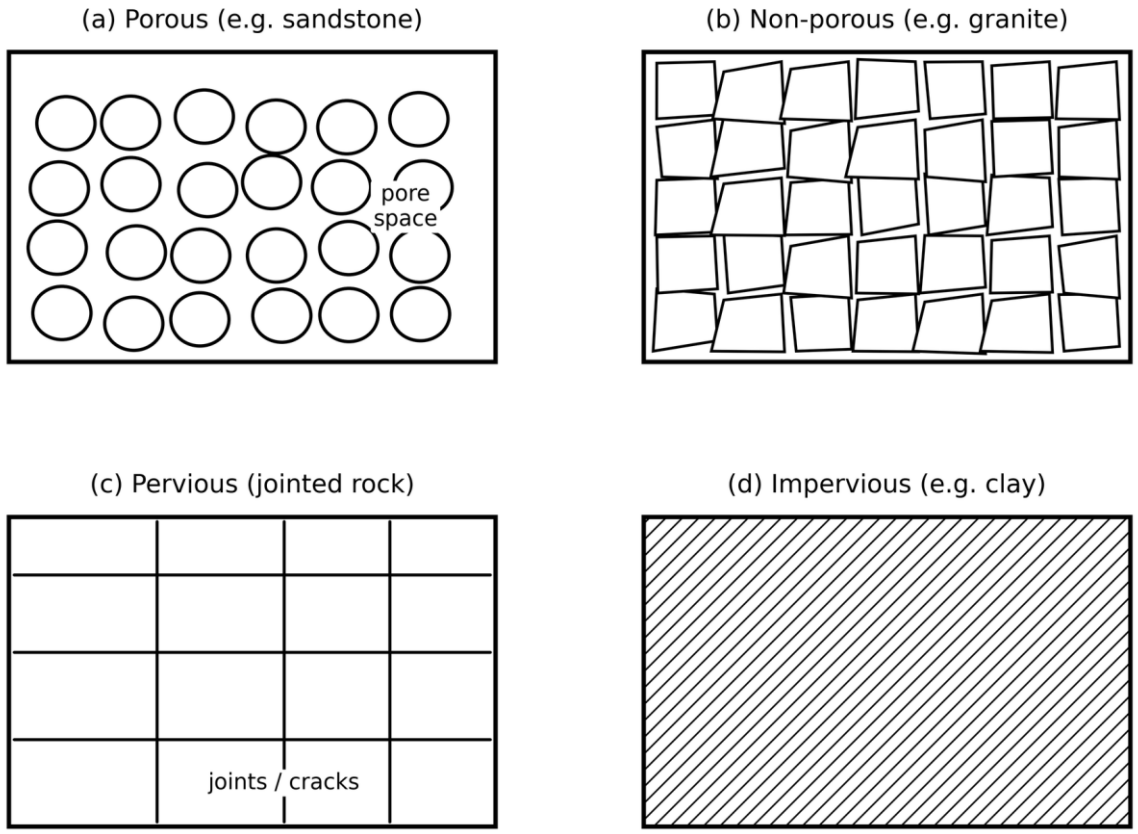


Figure 6.9: *Rock porosity*

Question 38

After a heavy rainy season the well water near Shinyanga stands high, but by the end of the dry months it has fallen far below. With the aid of a diagram, explain the water table and its types.

Model Answer

The water table is the upper surface of the zone of saturation, the level below which the ground is saturated with water, and it rises and falls with the seasons.

It marks the level below which every space in the rock is filled with water, and it follows the shape of the land in a subdued way. Its height is set by the rainfall, the shape of the land and the nature of the rock. A temporary water table is the high level reached in the rains, an intermittent water table gives springs only in the wet season, and a permanent water table is the level still found in the dry season. A perched water table is a separate, higher one, held up locally by a lens of impermeable rock above the main table.

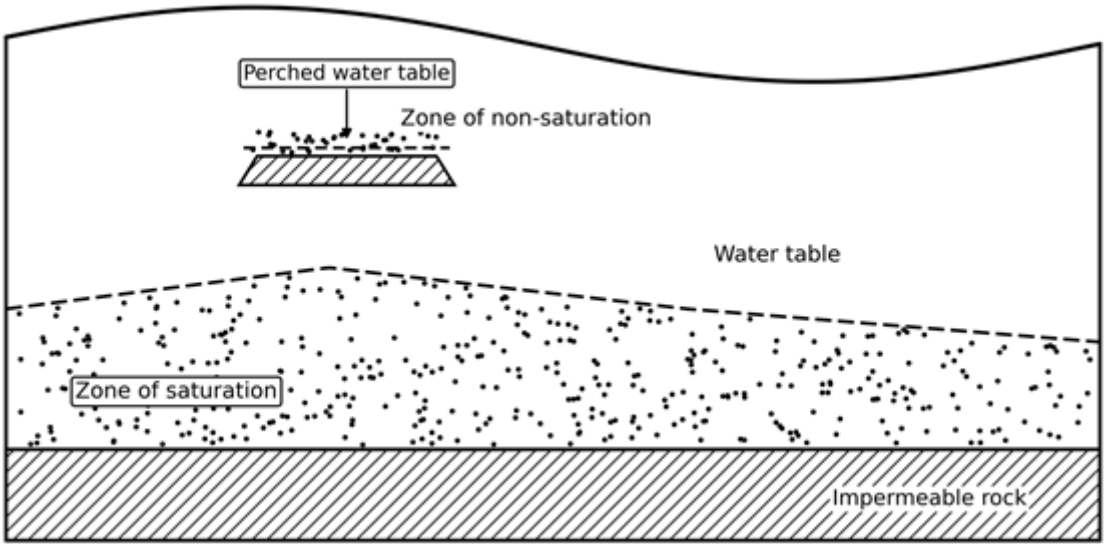


Figure 6.10: *The water table*

How to Draw It
Draw a block of ground with an undulating surface. Mark a dashed line for the water table, subdued below the surface, and stipple the saturated zone beneath it down to an impermeable base. Above a small lens of impermeable rock draw a short higher dashed line for a perched water table, and label the zones, the water table and the perched water table.

Question 39

A deep well section near Singida passes first through dry rock, then through rock that is wet only after the rains, and at last through rock that is always full of water. With the aid of a diagram, explain the zones of saturation and non-saturation.

Model Answer

Below the surface the rock is divided into a zone of non-saturation above and a zone of saturation below, separated by the water table.

1) **Zone of non-saturation:** the upper zone, also called the aeration or vadose zone, which is never completely filled with water but passes it downward, holding some for plant roots.
2) **Zone of intermittent saturation:** the band between the highest and lowest levels of the water table, which is saturated only in the wet season.
3) **Zone of permanent saturation:** the lowest zone, where the pore spaces are always filled with water, also called the aquifer.

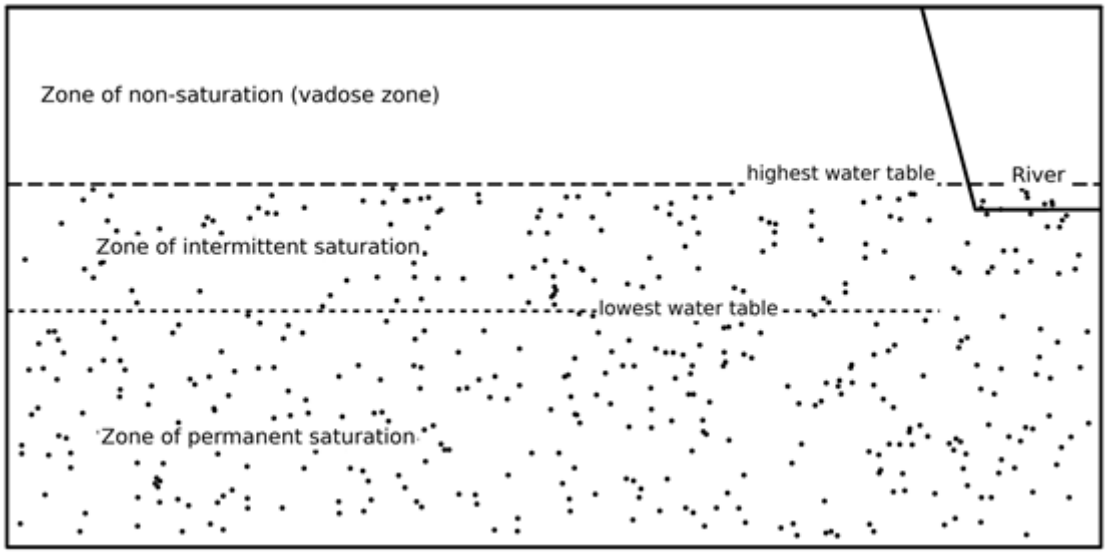


Figure 6.11: *The zones of saturation*

How to Draw It

Draw a block of ground and mark two horizontal dashed lines for the highest and lowest water table. Leave the top zone clear and label it the zone of non-saturation, stipple lightly between the two lines for the zone of intermittent saturation, and stipple heavily below the lowest line for the zone of permanent saturation. Add a river cutting down to the water table.

Question 40

A driller reports four kinds of rock layer below a site near Tabora: one that gives water freely, one that gives it slowly, one that holds it but will not yield it, and one that neither holds nor passes it. Distinguish the four geological formations of groundwater.

Model Answer

Groundwater formations are grouped by how well they store and transmit water, and there are four of them.

1) **Aquifer:** a body of saturated rock, both porous and permeable, that stores water and yields it freely, such as sandstone or fractured limestone.
2) **Aquitard:** a layer that transmits water only slowly, so that its yield is too small to be useful.
3) **Aquiclude:** an impermeable layer that holds a large amount of water but will not let it pass, such as clay or shale.
4) **Aquifuge:** an impermeable layer that neither holds nor transmits water, such as solid basalt or granite without cracks.

False Confidence Alert

Do not assume that a rock full of water is a good source. An aquiclude such as clay may be saturated yet useless for supply, because it cannot transmit water to a well; only an aquifer both holds water and gives it up.

Question 41

Near one borehole at Dodoma the water must be pumped up from the rock, while near another it rises on its own to the surface. With the aid of a diagram, distinguish a confined aquifer from an unconfined one.

Model Answer

An aquifer may be unconfined, open to the surface above, or confined, sealed between impermeable layers, and the difference decides whether its water is under pressure.

An unconfined aquifer is overlain by permeable rock, so it is recharged directly by rain soaking down from the surface, and its upper limit is simply the water table. A confined aquifer lies between two layers of impermeable rock, so it is recharged only where it outcrops at the surface, and the water within it is held under pressure. A well sunk into an unconfined aquifer must have its water pumped up, while a well sunk into a confined aquifer may flow on its own as an artesian well, because the trapped water is under pressure. Boreholes around Dodoma and Shinyanga are sited by reading exactly which of these conditions lies below.

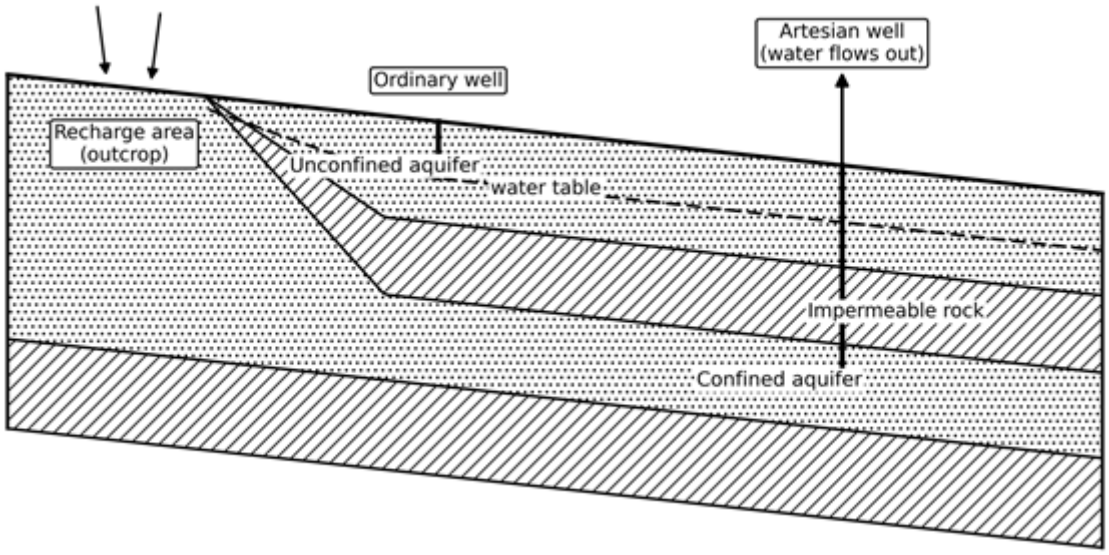


Figure 6.12: *Confined and unconfined aquifers*

How to Draw It
Draw gently dipping rock layers. Show a permeable aquifer near the surface with a water table for the unconfined aquifer, and below an impermeable layer show a second permeable aquifer sealed under it for the confined aquifer. Mark where the lower aquifer outcrops as the recharge area, draw an ordinary well into the upper aquifer and an artesian well into the lower one, and label each.

Question 42

On a hillside in the Usambara a line of springs breaks out at exactly the same height along the slope, where one rock layer rests on another. With the aid of a diagram, explain what a spring is and the main ways in which springs occur.

Model Answer

A spring is a natural outflow of groundwater at the surface, found where the water table meets the ground, and it occurs in several geological settings.

1) **Permeable rock over impermeable rock:** a line of springs breaks out at the junction on the slope where the water can sink no further.
2) **Well-jointed rocks forming a hill:** water enters the joints and emerges where the water table meets the surface.
3) **A dyke acting as a dam:** an impermeable dyke holds back the water, which escapes on its upslope side as a dyke spring.
4) **Limestone or chalk over impermeable rock:** a spring forms at the foot of the steep slope.
5) **Along a fault:** a fault brings permeable rock against impermeable rock, giving a fault spring.

6) **In a depression:** a spring forms where the surface cuts down to the water table.

On the Usambara slope the line of springs marks the junction where permeable rock rests on impermeable rock, so the water is forced out along it.

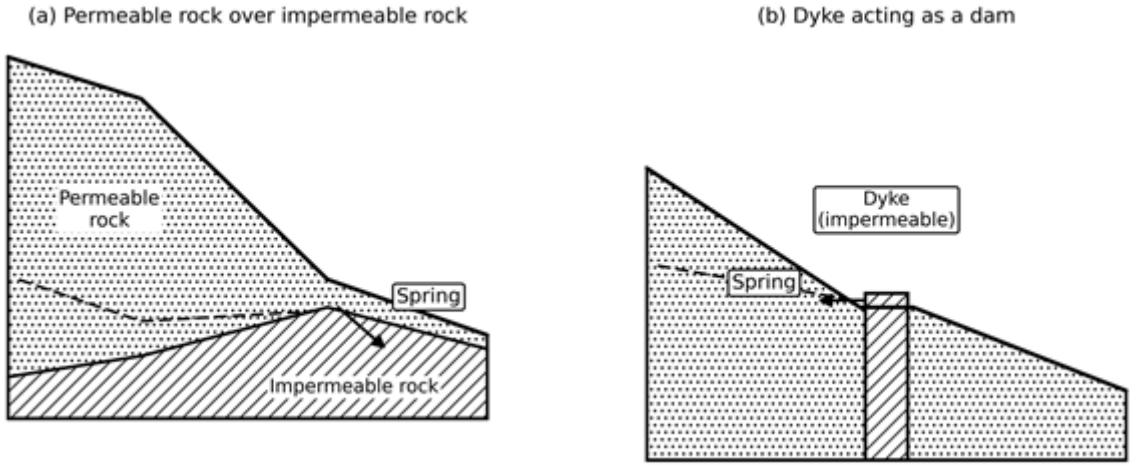


Figure 6.13: *How springs occur*

How to Draw It
Draw two scenes. In the first, show a hill of permeable rock resting on impermeable rock, with the water table inside and a spring breaking out at the junction on the slope. In the second, show an impermeable dyke cutting through permeable rock, damming the water so a spring escapes on its upslope side. Label the rocks, the water table and the springs.

False Confidence Alert
Do not treat springs as appearing at random. A spring marks a definite place where the geology forces the water table to meet the surface, such as a rock junction, a fault or a dyke, so its position can be read from the structure.

Question 43

Of three wells dug in the same village near Nzega, one gives water all year, one dries up in the long dry season, and one has never reached water at all. With the aid of a diagram, explain the types of wells in relation to the water table.

Model Answer

A well is a hole sunk to reach the water table, and whether it gives water depends on how deep it reaches relative to the saturated zones.

1) **Permanent or deep well:** sunk down to the zone of permanent saturation, so it holds water throughout the year.
2) **Shallow well:** sunk only to the zone of intermittent saturation, so it gives water in the wet season but dries up when the table falls.
3) **Dry well:** sunk only into the zone of non-saturation above the water table, so it never reaches water at all.

So among the three wells near Nzega only the deepest, reaching the permanent water table, can be relied on through the dry season.

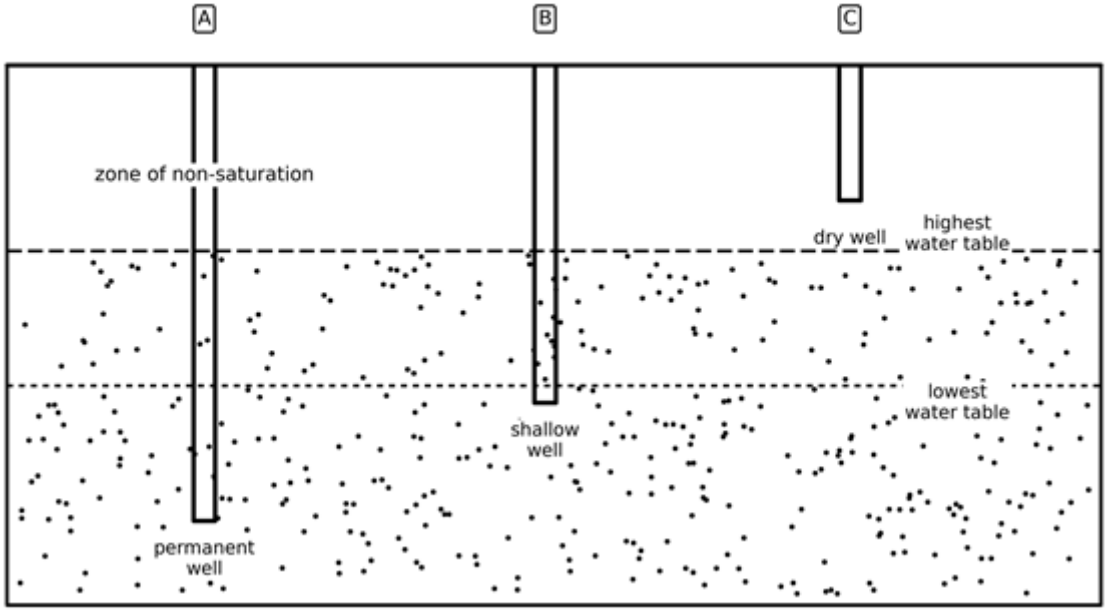


Figure 6.14: *Types of wells*

How to Draw It
Draw a block of ground with a dashed highest water table and a dotted lowest water table, and stipple the saturated rock. Draw three wells: a deep one reaching below the lowest table, a shallow one reaching only between the two tables, and a short one ending above the highest table. Label them permanent, shallow and dry.

Question 44

In some basins a borehole sunk into the rock sends water gushing up to the surface without any pump, fed by pressure from far away. With the aid of a diagram, explain how an artesian basin and an artesian well form, and state the conditions they require.

Model Answer

An artesian well is one in which water rises to the surface on its own, fed by the pressure of a confined aquifer held in an artesian basin.

An artesian basin forms where a permeable rock layer lies between two impermeable layers in the shape of a shallow syncline, with the permeable rock outcropping at the higher rims. Rain falling on the exposed rim recharges the aquifer, and because the water is trapped under the impermeable cap and fed from a height, it is held under great pressure. A well sunk into the basin lets this pressure drive the water up to the surface as an artesian well. Where the pressure is too weak to reach the surface, so that a pump is still needed, the well is called semi-artesian. Three conditions are required: a permeable layer set between two impermeable layers, an exposed rim in an area of good rainfall to recharge it, and a basin that dips to a lower centre so the pressure can build. Basins with these conditions are valued groundwater stores, as in the country around Dodoma.

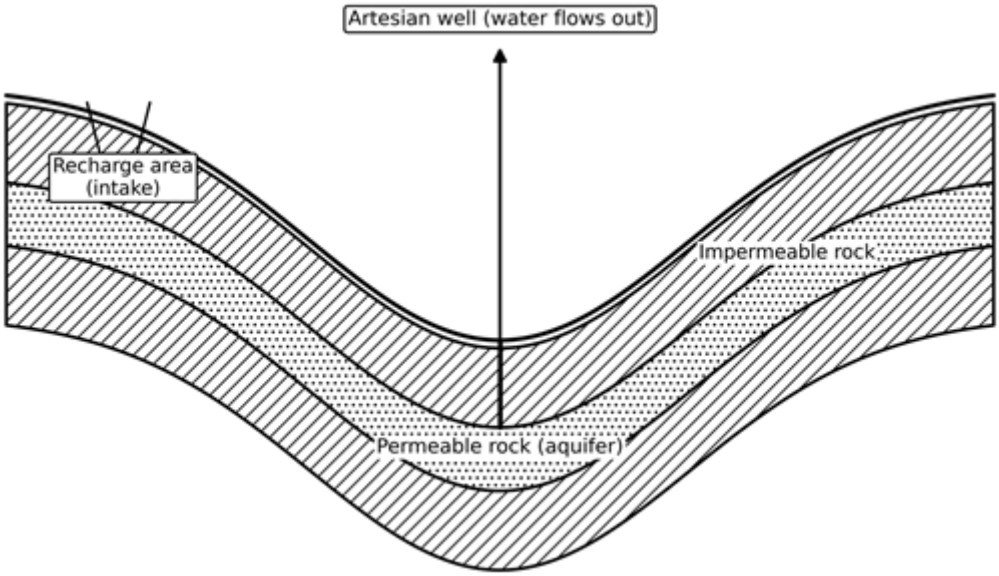


Figure 6.15: *An artesian basin and artesian well*

How to Draw It
Draw the rock layers as a shallow basin or syncline. Show a permeable aquifer between two impermeable layers, with the aquifer outcropping at the rims. Mark rain falling on one rim as the recharge area, and draw a well at the low centre with an arrow showing water flowing out above the surface. Label the permeable and impermeable rocks, the recharge area and the artesian well.

False Confidence Alert
Do not assume every well in an artesian basin gushes out. Only where the pressure surface lies above the ground does the water flow freely; where it lies below, the well is only semi-artesian and a pump is still needed.

Question 45

Two districts with the same rainfall, one on porous sandstone and one on solid granite, differ greatly in how much groundwater they hold. Account for the factors that affect the occurrence of groundwater.

Model Answer

The occurrence of groundwater depends on the rainfall, the rock, the slope and the plant cover of an area.

1) **Precipitation and evaporation:** high rainfall with low evaporation recharges the aquifer and raises the water table, while low rainfall and high evaporation lower it.
2) **Rock permeability:** permeable rocks such as sandstone and limestone let water in and store it, while impermeable granite and basalt give a dry water table.
3) **Gradient or slope:** on steep slopes water runs off quickly and little soaks in, while on gentle slopes it infiltrates well.
4) **Vegetation cover:** a plant cover slows the runoff and lets more water infiltrate to the groundwater.

So the district on porous sandstone near Tanga holds far more groundwater than the one on the solid granite of the central plateau, even under the same rainfall.

Question 46

Where a town near Mwanza lets its waste seep into the ground, the water drawn from nearby wells is no longer safe to drink. Account for the main sources of groundwater pollution.

Model Answer

Groundwater is polluted from several sources at the surface whose wastes and chemicals sink into the ground.

1) **Waste landfills:** rainwater passing through buried waste forms a toxic leachate that sinks into the groundwater.
2) **Surface impoundments:** shallow lagoons of liquid waste may leak through their liners into the subsoil.
3) **Pesticides and fertilizers:** farm chemicals that do not break down move downward with the water.
4) **Storage tanks and pipelines:** leaks of fuel, chemicals or sewage seep out and contaminate the ground.
5) **Mining activities:** acid mine drainage and the chemicals used to treat ore move through the fractures of the rock.

Around a town near Mwanza these sources, especially poorly managed waste and pit latrines, are why the water from shallow wells must be tested and treated before it is drunk.

Question 47

The water Tanzania can see and use most easily is the surface water of its rivers, lakes and the sea, all of it fed from the same sky. Explain what surface water is, where it comes from and how it relates to groundwater.

Model Answer

Surface water is all the water that lies on the Earth's surface, in both the freshwater bodies and the salt seas and oceans.

It includes the fresh water of creeks, ponds, wetlands, streams, rivers and lakes, and the saline water of the seas and oceans. It comes mainly from precipitation, and is fed by a combination of surface runoff and groundwater. Surface water and groundwater are not separate, since they feed into each other: water seeps from rivers down to recharge the groundwater, and groundwater seeps back up to keep the rivers flowing. The water moving in a well-defined channel like the Rufiji is the visible part of this exchange, which is why the river runs even in the dry season, as the groundwater feeds it.

Question 48

Why a river network in one part of Tanzania spreads like a tree and in another runs in straight lines is decided long before the first stream forms. Explain what a drainage system is and the factors that control it.

Model Answer

A drainage system is the origin and development of the streams of a region through time, the way the network begins and grows.

It is the whole pattern of streams, the way they originate and the way they arrange themselves. Two main factors control it. The first is the nature of the initial land surface and its slope, which sets the first direction of flow. The second is the geological structure, such as the folds, faults, joints, dips and the hardness of the rocks, which guides where the streams can cut, since water follows the lines of weak rock and avoids the resistant outcrops. So the same rain falling on differently structured ground builds quite different networks, as in the contrast between the streams of the central plateau and the rifted country of northern Tanzania.

Question 49

On a newly tilted land surface the first streams run straight down the slope, and later streams grow along the bands of weak rock to join them at right angles. With the aid of a diagram, explain the sequent (accordant) drainage system and its types.

Model Answer

A sequent or accordant drainage system follows the regional slope and fits the geological structure, and it is made up of four kinds of stream.

1) **Consequent stream:** the first stream to form, flowing straight down the initial slope, the master stream of the system.
2) **Subsequent stream:** a later stream that develops along the strike of the weak rock and joins the consequent at right angles.
3) **Obsequent stream:** a small tributary flowing in the opposite direction to the consequent, into a subsequent.
4) **Resequent stream:** a small tributary flowing in the same direction as the consequent, into a subsequent.

River Pangani, flowing from the high ground of Kilimanjaro and Meru straight down the regional slope, is a good example of a consequent stream.

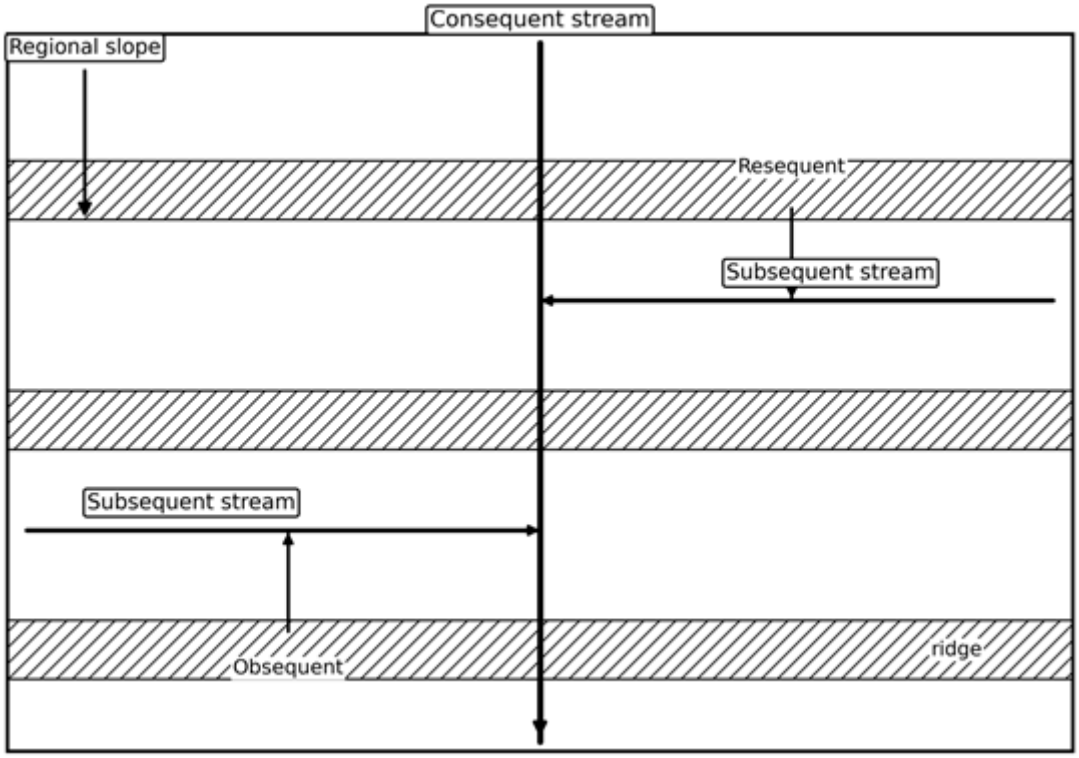


Figure 6.16: *Sequent (accordant) drainage*

How to Draw It
Draw a rectangle with two or three hatched bands across it for ridges and clear valleys between them. Draw a long stream straight down the slope for the consequent, and streams along the valleys joining it at right angles for the subsequents. Add a short tributary flowing against the consequent for the obsequent and one flowing with it for the resequent, mark the regional slope, and label each.

Question 50

Some Tanzanian rivers, like the Great Ruaha, hold their course straight across rising land instead of bending around it. With the aid of a diagram, explain the insequent (discordant) drainage system and its main types.

Model Answer

An insequent or discordant drainage system does not follow the regional slope and is not adjusted to the structure, because the rivers drain across it, and it has two main types.

1) **Antecedent drainage:** a river that keeps its original course by cutting down through land that rose across its path, as fast as the land was uplifted, so the river is older than the landform, as with the Great Ruaha.

2) **Superimposed drainage:** a river that kept the course it had on a former cover of rock and cut down into the older rock beneath without following its structure, so the river is younger than the rock it crosses, as with the Zambezi.

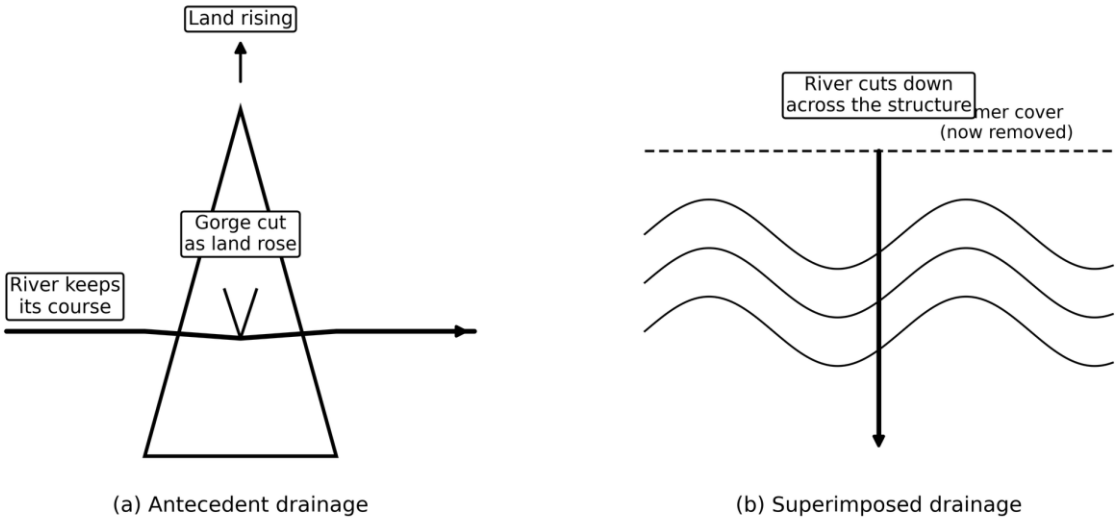


Figure 6.17: *Insequent (discordant) drainage*

How to Draw It
Draw two scenes. In the first, show a ridge rising across a river's path, with the river holding its course and cutting a gorge through the rise, for antecedent drainage. In the second, show a folded older rock with a former cover drawn as a dashed line above, and a river cutting straight down across the structure, for superimposed drainage. Label both.

False Confidence Alert
Do not confuse antecedent with superimposed drainage. In antecedent drainage the river is older than the uplift and cuts down to keep its course; in superimposed drainage the river is younger than the rock it crosses, having inherited its course from a cover that has since worn away.

Question 51

Not every Tanzanian river reaches the sea, since some, like those feeding Lake Eyasi, end in a closed inland basin. Explain inland drainage and where it is found.

Model Answer

Inland drainage is a system in which the rivers do not reach the ocean but empty instead into a lake or an inland sea.

Such a system is fed by rainwater, and sometimes by melting ice and snow, and the volume of its rivers varies greatly with the rainfall, so that many of its streams shrink or dry up in the dry season. It is found mainly in arid and semi-arid areas, where evaporation is high and the rivers cannot gather enough water to escape to the sea. In the closed basins of northern Tanzania, the rivers draining toward Lake Eyasi, Lake Natron and Lake Manyara make up inland drainage, ending in lakes that have no outlet to the ocean.

Question 52

Seen from above, the rivers of different regions trace very different shapes on the land, from the branches of a tree to a grid of straight lines. With the aid of a diagram, explain the main drainage patterns shaped by the rocks beneath.

Model Answer

A drainage pattern is the plan that rivers and their tributaries make on the land, and several common patterns are set by the underlying rock.

1) **Dendritic:** a tree-like pattern with tributaries joining at acute angles, formed on uniform rock.
2) **Trellis:** tributaries joining the main streams at right angles, formed on folded sedimentary rock.
3) **Radial:** streams flowing outward down the sides of a dome or cone, as on the slopes of Kilimanjaro.
4) **Annular:** streams arranged in curves around a dome of alternating hard and soft rock.
5) **Rectangular:** streams with sharp right-angle bends, following the joints and faults in the rock.

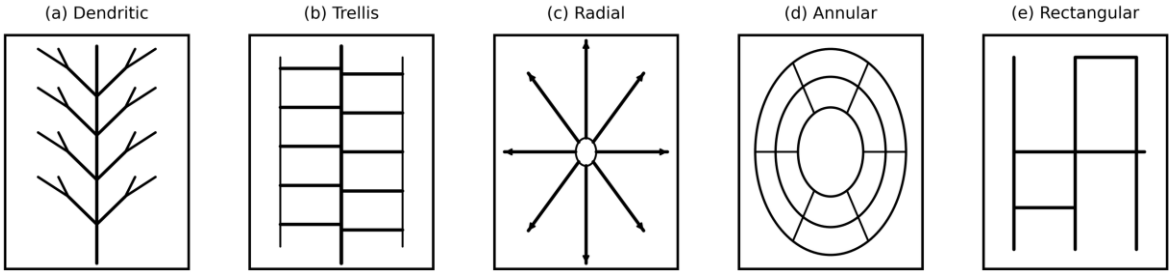


Figure 6.18: *Drainage patterns (I)*

How to Draw It
Draw five small boxes. Show a tree-like branching network for dendritic, a main stream with right-angle tributaries for trellis, streams running out from a central dome for radial, streams curving around a centre for annular, and streams with sharp right-angle bends for rectangular. Label each.

Question 53

Some rivers gather inward to a single basin, while others split into many channels across a wide plain. With the aid of a diagram, explain the centripetal, braided and anastomotic drainage patterns.

Model Answer

Beyond the common patterns, three more describe rivers that converge or divide.

1) **Centripetal:** streams that flow inward from the surrounding highlands toward a central basin or crater, the opposite of the radial pattern.
2) **Braided:** a river that splits into several channels separated by bars of sand and rejoins, common on broad flood plains of low gradient.
3) **Anastomotic:** a pattern of channels that branch and rejoin around islands, found on flood plains and reduced gradients.

The braided pattern is common where a river such as the Great Ruaha spreads across a wide, gently sloping plain and divides among its sand bars.

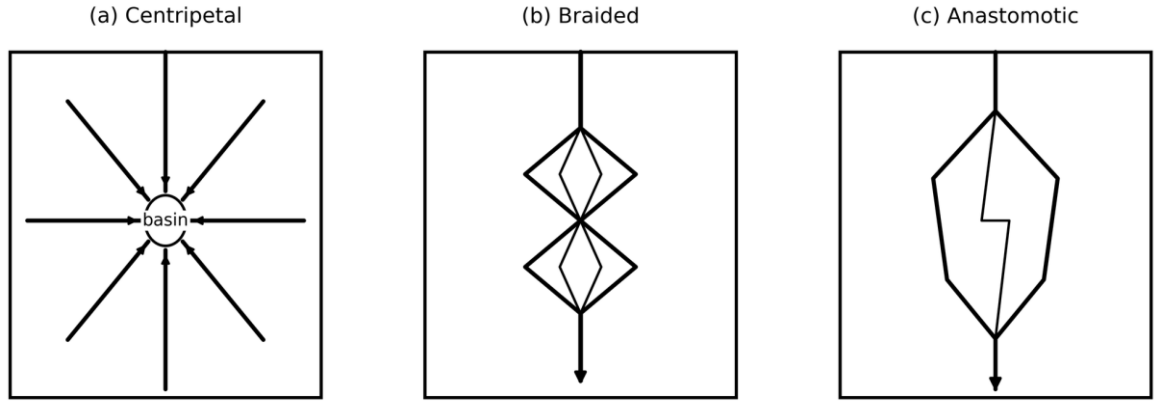


Figure 6.19: *Drainage patterns (II)*

How to Draw It
Draw three small boxes. Show streams flowing inward to a central basin for centripetal, a single channel splitting and rejoining around bars for braided, and channels branching and rejoining around islands for anastomotic. Label each.

Question 54

A student uses the terms drainage system and drainage pattern as if they meant the same thing, but a geographer keeps them apart. Distinguish a drainage system from a drainage pattern.

Model Answer

A drainage system and a drainage pattern are related but different: one is about how the streams develop, the other about the shape they make.

A drainage system refers to the origin and development of the streams of a region through time, that is, how the network came to be, whether it followed the slope and structure as a sequent system or cut across them as an insequent one. A drainage pattern refers instead to the layout or plan that the rivers and their tributaries trace on the land surface, such as dendritic, trellis or radial. So the system is about the history and adjustment of the streams, while the pattern is about their geometric shape. On the slopes of Kilimanjaro, for instance, the system may be consequent while the pattern it traces is radial.

False Confidence Alert
Do not use drainage system and drainage pattern as the same term. The system is how the streams originated and adjusted to the slope and structure; the pattern is the geometric shape they make on the map, and one region's system can show more than one pattern.

Question 55

From its source on the Kipengere Range to its mouth on the coast, a river like the Rufiji drains a vast area through countless smaller streams. Explain what a river is, together with the terms river basin and watershed.

Model Answer

A river is a natural flow of water along a channel from its source in the highlands to its mouth at a lake, sea or ocean.

Along its course a river is joined by smaller streams called tributaries, and as it nears the sea it may split into smaller channels called distributaries. The whole area drained by a river and its tributaries is called its river basin or catchment, and the line of high ground that separates one river basin from the next is called the watershed or divide. The Rufiji, gathering the waters of a huge basin from the Kipengere Range down

to the Indian Ocean, shows all of these, since its tributaries feed it, its basin collects the rain, and its watershed marks where its catchment ends and the next begins.

Question 56

Some Tanzanian rivers flow all year, others only in the rains, and a few only for hours after a storm. With the aid of a diagram, explain the three types of rivers by their flow.

Model Answer

Rivers are grouped into three types by how steadily they flow, namely perennial, intermittent and ephemeral.

1) **Perennial rivers:** permanent rivers that flow throughout the year, fed by reliable rain or by groundwater, as the Rufiji and the Congo.
2) **Intermittent rivers:** seasonal rivers that flow in the rainy season when rain is abundant and shrink or stop in the dry season, common in the tropics.
3) **Ephemeral rivers:** rivers that flow only briefly after a heavy storm and are dry the rest of the time, found in arid areas.

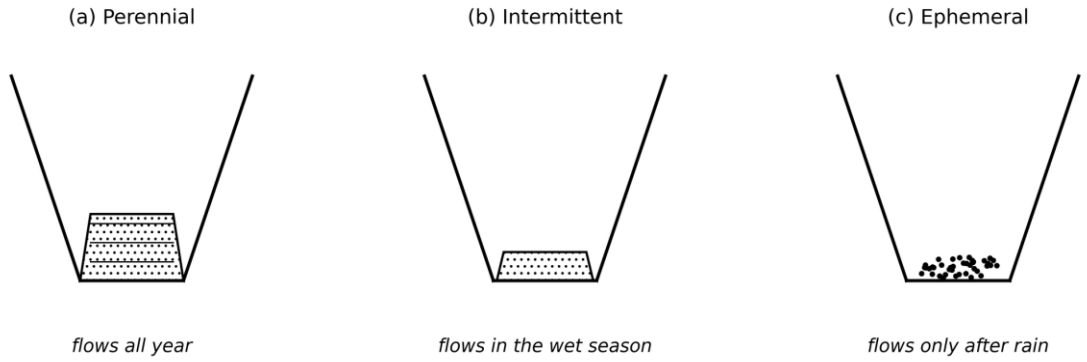


Figure 6.20: *Types of rivers*

How to Draw It
Draw three identical channel cross-sections. Fill the first with water for a perennial river that flows all year, give the second a shallow amount of water for an intermittent river that flows in the wet season, and leave the third as a dry, stippled bed for an ephemeral river that flows only after rain. Label each.

False Confidence Alert
Do not call every river that dries up ephemeral. An intermittent river flows for a whole season each year, while an ephemeral one flows only for hours or days after a single storm, so the two differ in how long and how regularly they run.

Question 57

The greatest lakes of Tanzania, the broad Victoria and the deep Tanganyika, were both made by movements of the Earth's crust, yet in opposite ways. With the aid of a diagram, explain the lakes formed by earth movements.

Model Answer

Lakes formed by earth movements, also called tectonic lakes, occupy basins made by the warping or faulting of the crust, and they are of two kinds.

1) **Crustal warping lakes:** formed where the crust gently sags or downwarps and water fills the broad, shallow basin, as in Lake Victoria, which lies in a downwarp between the two rift arms.

2) **Rift valley lakes:** formed where a block of crust drops between two faults to make a deep, steep-sided trough that fills with water, as in Lake Tanganyika, Lake Nyasa and Lake Rukwa.

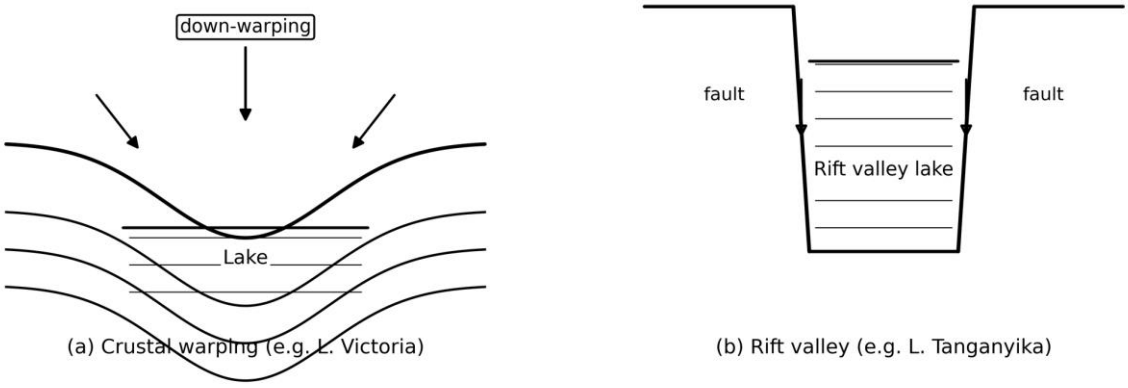


Figure 6.21: *Lakes formed by earth movements*

How to Draw It
Draw two cross-sections. In the first show the rock layers gently sagging into a broad downwarp filled with water for a crustal-warping lake. In the second show a block dropped between two fault scarps to make a deep trough filled with water for a rift valley lake. Label the warping, the faults and the lakes.

Question 58

On the volcanic highlands of Tanzania water fills the old crater of a volcano at Lake Chala and ponds behind ancient lava elsewhere. With the aid of a diagram, explain the lakes formed by vulcanicity.

Model Answer

Lakes formed by vulcanicity occupy hollows made by volcanic activity, and the commonest are crater, caldera and lava-dammed lakes.

1) **Crater and caldera lakes:** formed when water fills the crater left by a volcanic eruption, or the larger caldera made when the crater collapses, as at Lake Chala on the Tanzania-Kenya border and Lake Empakaai in the Ngorongoro area.

2) **Lava-dammed lakes:** formed when a lava flow blocks a river valley so that water collects behind the lava barrier, as at Lake Kivu by the western rift.

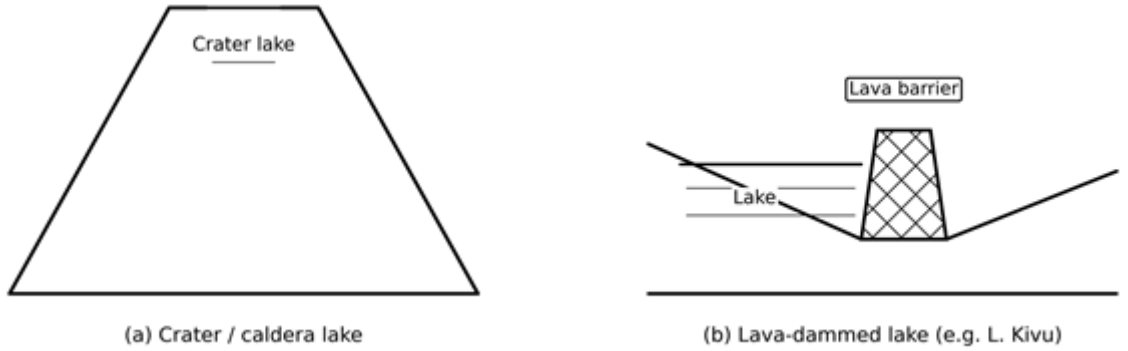


Figure 6.22: *Lakes formed by vulcanicity*

How to Draw It
Draw two scenes. In the first show a volcanic cone with water filling the crater at its summit for a crater lake. In the second show a lava flow blocking a valley, with water ponded behind the barrier, for a lava-dammed lake. Label the crater lake, the lava barrier and the lake.

Question 59

In the deserts beyond Tanzania the wind itself can scoop out a hollow deep enough to hold water, although the result is often only a salty swamp. Explain how lakes are formed by wind erosion.

Model Answer

In desert areas the wind can excavate hollows that reach down to the water table, and these may hold water as lakes.

As the dry wind blows across the loose sand and dust of a desert it deflates, or blows away, the surface, lowering it bit by bit until in places the hollow reaches the water table and water seeps in. Where an aquifer is exposed in this way a more permanent desert lake, called an oasis, may form. Many of these wind-cut lakes, however, are no more than muddy swamps, and where the dry climate evaporates them away what remains is a bed of salt called a playa or salt lake. The Qattara and Siwa depressions of Egypt are well-known examples, since Tanzania, lacking true desert, does not form these.

False Confidence Alert
Do not expect wind-eroded desert lakes to be true, lasting lakes. Many are only seasonal swamps, and where evaporation wins they dry to a salt-crusted playa, so a deflation hollow holds water only where it cuts down to the water table.

Question 60

A river winding across its flood plain can cut off one of its own loops to leave a curved lake behind, while along the coast a bar of sand can trap a lagoon. With the aid of a diagram, explain the lakes formed by deposition.

Model Answer

Lakes formed by deposition occupy hollows sealed off by the material that rivers, seas or oceans lay down, and they include ox-bow, delta and barrier lakes.

1) **Ox-bow lakes:** formed when a river cuts through the narrow neck of a meander and deposition seals the loop, leaving a curved lake beside the new channel.
2) **Delta and flood-plain lakes:** formed where silt and sand build up barriers behind which water is trapped, as on the Rufiji delta or behind the levees of a flood plain.
3) **Barrier lakes:** formed where a bar of sand built across a bay encloses a lagoon of water behind it.

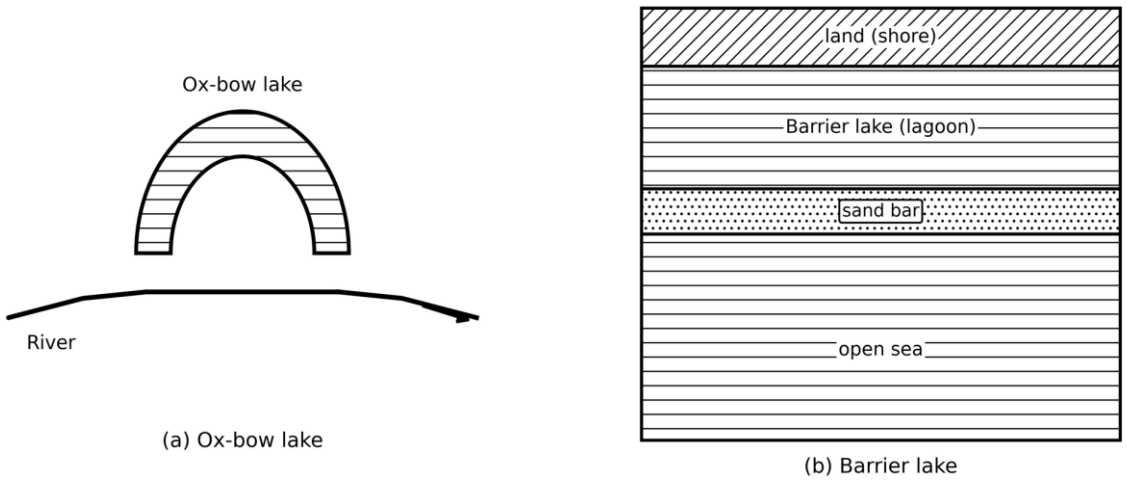


Figure 6.23: *Lakes formed by deposition*

How to Draw It
Draw two scenes. In the first show a river that has straightened its course, with the abandoned loop left beside it as a crescent-shaped ox-bow lake. In the second show a bar of sand built across a bay, enclosing a lagoon behind it with the open sea beyond, for a barrier lake. Label the river, the ox-bow lake, the sand bar, the lagoon and the sea.

Question 61

A lake can be born in an afternoon when a landslide blocks a valley, or built over years when people dam a river for power. Explain the lakes formed by landslides and those made by people.

Model Answer

Some lakes are dammed by landslides and other debris, while others are made deliberately by people as reservoirs.

1) **Landslide-dammed lakes:** formed when mass-movement material slides down and blocks a river valley, ponding water behind it; these are usually temporary, since the loose dam is soon breached.
2) **Man-made lakes (reservoirs):** formed deliberately by building a dam across a narrow, steep-sided river valley, to store water for irrigation or to generate hydroelectric power.

Tanzania's man-made lakes show this clearly, since the Mtera and Nyumba ya Mungu reservoirs were built across river valleys to store water and drive turbines, just as Lake Kariba was made on the Zambezi and Lake Nasser on the Nile.

Question 62

Asked in an examination to classify the world's lakes by how they were formed, a student must group them by the process behind each basin. With relevant examples, classify six types of lakes according to their mode of formation.

Model Answer

Lakes can be classified into six types according to the process that made the basin they fill.

1) **Tectonic lakes:** made by earth movements, by warping as in Lake Victoria or by rifting as in Lake Tanganyika.
2) **Volcanic lakes:** made by volcanic activity, filling a crater as at Lake Chala or held behind lava as at Lake Kivu.

3) **Wind-eroded lakes:** made where desert wind deflates a hollow down to the water table, as in the Qattara depression.
4) **Depositional lakes:** made where deposition seals a basin, as in an ox-bow lake or a barrier lagoon.
5) **Landslide-dammed lakes:** made where mass movement blocks a river valley.
6) **Man-made lakes:** made by people damming a river, as at the Mtera and Nyumba ya Mungu reservoirs.

Question 63

Between the dry land and the open water of the Kilombero Valley lies a broad belt that is neither quite land nor quite lake, flooded for much of the year. With the aid of a diagram, explain what a wetland is and where wetlands are found.

Model Answer

A wetland is an area of marsh, swamp, peatland or water, whether natural or artificial and whether permanent or temporary, where the water table stands at or near the surface for much of the year.

In a wetland the ground is saturated either permanently or seasonally, so that it takes on the character of a distinct ecosystem, with a special water-loving, or hydric, soil and plants adapted to flooding. Wetlands form the transition between dry land and open water, and they occur in every climate, from the polar regions to the tropics. In Tanzania they include the Rufiji Delta, the Kilombero Valley, Lake Natron and the Malagarasi-Moyowosi, each flooded for much of the year and rich in life.

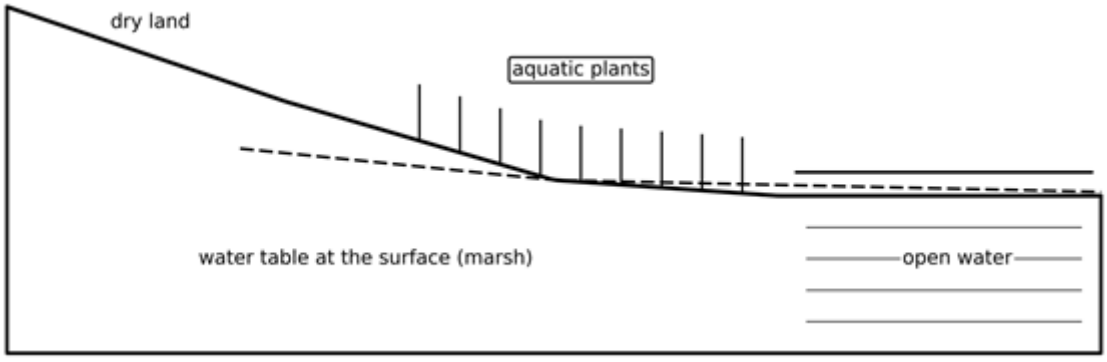


Figure 6.24: *A wetland*

How to Draw It
Draw a cross-section of land sloping gently into open water. Mark the water table as a dashed line standing at the surface in the middle to make a marsh, draw reeds and aquatic plants rooted there, and label the dry land, the marsh where the water table is at the surface, the aquatic plants and the open water.

Question 64

A wetland such as the Malagarasi looks like waste ground to some, yet it cleans water, holds back floods and teems with life. Account for the characteristics of wetlands and the functions they perform.

Model Answer

Wetlands have distinct characteristics, and from these flow several valuable functions in the environment.

Their key characteristic is a water table that stands at or near the surface for long enough each year to saturate the ground, giving them a special hydric soil and aquatic plants, and making them an ecotone, a zone of transition between dry land and open water. From these characteristics come their functions: they purify water by trapping sediment and absorbing pollutants, they control floods by holding back storm water and releasing it slowly, they store carbon in their waterlogged soils, and they stabilise shorelines. For

all these reasons the Malagarasi and wetlands like it are among the most biologically diverse of all ecosystems, home to a great range of plants and animals.

Question 65

The mangrove swamps along the Tanga coast and the inland Usangu flats are both wetlands, yet they belong to different families by where they lie. Explain the classification of wetlands according to their location.

Model Answer

By their location, wetlands are divided into coastal and inland wetlands.

Coastal (tidal) wetlands: found along the oceans and closely linked to estuaries, where sea water and fresh water mix and the tides reach; they are dominated by grasses, salt marshes and mangroves, as in the mangrove wetlands along the Tanga coast.

Inland (non-tidal) wetlands: found along streams and in poorly drained depressions and the shallow margins of lakes and rivers, away from the tides, as in the Usangu flats and the Malagarasi-Moyowosi.

Question 66

Where grasses stand in shallow water it is a marsh, but where trees rise from the same wet ground it is called a swamp. With the aid of a diagram, explain the classification of wetlands according to their soil and vegetation.

Model Answer

By their soil and the plants it supports, wetlands are divided into marshes, swamps, bogs and fens.

1) **Marshes:** areas of shallow fresh or salt water dominated by soft-stemmed grasses and reeds, on mineral-poor soil.
2) **Swamps:** wetlands on poorly drained mineral soil dominated by trees and woody shrubs rather than grasses, as in the forested swamps of the Kilombero.
3) **Bogs:** wetlands of wet, spongy, poorly drained peat, fed only by rainfall and therefore acidic.
4) **Fens:** wetlands of peaty soil dominated by grasses and reeds, fed mainly by groundwater and therefore alkaline.

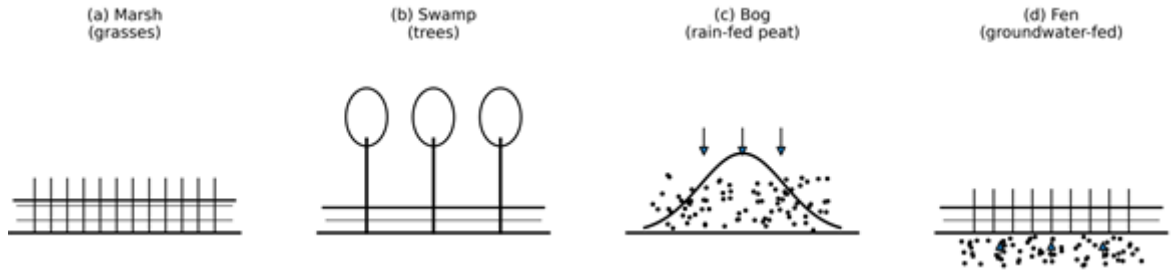


Figure 6.25: *Types of wetland by soil and vegetation*

How to Draw It
Draw four small panels. Show shallow water with grasses for a marsh, water with trees for a swamp, a raised spongy peat dome with rain falling on it for a bog, and a low peat surface fed by groundwater from below for a fen. Label each.

False Confidence Alert
Do not confuse a marsh with a swamp. Both are wet, but a marsh is dominated by grasses and reeds while a swamp is dominated by trees, so the vegetation, not just the water, tells them apart.

Question 67

The Indian Ocean off Dar es Salaam is part of one vast, open body of salt water, while a sea like the Mediterranean is half-enclosed by land. With the aid of a diagram, explain the difference between oceans and seas and their share of the Earth's water.

Model Answer

An ocean is a vast, open body of salt water covering most of the Earth, while a sea is a smaller body partly enclosed by land, and together they hold almost all the Earth's water.

An ocean is the largest mass of saline water, open and continuous, like the Indian Ocean that washes the Tanzanian coast. A sea is smaller than an ocean and larger than a lake, and it is partly shut in by land, like the Mediterranean or the Red Sea. Together the oceans and seas cover about 97 percent of the Earth's water, leaving only about 3 percent as fresh water in lakes, rivers, ice and the ground. These great water bodies matter because they shape climate, governing temperature, rainfall, humidity and wind.

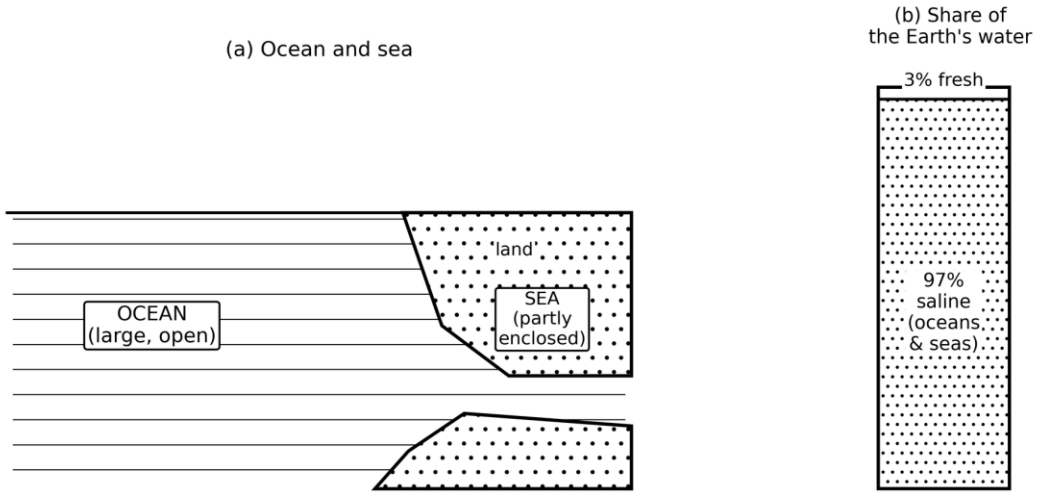


Figure 6.26: *Oceans and seas, and the share of the Earth's water*

How to Draw It
Draw a large open stretch of water and label it ocean, then show a smaller body of water half-enclosed by an arm of land and label it sea. Beside them draw a tall bar divided so that ninety-seven percent is shaded for the saline oceans and seas and three percent is left clear for fresh water. Label each.

False Confidence Alert
Do not treat sea and ocean as the same thing. An ocean is vast and open, while a sea is smaller and partly enclosed by land, so all the seas together are far smaller than the oceans.

Question 68

The water of the ocean is never still, but moves both across its surface as currents and up and down through its depths. With the aid of a diagram, explain the horizontal and vertical movements of ocean water.

Model Answer

Ocean water moves in two ways, horizontally to give currents and vertically to raise and lower water, both driven by differences in water density and by the wind.

The horizontal movement of water across the surface gives rise to ocean currents, such as warm and cool currents and the broad west-wind drift, which carry water and heat from one part of the ocean to another. The vertical movement raises bottom water to the surface, called upwelling, and sinks surface water to the depths, and it is governed by temperature and salinity, since cold and salty water is denser and sinks while

warmer water rises. Off coasts where cool water rises, as along the East African coast, upwelling brings up nutrients, while at the poles cold, dense water sinks and creeps toward the Equator.

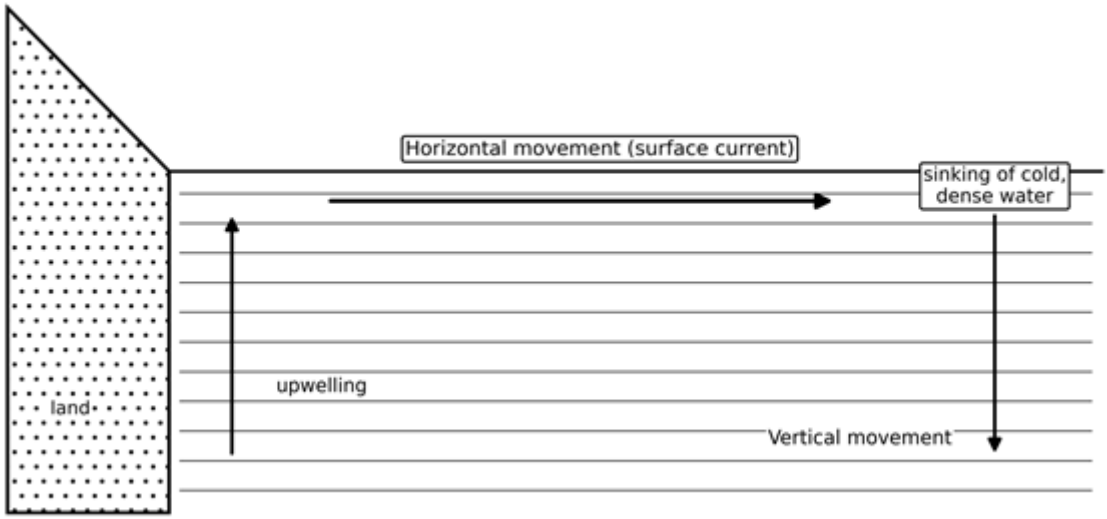


Figure 6.27: *Horizontal and vertical movements of ocean water*

How to Draw It
Draw an ocean with a coast on one side. Use a long horizontal arrow along the surface for the current to show horizontal movement, an upward arrow near the coast for upwelling, and a downward arrow further out for the sinking of cold, dense water. Label the horizontal and vertical movements.

Question 69

The warm current that washes the Tanzanian coast and the cool current that chills the shores of Namibia both belong to the great system of ocean currents. Explain ocean currents and how they are grouped.

Model Answer

Ocean currents are the horizontal movements of surface water, and they are grouped into warm and cool currents according to the water they carry.

Warm currents carry water from the warm tropics toward the cooler higher latitudes, while cool currents carry cold water from the high latitudes or from the depths back toward the Equator, often with upwelling along the western coasts of continents. The currents are driven mainly by the prevailing winds, and they are deflected by the shape of the continents and by the rotation of the Earth. The broad eastward movement of water in the southern ocean, driven by the westerly winds, is called the west-wind drift. The warm current along the East African coast keeps Tanzanian waters warm, while the cool Benguela current chills the coast of Namibia.

Question 70

What keeps the water of the world ocean turning over, from the Equator to the poles and from the surface to the deep, comes down to a few master controls. Account for the main factors that control ocean water circulation.

Model Answer

Ocean water circulation is driven by four main controls that together keep the water turning over.

1) **Water salinity:** saltier water is denser and sinks, so differences in salinity set the water moving, as where a salty body meets a fresher one.
2) **Water temperature:** the surface gains heat at the Equator and loses it at the poles, so warm surface water moves poleward and cold water sinks and returns, carrying heat around the globe.

3) **Surface wind:** the prevailing winds drive the surface currents, as the trade winds push the equatorial currents westward.

4) **The Coriolis effect:** the rotation of the Earth deflects the currents, to the right in the northern hemisphere and to the left in the southern, curving them into great loops.

Together these controls keep the water off the Tanzanian coast part of a circulation that reaches from the Equator to the poles.

REAL QUESTIONS

Question 71

Tanzania's water problems range from dry boreholes on the central plateau to floods in the Kilombero and pollution in the lakes, and a different branch of hydrology answers each. As a water officer, explain how the branches of hydrology guide the management of water in Tanzania.

Model Answer

Each branch of hydrology answers a particular Tanzanian water problem, so together they guide the whole task of managing the country's water.

1) **Surface hydrology:** measures the flow of rivers like the Rufiji and the level of Lake Victoria, guiding water supply and irrigation.

2) **Groundwater hydrology:** finds and protects the aquifers that feed the boreholes of the dry central plateau around Dodoma and Singida.

3) **Hydrometeorology:** forecasts the floods and droughts that strike the Kilombero Valley and the semi-arid centre.

4) **Isotope hydrology:** traces the origin and age of water, telling recent recharge from old, fossil water.

5) **Ecohydrology:** studies how the wetlands and forests of the Uluguru store and release water.

Question 72

A hydrologist studying two sub-basins of the Rufiji finds that the same rainfall behaves quite differently in each, although the total water of the cycle is unchanged. Explain why the hydrological cycle varies with the physical characteristics of a place.

Model Answer

The total water in the cycle stays constant, but the way it is shared among evaporation, runoff, infiltration and storage changes from place to place with the physical characteristics of the land.

Because the cycle is a closed system, the same rainfall is divided differently where the ground differs. On a steep, bare, clay sub-basin of the Rufiji most of the rain runs off at once as surface runoff and little soaks in, so the streams flood and the groundwater is poorly recharged. On a gentle, wooded, sandy sub-basin the same rain is intercepted, infiltrates and is stored, so the runoff is slow and the dry-season flow is well kept up. The slope, the soil, the rock, the vegetation and the temperature each shift the balance, which is why the cycle, though constant overall, looks different in every catchment.

Question 73

Farmers in the hot, dry plains around Dodoma lose much of their irrigation water to the air before their crops can use it. Advise them, in clear points, on how to reduce the loss of water to the atmosphere from their plots and ponds.

Model Answer

The farmers can cut their losses to evaporation and transpiration by shading the soil, watering wisely and sheltering their water.

1) **Mulch the soil:** cover the ground with grass or crop residues to shade it and cut evaporation from the soil surface.

2) **Water at the right time:** irrigate in the cool of the evening or early morning rather than in the heat of the midday Sun.
3) **Use drip or furrow irrigation:** deliver water to the roots instead of flooding a wide surface that evaporates freely.
4) **Shelter the ponds:** shade or cover the storage ponds and plant windbreaks to slow the drying wind across them.
5) **Keep a crop cover:** grow cover crops or practise agroforestry to shade the ground and lower the evapotranspiration loss.

Question 74

Two rice schemes in the Usangu plains, one flooded across a wide field and one watered under drip lines with a mulch, return very different amounts of water to the air. Account for how the management of land decides the rate of evapotranspiration.

Model Answer

How land is managed strongly decides the rate of evapotranspiration, because management changes how much water is supplied and how much of the surface is left exposed.

Where a field in the Usangu is flood-irrigated, water is spread over a wide, open surface and a great deal evaporates, so the loss is high. Under sprinkler irrigation the loss is medium, and under drip irrigation, which wets only the root zone, it is low. Mulching the surface with grasses shades the soil and cuts the direct heating that drives evaporation, lowering the loss further, while heavy use of fertiliser raises it, since the more vigorous plants take up and transpire more water. So the flooded scheme returns far more water to the air than the mulched, drip-fed one beside it, which is why the choice of method matters for every litre stored.

Question 75

As a Form Six student with knowledge of the Space and Dynamic topic, you are asked why rainfall is so unevenly spread across Tanzania and the world. Explain six factors affecting the distribution of precipitation.

Model Answer

Rainfall is unevenly distributed because six main factors decide how much of it reaches the ground in a given place.

1) **Distance from the Equator:** near the Equator, as in the Lake Victoria basin, heavy convectional rain falls, while the subtropics are dry.
2) **Altitude:** highlands force air to rise and cool, so mountains such as Kilimanjaro and the Uluguru are far wetter than the plains.
3) **Ocean currents:** a warm current off a coast adds moisture and rain, while a cool current brings dry, stable air.
4) **Prevailing winds:** onshore winds from the sea bring rain inland, while offshore winds from the land are dry.
5) **Nature and shape of the continent:** deep interiors far from the sea, like central Tanzania, receive less rain than the coast.
6) **Presence of water bodies:** large lakes and seas are evaporating surfaces that feed rain to nearby land, as Lake Victoria does to its basin.

Question 76

The afternoon thunderstorms of Mwanza, the wet windward slopes of the Uluguru and the converging rains of the long wet season are all different in origin. Account for the types of rainfall that bring Tanzania its rain.

Model Answer

Tanzania receives its rain from three kinds of process, which fall in different places and at different seasons.

1) **Convectional rainfall:** strong daytime heating around the Lake Victoria basin lifts warm moist air into towering clouds that give heavy afternoon thunderstorms, the commonest equatorial type.
2) **Orographic rainfall:** moist winds forced up the windward slopes of highlands such as the Uluguru, the Usambara and Kilimanjaro cool and drop heavy rain, leaving a dry rain shadow beyond.
3) **Convergence (cyclonic) rainfall:** where the Inter-Tropical Convergence Zone crosses the country, converging moist air rises and brings the steady rains of the wet seasons.

Question 77

In a forested catchment on the Uluguru, the amount of rain caught by the trees before it reaches the ground changes from one storm to the next. Describe how precipitation determines the quantity of interception in a catchment.

Model Answer

The quantity of interception depends closely on the precipitation, because the amount, duration, intensity and form of the rain decide how much the canopy can hold and lose.

When the rain is light and falls gently over a long time, as in drizzle, the canopy of the Uluguru forest catches and holds much of it, and a large share is lost again by evaporation before it ever reaches the soil, so interception is high. When the rain is heavy and intense, the storage capacity of the leaves is quickly filled and overtopped, the surplus drips through as throughfall and runs down as stemflow, and interception as a fraction of the total falls. Frequent small showers separated by dry spells give the greatest interception loss, because the canopy dries between them and intercepts afresh each time. So it is the character of the precipitation, more than the trees alone, that sets how much is intercepted.

Question 78

As Dar es Salaam has spread, its tarmac roads, cemented yards and iron roofs have replaced the open ground, and the city now floods more readily after heavy rain. Explain how this change of land cover has reduced infiltration and raised the flood risk.

Model Answer

Covering the ground with hard, impermeable surfaces cuts infiltration and forces almost all the rain to run off, which is why a built-up city like Dar es Salaam floods more easily than open land.

On open, vegetated ground much of a downpour soaks in, because the soil is porous and the roots keep it open, so infiltration is high and only the surplus runs off. When the same ground is sealed under tarmac, concrete and roofing, the water can no longer enter the soil at all, so infiltration falls to almost nothing and nearly the whole rainfall becomes surface runoff. This runoff gathers quickly and in great volume in the drains and low ground, overwhelms them, and produces the flash flooding seen in parts of Dar es Salaam after heavy rain. The loss of the soil's natural infiltration is therefore the root of the worsening urban floods.

Question 79

When a storm breaks over a catchment near Mbeya, the rain that finally swells the river is only what is left after several losses along the way. Describe how precipitation is transformed into total runoff.

Model Answer

Precipitation becomes total runoff only after it has passed through a series of losses and stores, so the runoff is the surplus that the catchment cannot hold.

As the storm begins over a catchment near Mbeya, the first rain is caught on the leaves by interception and held in hollows as depression storage, while some evaporates and some soaks in by infiltration, so little runs off at first. As the rain continues and the soil nears saturation, the infiltration rate falls, the stores fill,

and the surplus begins to flow over the surface as surface runoff. Below ground, water that infiltrated moves sideways as interflow and slowly downward to feed the baseflow. The total runoff reaching the river is the sum of this surface runoff, the interflow and the baseflow, all of it the water left once interception, storage, evaporation and infiltration have taken their share.

Question 80

As a hydrologist working in a single river basin such as the Pangani, you find that the same rainfall produces a fast flood at one place and a slow, steady rise at another. Explain why different locations within one basin respond differently to the same rain.

Model Answer

Different parts of one basin respond differently to the same rain because their slope, soil, rock, vegetation and position are not the same.

1) **Slope:** steep upper slopes shed water fast and flood quickly, while gentle lower ground lets water collect and soak in.
2) **Soil and rock:** places on clay or bare rock shed the water, while places on sand or porous rock absorb it.
3) **Vegetation:** well-wooded parts intercept and slow the water, while cleared or built-up parts speed it off.
4) **Position in the basin:** the lower reaches receive the gathered runoff of the whole basin and rise later but higher, while the headwaters respond at once.
5) **Land use:** cultivated, compacted or paved ground runs off faster than land under natural cover.

So within the Pangani basin the steep, cleared headwaters near the mountains flood fast, while the gentle, sandy lower plains rise slowly.

Question 81

Foresters argue that protecting the woodland on the Uluguru slopes will reduce the flash floods that reach the towns below. Explain how a vegetation cover reduces overland flow.

Model Answer

A vegetation cover reduces overland flow in several linked ways, all of which hold the water back or help it soak in rather than rush over the surface.

1) **Interception:** the canopy catches the rain and slows it, so less reaches the ground at once and some is evaporated away.
2) **Better infiltration:** roots open the soil and keep it porous, so more water soaks in instead of running off.
3) **Slower flow:** stems, litter and undergrowth roughen the surface and slow the water that does run, giving it time to infiltrate.
4) **Soil protection:** the cover shields the soil from the beating rain that would otherwise seal its pores and keeps infiltration high.

So protecting the woodland on the Uluguru keeps more of each storm in the soil and slows the rest, which is why the cleared slopes flood the towns below far more readily than the forested ones.

Question 82

Two villages, A and B, on the variable rocks of the central plateau each sank a well; the well in village A yields water all year, while the well in village B dried up for several months. Explain the possible reasons for such variation.

Model Answer

The two wells differ because the rainfall, the rock, the depth and the setting that feed them are not the same.

1) **Rainfall and recharge:** village A may lie where rainfall is higher and recharges the aquifer well, while village B is in a drier place with little recharge.
2) **Rock permeability:** village A may sit on porous, permeable rock that stores much water, while village B is on impermeable rock with a poor, low water table.
3) **Depth of the well:** the well in A may reach the zone of permanent saturation, while the well in B reaches only the intermittent zone and dries when the table falls.
4) **Position in the landscape:** village A may lie in a valley where the water table is near the surface, while village B is on high ground where it lies deep.
5) **Evaporation and use:** high evaporation and heavy drawing of water in B may lower its table faster than the rains can refill it.

Such contrasts are common on the central plateau around Singida and Manyoni, where the rock and the depth to water can change over a short distance.

Question 83

As an environmental officer in a fast-growing town such as Dodoma that depends on boreholes, you must keep the groundwater clean and lasting. Explain the planning strategies you would use to maintain the quality and supply of groundwater.

Model Answer

Protecting a town's groundwater means controlling what pollutes it, guarding what recharges it, and regulating how much is drawn.

1) **Control the pollution sources:** site latrines, waste dumps and fuel tanks away from and below the boreholes, and line or seal them.
2) **Protect the recharge areas:** keep the ground where rain soaks in free of building and pollution so the aquifer is replenished.
3) **Regulate abstraction:** license and limit the number and pumping of boreholes so the water table is not drawn down faster than it recharges.
4) **Monitor the water:** test the wells regularly for pollutants and watch the level of the water table so problems are caught early.
5) **Educate the public:** teach proper waste disposal and water saving, and treat sewage before it can seep into the ground.

Question 84

In much of semi-arid Tanzania the borehole is the difference between a village that survives the dry season and one that does not. To what extent is groundwater valuable to the community?

Model Answer

Groundwater is of very great value to dry-land communities, although that value has limits that must be respected.

1) **Reliable water supply:** groundwater keeps flowing when the streams have dried, giving homes and livestock water through the dry season around Tabora and Shinyanga.
2) **Agriculture:** boreholes water gardens and herds and support farming where surface water fails.
3) **Clean water:** it is naturally filtered and low in salt, so it is often safer to drink than open surface water.
4) **Towns and industry:** it supplies the growing towns of the dry interior where rivers are few.

Yet its value has limits, since groundwater recharges slowly and can be over-pumped, polluted or made salty, so it serves only as long as it is used carefully. On balance, for the dry-land communities of central Tanzania it is the most valuable water they have.

Question 85

The wells of a busy district near Mwanza and the streams that cross it are both losing their cleanness to careless waste. Suggest possible ways of minimising the pollution of both ground and surface water.

Model Answer

Both ground and surface water can be kept clean by controlling waste, treating sewage, managing farm chemicals and guarding the catchments.

1) **Proper waste disposal:** collect and treat household and industrial waste instead of dumping it where it can leach into the water.
2) **Treat sewage:** build and use proper sewage and septic systems so that human waste does not reach the wells and streams.
3) **Control farm chemicals:** use fertilisers and pesticides sparingly and away from water, and keep buffer strips of grass along the streams.
4) **Site and line stores safely:** keep fuel tanks, latrines and dumps away from water sources and line them to prevent leaks.
5) **Protect catchments and educate:** keep the catchments wooded to filter the runoff, and teach the community of Mwanza to guard its water.

Question 86

The nature of the surface and the geological structure are said to be the main forces that shape the drainage of an area. Discuss this statement with reference to Tanzania.

Model Answer

The drainage of an area is shaped chiefly by the nature of its initial surface and slope and by its geological structure, since these decide where the streams begin and where they can cut.

The initial surface and slope set the first direction of flow, so consequent streams run down the regional slope, as the Pangani runs from the high ground of Kilimanjaro and Meru. The geological structure then guides the network, because streams follow the lines of weak rock, the faults and the joints, and avoid the resistant outcrops. In the rifted north of Tanzania the faulting has thrown the rivers into closed basins of inland drainage toward Lake Eyasi and Lake Natron, while on uniform rock a tree-like dendritic pattern develops and on a volcanic cone like Kilimanjaro a radial one. So although climate provides the water, it is the surface and the structure that decide the shape the drainage takes.

Question 87

The nature of the rock and the relief structures of an area determine the development of its river patterns. With the aid of diagrams, justify this statement in six points.

Model Answer

Rock and relief control the development of river patterns, because the streams follow the slope, the structure and the differences in rock hardness, so each pattern records a particular structure.

1) **Dendritic pattern:** develops on uniform rock of even hardness, where the streams branch freely like a tree because no structure guides them.
2) **Trellis pattern:** develops on folded sedimentary rock, where the main streams follow the soft valleys and the tributaries join at right angles along the hard ridges.
3) **Radial pattern:** develops on a dome or a volcanic cone such as Kilimanjaro, where the streams flow outward down the slopes.

4) **Annular pattern:** develops on a dissected dome of alternating hard and soft rock, where the streams curve along the rings of weak rock.

5) **Rectangular pattern:** develops where joints and faults cross at right angles, so the streams bend sharply to follow them.

6) **Centripetal pattern:** develops in a basin or crater, where the relief gathers the streams inward to the centre.

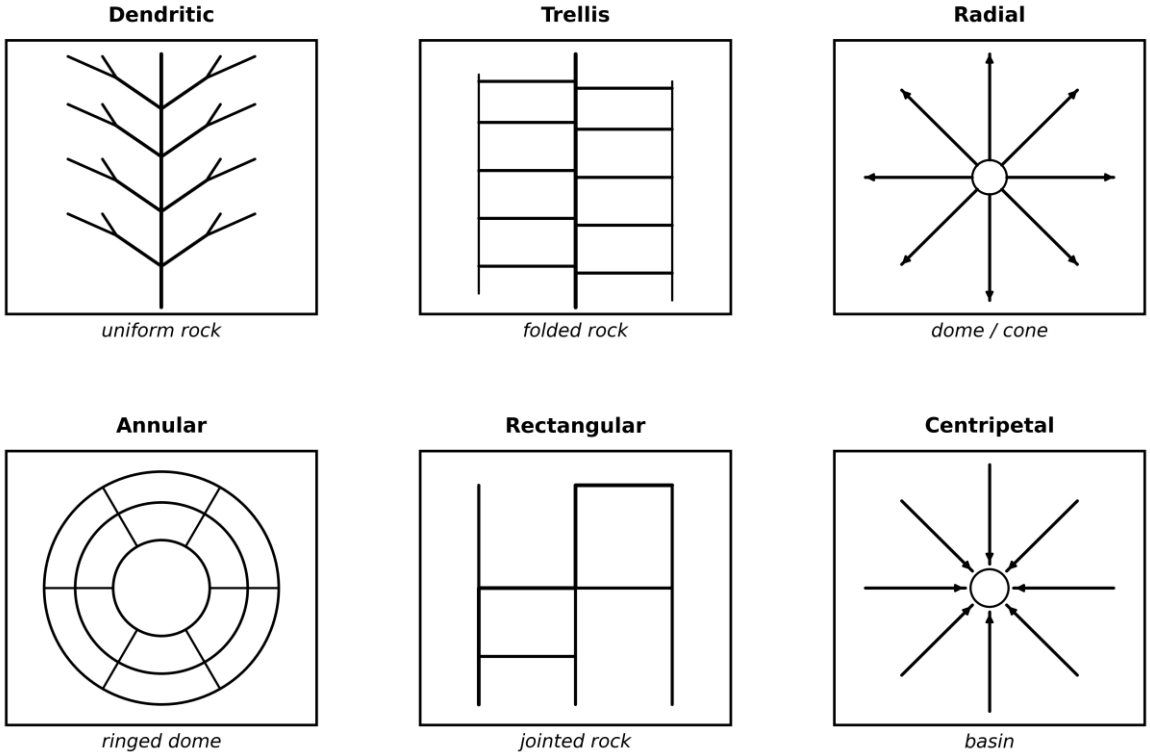


Figure 6.28: *Rock and relief control of drainage patterns*

How to Draw It
Draw small sketches of the patterns side by side. Show a tree-like network on uniform rock for dendritic, right-angle tributaries on folded rock for trellis, outward streams on a dome for radial, curving streams on a ringed dome for annular, sharp right-angle bends on jointed rock for rectangular, and inward streams in a basin for centripetal. Label each pattern with the structure that produces it.

Question 88

Using examples of socio-economic activities in your own area, explain how they contribute to the pollution of surface water.

Model Answer

Many everyday activities pour wastes and chemicals into the rivers and lakes, and together they pollute the surface water.

1) **Farming:** fertilisers, pesticides and soil washed from the fields run off into the rivers, as from the farms of the Kilombero.

2) **Industry and mining:** factories and mines discharge chemicals and silt into the streams, as around the goldfields of Geita near Lake Victoria.

3) **Domestic waste and sewage:** towns pour untreated sewage and rubbish into the rivers and the lake, as into the Mwanza gulf of Lake Victoria.

4) **Livestock:** cattle watering and dung along the banks foul the streams and ponds.

5) **Fishing and boats:** oil, fuel and waste from boats and landing sites pollute the lakes.

Question 89

Describe the concept of stream order as proposed by R. E. Horton and refined by A. N. Strahler, and show the advantages and disadvantages of the method.

Model Answer

Stream order is a way of ranking the streams of a network by their place in its branching, first set out by Horton and refined by Strahler.

In the Strahler method the smallest unbranched streams at the head of the network are called first-order streams. Where two first-order streams meet they form a second-order stream, where two second-order streams meet they form a third-order stream, and so on. The order rises only when two streams of the same order join, so a low-order stream entering a higher one does not raise its order, and the order of the whole basin is that of its largest trunk stream, as could be worked out for the Rufiji network.

Advantages: it is simple and objective, it allows different networks to be compared, and the order relates well to the basin's size, its discharge and the length of its streams.

Disadvantages: it ignores the many small tributaries that join a higher-order stream, it depends on the scale of the map since a finer map shows more first-order streams, and it treats all junctions alike however large or small.

False Confidence Alert
Do not think that any stream joining another raises its order. The order rises only when two streams of the same order meet, so a first-order stream joining a third-order one leaves it third-order.

Question 90

Tanzania is endowed with many lakes, which were formed in a variety of ways. Discuss the modes of formation that gave the country its lakes.

Model Answer

Tanzania's many lakes were formed by several different processes, from the movement of the crust to the hand of people.

1) **Crustal warping:** Lake Victoria fills a broad downwarp of the crust between the two rift arms.
2) **Rifting (faulting):** Lake Tanganyika, Lake Nyasa and Lake Rukwa fill deep troughs dropped between faults in the Rift Valley.
3) **Vulcanicity:** Lake Chala fills a volcanic crater, and Lake Empakaai a caldera in the Ngorongoro highlands.
4) **Deposition:** ox-bow lakes lie along the flood plains of rivers such as the Kilombero.
5) **Human action:** Lake Mtera and the Nyumba ya Mungu reservoir were made by damming rivers for power and water.

Question 91

Describe the formation of five dammed lakes and examine three of their negative effects on the physical environment and human life.

Model Answer

A dammed lake is one held back by a barrier, whether of lava, debris, deposition or a man-made wall, and five kinds form in this way.

1) **Lava-dammed lake:** a lava flow blocks a valley and ponds water behind it, as at Lake Kivu.
2) **Landslide-dammed lake:** mass-movement debris blocks a valley and holds back a temporary lake.

3) **Man-made reservoir:** a dam built across a valley stores water, as at Mtera and Nyumba ya Mungu.

4) **Ox-bow lake:** deposition seals the neck of a cut-off meander, leaving a curved lake.

5) **Barrier (lagoon) lake:** a sand bar built across a bay dams a lagoon behind it.

Three negative effects follow especially from the man-made reservoirs. First, they flood farmland and homes and displace people, as the dams of the Rufiji basin have done. Second, the still water breeds mosquitoes and bilharzia snails and drowns the former river life. Third, the dam traps the silt that once fertilised the land below, starving the lower valley and changing the river's flow.

Question 92

The Mtera and Nyumba ya Mungu reservoirs were built at great cost to serve Tanzania's development, yet they also brought losses. Assess the value of man-made lakes to Tanzania.

Model Answer

Man-made lakes are of great value to Tanzania's development, although they bring real costs that must be set against their benefits.

1) **Hydroelectric power:** the dams at Mtera and Kidatu and the Julius Nyerere plant on the Rufiji generate much of the national electricity.

2) **Irrigation:** the stored water feeds irrigation schemes and steadies the supply through the dry season.

3) **Water supply and fisheries:** the reservoirs supply towns and support a fishing industry.

4) **Flood control:** the dams hold back floodwater and release it steadily.

Against these stand real costs, since the reservoirs flooded farmland and displaced communities, trapped the silt that once fertilised the lower valley, and made still water where disease can breed. On balance, for a country that needs power and water the man-made lakes are highly valuable, provided their human and environmental costs are managed.

False Confidence Alert
Do not weigh a reservoir by its power alone. The same dam that lights cities also floods farmland, displaces people and traps the silt that fed the valley below, so its true value is its benefits minus these costs.

Question 93

You have been appointed to address a meeting in your village on how human activities are a threat to wetlands. Using eight points, substantiate the statement.

Model Answer

Human activities threaten wetlands such as the Kilombero and the Malagarasi in many ways, each of which degrades or destroys them.

1) **Drainage for farming:** people drain the wetland to plant rice and sugar, destroying the very feature that made it valuable.

2) **Overgrazing:** herds trample and strip the wetland vegetation and expose the soil.

3) **Pollution:** farm chemicals, sewage and waste poison the water and the life within it.

4) **Over-fishing:** too much fishing, and the use of poisons and fine nets, empties the wetland of fish.

5) **Burning:** setting fire to the reeds and grasses to clear or to hunt destroys the cover.

6) **Cutting vegetation:** harvesting reeds, papyrus and trees faster than they can regrow degrades the wetland.

7) **Building and settlement:** putting up houses, roads and dams on or around the wetland blocks its water and shrinks it.

8) **Brick-making and water abstraction:** digging clay and drawing off water for irrigation dry and scar the wetland.

Question 94

Many people treat a wetland as idle wasteland to be filled or drained, yet wetland areas are not wasteland. Using eight points, explain how people wrongly turn wetland areas into wasteland.

Model Answer

People turn living, productive wetlands such as the Rufiji Delta and the Kilombero Valley into true wasteland by abusing them in eight common ways.

1) **Draining them for farmland:** which destroys the very feature that made them valuable.
2) **Filling them:** with soil and rubbish to make building plots.
3) **Polluting them:** with sewage, chemicals and solid waste until the life within them dies.
4) **Over-cultivating their edges:** so that the soil erodes and silts them up.
5) **Cutting and burning their vegetation:** until the ground is left bare.
6) **Overgrazing them:** so that the cover is lost and the soil is trampled hard.
7) **Damming or diverting their rivers:** so that the wetland is starved of water and dries out.
8) **Mining sand and clay from them:** leaving scarred, lifeless pits.

Each of these treats a system that purified water, stored carbon and fed thousands as if it were empty ground, and so turns a wetland into wasteland.

Question 95

The Rufiji Delta, the Kilombero Valley and the Malagarasi support millions of Tanzanians who may never call them wetlands. Assess the value of Tanzania's wetlands to the people who live around them.

Model Answer

Tanzania's wetlands are of great value to the people around them, which is exactly why their loss would be so costly.

1) **Fisheries:** the wetlands are rich breeding grounds that supply much of the country's fish and protein.
2) **Farming:** their fertile, watered soils grow rice and sugar, as in the Kilombero Valley.
3) **Grazing and water:** they give dry-season pasture and water for livestock.
4) **Building and craft materials:** reeds, papyrus and clay supply thatch, mats and bricks.
5) **Water purification and flood control:** they clean the water and hold back the floods that would harm the towns.
6) **Biodiversity and tourism:** they shelter birds and wildlife that draw visitors.

Because so many livelihoods rest on the Rufiji, Kilombero and Malagarasi wetlands, they are of great value, and their loss to drainage and pollution would be a heavy blow to the people who depend on them.

Question 96

Juma, an oceanographer, concludes that different oceans and seas hold different concentrations of soluble salts. In six points, describe the determinants of the difference in salinity that he noticed.

Model Answer

The salinity of a sea or ocean is set by how much water is added or removed and how freely it mixes, which differ from place to place.

1) **Evaporation:** where evaporation is high, as in the hot, enclosed Red Sea, the water left behind is saltier.

2) **Precipitation and river inflow:** heavy rain and large rivers dilute the water and lower its salinity.

3) **Inflow from melting ice:** near the poles, melting ice freshens the water and lowers its salinity.

4) **Mixing by currents:** currents carry salty and fresh water about and even out the differences.

5) **Degree of enclosure:** a nearly closed sea with little exchange, like the Mediterranean, grows saltier than the open ocean, while the open Indian Ocean off Tanzania stays near the average.

6) **Temperature:** warm tropical water evaporates faster and tends to be saltier than cold water, other things being equal.

False Confidence Alert
Do not put all of salinity down to evaporation. River inflow, rainfall, melting ice, mixing by currents and how enclosed a sea is all change the salt content, so the hottest sea is not automatically the saltiest.

Question 97

Analyze six factors that influence the movement of ocean water, whether across its surface or through its depths.

Model Answer

The movement of ocean water, both at the surface and in the depths, is driven by six main factors.

1) **Prevailing winds:** the trade winds and the westerlies drag the surface water along to make the currents, as felt along the East African coast.

2) **Differences in temperature:** warm water is lighter and spreads poleward while cold water sinks, driving a deep circulation.

3) **Differences in salinity:** saltier, denser water sinks below fresher water and sets the deep water moving.

4) **The Coriolis effect:** the Earth's rotation deflects the moving water, curving the currents to the right in the north and to the left in the south.

5) **The shape of the coasts and continents:** the land deflects the currents and channels them along the coasts.

6) **The Sun and Moon (tides):** their gravitational pull raises the tides that move water in and out along the shores.

Question 98

In three points classify the global winds, and assess the effects of wind and ocean currents on temperature and rainfall, giving two points for each effect.

Model Answer

The global winds fall into three belts, and together with the ocean currents they strongly shape both temperature and rainfall.

1) **Trade winds:** blow from the subtropical highs toward the Equator, from the north-east and the south-east.

2) **Westerlies:** blow from the subtropical highs toward the higher latitudes, from the west.

3) **Polar easterlies:** blow from the polar highs toward the lower latitudes, from the east.

Effects on temperature

First, warm winds and warm currents raise the temperature of the coasts they reach, as the warm current keeps the Tanzanian coast mild. Second, cold winds and cool currents lower it, as the cool Benguela current chills the coast of Namibia.

Effects on rainfall

First, onshore winds crossing a warm current pick up moisture and bring rain to the coast. Second, winds crossing a cool current or blowing offshore stay dry and bring drought, which is why coasts beside cool currents, like the Namib beside the Benguela, are deserts.

HOT QUESTIONS

Question 99

Hydrology is sometimes called the meeting place of all the other branches of physical geography, since water touches the air, the rocks, the soil and life alike. Assess the claim that hydrology is an integrating science.

Model Answer

The claim is largely sound, because the movement of water links every sphere of the physical world, although hydrology remains a distinct science with its own methods.

In its favour, water passes through and binds together all the spheres. It rises from the ocean and the land into the atmosphere by evaporation, falls back through the weather as precipitation, runs over and soaks into the rocks and soils of the lithosphere, and is taken up and released by the plants of the biosphere. To follow a single drop from the Indian Ocean over the Uluguru and down the Ruvu is to cross all four spheres, so hydrology cannot be studied apart from climatology, geology, pedology and biology.

Yet hydrology is not merely the sum of the others, since it has its own laws, its own quantities such as discharge and infiltration, and its own methods of measurement and forecasting, so it stands as a science in its own right.

So hydrology is best seen as an integrating science that draws the spheres together through the common thread of water, while keeping its own distinct identity.

Question 100

A teacher tells the class that the hydrological cycle has neither a beginning nor an end. Substantiate this statement.

Model Answer

The statement is largely true, because the cycle turns continuously with no fixed starting or finishing point, although strictly the water itself once had an origin.

In its favour, the cycle is a closed loop driven endlessly by the Sun and gravity. Water evaporates from Lake Victoria, condenses into cloud, falls as rain, runs down the Kagera and back to the lake, only to rise again, and no point in this round can be called the first or the last. Because the total water stays constant while only its distribution changes, the wheel simply keeps turning.

Yet one may object that the water on Earth did have an ultimate origin in the planet's early history, and that any single molecule must at some moment have entered the cycle, so the cycle is endless in its working rather than literally without beginning.

So for all practical purposes the hydrological cycle has neither a beginning nor an end, since it has run ceaselessly for as long as there has been water and a Sun to lift it.

False Confidence Alert
Take 'endless' to mean ceaseless in its working, not that the Earth's water had no origin. The cycle is a loop with no first or last step, but the water in it did once come into being.

Question 101

The components of input, process, output and storage are said to be the key to understanding how water reaches the ground. Elaborate on how these components explain the working of the hydrological cycle.

Model Answer

Seen as a system of input, process, output and storage, the hydrological cycle becomes easy to follow, because each component names one part of the journey of water to and from the ground.

The input is the water that enters the system, almost all of it as precipitation, the rain that feeds a catchment like the Pangani. The processes are the movements that act on that water once it arrives, since infiltration carries it into the soil, runoff carries it over the surface, percolation takes it down to the groundwater, and transpiration and condensation move it through the plants and the air. The storage is the water held for a time along the way, in the soil, the rocks, the rivers and the lakes, as in Lake Jipe and the aquifers below. The output is the water that leaves, chiefly by evaporation and transpiration back to the atmosphere.

So by sorting the cycle into what comes in, what happens to it, what is held and what goes out, the input-process-output-storage view explains exactly how, and how much, water reaches and leaves the ground in any catchment.

Question 102

Geographers measure evaporation and transpiration together as one quantity, evapotranspiration, rather than apart. Examine why the two cannot easily be separated.

Model Answer

The two are combined because they happen at the same time, by the same driving forces, over the same ground, so that in practice they cannot be told apart.

In its favour, evaporation and transpiration go on side by side over any vegetated land, such as a maize field near Iringa, since water leaves the damp soil by evaporation while it leaves the plants by transpiration, and both are driven by the same heat, the same dry air and the same wind. No instrument can catch the vapour rising from the soil separately from the vapour leaving the leaves, because they mix in the same air the moment they form.

It is true that in special conditions one can dominate, as transpiration does over a dense crop and soil evaporation does over bare, wet ground, so the two are not identical processes.

So although evaporation and transpiration are distinct in nature, they are inseparable in practice, which is why they are measured and modelled together as evapotranspiration.

Question 103

Tanzania's farmers depend on rain that comes in three different ways, but not all of it is equally dependable. Assess which type of rainfall matters most for the country's agriculture.

Model Answer

All three types feed Tanzanian farming, but the convergence rainfall of the Inter-Tropical Convergence Zone matters most, because it brings the broad, seasonal rains on which the staple crops depend, although the other types are vital in their own places.

In its favour, the convergence rains of the long and short wet seasons fall over most of the country and set the calendar of planting and harvest for the staple crops, so the success of a whole season turns on whether these rains come and how long they last.

Yet the other types are indispensable where they fall. The orographic rain of the windward highlands waters the coffee and banana of Kilimanjaro and the Uluguru, and the convectional rain of the Lake Victoria basin gives that region its reliable afternoon storms, so no one type serves the whole country.

So while convergence rainfall is the most important for Tanzanian agriculture as a whole, the orographic and convectional types are decisive in the highlands and the lake basin, and the country depends on all three.

Question 104

It seems a paradox that the hottest deserts, where evaporation is fiercest, are also the driest places on Earth. Examine why deserts receive so little rain even though evaporation there is high.

Model Answer

The paradox dissolves once it is seen that high evaporation does not by itself make rain, because rain needs rising, cooling, saturated air, and the desert air is the opposite.

In its favour, evaporation only lifts water vapour into the air, while rain falls only when that vapour is cooled to its dew point and condenses, which needs the air to rise. Over deserts such as the Sahara and the Namib the air is sinking, not rising, under the subtropical high pressure, so it warms and dries instead of cooling, and the vapour never condenses. What little rain does form often evaporates again before it reaches the hot ground.

It is true that deserts beside cool ocean currents, like the Namib, are dry for a further reason, since the cool current chills and stabilises the air and starves it of moisture, but the result is the same.

So a desert is dry not for want of evaporation but for want of uplift, since without rising, cooling air the abundant vapour simply stays aloft, and the land below stays parched.

False Confidence Alert
Do not think a hot, evaporating place must be rainy. Evaporation only lifts vapour into the air; rain needs that vapour to rise and cool, and over a desert the air is sinking and warming, so it never condenses.

Question 105

Foresters and engineers watching a catchment care less about how much rain falls than about how much the soil and trees can hold back. Assess the view that interception and infiltration are the true controls of runoff.

Model Answer

The view is largely sound, because interception and infiltration are the losses that decide how much rain becomes runoff, although the rainfall itself and the slope also matter.

In its favour, the rain that is caught on the canopy and the rain that soaks into the soil never become surface runoff, so the more a catchment can intercept and infiltrate, the less it floods. A well-wooded, porous catchment on the Uluguru holds back much of a storm and releases it slowly, while a cleared, compacted one sheds nearly all of it at once, even under the same rain.

Yet these losses are not the whole story, since a downpour heavy and long enough will overwhelm any canopy and saturate any soil, and a steep slope will shed water however porous it is, so the rainfall and the relief set limits on what interception and infiltration can do.

So interception and infiltration are the chief controls of runoff within a given storm and slope, which is why protecting the soil and the forest is the surest way to tame a catchment's floods.

Question 106

When a Tanzanian town floods within an hour of a storm, the water that drowns its streets has taken the quickest path to the river. Assess which type of runoff poses the greater flood risk.

Model Answer

Surface runoff poses by far the greater flood risk, because it reaches the river fastest and in the greatest volume, although baseflow matters for the opposite reason of keeping rivers alive.

In its favour, surface runoff, or overland flow, travels straight over the ground to the channel and arrives within minutes, so it is what produces the sudden, dangerous flash floods seen in built-up Dar es Salaam, where the sealed surfaces send almost the whole storm overland at once. Sub-surface flow and baseflow,

by contrast, move slowly through the soil and rock and arrive long after, so they swell rivers gently rather than flooding them.

Yet baseflow is not without its role, since it sustains the dry-season flow that surface runoff cannot, and a soil so saturated that it can no longer infiltrate will turn even gentle rain into damaging overland flow.

So surface runoff is the type to fear in a flood, which is why keeping the ground open to infiltration, rather than sealing it under concrete, is the key to protecting a town.

Question 107

It is often said that the movement of groundwater is governed by the porosity of the rock. Discuss this view.

Model Answer

The view is only partly true, because porosity decides how much water a rock can hold, but it is permeability, the connection of the pores, that decides whether the water can move.

In its favour, porosity does matter, since a rock with no pores, like solid granite, holds no water to move, while a porous rock like sandstone holds a great deal, so without pore space there can be no groundwater flow at all. To this extent the movement does depend on porosity.

Yet porosity alone does not move water. Clay is highly porous, holding much water in its tiny pores, but those pores are so small and unconnected that the water cannot pass, so the clay is impermeable and the water stagnant. It is permeability, the size and connection of the pores, together with the slope of the water table, that truly governs the flow, as the slow seep through the rocks of the Makonde Plateau shows.

So while porosity sets how much water a rock can store, it is permeability that governs how that water moves, and the two must not be confused.

False Confidence Alert
Do not credit groundwater movement to porosity alone. Porosity is how much water a rock holds; permeability is whether the pores connect so the water can flow, and a porous clay holds much water yet moves none.

Question 108

Unmonitored groundwater is likely to cause health risks to those who use it. Justify this statement.

Model Answer

The statement is sound, because groundwater that is never tested can become polluted without warning, and the people who drink it may fall ill before the danger is ever seen.

In its favour, groundwater looks clean and clear even when it is not, since it carries no obvious colour or smell, so pollution from a leaking latrine, a waste dump or farm chemicals can enter a borehole unnoticed. Around growing towns like Mwanza, where pit latrines sit close to shallow wells, the water can carry the germs of cholera, typhoid and dysentery, or a slow load of nitrates and heavy metals, and without testing no one knows until people sicken.

It is true that some groundwater, deep and well protected, stays pure for years, so not every unmonitored well is dangerous.

So because the pollution of groundwater is hidden and its effects on health are serious, monitoring is essential, and to leave it unmonitored is indeed to risk the health of all who use it.

Question 109

Subsurface and groundwater are said to be best understood through their vertical distribution. Justify this statement.

Model Answer

The statement is sound, because water below the ground is arranged in distinct layers from the surface downward, so reading it from top to bottom is the natural way to understand it.

In its favour, the ground beneath us is divided vertically into clear zones. At the top lies the zone of non-saturation, the aeration or vadose zone, where the pores hold both air and water and plants draw their moisture. Below it lies the water table, and beneath that the zone of saturation, where every pore is full of water and the aquifer is found. A well sunk near Singida passes through these zones in order, and only by knowing their vertical arrangement can one tell how deep to dig to reach lasting water.

It is true that groundwater also varies sideways, from one rock to the next, so the vertical picture is not the whole story.

So because water below ground is layered by depth into the unsaturated zone, the water table and the saturated zone, its vertical distribution is indeed the clearest key to understanding and using it.

Question 110

Drainage is sometimes called a faithful servant of the rocks beneath it. Justify the statement that a drainage system is a function of geological structure.

Model Answer

The statement is largely true, because the structure of the rocks guides where streams begin, where they run and what pattern they make, although slope and climate also play their part.

In its favour, the streams of a region follow the lines the structure offers them. They run along the faults, the joints and the bands of weak rock and avoid the resistant outcrops, so a folded structure gives a trellis pattern, a jointed one a rectangular pattern, and a dome a radial pattern, as on Kilimanjaro. In the rifted north of Tanzania the faulting has turned the rivers inward to closed basins toward Lake Eyasi and Lake Natron, a drainage shaped wholly by structure.

Yet structure is not the only master, since the initial slope of the land sets the first consequent streams before the structure takes hold, and the climate decides whether there is enough water to cut at all.

So a drainage system is very largely a function of geological structure, which guides the network, though the slope that starts it and the climate that feeds it share in the result.

Question 111

Surface water and groundwater are often treated as two separate resources, yet they are said to be reservoirs that feed into each other. Discuss.

Model Answer

The statement is true, because surface water and groundwater are not separate stores but two parts of one system that constantly exchange water.

In its favour, the two pass water to each other all the time. Where a river runs higher than the water table it loses water downward, recharging the groundwater, as a flooding river does across its plain. Where the water table stands higher than the river, the groundwater seeps back up to feed the channel, which is exactly what keeps the Ruvu and the Pangani flowing through the dry season after the rains have stopped. The same water moves back and forth between the surface and the rock.

It is true that the exchange can be slow, and that a polluted or over-pumped groundwater takes long to show its effect on the rivers, so the link is real but not always quick.

So surface water and groundwater are indeed one connected resource, two reservoirs feeding each other, which is why neither can be used or protected without regard to the other.

Question 112

Of all the influences on a river, climate is said to be the single most important factor affecting the volume of its water. Discuss this view.

Model Answer

The view is largely sound, because climate supplies and removes the water of a river through rainfall and evaporation, although the rocks, relief and vegetation of the basin also shape the flow.

In its favour, climate is the source of all a river's water and the chief cause of its loss. The rainfall of the basin decides how much water enters, so the great flow of the Rufiji reflects the heavy rains of its highlands, while the small, seasonal flow of a central river reflects the meagre rain of the semi-arid plateau. Temperature and evaporation then decide how much is lost on the way, so a hot climate strips a river even as it flows, and where the rains fail in drought even a large river shrinks.

Yet climate does not act alone, since the rock decides how much water is stored and released, the relief decides how fast it runs off, and the vegetation evens out the flow, so two basins under the same climate can carry very different rivers.

So climate is indeed the single most important control of a river's volume, because it sets the supply and the loss, though the rock, relief and vegetation of the basin decide how that climate is finally expressed in the flow.

Question 113

A river rarely keeps the same course for long, but works steadily to abandon its bends and strike a new path. With the aid of a diagram, show how a river changes its course.

Model Answer

A river changes its course chiefly by the migration and cutting-off of its meanders, swinging sideways across its flood plain until it abandons a loop and takes a straighter path.

On its lower course a river swings in great meanders. On the outer bank of each bend the current is fastest, so it erodes and the bend grows, while on the inner bank the current is slow, so it deposits and builds a slip-off slope. As the bends enlarge, the necks of land between them grow narrower, until in a flood the river cuts straight through a neck, taking the shorter path. The cut-off loop is then sealed by deposition and left to one side as an ox-bow lake, while the river flows on in its new, straighter course. Repeated across the plain, as on the flood plains of the Kilombero, this is how a river steadily remakes its own channel.

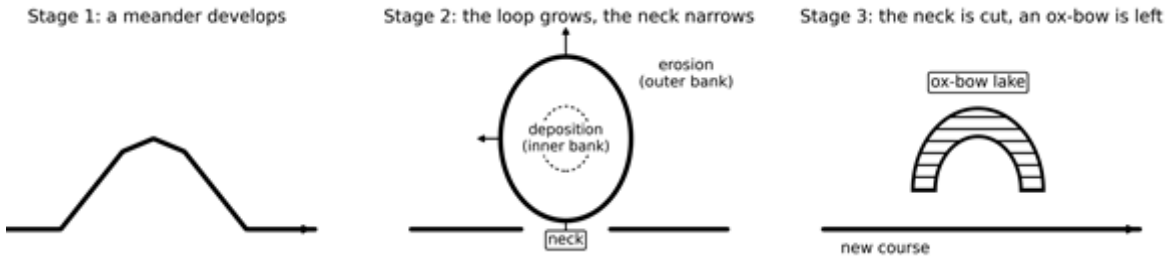


Figure 6.29: *How a river changes its course*

How to Draw It
Draw the change in three stages. In the first show a river in a gentle meander. In the second show the meander grown into a tight loop, with arrows marking erosion on the outer bank and deposition on the inner, and the neck narrowed. In the third show the neck cut through, the river flowing straight across, and the abandoned loop left beside it as an ox-bow lake. Label the erosion, the deposition, the neck, the new course and the ox-bow lake.

Question 114

The lakes of the world are most usefully grouped not by size or depth but by the process that made them. Describe the classification of lakes according to their modes of formation.

Model Answer

Lakes are best classified by the process that hollowed out or dammed the basin they fill, which gives several clear groups.

1) **Tectonic lakes:** made by earth movements, by the gentle warping that holds Lake Victoria or the faulting that holds Lake Tanganyika.
2) **Volcanic lakes:** made by volcanic activity, filling a crater or caldera as at Lake Chala, or held behind a lava flow as at Lake Kivu.
3) **Wind-eroded lakes:** made where desert wind deflates a hollow down to the water table, as in the Qattara depression.
4) **Depositional lakes:** made where deposition seals a basin, as in an ox-bow lake or a barrier lagoon.
5) **Glacial lakes:** made where ice has gouged or dammed a basin, common in once-glaciated lands.
6) **Landslide-dammed lakes:** made where a landslide blocks a river valley.
7) **Man-made lakes:** made by people damming a river, as at the Mtera and Nyumba ya Mungu reservoirs.

So from the rifting that made Tanganyika to the dam that made Mtera, every lake can be placed by the process that formed its basin.

Question 115

Tabulate the composition of ten big lakes of the world and suggest the dominant economic activity that each can support.

Model Answer

Ten of the world's big lakes, set out by their composition and the dominant economic activity each best supports, are as follows.

1) **Lake Victoria (East Africa):** a vast freshwater lake of crustal warping; supports a great fishing industry and water transport.
2) **Lake Tanganyika:** a deep freshwater rift lake; supports fishing and inter-territorial transport.
3) **Lake Nyasa:** a deep freshwater rift lake; supports fishing and tourism.
4) **Lake Rukwa:** a shallow, brackish inland lake; supports seasonal fishing.
5) **Lake Natron:** a shallow saline soda lake; supports soda extraction and flamingo tourism.
6) **Lake Chad:** a shallow freshwater lake; supports fishing, irrigation and herding.
7) **Caspian Sea:** the world's largest saline lake; supports oil and gas and sturgeon fishing for caviar.
8) **Lake Superior:** a huge freshwater glacial lake; supports shipping and fishing.
9) **Lake Baikal:** the deepest freshwater lake; supports fishing and tourism.
10) **Dead Sea:** an intensely saline lake; supports mineral extraction and health tourism.

So a lake's composition, whether fresh or saline, deep or shallow, largely decides the activity it can best support, from the fisheries of Lake Victoria to the soda of Lake Natron.

Question 116

Increasingly, governments pass laws and plans to protect wetlands that earlier generations would have drained. In the context of the services they provide, explain why wetlands are increasingly becoming an important conservation target.

Model Answer

Wetlands are increasingly protected because the world has come to recognise the many valuable services they quietly provide, services that are costly or impossible to replace once a wetland is lost.

1) **Water purification:** they filter sediment and absorb pollutants, cleaning the water that passes through, as the Kilombero does for its river.
2) **Flood control:** they hold back and slowly release storm water, sparing the towns downstream.
3) **Carbon storage:** their waterlogged soils lock up carbon, helping to slow climate change.
4) **Biodiversity:** they are among the richest of all habitats, sheltering fish, birds and wildlife.
5) **Livelihoods:** they support fisheries, farming, grazing and materials for millions, as in the Rufiji Delta and the Malagarasi.
6) **Shoreline and water supply:** they stabilise shores and recharge the groundwater.

Because these services were long taken for granted and are lost the moment a wetland is drained, and because so many are now disappearing, countries increasingly mark wetlands like the Rufiji and the Malagarasi as conservation targets protected by law.

Question 117

Wetlands are so varied that geographers classify them in more than one way at once. Describe the classification of wetlands based on their location and on their soil.

Model Answer

Wetlands are classified in two complementary ways, by where they lie and by the soil and vegetation they carry.

By location

By location, wetlands are either coastal or inland. Coastal, or tidal, wetlands lie along the oceans and estuaries where sea water and fresh water mix and the tides reach, and they are dominated by salt marshes and mangroves, as along the Tanga coast. Inland, or non-tidal, wetlands lie along streams and in poorly drained depressions and lake margins away from the tides, as in the Usangu flats and the Malagarasi.

By soil and vegetation

By soil and the plants it supports, wetlands are marshes, swamps, bogs and fens. Marshes are shallow waters of grasses and reeds on mineral-poor soil; swamps are wooded wetlands of trees on poorly drained mineral soil, as in the forested swamps of the Kilombero; bogs are wet, spongy peatlands fed only by rain and therefore acidic; and fens are peatlands of grasses fed by groundwater and therefore alkaline.

Question 118

Neither the ocean nor the atmosphere can be understood alone, since each drives the other. Show how the interaction between the ocean and the atmosphere controls the circulation of ocean water.

Model Answer

The circulation of ocean water is controlled by a constant give-and-take between the ocean and the atmosphere, in which the winds drive the water and the water in turn shapes the winds and climate.

The atmosphere acts first through its winds, since the trade winds and the westerlies drag the surface water along to make the great currents, pushing the equatorial currents westward and the drift eastward in the southern ocean. The Sun's uneven heating, an atmospheric matter, also sets up the differences in temperature and, through evaporation, in salinity that make warm water spread poleward and cold, salty water sink, driving the deep circulation. The ocean then acts back on the atmosphere, since the warm and cool currents it carries heat and cool the air above them, as the warm current warms the Tanzanian coast and the cool Benguela chills the Namibian, altering the winds and rainfall that drive the next round.

So the circulation of the ocean is the product of a loop between sea and sky, in which wind moves water and water moves weather, neither working without the other.

Question 119

Drawing on what you have seen in your own area, explain how climate change has influenced the hydrological cycle.

Model Answer

Climate change has disturbed every part of the hydrological cycle, speeding up some processes, shifting the rainfall, and making the extremes of flood and drought more severe.

1) **Evaporation and evapotranspiration:** rising temperatures speed the loss of water from soils, rivers and wetlands, drying ponds, shrinking lakes and helping wetlands disappear.
2) **Precipitation:** the rains have grown less reliable and more uneven, with the seasons shifting and the totals changing, so droughts and downpours both become more common.
3) **Groundwater:** erratic rain and heavier evaporation upset the recharge of aquifers, while along the coast a rising sea pushes salt water into the fresh groundwater.
4) **Surface water:** rivers and wetlands lose water to the fiercer evaporation, and some perennial rivers turn seasonal.
5) **Sea level and hazards:** the warming melts ice and raises the sea, while the disturbed cycle brings more floods, storms and prolonged droughts.

In Tanzania these changes are already felt, in the retreating ice of Kilimanjaro, the more violent floods and droughts, and the saltier wells of the coast, so climate change has not added a new process to the cycle but has unsettled the balance of the one we have, with heavy consequences for water and for life.

PART TWO

EXAMINATIONS QUESTIONS

This examination section is where knowing becomes answering. The chapters before it have built your understanding of physical geography process by process; here that understanding is put to work under the conditions of the national examination itself. Everything that follows is set at full examination standard, with no tiers and no scaffolding, and it is arranged in two parts: sixty short-answer questions, each worth fifteen marks, which test whether you can give a precise and well-ordered response to a focused demand, and ninety essay questions, each worth twenty marks, which ask you to build a full argument point by point, from a clear introduction to a reasoned conclusion. Every question is drawn from the Form Five and Form Six physical syllabus and written in the language of recent Advanced papers, with Tanzania as the living example throughout, from the rifting at Lake Natron to the soils of the Southern Highlands and the currents of the Indian Ocean. Work each question first under the clock, with the solutions closed, as though the examiner were already waiting; only then turn to the model answers, to mark yourself honestly, to see where the marks truly lie, and to practise writing geography that explains rather than merely describes. Used in this way, the questions that follow are the surest bridge between the syllabus you have studied and the grade you intend to earn.

SHORT-ANSWER QUESTIONS

Question 1

When the Atlantic coasts of South America and Africa are placed side by side, they close like the pieces of a jig-saw. With evidence, justify the view that the present continents were once joined in a single landmass. Give six points.

Question 2

Identical fossils of the reptile Mesosaurus occur in both Brazil and southern Africa, though the animal could never have crossed an ocean.

(a) Explain how fossils provide evidence for continental drift.

(b) Explain how ancient glaciation now found in tropical lands provides evidence for continental drift.

Question 3

Down the middle of the Atlantic runs a submarine ridge, and the ocean-floor rocks grow older away from it on both sides.

(a) Explain what is meant by sea-floor spreading.

(b) Explain how each of the following provides evidence for it:

(i) the ages of the ocean-floor rocks;

(ii) the magnetic stripes of the ocean floor.

Question 4

The world's volcanoes, ocean trenches and mountain belts cluster along the edges of the moving plates.

Explain the landforms produced at the main types of plate boundary, giving an example in each case.

Question 5

Plates of solid rock drift slowly across the face of the Earth, yet no visible engine pushes them.

Account for the movement of the lithospheric plates.

Question 6

Scandinavia is still rising out of the sea today, thousands of years after the ice sheet that once covered it melted away.

(a) Explain the concept of isostasy.

(b) Using examples, show how the crust adjusts when a load is added to it and when a load is removed.

Question 7

At Lake Natron the floor of the Great Rift Valley is dropping while its steep shoulders stand high above.

Explain how the process of plate divergence has produced the East African Rift System.

Question 8

A Form Five class is told that everything from the air over Dodoma to the rocks beneath it belongs to one working machine called the Earth system.

With reference to the four major spheres of the Earth, explain how the planet operates as a single integrated system. Give six points.

Question 9

A traveller notices that the air on the slopes of Kilimanjaro is bitterly cold even though the mountain sits almost on the Equator where the noon Sun is nearly overhead.

(a) What is meant by the term insolation.

(b) Account for the way the following factors control the temperature of a place:

(i) Latitude and the angle of the Sun.

(ii) Altitude.

Question 10

Dar es Salaam on the coast stays warm and even through the year while Dodoma in the interior swings from hot days to chilly nights.

Account for the influence of distance from the sea, ocean currents, cloud cover and prevailing winds on the temperature of a place. Give six points.

Question 11

A surveyor records that fresh snow on the summit of Kilimanjaro throws back most of the sunlight while the dark waters of Lake Victoria swallow nearly all of it.

(a) Define the term albedo.

(b) Explain how differences in albedo between surfaces affect the radiation balance and the heating of those surfaces. Refer to named surfaces with their approximate values.

Question 12

A pupil in Tabora asks why the daytime sky is blue when sunlight itself looks white.

Distinguish between reflection and scattering of solar radiation, and explain why the sky appears blue by day and reddish at sunset. Give six points.

Question 13

Scientists note that the Earth receives a fixed supply of solar energy yet its average temperature stays roughly steady from decade to decade.

Explain how the global heat budget is kept in balance and how the greenhouse effect keeps the Earth warm. Give six points.

Question 14

Records show that the ice cap on Kilimanjaro has shrunk dramatically within living memory while droughts have become more frequent.

Climate change is caused by both natural and human factors. Examine these causes and the effects of climate change. Give six points.

Question 15

An air sample taken over Dodoma is found to be mostly a single gas that living things cannot breathe directly, with the life-giving oxygen forming only about a fifth.

Describe the composition of the atmosphere, distinguishing its permanent gases from its variable constituents. Give six points.

Question 16

A weather balloon released at Dodoma records the temperature falling steadily as it climbs, then rising again higher up, before it finally bursts.

Describe the vertical structure of the atmosphere from the surface upward, noting the temperature behaviour of each layer. Give six points.

Question 17

A village elder near Tabora believes the sky has a solid ceiling where it ends, while a CFC-laden refrigerant gas is quietly thinning the ozone far above.

(a) Explain why the popular belief that the sky has an end or a solid ceiling is a misconception.

(b) Explain the importance of the ozone layer and how it is depleted by chlorofluorocarbons.

Question 18

The growing traffic and industries of Dar es Salaam are releasing smoke and gases that hang over the city on still mornings.

Examine the human activities that pollute the air and the measures that can be taken to control air pollution. Give six points.

Question 19

A Form Five student insists that all the major features of the earth, from mountains to plains, were simply laid down when the earth first cooled and have not changed since.

Using the concept of endogenic forces and diastrophism, correct this view in six points.

Question 20

On 10 September 2016 a tremor of about magnitude 5.9 struck the Kagera region of north western Tanzania, killing people in Bukoba and damaging many buildings.

(a) Define an earthquake and distinguish between the focus and the epicentre.

(b) Explain four causes of earthquakes such as the Kagera event.

Question 21

A seismograph in Arusha records three sets of waves arriving one after another from a distant earthquake, and a newspaper later reports its magnitude on the Richter scale.

(a) Identify the three main types of seismic waves and state one property of each.

(b**)** Distinguish between the magnitude and the intensity of an earthquake.

(i) Name the scale used to measure each.

(ii) Explain why two places at the same distance may report different intensities.

Question 22

On a field study of northern Tanzania a class sees the steaming cone of Ol Doinyo Lengai, the vast bowl of Ngorongoro and the snow capped dome of Kilimanjaro, and the teacher explains that magma behaves differently in each case.

(a) Distinguish between acidic lava and basic lava.

(b) Explain six extrusive volcanic features, giving a named example of each where possible.

Question 23

Investors are surprised to learn that the same volcanic activity that threatens lives around Ol Doinyo Lengai is also the reason farmers prosper on the slopes of Kilimanjaro and engineers test for power in the Rift Valley.

Examine six ways in which vulcanicity affects human life and activity in Tanzania, showing both harmful and beneficial sides. Give six points.

Question 24

A traveller drives east from Lake Tanganyika, crosses a steep cliff onto a flat sunken floor holding a deep lake, then climbs onto the raised block of the Uluguru Mountains, and wonders what built such contrasting relief.

With named Tanzanian examples, explain six landforms produced by faulting. Give six points.

Question 25

A geography textbook describes the East African Rift System as splitting into two arms across the region, one studded with volcanoes and shallow soda lakes, the other holding some of the deepest lakes in the world.

(a) Describe the difference between the eastern and western branches of the East African Rift System.

(b) Explain three indirect effects of rift faulting on the drainage of the region.

Question 26

A diagram shows rock layers bent into a series of upfolds and downfolds, some leaning over and one lying almost flat, and a candidate is asked to interpret what compression has done to the strata.

(a) Define folding and name the parts of a simple fold.

(b) Describe four types of folds according to their shape.

Question 27

A regional planner notes that across Tanzania the rich farmland, the deep lakes used for fishing and transport, the geothermal prospects and the tourist highlands all trace back to forces working inside the earth.

Assess six ways in which endogenic processes have shaped both the relief and the human activities of Tanzania. Give six points.

Question 28

A student writes that denudation is just another word for erosion. Her teacher marks it half right, because denudation is wider than that.

Explain what is meant by denudation and identify the processes and energy sources involved. Give six points.

Question 29

On the bare granite domes near Dodoma the rock peels off in curved sheets like the layers of an onion, and travellers wonder what could strip solid stone in a land with no frost.

Describe six processes of mechanical weathering and show how each breaks rock apart.

Question 30

Rainwater is a weak acid, and over centuries it eats into rock so quietly that the change is seen only in the rounded outcrops and the caves it leaves behind.

(a) Distinguish between mechanical weathering and chemical weathering.

(b) Explain four processes of chemical weathering, naming the rock or mineral each one attacks.

(i) two processes that affect limestone or iron-bearing rock

(ii) two processes that affect other minerals

Question 31

In April 2022 saturated hillsides at Lwandai in Lushoto gave way and mud flowed down onto homes below, a reminder that whole slopes can move, not just single stones.

Explain six factors that cause or trigger mass wasting on slopes.

Question 32

In a true hot desert the wind is armed with sand, and it both scoops out hollows and carves the standing rock into strange shapes before piling the grains into dunes.

(a) Distinguish between deflation and abrasion as processes of wind erosion.

(b) Describe four landforms produced by wind in a hot desert.

Question 33

It rarely rains in a desert, but when it does the water rushes over bare ground with nothing to hold it back, and a single storm can shape the land for years.

Describe six landforms produced by running water in hot desert areas. Refer to diagrams where helpful.

Question 34

Near Tanga the Amboni caves run for kilometres underground, hollowed out of limestone by nothing more than rainwater seeping along the joints.

Explain how the chief surface and underground features of a karst limestone area are formed. Give six points.

Question 35

A river is never still: in the same channel it loosens rock, carries the waste downstream and finally lays it down, doing different work at different places along its course.

(a) Explain four processes by which a river erodes its channel.

(b) Explain four processes by which a river transports its load.

Question 36

A river writes its history in the land: a narrow gorge high in the hills, a wide looping bend on the plain, each shape telling which kind of cutting was at work.

Describe how each of the following river landforms is formed: a V-shaped valley, a waterfall, a meander and an ox-bow lake. Refer to diagrams where helpful.

Question 37

Where the Rufiji finally meets the sea it slows, drops its load and splits into many mouths, building new land out into the Indian Ocean.

Explain how each of the following depositional landforms is formed: a flood plain, a natural levee and a delta.

Question 38

When the land is lifted or the sea falls, a tired old river suddenly finds new energy and begins to cut down once more, leaving tell-tale steps and benches in its valley.

(a) Explain what is meant by river rejuvenation and state two ways it can be caused.

(b) Describe three landforms that result from rejuvenation, and explain what river capture is.

(i) the three rejuvenation landforms

(ii) river capture

Question 39

On the Dar es Salaam coast the same waves that gnaw a headland into caves and arches also build the long sand spits that curl across the bays.

Describe six coastal landforms, three made by wave erosion and three by wave deposition, naming a coast for each.

Question 40

Twice a month the tides run unusually high, and over far longer spans the whole level of the sea itself rises or falls, drowning some coasts and raising others.

(a) Distinguish between spring tides and neap tides.

(b) Distinguish between a eustatic and an isostatic change of sea level, and name one landform of a submergent coast.

(i) the two kinds of sea-level change

(ii) one submergent landform

Question 41

A rock collected near Dodoma is an aggregate of several minerals, and the same rock can be filed in more than one way.

Explain what a rock is and account for the three bases on which rocks are classified.

Question 42

The coarse Dodoma granite and the fine, dark Rungwe basalt are both igneous, yet they look nothing alike.

(a) State two diagnostic characteristics that mark a rock as igneous.

(b) Account for the contrast between the two named rocks under each of the following.

(i) their texture

(ii) their chemical composition

Question 43

The Tanga limestone, the coal of Kiwira and the sandstone of the Karoo basins all settled, layer upon layer, at the Earth's surface.

Explain how sedimentary rocks form and account for the three groups into which they are classified by origin. Give six points.

Question 44

Heat and pressure deep in the Usambara basement turned shale into slate and limestone into marble without ever melting them.

(a) Explain what is meant by metamorphism.

(b) Account for the work of the three agents of metamorphism and distinguish foliated from non-foliated metamorphic rock with named examples.

Question 45

The granite of Dodoma may one day become sand, then sandstone, then quartzite, and finally melt back to magma.

With reference to the rock cycle, explain how the three rock families are continually converted into one another. Give six points.

Question 46

To map the country, the Geological Survey must say which rock is older and how old it is in years.

(a) Distinguish relative age from absolute age.

(b) Account for the methods used to establish each.

(i) relative dating

(ii) absolute dating

Question 47

The deep volcanic soils of Kilimanjaro and the thin soils of a steep Uluguru slope formed from the same five factors working together.

Explain the five factors that work together to form a soil from its parent rock.

Question 48

A pit dug in a mature soil at Rungwe shows clear layers, from dark topsoil down to broken parent rock.

With reference to a soil profile, explain the main horizons and the processes that move material between them.

Question 49

The fertile volcanic soils of Rungwe carry dense farms, yet the bared slopes of Kondoa are scarred by gullies.

(a) State three factors that determine the productivity of a soil.

(b) Account for the three forms of soil erosion by running water and explain two measures by which the erosion can be controlled.

Question 50

A class is told that the water that fell as rain on the Uluguru Mountains last century may be evaporating from the Indian Ocean off Dar es Salaam today.

Explain how the hydrological cycle keeps the total quantity of water on Earth constant while moving it endlessly between store and store. Give six points.

Question 51

Two equal pans of water are left out at Dodoma, one in still shaded air and one in open sun on a windy afternoon; by evening the second has lost far more water.

(a) Distinguish between evaporation and evapotranspiration.

(b) Account for the difference between the two pans by explaining four factors that control the rate of evaporation.

(i) two factors linked to the state of the air

(ii) two factors linked to the water surface itself

Question 52

On the windward slopes of Mount Kilimanjaro rain falls almost daily, yet a short distance away on the leeward side near Same the land is dry scrub.

With reference to the three main types of rainfall, explain how each is formed and identify a Tanzanian setting where it occurs.

Question 53

During a heavy storm a bare overgrazed hillside near Kondoa sheds muddy water within minutes, while a neighbouring wooded slope releases its water slowly and clear for days.

Explain six factors that determine how much storm rainfall becomes surface runoff rather than soaking into the ground.

Question 54

A borehole sunk on the plains near Dodoma passes through dry crumbly material for several metres before the drill suddenly brings up saturated, dripping sand.

(a) Using the borehole as your reference, distinguish the zone of aeration from the zone of saturation and define the water table.

(b) Explain the meaning of an aquifer, an aquiclude and an aquifuge, giving a rock example of each.

Question 55

In a saucer shaped basin a layer of porous rock dips down between two impermeable layers, and a well sunk into it gushes water to the surface without any pumping.

Explain the conditions necessary for the formation of an artesian basin and an artesian well, and describe how a spring forms. Give six points.

Question 56

On one map the streams branch like the veins of a leaf, while on a map of folded ridges the main rivers run in parallel with short tributaries joining at sharp right angles.

With named examples of pattern, explain how rock structure and relief control the development of drainage patterns. Give six points.

Question 57

The Great Ruaha flows strongly in the rains but in a severe dry season stretches of its bed in the Ruaha National Park lie as dry sand, stranding hippos in shrinking pools.

(a) Define a drainage basin and a watershed.

(b) Explain the three types of river regime and state the climatic condition that produces each.

Question 58

Lake Tanganyika lies in a long deep trough, Lake Victoria spreads broad and shallow over a gentle sag, and the small Momela lakes sit in old volcanic hollows near Arusha.

Classify lakes according to their mode of formation, explaining six processes and naming a Tanzanian example of each.

Question 59

The Kilombero valley holds one of East Africa's largest seasonal floodplains, rich in fish and grazing, yet each year more of it is drained and ploughed for rice and sugar.

(a) Distinguish between a swamp and a bog.

(b) Explain four threats facing wetlands such as the Kilombero floodplain.

Question 60

Sea water tastes salty everywhere, yet the surface of the open tropical Indian Ocean off Tanga is saltier than the water near the mouth of the Rufiji where the river pours in.

Explain four factors that control the salinity of ocean surface water, and outline the three ways in which ocean water moves.

ESSAY QUESTIONS

Question 61

Alfred Wegener argued in 1912 that the separate continents of today were once united in a single supercontinent he called Pangaea. Justify the theory of continental drift in eight points.

Question 62

When Wegener first proposed continental drift, the scientific world rejected it for nearly fifty years, yet today it is accepted as fact. Examine the reasons the theory was at first rejected and later vindicated, in eight points.

Question 63

If the continents were once a single mass, that mass must have broken into the pieces we see today in an orderly sequence. Account for the break-up of Pangaea into the present continents, in six points.

Question 64

Along the floor of every ocean runs a ridge where new crust is endlessly created and the sea floor is slowly carried apart. Explain the process of sea-floor spreading and the evidence for it, in eight points.

Question 65

Sea-floor spreading is often said to have rescued Wegener's continental drift by supplying the very thing it lacked. Justify this statement in six points.

Question 66

The world's great mountain ranges, ocean trenches and belts of volcanoes are concentrated along the edges of the moving plates. Account for the landforms produced at the main types of plate boundary, in eight points, with the aid of diagrams.

Question 67

Although the plates move only a few centimetres in a year, the forces that move them are vast and come from deep within the Earth. Explain the mechanism that drives the movement of the plates, in six points.

Question 68

Plate tectonics is often described as the single theory that ties together the whole of physical geology. Assess this claim in eight points.

Question 69

The Earth's crust rests in a delicate balance on the denser mantle below, and adjusts its height whenever a load is added or taken away. Explain the concept of isostasy and isostatic adjustment, in six points, with examples.

Question 70

The East African Rift System runs the length of Tanzania, marked by deep lakes, steep escarpments and active volcanoes, and is regarded as an ocean in the making. Account for the formation of the East African Rift System as a product of plate divergence, in eight points.

Question 71

A Form Five geographer is told that the planet works like one great machine whose parts never act alone. Justify the view that the Earth functions as a single integrated system of four interacting spheres in eight points.

Question 72

A teacher reminds the class that long voyages, satellite photographs and the curved horizon over the Indian Ocean all tell the same story about the planet. Examine the evidence that the Earth is spherical in shape in six points.

Question 73

A meteorologist explains that Dar es Salaam is reliably hotter than Mbeya in the Southern Highlands even though both lie in the same country. Account for the factors that determine the hotness or coldness of a place in eight points.

Question 74

A pilot notes that the cabin display shows the outside air growing colder the higher the aircraft climbs over Tanzania, even when flying towards the Equator. Explain why temperature generally decreases with increasing altitude in six points.

Question 75

A coastal fisherman in Dar es Salaam enjoys steady mild temperatures all year, while his cousin in Dodoma roasts by day and shivers by night. Account for the moderating influence of the sea on the temperature of coastal places in six points.

Question 76

A researcher measures that the snow of Kilimanjaro reflects most of the sunlight reaching it while the dark waters of Lake Victoria absorb nearly all of theirs. Assess the importance of reflection, absorption and albedo in controlling the radiation balance of the Earth surface in eight points.

Question 77

A child in Tabora wonders why the daytime sky overhead is blue while the setting Sun glows red over Lake Victoria. Explain why the sky appears blue by day and red at sunset in six points.

Question 78

A climate scientist points out that the Earth absorbs solar energy without end yet its average temperature has stayed nearly steady for centuries. Explain how the global heat budget is maintained in balance in eight points.

Question 79

A farmer near Tabora is surprised to learn that the very gases blamed for global warming are also what keep the Earth warm enough to grow crops. Explain the greenhouse effect and assess its importance to life on Earth in six points.

Question 80

An elder recalls that the ice cap of Kilimanjaro was once vast, while scientists warn that the climate is now changing faster than at any time in memory. Examine the natural and human causes of climate change in eight points.

Question 81

A coastal planner in Dar es Salaam studies maps showing the shoreline creeping inland while the snows of Kilimanjaro continue to shrink. Assess the effects of climate change on the physical and human environment in eight points.

Question 82

A district officer in Dodoma asks what practical steps can slow climate change before its droughts worsen. Suggest measures that can be taken to reduce climate change and its effects in six points.

Question 83

A laboratory technician analysing air from over Dodoma finds it is mostly an unreactive gas, with breathable oxygen making up only about a fifth. Explain the composition of the atmosphere and the usefulness of its main constituents in six points.

Question 84

A weather balloon launched from Dodoma records the air first cooling, then warming, then cooling again as it rises through distinct layers. Explain the vertical structure of the atmosphere and the characteristics of each layer in eight points.

Question 85

A villager near Tabora insists the sky has a solid roof where it ends, unaware that high above, a thinning ozone layer is letting in more harmful rays. Examine why the idea that the sky has an end is a misconception and explain the value and depletion of the ozone layer in six points.

Question 86

On still mornings a brown haze of vehicle and factory fumes hangs over the streets of Dar es Salaam. Examine the human activities that pollute the air and the measures that can be taken to control them in six points.

Question 87

A biology teacher reminds the class that the carbon in a tree near Tabora may once have been gas in the air and may one day rest in the rocks beneath the Indian Ocean. Explain how the biogeochemical cycles link the four spheres of the Earth in eight points.

Question 88

A learner claims that the earth surface is shaped only by rivers, wind and waves working from outside. Drawing on the nature of endogenic forces and diastrophism, explain why internal forces are equally important in shaping the earth, in eight points.

Question 89

When a tremor of about magnitude 5.9 struck the Kagera region of Tanzania in 2016, some buildings collapsed while others nearby stood firm. With reference to the factors that determine the destructiveness of an earthquake, explain why earthquakes vary so greatly in their effects, in eight points.

Question 90

A coastal community in Tanzania, remembering how the 2004 Indian Ocean tsunami reached the East African shore, wants to know how earthquakes are studied and how their dangers can be reduced. Describe how earthquakes are measured and detected and outline the precautions against their effects, in eight points.

Question 91

A teacher tells a class that the effects of an earthquake are not all bad and not all immediate. Discuss the effects of earthquakes on the physical landscape and on human life, in six points.

Question 92

A field party in Tanzania observes a great dome of igneous rock laid bare by erosion, a sheet of rock lying along the bedding and another cutting sharply across it. Using these and other examples, explain the intrusive and extrusive features formed by vulcanicity, in eight points.

Question 93

Tourists climb Kilimanjaro, farmers thrive on its slopes and engineers drill for power in the Rift Valley, yet the people of the same region also fear eruptions and tremors. Evaluate the positive and negative effects of vulcanicity, in six points.

Question 94

A student is puzzled that one Tanzanian volcano erupts gently while another can blow its summit apart. Account for the different types of volcanic eruption and the cones they build, in six points.

Question 95

The East African Rift System has been called one of the great wonders of the earth, splitting the continent and cradling its deepest lakes. Explain the process of faulting and the landforms and features of the rift system, in eight points.

Question 96

A class is shown two diagrams, one of a block standing high between two faults and another of a block sunk low between two faults, and is asked how such opposite forms arise from the same process. Explain the formation of block mountains and rift valleys by faulting, in six points.

Question 97

A development officer argues that the East African Rift System is far more than a line of scenery, since it underpins fishing, water supply, energy and tourism across the region. Discuss the significance of the East African Rift System to the people of Tanzania, in six points.

Question 98

A student observes that some of the world greatest mountain ranges are made of rock layers bent into great arches and troughs, yet Tanzania has no such ranges of its own. Explain the process of folding and the landforms it produces, in eight points.

Question 99

A learner cannot understand why the Himalaya are jagged and towering while the Cape Ranges of South Africa are low and rounded, though both were formed by folding. Compare young fold mountains and old fold mountains, in six points.

Question 100

A geographer remarks that almost everything distinctive about the Tanzanian landscape, from its snow capped peaks to its deep lakes and fertile highlands, can be traced to forces working inside the earth. Examine how endogenic processes have shaped the landscape and influenced human activities in Tanzania, in eight points.

Question 101

Rock that looks solid and everlasting is in truth under constant attack from the air, the water and the heat around it. Examine the processes of mechanical weathering that break rock apart in eight points.

Question 102

Rainwater is a weak acid, and given time it can rot solid granite into clay and hollow whole hills into caves. Explain the processes of chemical weathering and the changes each brings about in eight points.

Question 103

Two cliffs of the same age may tell very different stories: one stands bold and fresh, the other is crumbling to soil. Examine the factors that control the type and rate of weathering in eight points.

Question 104

In the rainy season whole hillsides in the Tanzanian highlands can come loose and slide down upon the homes below. Examine the types of mass wasting and how each moves down the slope in eight points.

Question 105

When mud flowed onto the homes at Lwandai in Lushoto it was no accident of nature alone, for human hands had helped to loosen the slope. Assess the causes of mass wasting and the measures that can control it in eight points.

Question 106

In the heart of the Sahara the wind is the master sculptor, lifting the loose sand and hurling it against the standing rock until the desert is carved into strange and striking shapes. Explain the landforms produced by wind erosion in hot deserts in eight points.

Question 107

When the desert wind drops, the sand it carried settles into great waves and ridges that march slowly across the land. Explain how wind deposits its load and the depositional landforms it builds in eight points.

Question 108

It seems strange to speak of rivers in a desert, yet the boldest features of many dry lands were cut not by wind but by sudden floods of water. Account for the landforms produced by running water in hot deserts in eight points.

Question 109

A desert traveller may see a flat-topped hill standing alone and a fan of gravel spilling from a dry valley mouth, and wonder how water built them where rain so rarely falls. Distinguish the erosional from the depositional work of water in hot deserts in eight points.

Question 110

At Amboni near Tanga whole hills are honeycombed with caves and the bare rock above is cut into a maze of grooves, all the work of ordinary rainwater on limestone. Account for the surface and underground features of a karst region in eight points.

Question 111

A river does three kinds of work at once, loosening rock here, sweeping it along there, and laying it down further on, and a single channel shows all three at different points. Explain the processes of river erosion, transport and deposition in eight points.

Question 112

It is no accident that some rivers run straight down a slope while others branch like a tree or run in parallel lines, for the rock and the relief beneath guide them. Examine how rock and relief control the development of river and drainage patterns in eight points.

Question 113

As a river leaves the hills its valley changes from a narrow gash to a wide trough, and the landforms along the way record the changing struggle between the river and the land. Explain the landforms of the upper and middle course of a river in eight points.

Question 114

Where the Rufiji nears the sea it has finished cutting and begins to build, raising banks, spreading plains and pushing new land out into the ocean. Explain the depositional landforms of the lower course of a river in eight points.

Question 115

A meander seems a simple bend in a river, yet within that single curve the river both tears away one bank and builds up the other, and in time it can cut the loop off altogether. Account for the formation of meanders and ox-bow lakes in eight points.

Question 116

An old river winding lazily across its plain may suddenly be given new life, cutting down into its own bed and leaving its former plain stranded high on the valley side. Explain river rejuvenation, its causes and its resulting landforms in eight points.

Question 117

The same restless sea that smashes a headland into caves, arches and lonely stacks will gently build a curving beach in the bay beside it. Explain the landforms produced by wave erosion and wave deposition along a coast in eight points.

Question 118

A swimmer at Nungwi may notice that the waves seem to push the sand steadily along the shore, never straight in, and this quiet sideways drift is forever reshaping the coast. Explain longshore drift and the depositional landforms it builds in eight points.

Question 119

The sea is never quite at the same level: it rises and falls twice a day with the tides, and over the ages it has crept up some coasts and drawn back from others. Examine tides and changes of sea level and their effects on the coast in eight points.

Question 120

The warm shallow seas off Zanzibar and Mafia are ringed with coral, the limestone work of tiny living creatures that can build whole islands given the right conditions. Explain the conditions for coral growth and the types and origin of coral reefs in eight points.

Question 121

The fishermen of Mafia know that the reef offshore is more than a beautiful thing, for it breaks the force of the waves, fills their nets and brings visitors to their shores. Assess the significance of coastal landforms and coral reefs to human life in eight points.

Question 122

The rock picked up on a Dodoma hillside can be filed by how it formed, by its chemistry and by its age. Examine the bases on which rocks are classified and the difficulties of the task, in eight points.

Question 123

The Dodoma granite cooled slowly and deep, while the Rungwe basalt cooled fast at the surface, and their textures still record it. Explain how igneous rocks are classified by their mode of formation and by the texture that cooling leaves, in eight points.

Question 124

Geologists call igneous rock the mother rock of the crust. Account for the formation of igneous rock and assess how far it deserves to be called the parent of the other two families, in six points.

Question 125

An examination asked candidates to defend the worth of sedimentary rocks, the very rocks that hold Tanzania's cement limestone and its coal. Support the claim that sedimentary rocks are both an industrial raw material and a source of energy, in eight points.

Question 126

Of the three rock families, only sedimentary rock keeps the fossils of past life and the record of past surroundings. Account for the characteristics of sedimentary rocks and explain why they alone preserve this record, in six points.

Question 127

A class examining a banded gneiss and a plain marble must decide what changed them and why one is striped and the other is not. Explain the agents and the types of metamorphism and account for the contrast between foliated and non-foliated rock, in eight points.

Question 128

A teacher tells the class that rock formation is an endless process with no true beginning or end. Explain the rock cycle and assess this claim, in eight points.

Question 129

Mapping the Dodoma basement, a geologist must say both which rock is older and how old it is in years. Explain the methods of relative and absolute dating, in eight points.

Question 130

The geological time scale hangs the whole history of the Earth on a ladder of eons, eras and periods. Examine the structure of the time scale and its usefulness to a working geologist, in six points.

Question 131

An examination asked how parent rock, climate and living organisms shape a soil, the very factors that gave Kilimanjaro its deep soils and Kondoa its thin ones. Explain how the five factors of soil formation work together to make a soil, in eight points.

Question 132

A pit dug in a mature Rungwe soil shows clear layers, from dark topsoil down to broken bedrock, each shaped by water moving through the soil. Account for the horizons of a soil profile and the processes that build them, in eight points.

Question 133

An examination asked candidates to weigh what makes a soil productive, the difference between the rich farms of Rungwe and a worn-out field nearby. Examine the factors to consider when assessing the productivity of a soil, in eight points.

Question 134

An examination called soil erosion a product of both natural forces and human acts, the very mix that gullied the slopes of Kondoa. Explain the causes of soil erosion and the measures by which it can be conserved, in eight points.

Question 135

A student claims that since rain keeps falling, the Earth must be steadily gaining water. Examine the operation of the hydrological cycle and show why the global store of water remains essentially constant in eight points.

Question 136

Catchment after catchment in Tanzania is being deforested, drained and dammed. Assess how human activities disturb the natural operation of the hydrological cycle within a drainage basin in eight points.

Question 137

An open reservoir in the dry interior loses far more water to the air than an equal one on the humid coast. Explain the factors that control the rate of evaporation and evapotranspiration in eight points.

Question 138

Rain reaches the ground in several ways, from afternoon thunderstorms on the plains to steady mountain rain. Examine the formation of the main types of precipitation and the conditions that favour each in eight points.

Question 139

Rainfall in Tanzania ranges from over two thousand millimetres on some highland slopes to under five hundred in parts of the central plateau. Account for the uneven distribution of rainfall in eight points.

Question 140

On a bare overgrazed slope a storm produces muddy floods within minutes, while a forested slope nearby stays firm and releases clear water for days. Examine the factors that control the generation of surface runoff in eight points.

Question 141

A borehole on the Dodoma plains passes through dry material before striking saturated, dripping sand, and the depth at which water is struck differs from one site to the next. Examine the occurrence of groundwater and why the amount of pore water varies from place to place in eight points.

Question 142

In some basins a well gushes water to the surface without any pump, while elsewhere the same depth yields nothing. Examine the conditions that create artesian and other groundwater supplies and their value to people in eight points.

Question 143

On one map streams branch like the veins of a leaf, while on another they run in parallel ridges with right angle junctions. Examine how rock structure and relief control the development of drainage patterns in eight points.

Question 144

Some rivers in Tanzania clearly follow the slope and the soft rock, yet others cut straight across hard ridges as though the structure were not there. Examine the main types of drainage system and how each develops in eight points.

Question 145

The Great Ruaha runs full in the rains but parts of its bed lie as dry sand in a severe dry season, while the Pangani flows the whole year round. Examine the factors that control the regime of a river in eight points.

Question 146

Tanzania holds a deep rift lake, a vast shallow lake, soda lakes, crater lakes and great man made reservoirs. Classify the lakes of Tanzania according to their mode of formation in eight points.

Question 147

Lake Victoria supports millions of people yet its waters are increasingly choked with weed and pollution. Assess the importance of lakes to Tanzania and the problems that threaten them in eight points.

Question 148

The Kilombero valley teems with fish and grazing in the floods, yet each year more of it is drained for rice and sugar. Examine the value of wetlands and the threats facing them in eight points.

Question 149

The sea along the Tanga coast never lies still: it rises and falls twice a day, breaks endlessly on the shore and drifts steadily along the coast. Examine the factors that influence the movement of ocean water in eight points.

Question 150

A warm current washes the East African coast while a cold current chills the coast of south west Africa, and their effects on climate are strikingly different. Examine how global winds and ocean currents affect the temperature and rainfall of coastlands in eight points.

PART THREE
MODEL SOLUTIONS TO THE EXAMINATION QUESTIONS

SHORT-ANSWER SOLUTIONS

Question 1

The continents were once united in the supercontinent Pangaea, as several independent evidences show.

1) **Jig-saw fit of the continental shelves:** matched along the edge of the continental shelf, their true rim, South America and Africa fit together with very little gap or overlap, a fit far too close to be the work of chance.
2) **Continuity of rocks across the ocean:** the ancient rocks of eastern Brazil match those of West Africa in kind, age and structure, showing that one block was later torn in two.
3) **Truncated fold-mountain belts:** fold ranges that end at one coast continue on the other, as the Cape ranges of South Africa reappear in Argentina, so the belt formed before the ocean opened.
4) **Matching fossils of land species:** identical fossils of Mesosaurus and the Glossopteris flora occur on continents now far apart, although these land species could not have crossed deep oceans.
5) **Ancient glaciation of tropical lands:** tillites and ice-scratched pavements now lie in tropical Brazil, central Africa and India, showing these lands once lay together near the South Pole.
6) **Matching mineral belts within Gondwana:** ore belts of West Africa line up with those of Brazil when the continents are rejoined, and Tanzania itself lay within Gondwana, its Mozambique Belt rocks continuing into Madagascar and India.

Examiner's Note

Justify means marshal evidence to support the claim, so each point must be argued as impossible unless the continents were once joined, not merely named. Six developed evidences with a sketch of the fit earn full marks.

Question 2

(a)

Identical land fossils across oceans: Mesosaurus, a freshwater reptile, and the seed-fern Glossopteris are found on continents now divided by wide oceans, and because such land species cannot cross deep salt water the lands must once have been joined for them to spread.

A shared community of species: the land reptile Lystrosaurus too is found in Africa, India and Antarctica, an impossible spread unless these lands were united in Gondwana, of which Tanzania formed a part.

(b)

Glacial deposits in present hot lands: tillites and ice-scratched pavements of the same age lie today in tropical Brazil, central Africa and India, where no ice could form now, showing these lands once lay together in cold high latitudes.

A single reassembled ice cap: when the continents are fitted back together the scattered glaciated areas join into one ice sheet whose ice flowed outward from a single centre, confirming the former union.

Examiner's Note

Two balanced parts, fossils and palaeoclimate; in each the marks lie in tying the evidence to the impossibility of crossing or forming across an ocean, not in naming the fossils or deposits.

False Confidence Alert

Writing that the same fossils mean the two places merely shared a climate misses the point. The argument is that land organisms cannot cross deep oceans, so the lands must have been physically joined.

Question 3

(a) Sea-floor spreading is the process by which new oceanic crust is created at a mid-ocean ridge and moves outward on both sides, so that the ocean slowly widens while old crust is destroyed at the trenches.

(b)

The ages of the ocean-floor rocks: the youngest rocks lie along the ridge and grow older with distance on either side in a mirror-image pattern, which can only happen if crust is created at the ridge and carried away.

The magnetic stripes: as the new basalt cools it locks in the Earth's magnetic field, and because that field reverses through time the floor carries matching parallel stripes of normal and reversed magnetism on both sides of the ridge, and the same sea-floor spreading is beginning today in the Red Sea on Africa's own margin.

Examiner's Note

Keep (a) to one clear sentence; the weight is in (b), where the reversal stripes must be explained through cooling and field reversal, not merely named. A **labelled sketch of the ridge** and its stripes is credited.

Question 4

Each type of plate margin builds its own family of landforms.

1) **Divergent (constructive) boundary:** plates move apart and magma rises to fill the gap, building a mid-ocean ridge beneath the sea or, on land, a rift valley with volcanoes, as in the East African Rift at Lake Natron.
2) **Convergent boundary, ocean meeting land:** the denser oceanic plate is subducted beneath the continent, forming a deep ocean trench, a chain of fold mountains and explosive volcanoes, as along the Andes.
3) **Convergent boundary, continent meeting continent:** neither plate can sink, so the crust is crushed upward into very high fold mountains such as the Himalayas, but without volcanoes.
4) **Transform (conservative) boundary:** plates slide past one another and crust is neither made nor destroyed, so no volcanoes form, but severe earthquakes occur as the locked rocks slip, as along the San Andreas Fault.

Examiner's Note

Convergence has two cases, so four landform sets are expected, each with its process and a named example; the process that builds the landform carries the marks. Remember that transform margins give earthquakes, not volcanoes.

Question 5

Plate movement is driven by heat escaping from the Earth's interior, acting through three connected forces.

1) **Heat and mantle convection:** heat from radioactive decay sets up slow convection cells in the solid mantle, and the rising, sideways-spreading rock drags the plate resting upon it along like a raft on a slow current.
2) **Ridge push:** at a mid-ocean ridge the new, raised, hot crust cools and slides down the slope of the bulge under gravity, pushing the plate away from the ridge.
3) **Slab pull:** where a cold, dense plate edge sinks at a trench its weight pulls the rest of the plate after it, and this is now thought to be the strongest of the forces.
4) **A slow combined motion:** acting together these forces move the African plate only a few centimetres a year, slowly widening the East African Rift.

Examiner's Note

Trace the chain from the heat source to the three forces; naming convection alone caps the marks. **A labelled convection-cell diagram** is credited.

False Confidence Alert

It is wrong to say the plates float and drift on a liquid mantle. The mantle is solid rock that flows only slowly by convection; the plates are carried by it, not floated on molten rock.

Question 6

(a) Isostasy is the state of balance in which the lighter crust floats upon the denser mantle, each block standing at the height at which its weight is supported, as wood floats on water and a high mountain is held up by a deep root.

(b)

Adding a load depresses the crust: the growth of a heavy ice sheet, or the piling of thick sediment in a delta, presses the crust down into the mantle so that the land sinks.

Removing a load allows uplift: when the ice melts or highlands are worn away by erosion the crust slowly rises again, which is why Scandinavia and the stripped East African highlands are still rising, the slow creep of the mantle making the uplift take thousands of years.

Examiner's Note

Define the floating balance in (a), then in (b) pair a loading case with an unloading case. The slow flow of the mantle is the point that explains why uplift continues long after the ice has gone.

Question 7

The rift is forming where the African plate is splitting into the Nubian and Somali plates.

1) **Doming and tension:** a rising plume of hot mantle domes up and heats the crust, stretching and thinning it so that it is placed under tension.
2) **Normal faulting and a sinking graben:** the stretched crust breaks along parallel normal faults and the central block sinks between them as a graben, forming the flat rift floor between steep shoulder scarps.
3) **Rift lakes:** water gathers on the sunken floor as deep lakes such as Tanganyika and shallow soda lakes such as Natron and Eyasi.
4) **Volcanism along the faults:** magma rises along the deep fractures to build volcanoes such as Ol Doinyo Lengai, Kilimanjaro and Meru.
5) **An ocean in the making:** if the splitting continues the floor will drop below sea level and a new ocean will form, as is already beginning in the Afar region.

Examiner's Note

The stem wants the divergence mechanism, so doming, tension, faulting and the sinking graben are the marked steps, with the lakes and volcanoes as results; Tanzanian examples anchor the answer.

Question 8

The Earth is an integrated system in which four interacting spheres exchange energy and matter while the planet as a whole remains open to energy but closed to matter.

1) **The atmosphere:** This is the envelope of gases held to the Earth by gravity, supplying oxygen and carbon dioxide and driving weather and climate over places such as Dodoma in the interior of Tanzania.

2) **The hydrosphere:** This is all the water of the planet in liquid, solid and gaseous form, including oceans, rivers and lakes such as Lake Victoria, which store and move heat and moisture.

3) **The lithosphere or geosphere:** This is the solid rocky outer shell of the Earth, providing the surface, soils and minerals on which life and human activity rest, as on the plains around Tabora.

4) **The biosphere:** This is the zone of all living things, plants, animals and microbes, which links the other spheres by photosynthesis and respiration, seen in the miombo woodlands of central Tanzania.

5) **Constant exchange of matter and energy:** The spheres are not separate but trade materials and heat continuously, for example water evaporating from Lake Victoria into the atmosphere and returning as rain.

6) **Open for energy but closed for matter:** Solar energy enters and heat escapes to space, yet almost no matter is gained or lost, so the same water and carbon are recycled endlessly over Tanzania.

Examiner's Note

The command is explain, so each sphere must be defined and its role in the system shown; marks lie in the linkage between spheres, not in mere naming. The discriminator is the open-for-energy, closed-for-matter idea.

Question 9

(a) Insolation is the incoming solar radiation received at the surface of the Earth, measured as energy per unit area over a given time.

Key qualifier: It is the short-wave radiation actually reaching the ground, which varies with the angle and duration of the Sun, as received strongly at Dar es Salaam near the Equator.

(b)

Latitude and angle of the Sun: Near the Equator the Sun is high so its rays strike steeply and heat a small area intensely, while towards the poles the same beam spreads over a larger slanted area and passes through more atmosphere, so Dodoma is hotter than high-latitude lands.

Altitude: Air temperature falls with height because the lower, denser air near the surface is warmed from below and pressure decreases upward, so highland stations such as Kilimanjaro and the Southern Highlands are far cooler than lowland Dar es Salaam at the same latitude.

Examiner's Note

Part (a) is define and earns marks for a precise statement; part (b) is account for and rewards the mechanism of why each factor changes temperature. The discriminator is explaining the spreading of the beam, not just stating that it is colder.

False Confidence Alert

Many candidates say highlands are cold because they are nearer the Sun, which is wrong; the few kilometres of height are negligible against the distance to the Sun, and air actually cools because it is heated from the ground upward.

Question 10

The temperature of a place is moderated or modified by its nearness to water, the currents bathing its coast, the clouds above it and the winds reaching it.

1) **Distance from the sea:** Water heats and cools slowly while land heats and cools quickly, so coastal Dar es Salaam has a small temperature range while interior Dodoma has a large one, a contrast called continentality.

2) **Warm ocean currents:** A warm current raises the temperature of the air passing over it and of the adjacent coast, as the warm waters of the Indian Ocean keep the Tanzanian coast mild throughout the year.

3) **Cold ocean currents:** A cold current chills the overlying air and lowers coastal temperatures, as the cold Benguela Current cools the coast of Namibia in southern Africa.

4) **Cloud cover by day:** Thick cloud reflects incoming insolation and keeps daytime temperatures lower, so an overcast day in the Southern Highlands is cooler than a clear one.

5) **Cloud cover by night:** At night clouds trap outgoing heat and keep temperatures higher, which is why cloudless nights in Dodoma become cold while cloudy coastal nights stay warm.

6) **Prevailing winds:** Winds carry the temperature of the region they come from, so winds off the warm ocean warm the coast while winds off a hot interior raise temperatures inland over Tabora.

Examiner's Note

The command is account for, so each factor needs a stated cause and effect on temperature; the marks lie in the contrast between land and sea behaviour. The discriminator is treating day and night cloud effects as opposite.

Question 11

(a) Albedo is the proportion of incoming solar radiation that a surface reflects back, usually expressed as a percentage or fraction.

Key qualifier: A bright surface has a high albedo and a dark surface a low one, as seen between bright snow and dark water on and around Kilimanjaro.

(b) A surface with high albedo reflects most insolation and absorbs little, so it stays cool, while a low-albedo surface absorbs most insolation and warms strongly, controlling the local radiation balance.

1) **Fresh snow, about 85 percent:** It reflects almost all sunlight and absorbs very little, so the snow and ice of Kilimanjaro remain near freezing even under the equatorial Sun.

2) **Desert sand, about 40 percent:** It reflects a fair share but still absorbs enough to grow very hot by day, as in the semi-arid lands around Dodoma.

3) **Grass, about 25 percent:** Green vegetation reflects only a quarter of the light and absorbs the rest, warming moderately, as on the grazing plains of the interior.

4) **Water and dark soil, under 10 percent:** These absorb almost all the radiation reaching them and warm steadily, so Lake Victoria stores great quantities of heat.

Examiner's Note

Part (a) is define; part (b) is explain and rewards linking the reflected fraction to how much a surface absorbs and heats. Quoting the named values with their surfaces is the discriminator.

Question 12

Reflection turns radiation back from a surface in a single direction, while scattering redirects it in many directions by tiny particles, and the selective scattering of blue light colours the sky.

1) **Reflection defined:** This is the bouncing of radiation off a surface such as cloud tops or snow back towards space in a regular way, as bright clouds over Tabora reflect sunlight.

2) **Scattering defined:** This is the redirection of incoming radiation in all directions by gas molecules and dust in the atmosphere, so light reaches us even from parts of the sky away from the Sun.

3) **Rayleigh scattering:** The smallest gas molecules scatter short blue wavelengths far more strongly than long red ones, a process named Rayleigh scattering.

4) **Why the sky is blue:** Because blue light is scattered in every direction across the sky over Tabora, we see scattered blue light coming from all parts of the daytime sky.

5) **Why sunsets are reddish:** At sunset the light travels a longer slanting path through the air, the blue is scattered away, and the reddish wavelengths that survive reach the eye, reddening sunsets over Lake Victoria.

6) **Effect on the radiation balance:** Scattering returns some incoming radiation to space and softens the light reaching the ground, forming part of the planetary reflection in the heat budget.

Examiner's Note

The command is distinguish then explain; marks lie in a clear contrast of direction between reflection and scattering and in naming Rayleigh scattering. The discriminator is explaining the longer path at sunset.

False Confidence Alert

A common error is to say the sky is blue because it reflects the blue sea; in fact the colour comes from blue light being scattered by air molecules, and the sky is blue even over dry inland Dodoma far from any sea.

Question 13

The heat budget stays balanced because the energy the Earth absorbs from the Sun is matched over the year by the energy it radiates to space, while greenhouse gases trap part of the outgoing heat and warm the surface.

1) **Incoming short-wave radiation:** The Earth gains energy as short-wave solar radiation, strongest in the tropics where places such as Dar es Salaam receive intense overhead Sun.
2) **Reflection and absorption:** About a third of this incoming energy is reflected to space by clouds, gases and bright surfaces while the rest is absorbed by the atmosphere and ground.
3) **Outgoing long-wave radiation:** The warmed Earth re-radiates energy as long-wave infrared heat, and over a year this loss balances the gain so the global average temperature holds steady.
4) **Greenhouse gases absorb outgoing heat:** Gases such as carbon dioxide, methane and water vapour absorb much of this outgoing long-wave radiation instead of letting it escape directly.
5) **Re-radiation back to the surface:** These gases re-emit the trapped heat in all directions, including back down, raising surface temperatures well above the freezing values they would otherwise have.
6) **A naturally warm and habitable Earth:** Without this natural greenhouse effect the Earth would be far too cold for life, so warm farmlands such as those around Tabora depend on it.

Examiner's Note

The command is explain, so the balance of incoming gain against outgoing loss must be shown, then the trapping of long-wave heat; marks lie in distinguishing short-wave in from long-wave out. The discriminator is treating the natural greenhouse effect as beneficial.

Question 14

Climate change arises from natural forces acting over long periods and from recent human activity, and its effects are already visible in melting ice, rising seas and worsening drought.

1) **Natural volcanic causes:** Large eruptions throw ash and gases high into the atmosphere that block sunlight and cool the climate for a time, a recognised natural driver.
2) **Natural orbital and solar causes:** Slow changes in the Earth orbit and shifts in the energy output of the Sun alter how much insolation the planet receives over thousands of years.
3) **Human burning of fossil fuels:** The burning of coal, oil and gas releases carbon dioxide that strengthens the greenhouse effect and warms the planet, the leading human cause.
4) **Human deforestation:** Clearing forests, as in parts of Tanzania, removes trees that absorb carbon dioxide and so adds to atmospheric greenhouse gases.
5) **Glacier retreat and sea-level rise:** Warming melts ice, and the famous glaciers of Kilimanjaro have retreated sharply, while meltwater and warmer seas raise sea level along the Dar es Salaam coast.

6) **Drought and disrupted rainfall:** Higher temperatures and shifting rainfall bring more frequent droughts that threaten farming in the interior around Dodoma and Tabora.

Examiner's Note

The command is examine, so causes must be split into natural and human and weighed against the effects; marks lie in keeping the two groups of causes distinct. The discriminator is naming specific effects rather than vague harm.

Question 15

The atmosphere is a mixture dominated by two permanent gases, with several minor permanent gases and a set of variable constituents that change from place to place and time to time.

1) **Nitrogen, about 78 percent:** Nitrogen is the most abundant permanent gas and forms more than three quarters of dry air, important for life through the nitrogen cycle over lands such as Tabora.
2) **Oxygen, about 21 percent:** Oxygen forms about a fifth of the air and is essential for the respiration of people, animals and plants and for combustion.
3) **Argon and carbon dioxide:** Argon makes up most of the remaining one percent as an inert gas, while a small but vital amount of carbon dioxide supports photosynthesis and the greenhouse effect.
4) **Water vapour, variable:** Water vapour varies greatly, being abundant in the humid air of coastal Dar es Salaam but scarce over the dry interior, and it controls humidity and rainfall.
5) **Dust and aerosols, variable:** Tiny solid particles of dust, smoke and salt vary with place and supply the nuclei on which water condenses to form cloud and rain.
6) **Ozone, variable:** Ozone is a variable trace gas concentrated in the stratosphere, where it shields the surface from harmful ultraviolet radiation.

Examiner's Note

The command is describe, so the answer must give proportions and separate permanent from variable gases; marks lie in the correct percentages and in placing water vapour, dust and ozone among the variables. The discriminator is the permanent-versus-variable split.

Question 16

The atmosphere is arranged in layers that alternate in their temperature behaviour, from the weather-bearing troposphere at the base to the thin exosphere merging into space.

1) **The troposphere:** This lowest layer holds most of the air, water vapour and weather, and temperature falls with height at an average lapse rate of about 6.5 degrees Celsius per kilometre over places such as Dodoma.
2) **The tropopause boundary:** At the top of the troposphere the temperature stops falling, marking the boundary above which weather largely ceases.
3) **The stratosphere:** Here temperature rises with height because the ozone layer absorbs ultraviolet radiation, and the calm air is favoured by high-flying aircraft.
4) **The mesosphere:** Above the stratosphere temperature falls again to its lowest values, and most meteors burn up in this layer.
5) **The thermosphere or ionosphere:** Here temperature rises steeply as the thin air absorbs intense solar radiation, and electrically charged particles reflect radio waves used in communication.
6) **The exosphere:** This outermost layer has extremely thin air that gradually merges into outer space, so there is no sharp edge to the sky above Tanzania.

Examiner's Note

The command is describe, so layers must be named in order with their temperature trend; marks lie in the alternating fall and rise of temperature. The discriminator is quoting the lapse rate and the ozone-driven warming of the stratosphere.

Question 17

(a) The sky has no end or ceiling because the atmosphere simply grows thinner with height and fades gradually into the vacuum of space.

No solid boundary: Air is a mixture of gases held by gravity, and its density decreases steadily upward through the layers above Tabora, so there is no surface to mark an edge.

A gradual fade to space: In the exosphere the few remaining molecules drift off into space, meaning the blue we see is scattered light, not a dome covering the Earth.

(b) The ozone layer is vital because it absorbs harmful ultraviolet radiation, and it is destroyed when chlorine from chlorofluorocarbons breaks ozone molecules apart.

Shielding from ultraviolet: Ozone in the stratosphere absorbs most of the Sun harmful ultraviolet rays, protecting people in Tanzania from skin cancer, eye damage and crop harm.

Depletion by chlorofluorocarbons: Chlorofluorocarbons from old refrigerators and aerosols rise to the stratosphere where ultraviolet light frees chlorine atoms that destroy many ozone molecules each, thinning the layer.

Examiner's Note

Both parts use explain; part (a) rewards the gradual thinning of air, part (b) the protective role of ozone and the chlorine mechanism. The discriminator is explaining why there is no edge rather than merely asserting it.

False Confidence Alert

Some candidates state that aeroplanes or birds reach the end of the sky; in truth no boundary exists, for the air thins continuously and the apparent ceiling is only scattered light seen from below.

Question 18

Air pollution comes from human activities that release harmful gases and particles, and it can be reduced by controlling those sources and treating the emissions.

1) **Burning of fossil fuels:** Motor vehicles, power stations and industries burn fuels that release carbon monoxide, sulphur dioxide and soot, as seen in the traffic fumes of Dar es Salaam.
2) **Industrial emissions and open burning:** Factories and the open burning of waste and bush release smoke and toxic gases that foul the air, a growing problem in urban Tanzania.
3) **Domestic use of wood and charcoal:** The widespread burning of firewood and charcoal for cooking fills indoor and town air with smoke and particles in many Tanzanian households.
4) **Control by clean energy and transport:** Switching to cleaner energy such as gas and electricity and improving public transport cuts the emissions from fuel burning in cities like Dar es Salaam.
5) **Control by emission treatment and law:** Fitting filters and catalytic converters and enforcing emission standards and laws reduces the harmful gases released by industries and vehicles.
6) **Control by planting trees and education:** Planting trees that absorb carbon dioxide and educating the public to avoid open burning help clean and protect the air over towns and villages.

Examiner's Note

The command is examine, so both the polluting activities and the control measures must be paired and balanced; marks lie in naming specific sources and matching remedies. The discriminator is offering practical, named controls.

Question 19

Endogenic forces are internal forces that originate within the earth and continue to operate today, reshaping the crust through diastrophism, which is the large scale deformation of the crust.

1) **Source of energy is internal:** Endogenic forces draw their energy from inside the earth, mainly from the decay of radioactive minerals such as uranium, from the primordial heat trapped since the earth formed, and to a small extent from the earth rotation, so the earth is still thermally active and not a dead cooled body.
2) **Diastrophism is ongoing deformation:** Diastrophism is the slow bending, breaking and lifting of crustal rocks; it proves the crust is still being worked, as shown by the rising blocks of the Usambara Mountains in Tanzania which are not original cooling features but products of later movement.
3) **Orogenic movements build mountains:** Orogenic, or mountain building, movements are horizontal forces that compress or tear the crust to raise fold and block mountains; the East African Rift faulting that lifted the Pare and Usambara ranges happened long after the earth cooled.
4) **Epeirogenic movements raise continents:** Epeirogenic movements are broad vertical uplifts or subsidences of large parts of a continent, such as the general uplift of the East African plateau, which tilted the land and is far younger than the original crust.
5) **Warping reshapes wide areas:** Warping is the gentle up bending (upwarping) or down bending (downwarping) of extensive areas; the downwarped basin holding Lake Victoria in Tanzania was hollowed by such movement, not by original cooling.
6) **The crust is dynamic, not fixed:** Because these internal forces keep acting, the relief of Tanzania, including its rift valleys and plateaus, is constantly though slowly being remade, which directly contradicts the idea of a finished, unchanging earth.

Examiner's Note

The command word is correct using the concept; marks lie in tying each point to endogenic energy or diastrophic movement with a named example. The discriminator is whether the candidate shows the earth is still active rather than merely listing features.

Question 20

(a) An earthquake is a sudden shaking or vibration of part of the earth crust caused by the rapid release of stored energy as rocks break or shift along a weakness, the energy travelling outward as seismic waves.

Focus: The focus, or hypocentre, is the point inside the earth where the rocks first rupture and the energy is released; for the Kagera quake this lay at shallow depth beneath the crust.

Epicentre: The epicentre is the point on the earth surface directly above the focus, where shaking is usually strongest; for the 2016 event the epicentre lay near Lake Victoria close to Bukoba.

(b)

1) **Tectonic movement:** Most earthquakes, including the Kagera tremor, are tectonic, caused when crustal blocks move suddenly along faults of the East African Rift System, releasing built up stress.
2) **Volcanic activity:** The rise of magma and the violent escape of gases beneath a volcano shake the surrounding ground; tremors are felt around the active Ol Doinyo Lengai in northern Tanzania.

3) **Isostatic adjustment:** When the crust is loaded or unloaded, for example by erosion stripping highlands or by sediment piling in basins, it slowly rises or sinks to regain balance, and this readjustment can trigger tremors.

4) **Collapse and human causes:** The collapse of underground caverns or old mine workings, and the filling of large reservoirs whose water weight strains the crust, can also set off minor earthquakes.

Examiner's Note

Part (a) tests precise definition; marks turn on the contrast between focus (inside) and epicentre (surface). In (b) credit the named mechanism plus a relevant example, not a bare list.

False Confidence Alert

Many candidates write that the focus is on the surface and the epicentre is underground. It is the reverse; the focus is the underground origin and the epicentre is the surface point above it, so swapping them loses easy marks.

Question 21

(a) Seismic waves are the energy waves that travel from the focus of an earthquake and are detected by a seismograph.

Primary (P) waves: These are the fastest waves and arrive first; they are longitudinal, pushing and pulling the rock back and forth, and can pass through solids and liquids.

Secondary (S) waves: These are slower and arrive second; they are transverse, shaking rock up and down or side to side, and cannot pass through liquids.

Surface waves: These are the slowest but most destructive, travelling along the surface as Love waves, which shake from side to side, and Rayleigh waves, which roll like ocean waves, causing most damage to buildings such as those wrecked in Bukoba in 2016.

(b)

(i) Scales used: Magnitude is measured on the Richter scale, which gives a single number for the energy released, while intensity is measured on the Mercalli scale, which grades shaking and damage in Roman numerals from I to XII.

(ii) Why intensity differs: Magnitude is fixed for one earthquake, but intensity varies from place to place; a town built on soft sediment, like parts of the lakeshore near Bukoba, shakes far more violently than a neighbouring town on hard rock the same distance away, because loose ground amplifies the waves.

Examiner's Note

The discriminator is keeping magnitude (energy, one value, Richter) separate from intensity (felt effect, varies, Mercalli). Marks in (a) need the property, not just the name.

False Confidence Alert

A common error is to treat magnitude and intensity as the same thing measured on one scale. They are not; magnitude is a single Richter figure of energy released, while intensity is the Mercalli grade of damage, which differs from place to place for one and the same quake.

Question 22

(a) Lava is molten rock that has reached the surface, and its behaviour depends on its silica content.

Acidic lava: Acidic lava is rich in silica, light coloured, very viscous and flows slowly; it cools fast, traps gas and so erupts violently to build steep sided cones.

Basic lava: Basic lava is poor in silica, dark, very fluid and flows far before cooling; it releases gas gently and builds low, broad cones.

(b) Extrusive features are volcanic landforms built on the surface by erupted material.

1) **Composite cone:** A tall, steep cone built of alternating layers of lava and ash from repeated eruptions, such as Mount Meru near Arusha.
2) **Shield cone:** A low, broad, gently sloping cone formed by very fluid basic lava that spreads widely before solidifying, the form underlying much of Kilimanjaro broad base.
3) **Ash and cinder cone:** A small, steep cone made mainly of loose ash and cinders thrown out during explosive eruptions, common among the parasitic cones around the Rungwe volcanic area.
4) **Crater:** A funnel shaped hollow at the top of a cone marking the vent through which material is erupted, such as the active crater of Ol Doinyo Lengai.
5) **Caldera:** A huge basin, far wider than a crater, formed when the summit of a volcano collapses into the emptied magma chamber after a great eruption, the outstanding example being Ngorongoro Caldera in Tanzania.
6) **Geysers and fumaroles:** Geysers spout hot water and steam, while fumaroles release only volcanic gases and steam; both occur in the geothermally active Lake Natron and Rungwe areas.

Examiner's Note

Part (a) hinges on the silica, viscosity and eruption style contrast. In (b) the discriminator is keeping extrusive (surface) features separate from intrusive ones and naming a real example.

False Confidence Alert

Students often write that basic lava is the more explosive because it is hotter. The reverse is true; acidic lava is more viscous, traps gas and so erupts more violently, while fluid basic lava erupts quietly and spreads far.

Question 23

Vulcanicity, the movement of magma into or onto the crust, brings both serious dangers and valuable gains to the people who live near volcanoes.

1) **Fertile volcanic soils:** Weathered lava and ash break down into deep, mineral rich soils; the productive coffee, banana and maize farms on the slopes of Kilimanjaro and Meru depend directly on these volcanic soils.
2) **Geothermal energy:** Heat from molten rock near the surface can be tapped to generate electricity; the Ngozi and Songwe sites in the Rungwe area of southern Tanzania are being explored for geothermal power.
3) **Tourism and revenue:** Spectacular volcanic scenery attracts visitors and earns foreign exchange; Kilimanjaro, Ngorongoro Caldera and Ol Doinyo Lengai draw thousands of tourists and climbers each year.
4) **Valuable minerals:** Volcanic and associated processes concentrate minerals; the soda ash of Lake Natron and building stone from volcanic rock are won from these areas.
5) **Destruction by eruptions:** Lava flows, ash falls and volcanic gases can bury farmland, destroy property and harm health; eruptions of Ol Doinyo Lengai have blanketed nearby Maasai grazing land in ash.
6) **Earthquakes and steep, hazardous land:** Volcanic activity triggers tremors and creates steep, unstable slopes prone to landslides, making settlement and farming on high volcanic ground risky.

Examiner's Note

The command word is examine, so each point needs a brief reason, and the balance of harmful and beneficial sides is the discriminator. Marks lie in named Tanzanian examples, not generalities.

Question 24

Faulting is the fracturing of crustal rocks along which the blocks are displaced by tension or compression, and it produces several distinctive landforms.

1) **Rift valley (graben):** A long, narrow trough formed when a central block sinks between two roughly parallel faults as the crust is stretched; the western arm of the East African Rift holding Lake Tanganyika is a clear example.
2) **Block or horst mountain:** An upstanding block left high when the land on either side sinks, or when the block itself is pushed up between faults; the Usambara, Pare and Uluguru Mountains of Tanzania are fault blocks.
3) **Fault scarp:** A steep cliff or slope marking the exposed face of a fault where one block stands above another, as seen along the edges of the rift near Lake Nyasa.
4) **Tilted block:** Where faulting lifts one side of a block more than the other, the block is tilted to form an asymmetrical upland with one steep and one gentle slope, common along the rift shoulders.
5) **Rift lakes:** Water collecting on the floor of a graben forms long, deep lakes; Lake Tanganyika and Lake Nyasa fill the deep western rift, while shallow soda lakes such as Natron and Eyasi occupy the eastern branch.
6) **Step faulting:** A series of parallel faults can let the land drop in stages like giant steps down into the rift, producing the stepped descent seen on parts of the rift margin.

Examiner's Note

Marks lie in the formation process plus a named Tanzanian landform for each point. The discriminator is distinguishing the sunken graben from the upstanding horst rather than blurring the two.

Question 25

(a) The East African Rift System is a great series of faults running through East Africa, and in Tanzania it divides into two distinct branches.

Eastern (volcanic) branch: The eastern branch passes through northern Tanzania and is marked by intense volcanic activity and shallow, salty soda lakes; Ol Doinyo Lengai, Lake Natron and Lake Eyasi lie along it.

Western (deep lake) branch: The western branch runs along the western edge of Tanzania and is marked by deep, steep sided troughs holding very deep fresh water lakes, notably Lake Tanganyika and Lake Nyasa, with less volcanic activity.

(b) Faulting does not only create lakes directly; it also reshapes rivers in indirect ways.

Reversal of rivers: Uplift along a fault can block and turn back a river; the Kagera River was reversed by rift movement and now flows eastward into Lake Victoria instead of westward.

Formation of waterfalls and rapids: Where a river crosses a fault scarp it plunges over the sudden drop, creating waterfalls and rapids along its course on the rift margins.

Ponding and lake formation: Faulting can dam a valley so that the river water collects behind the barrier to form a lake, altering the whole drainage pattern of the area.

Examiner's Note

In (a) the discriminator is the contrast volcanic-and-soda-lakes (east) versus deep-fresh-lakes (west). Part (b) credits indirect drainage effects with the reversed Kagera as the key example.

False Confidence Alert

Many candidates assume the deep rift lakes such as Tanganyika were scooped out by rivers. They were not; they fill troughs created when crustal blocks sank between faults, so river erosion is not their cause.

Question 26

(a) Folding is the bending of crustal rock layers into waves by compressional forces acting horizontally, without the rocks breaking.

Anticline: The up arched part of a fold, where the limbs dip away from the crest.

Syncline: The down sagging part of a fold, where the limbs dip towards the trough.

Limbs and axis: The limbs are the two sloping sides of a fold, while the axis is the central line about which the layers are bent.

(b) Folds are classed by how far compression has tilted and pushed the limbs.

1) **Simple or symmetrical fold:** A gentle fold whose two limbs dip away from the axis at about equal angles, formed by moderate compression.
2) **Asymmetrical fold:** A fold in which one limb is steeper than the other because compression was stronger from one side.
3) **Overfold:** A fold pushed so far that one limb is bent over the other, both limbs dipping in the same direction.
4) **Recumbent fold:** A fold pressed almost horizontal by intense compression, so the axis lies nearly flat; where it shears and slides forward it becomes a nappe, as seen in the Atlas Mountains of north Africa.

Examiner's Note

Part (a) needs accurate naming of anticline, syncline, limbs and axis. In (b) the discriminator is the increasing intensity of compression from symmetrical through to recumbent, with an African example where folding occurs.

Question 27

Endogenic processes, namely vulcanicity, faulting, folding and broad earth movements, have built much of the Tanzanian landscape and strongly influence how people live and work.

1) **Building highland relief:** Faulting and vulcanicity have raised the block mountains and volcanic peaks, from the Usambara and Pare ranges to Kilimanjaro and Meru, giving Tanzania its varied, often cool highland relief.
2) **Creating fertile farming zones:** Volcanic soils on Kilimanjaro and Meru and in the rift highlands support dense farming of coffee, bananas and maize, so the most productive agriculture follows the volcanic uplands.
3) **Forming lakes for fishing and transport:** Rift faulting created the deep lakes Tanganyika and Nyasa, which provide fisheries, fresh water and cheap water transport for the surrounding communities.
4) **Concentrating settlement:** The cool, fertile, well watered volcanic and fault highlands attract dense settlement, as around Kilimanjaro and the Southern Highlands, whereas the dry rift floors are thinly peopled.
5) **Providing energy and mineral resources:** Volcanic activity offers geothermal power potential in the Rungwe area, while soda ash from Lake Natron and other rift minerals support industry and export.
6) **Supporting tourism and posing hazards:** Volcanic and rift scenery such as Ngorongoro and Kilimanjaro earns large tourist revenue, yet the same forces bring earthquakes, like the 2016 Kagera quake, and steep, unstable slopes.

Examiner's Note

The command word is assess, so each point must link a landform to a human consequence. Marks lie in the relief-to-activity connection backed by named Tanzanian examples.

Question 28

Denudation is the total wearing down and lowering of the land surface by exogenic processes, and it is the sum of three linked actions powered by sources outside the Earth.

Meaning: Denudation is the stripping away and general lowering of the land surface over time, so that high ground is reduced and the rock waste is moved to lower areas, as is happening to the worn plateaus of central Tanzania.

Weathering: It begins with weathering, the breakdown of rock in place into loose material without any movement, for example the rounded core boulders left by exfoliation on the granite hills near Dodoma.

Mass wasting: It includes mass wasting, the downslope movement of weathered material under gravity, such as the soil creep and landslides on the steep slopes of the Usambara Mountains.

Erosion: It includes erosion, the wearing away and removal of material by moving agents such as rivers, wind, waves and ice, for instance the cutting of valleys by the Pangani River.

Energy of the Sun: The chief energy source is the Sun, which drives the heating, the winds, the rain and the rivers that attack and carry the rock, so that exogenic work is solar work in disguise.

Energy of gravity: Gravity is the second source, pulling all loosened material and all moving water downhill, so that denudation always works from higher to lower ground and never the reverse.

Examiner's Note

The command word is explain, so define denudation and give reasons. Most marks lie in separating weathering, mass wasting and erosion rather than treating them as one. The discriminator is naming both energy sources, the Sun and gravity.

Question 29

Mechanical weathering breaks rock into smaller pieces by physical stress alone, without changing its chemical make-up, and it works through several distinct processes.

1) **Exfoliation:** Repeated heating and cooling makes the outer skin of a rock expand and contract more than the inside, so curved shells peel away, as on the granite domes near Dodoma.
2) **Insolation weathering:** In hot deserts the different minerals in a rock expand by different amounts under fierce daytime heat and contract at night, so the rock crumbles grain by grain, as on the rocky surfaces of the Sahara.
3) **Frost action:** Where it is cold, water seeps into cracks, freezes, expands by about a tenth and prises the rock apart, a process seen high on the frost-shattered summit rocks of Kilimanjaro.
4) **Salt crystallisation:** In dry and coastal places salty water enters pores and evaporates, leaving crystals that grow and push the grains apart, weakening rock along the Tanga coast.
5) **Pressure release:** When overlying rock is removed by erosion the buried rock below is freed of its load, expands upward and cracks into sheets parallel to the surface, helping form the bare domes of the central plateau.
6) **Wetting and drying:** Some clay-rich rocks swell when wet and shrink when dry, and the repeated swelling and shrinking flakes the surface and opens cracks during the alternating wet and dry seasons of Tanzania.

Examiner's Note

The command word is describe, so set out how each process physically works. Marks lie in the mechanism, the actual stress that splits the rock, not just the name. A common discriminator is keeping these physical, with no chemical change.

Question 30

(a) The two differ in whether the rock is merely broken or actually altered.

Mechanical: Mechanical weathering breaks rock into smaller fragments by physical force alone, and the broken pieces keep the same chemical composition as the parent rock.

Chemical: Chemical weathering alters the minerals of the rock by chemical reaction, usually with water, so that new and softer substances form and the rock decays rather than simply cracks.

(b)

1) **Carbonation:** Rainwater charged with carbon dioxide forms a weak carbonic acid that dissolves limestone into soluble calcium bicarbonate, the process that hollows out the Amboni caves near Tanga.
2) **Oxidation:** Oxygen in moist air combines with iron minerals in the rock to form rust-coloured iron oxides that crumble easily, staining and weakening iron-bearing rocks of the interior.
3) **Hydrolysis:** Water reacts with feldspar in granite and turns it into soft clay, so the rock loses its strength and rots from within, decaying the granites of central Tanzania.
4) **Hydration:** Certain minerals take water into their structure and swell, setting up stress that flakes the rock surface and prepares it for further decay in the humid coastal belt.

Examiner's Note

In (a) the marks lie in the contrast, broken versus chemically altered, not two separate definitions. In (b) explain the reaction and name the target mineral. The discriminator is matching carbonation to limestone and oxidation to iron.

False Confidence Alert

Calling chemical weathering a form of erosion loses marks. Weathering breaks rock in place with no transport, while erosion wears away and carries material off, so carbonation dissolving limestone is weathering, not erosion.

Question 31

Mass wasting is the downslope movement of weathered material under gravity, and several factors decide whether and how fast a slope will move.

1) **Gravity and slope angle:** Gravity is the driving force, and the steeper the slope the greater the downhill pull, so the abrupt slopes of the Usambara Mountains move material far more readily than gentle ground.
2) **Water content:** Heavy or prolonged rain soaks the soil, adds weight and reduces the friction holding grains together, which is why the saturated slopes at Lwandai in Lushoto flowed as mud in 2022.
3) **Nature of the material:** Loose, deeply weathered and clay-rich material slides far more easily than solid rock, so the thick weathered mantle of the Tukuyu area is prone to slumping.
4) **Loss of vegetation:** Plant roots bind the soil and draw out water, so when forest is cleared for farming the slopes lose their anchor and slip, a problem on the cultivated highlands around Lushoto.
5) **Undercutting:** Rivers, waves or road cuttings that remove the base of a slope take away its support, so the mass above loses balance and collapses, a frequent cause of failures along mountain roads.
6) **Earth tremors and shaking:** Vibration from earthquakes along the Rift jolts loose material past its point of balance and sets rockfalls and landslides in motion on already steep ground.

Examiner's Note

The command word is explain, so give the reason each factor matters, not just a list. Marks lie in linking the factor to the loss of slope stability. The discriminator is separating the steady factors, such as slope and material, from the triggers, such as rain and tremors.

Question 32

(a) The two wind processes differ in whether the wind lifts material or uses it as a tool.

Deflation: Deflation is the lifting and removal of loose dry sand and dust by the wind, lowering the surface and leaving hollows, a process active across the dry Sahara.

Abrasion: Abrasion is the wearing and scouring of standing rock by the sand the wind carries, so the wind sandblasts the rock much as a worker sandblasts stone.

(b)

1) **Deflation hollow:** Where the wind scoops out loose material it leaves a shallow basin called a deflation hollow, common on the sandy floors of the Sahara.
2) **Zeugen:** Where hard rock lies over soft rock, abrasion near the ground cuts the soft rock faster and leaves tabular ridges called zeugen standing above the furrows in the Sahara.
3) **Yardang:** Where hard and soft rocks stand on end, the wind etches out the soft bands and leaves the hard bands as sharp parallel ridges called yardangs.
4) **Barchan dune:** Where sand is moved and deposited, a crescent-shaped barchan dune forms with its horns pointing downwind, the classic mobile dune of the Sahara.

Examiner's Note

In (a) the discriminator is that deflation removes loose grains while abrasion uses those grains to carve solid rock. In (b) marks lie in shape and how the wind made it. Tanzania has no true hot desert, so Saharan examples are correct here.

False Confidence Alert

Do not place hot-desert dunes in Tanzania. The country has no true hot desert, so barchans, zeugen and yardangs must be illustrated from the Sahara or Namib; an invented Tanzanian desert example is penalised.

Question 33

Although deserts are dry, rare violent storms send water racing over bare unprotected ground, and this running water carves and deposits several distinct landforms.

1) **Wadi:** A wadi is a steep-sided desert valley cut by an occasional flood and left dry for most of the year, a common channel across the Sahara.
2) **Rills and gullies:** Sudden runoff scores the bare slopes into small channels called rills, which deepen into larger gullies, dissecting the unprotected surfaces of arid land.
3) **Pediment:** A pediment is a gently sloping rock surface at the foot of desert highlands, worn smooth by sheets of running water spreading out from the hills.
4) **Alluvial fan:** Where a flooded channel leaves the hills onto flatter ground it drops its load in a fan-shaped spread of sediment called an alluvial fan, widening out from the mountain front.
5) **Bajada:** Where several alluvial fans grow side by side and merge along the mountain base they form a continuous apron of sediment called a bajada.
6) **Playa:** Floodwater collecting in a closed desert basin forms a shallow temporary lake that dries to leave a flat salt-crusted floor called a playa, found on the floors of arid basins.

Examiner's Note

The command word is describe, so name the form and how water made it. Marks lie in showing water, not wind, as the agent. The discriminator is distinguishing erosional forms such as the wadi from depositional ones such as the bajada.

Question 34

Karst features form because limestone is jointed and is slowly dissolved by rainwater charged with carbon dioxide through carbonation, which works along the joints both at the surface and underground.

1) **Clints and grikes:** Rainwater widens the joints of bare limestone by solution into deep grooves called grikes, leaving upstanding blocks called clints between them on the exposed limestone surface.
2) **Dolines:** Solution at a joint intersection, or the collapse of a cave roof, opens a funnel-shaped surface hollow called a doline, the basic enclosed depression of karst country.
3) **Uvala:** Where several neighbouring dolines enlarge and join together they form a larger irregular depression called an uvala.
4) **Caves:** Underground, water flowing along the joints and bedding planes dissolves the limestone into long cave systems, as at the Amboni caves near Tanga.
5) **Stalactites and stalagmites:** In the caves, dripping water deposits calcium carbonate to grow icicle-like stalactites from the roof and rounded stalagmites from the floor below them.
6) **Pillars:** Where a stalactite and a stalagmite continue to grow until they meet and join, they form a continuous column or pillar of calcium carbonate from floor to roof.

Examiner's Note

The command word is explain, so give the chemical process, carbonation, and how each feature grows. Marks lie in the dissolving of limestone along joints, not mere description. The discriminator is that stalactites and stalagmites are deposited, while caves and grikes are dissolved out.

False Confidence Alert

Mixing up stalactites and stalagmites costs marks. The stalactite hangs tight to the ceiling, while the stalagmite grows up from the ground; both are deposits of calcium carbonate left by dripping water, not features dissolved out of the rock.

Question 35

(a) A river wears away its bed and banks by several distinct erosional processes.

1) **Hydraulic action:** The sheer force of moving water pushes into cracks in the bed and banks, compresses trapped air and loosens and plucks out the rock, strong in the flood flows of the Rufiji.
2) **Abrasion:** The river uses the sand and stones it carries as tools to scour and grind its bed and banks, the chief way it deepens its channel.
3) **Attrition:** The transported stones strike one another and the bed and gradually wear each other down into smaller, smoother and rounder fragments as they travel.
4) **Solution:** Water dissolves soluble minerals from the bed and banks, such as the limestone along parts of the Pangani, carrying them away unseen in solution.

(b) Having loosened its load, the river carries it downstream in four ways at once.

1) **Traction:** The largest boulders are rolled and dragged along the bed by the force of the current, moving only during strong flow.
2) **Saltation:** Smaller stones and coarse sand are bounced along the bed in a series of hops as the current lifts them briefly and drops them again.
3) **Suspension:** Fine clay and silt are held up within the moving water and carried along without touching the bed, giving the Rufiji its brown flood colour.
4) **Solution:** Dissolved minerals are carried invisibly in the water itself, moving downstream as a chemical load with no visible particles.

Examiner's Note

The command word is explain, so give how each process works, not just the term. Marks lie in mechanism, for example hydraulic action as water force against attrition as stones wearing each other. The discriminator is keeping erosion in (a) and transport in (b) cleanly apart.

Question 36

These four landforms record the changing work of a river as vertical erosion gives way to lateral erosion and deposition along its course.

1) **V-shaped valley:** In its upper course the river cuts downward by vertical erosion while weathering and runoff wear back the sides, so the valley takes a narrow V-shaped cross profile, as in the upper Pangani.
2) **Waterfall:** Where a band of hard rock lies across the channel above softer rock, the river wears the soft rock away faster, undercuts the hard band and leaves a step over which the water plunges as a waterfall.
3) **Meander:** On gentler ground the river swings from side to side, eroding the outer bank where flow is fast and depositing on the inner bank where it is slow, so the channel develops sweeping bends called meanders, well shown on the lower Rufiji.
4) **Ox-bow lake:** As a meander grows, its narrow neck is gradually cut through, especially in flood, so the river takes the short straight course and abandons the loop, which is sealed off as a curved ox-bow lake.

Examiner's Note

The command word is describe, so set out the sequence that makes each form. Marks lie in the process behind the shape, for example hard-over-soft rock for the waterfall and outer-bank erosion for the meander. The discriminator is explaining formation, not merely how each looks.

False Confidence Alert

Describing a waterfall only by how it looks, a wall of falling water, earns little. The marks lie in explaining the retreat of a hard band of rock over softer rock beneath, with undercutting and collapse, which is why the step exists at all.

Question 37

In its lower course a river loses energy and deposits its load, building several landforms out of the sediment it can no longer carry.

1) **Flood plain by deposition:** When a river overflows in flood the water spreads onto the valley floor, slows and drops its load, and repeated floods build a wide flat plain of fertile alluvium, as along the lower Rufiji.
2) **Flood plain widening:** Migrating meanders also sweep across the valley floor over time, planing it flat and broadening the flood plain on either side of the channel.
3) **Levee formation:** During a flood the river drops its coarsest load first at the channel edge as the water slows on leaving the channel, so raised banks called natural levees are built up along the sides.
4) **Levee in later floods:** Once formed, the levees stand above the plain and help to keep the river within its banks between floods, sometimes raising the channel above the surrounding land.
5) **Delta deposition:** Where the river meets the still water of the sea it slows sharply and deposits its load at the mouth, and where the sea is calm the sediment builds out into a delta, as the Rufiji has built its arcuate delta.
6) **Delta channels:** The deposited sediment forces the river to split into many shifting branches called distributaries that carry the water across the delta to the sea.

Examiner's Note

The command word is explain, so give why deposition happens, the loss of energy, for each form. Marks lie in linking slowing water to dropped load. The discriminator is naming the Rufiji arcuate delta and the role of distributaries.

Question 38

(a) Rejuvenation is the renewal of a river's downcutting power.

Meaning: Rejuvenation is the renewed vertical erosion of a river when its energy is increased, so that a river which had nearly reached its base level begins to cut down into its bed again.

By land uplift: It can be caused by uplift of the land, which steepens the gradient and gives the river fresh energy to cut downward, as along the uplifted blocks of the Rift margins.

By fall in sea level: It can also be caused by a fall in sea level, which lowers the river's base level and forces it to cut down to reach the new level of the sea.

(b)

1) **Knick-point:** A knick-point is a sharp break of slope, often marked by rapids or a small waterfall, where the renewed downcutting from below has worked its way upstream into the older gentle profile.
2) **River terraces:** River terraces are flat benches of the old flood plain left stranded above the river on the valley sides after the rejuvenated river has cut down below them.
3) **Incised meanders:** Incised meanders are deep winding valleys formed when a meandering river, rejuvenated, cuts its bends downward into the rock while keeping their looping plan.
4) **River capture:** River capture is the diversion of one river by another, when a strong river eroding headward cuts back into the valley of a weaker neighbour and beheads it, diverting its upper water into its own channel.

Examiner's Note

In (a) the marks lie in renewed downcutting plus a correct cause, uplift or falling sea level. In (b) describe each form by how rejuvenation made it. The discriminator is that capture is one river stealing another, with headward erosion and a beheaded stream.

Question 39

Waves both wear away and build up the coast, so the shore carries erosional forms cut by destructive waves and depositional forms built by constructive waves and longshore drift.

1) **Cliff and wave-cut platform:** Destructive waves attack the base of high ground and undercut it, so the rock above collapses and the cliff retreats, leaving a gently sloping wave-cut platform at its foot along rocky stretches of the Tanga coast.
2) **Cave, arch and stack:** Waves pick out lines of weakness in a headland, opening a cave that may cut right through to form an arch; when the arch roof falls an isolated stack is left standing offshore, as off parts of the Dar es Salaam coast.
3) **Blowhole:** Where a cave is enlarged upward to the cliff top, waves force air and spray up through the opening as a blowhole, throwing spray into the air during high seas.
4) **Beach:** Constructive waves wash sand and shingle onshore and pile it up between the tide marks to build a beach, such as the broad sands of Nungwi in Zanzibar.
5) **Spit:** Where longshore drift carries sand along the coast and the shoreline turns, the sand is deposited as a long ridge growing out into the open water as a spit, often with a curved end.

6) **Tombolo:** Where a spit or bar of deposited sand grows out far enough to join an offshore island to the mainland, the link is called a tombolo.

Examiner's Note

The command word is describe, so give the wave action behind each form. Marks lie in matching destructive waves to erosion and constructive waves and drift to deposition. The discriminator is keeping the two groups distinct.

Question 40

(a) Spring and neap tides differ in their range because of the changing pull of the Sun and Moon.

Spring tides: Spring tides are tides of large range, with very high high-water and very low low-water, occurring when the Sun and Moon pull in line and combine their gravitational pull at new and full Moon.

Neap tides: Neap tides are tides of small range, with lower high-water and higher low-water, occurring when the Sun and Moon pull at right angles so their forces partly cancel, near the half Moon.

(b)

Eustatic change: A eustatic change is a worldwide rise or fall in the level of the sea itself, caused for example by water locked into or released from ice sheets, and it affects all coasts together.

Isostatic change: An isostatic change is a local rise or fall of the land relative to the sea, caused for example by the land rising after the weight of an ice sheet is removed, and it affects only that region.

Submergent landform: A drowned coast shows submergent landforms such as a ria, a winding inlet formed when the sea floods a former river valley as the relative sea level rises, as along parts of the Tanzanian coast, while raised beaches near Tanga record uplift of the land.

Examiner's Note

In (a) the marks lie in the alignment of Sun and Moon producing the contrast in range. In (b) the discriminator is worldwide sea versus local land movement. Name a genuine submergent form such as a ria, fiord or estuary.

False Confidence Alert

Eustatic and isostatic are not interchangeable. A eustatic change moves the whole world ocean, while an isostatic change moves the land in one region; confusing the global sea with local land movement loses the distinction the examiner is testing.

Question 41

A rock is a natural aggregate of one or more minerals, and geologists sort it three ways at once.

1) **A rock is an aggregate of minerals:** A rock is a solid mass formed of one or more minerals bound together, so that the Dodoma granite is built of the separate minerals quartz, feldspar and mica grown into one body.

2) **Built from a few chief crustal elements:** Almost every rock is made from a short list of elements led by oxygen and silicon, with aluminium, iron and a few others, so that the silica that dominates the Dodoma granite is simply silicon joined to oxygen.

3) **Classification by mode of formation:** The first basis sorts rocks by how they formed, into igneous from cooled magma, sedimentary from settled sediment and metamorphic from altered rock, so the Dodoma granite is filed as igneous.

4) **Classification by chemical composition:** The second basis sorts rocks by the chemistry of their minerals, chiefly by silica content, so the silica-rich Dodoma granite is named acidic while the Rungwe basalt is named basic.

5) **Classification by age:** The third basis sorts rocks by the time of their formation, ordering them oldest first, so the ancient Dodoma granite of the basement is placed far below the young volcanic rock of the rift.

6) **One rock named under all three:** Because the three bases ask different questions, the one Dodoma granite is at once igneous by origin, acidic by chemistry and very old by age, which is why a single rock carries three different labels.

Examiner's Note

Define the aggregate first, then give all three bases; the marks lie in showing why one rock can be named under each. A candidate who lists only rock types, not bases, caps the score.

Question 42

(a) Igneous rock carries two unmistakable marks.

Crystalline and without strata: Igneous rock is hard and crystalline and shows no bedding layers, because it cooled from molten magma rather than settling in beds, as in the unbedded Dodoma granite.

No fossils: Igneous rock holds no fossils, since the great heat of the magma would destroy any remains, so the Rungwe basalt is fossil-free.

(b)

(i) Texture from rate of cooling: The Dodoma granite cooled slowly deep underground, so large crystals had time to grow and the rock is coarse and phaneritic, while the Rungwe basalt cooled fast at the surface, giving the small crystals of a fine, aphanitic rock.

(ii) Composition from silica content: The pale Dodoma granite is acidic, rich in silica at over sixty-five percent, whereas the dark Rungwe basalt is basic, poor in silica and rich in iron and magnesium, which is why it is heavier and darker.

Examiner's Note

Part (a) wants only true diagnostic marks; part (b) carries the weight, where texture must be tied to cooling rate and composition to silica. Pairing the two named rocks throughout is what earns full marks.

False Confidence Alert

Naming a rock igneous because it is hard is unsafe, since quartzite and many sedimentary rocks are hard too. The sure marks are the interlocking crystals, the absence of strata and the absence of fossils together.

Question 43

Sedimentary rock builds at the surface from settled material, and falls into three groups by where that material came from.

1) **Formation by settling and compaction:** Loose sediment accumulates in layers, then the weight of later beds compacts it and natural cement binds the grains into solid rock, so the name comes from the Latin sedere, to settle, as in the bedded Tanga limestone.

2) **Strata and fossils as the family mark:** Because the sediment was laid down bed upon bed, sedimentary rock shows clear strata and may bury the remains of life as fossils, neither of which the crystalline igneous rocks carry.

3) **Mechanically formed, or clastic:** The first group is built of broken fragments of older rock graded by size, from the fine argillaceous shale through the sandy arenaceous sandstone to the coarse rudaceous conglomerate, as in the Karoo sandstones.

4) **Organically formed:** The second group is built from the remains of living things, giving the calcareous limestone of Tanga from shells and coral and the carbonaceous coal of Kiwira from buried plants.

5) **Chemically formed:** The third group forms when minerals dissolved in water are precipitated, often as a lake or sea dries up, giving rock salt and gypsum from evaporation.

6) **Industrial raw material and energy:** Because of this varied origin the family supplies both raw materials, such as the Tanga limestone burnt for cement, and energy, such as the Kiwira coal, which is why it matters so much to a developing economy.

Examiner's Note

Explain the settling origin, then give the three origin groups with a named rock for each; the discriminator is naming a real Tanzanian rock per group. Listing rock names without the three groups caps the marks.

Question 44

(a) Metamorphism is recrystallisation in the solid state.

Change without melting: Metamorphism is the change of a rock's minerals and texture in the solid state, brought about by heat, pressure and chemically active fluids, so that an earlier rock is made over without ever melting, as the Usambara limestone became marble.

(b) Three agents drive the change, and the texture it leaves takes two forms.

1) **Heat as the master agent:** Heat recrystallises the minerals into new, often larger crystals, and is taken as the master agent because it can act alone, as where magma bakes the limestone of a contact zone into marble.

2) **Pressure:** Directed pressure from deep burial or mountain-building squeezes and flattens the minerals, aligning them so that the rock gains a banded grain, as shale is pressed into slate.

3) **Chemically active fluids:** Hot fluids moving through the rock add or remove ions and so change its very chemistry, helping new minerals to grow during the change.

4) **Foliated rock:** Where directed pressure aligns the minerals into bands or sheets the rock is foliated, as in the slate, schist and gneiss formed in the Usambara basement, which split along the banding.

5) **Non-foliated rock:** Where the change is by heat without directed pressure no banding forms, so the rock is non-foliated, as limestone becomes marble and sandstone becomes quartzite.

Examiner's Note

Define the solid-state change in (a), then in (b) give all three agents and contrast the two textures with named parent-to-product pairs. The marks turn on foliation arising from directed pressure, not heat.

Question 45

The rock cycle is the endless conversion of the three families, driven by internal heat and the surface processes.

1) **Magma yields igneous rock:** The cycle starts as molten magma cools and solidifies into igneous rock, the primary rock of the crust, as the Dodoma granite formed from a deep, slow-cooling body of magma.

2) **Igneous rock weathered into sediment:** Exposed at the surface, the granite is broken by weathering and its grains are carried off by rivers, so the hard rock is reduced to loose sediment such as sand.

3) **Sediment compacted into sedimentary rock:** The sediment settles in layers, is compacted and cemented, and becomes sedimentary rock, so the granite sand may end as a bed of sandstone in a basin like the Karoo.

4) **Burial turns rock metamorphic:** Where the sedimentary or igneous rock is buried deep and met by heat and pressure it recrystallises into metamorphic rock, so the sandstone is remade as quartzite.

5) **Melting closes the loop:** Carried still deeper, any rock may melt back into magma, which on cooling forms new igneous rock, so the path returns to where it began and the cycle is endless, not linear.

6) **Driven by two engines and full of short-cuts:** The whole cycle is powered by the Earth's internal heat below and by the hydrological cycle and weathering above, and a rock may skip a stage, as igneous rock taken straight to depth becomes metamorphic without ever being sediment.

Examiner's Note

Trace the loop in order and name the engine at each step; the marks lie in showing it as endless and reversible, not a one-way list. Note the short-cuts that skip a stage to earn the top band.

Question 46

(a) The two kinds of age answer different questions.

Relative orders, absolute dates: Relative age only puts rocks in order from oldest to youngest, while absolute age gives the actual age in years, so a geologist in the Dodoma basement may know one bed is older than another long before knowing its age in millions of years.

(b)

(i) Relative dating by stratigraphic laws: Relative dating rests on the law of superposition, that in undisturbed beds the lowest is oldest, helped by original horizontality, by cross-cutting relationships in which a fault or intrusion is younger than the rock it cuts, by included fragments which are older than their host, and by fossil succession, which matches beds of the same age across the Karoo basins.

(ii) Absolute dating by radioactive decay: Absolute dating uses the steady decay of a radioactive element at a fixed half-life, so the change of uranium to lead dates the oldest basement rocks in billions of years, while carbon-14, with its short half-life, dates only recent once-living material such as wood or bone.

Examiner's Note

Keep (a) to the order-versus-years distinction; (b) carries the weight and must name the actual laws and the decay clocks, not just the words. Tying carbon-14 to young material only is the discriminator.

False Confidence Alert

Many think carbon-14 can date a granite or a dinosaur bone of hundreds of millions of years. Its half-life is far too short, so old rock is dated by uranium to lead, and carbon-14 is kept for recent organic material.

Question 47

Soil is a function of five factors acting together upon a weathering parent rock.

1) **Parent material:** The parent rock supplies the mineral grains and sets the early texture and chemistry of the soil, so the mafic volcanic rock of Kilimanjaro yields a rich soil while a quartzite gives almost none.

2) **Climate, the leading factor:** Climate is often the dominant factor, for warmth and heavy rain speed the weathering of the parent rock and drive the leaching of minerals, so the hot, wet highlands form deep soils far faster than the dry centre at Dodoma.

3) **Relief, or topography:** Slope governs how deep a soil can lie, so the steep Uluguru slopes lose their soil to wash and stay thin and dry, while the gentle valley floors hold deep, moist soils.

4) **Living organisms:** Plants, animals and microbes add humus, mix the layers and release nutrients, so the dense forest litter of the Usambara highlands builds a dark, fertile topsoil through decay and the burrowing of soil animals.

5) **Time:** Soil forms only slowly, so a thin immature soil deepens into a mature, well-layered profile only over hundreds or thousands of years of weathering, as on the long-stable plateau surfaces.

6) **The factors act together:** No factor works alone, so the deep, fertile soil of Kilimanjaro is the joint product of rich parent ash, a warm wet climate, gentle middle slopes, lush vegetation and long time, which is why the same rock gives different soils in different places.

Examiner's Note

Name all five factors and develop each with an example; the discriminator is showing they act together, not singly, and that climate often leads. Confusing weathering itself with the wider soil-forming process caps the marks.

Question 48

A mature soil profile is a set of layered horizons shaped by the downward movement of water and material.

1) **The O and A horizons at the top:** The surface O horizon is the litter of dead leaves and the dark, humus-rich A horizon is the topsoil where roots and soil life are richest, as in the deep dark topsoil of the Rungwe volcanic soils.

2) **The B horizon below:** The B horizon, or subsoil, is the zone of accumulation where clay, iron and other material washed from above are deposited, so it is denser and often brighter coloured than the topsoil.

3) **The C and R horizons at the base:** The C horizon is the weathered, broken parent rock, the regolith from which the soil grew, and beneath it the R horizon is the solid unweathered bedrock, such as the basement gneiss under a Rungwe soil.

4) **Leaching:** Leaching is the washing of dissolved minerals down out of the topsoil by percolating rainwater, which strips the upper layers of nutrients in the wet highlands and leaves them less fertile.

5) **Eluviation and illuviation:** Eluviation is the washing-out of fine clay and material from the upper A horizon, and illuviation is its deposition lower down in the B horizon, so the two together move material from top to subsoil.

6) **Humification:** Humification is the breakdown of dead plant and animal matter by soil organisms into dark humus in the A horizon, which gives the topsoil its colour, its crumb structure and much of its fertility.

Examiner's Note

Name the horizons in order top to bottom, then give the linking processes; the marks lie in tying each process to the movement between named horizons. **A labelled profile sketch** earns the construction marks.

Question 49

(a) Soil productivity rests on several measurable factors.

Plant nutrients and humus: A productive soil is rich in plant nutrients and in humus, so the well-supplied volcanic soil of Rungwe yields heavily while a leached soil does not.

Texture, depth and water: A good crumb texture, a deep rooting layer and a steady supply of moisture all raise productivity, so a deep loam outyields a thin or waterlogged soil.

Soil reaction and life: A balanced acidity and an active population of soil organisms keep nutrients available, so a soil neither strongly acid nor strongly saline supports the fullest growth.

(b)

1) **Sheet erosion:** Sheet erosion is the even removal of a thin layer of topsoil from a whole slope by a film of running water, which quietly strips the most fertile layer from cultivated land such as the cleared Kondoa hills.

2) **Rill erosion:** Rill erosion occurs where the flow gathers into small channels that cut shallow grooves into the soil, the first clear sign that the wash is concentrating.

3) **Gully erosion:** Gully erosion is the deepening of those channels into large, steep-sided trenches too big to plough across, the deep gullies of Kondoa being the severe end of the process.

4) **Control by terracing and contour ploughing:** Cutting the slope into level terraces and ploughing along the contour rather than up and down it both hold back the runoff and let it soak in, sharply cutting the wash on the Kondoa slopes.

5) **Control by cover crops and afforestation:** Keeping the ground under cover crops and planting trees shield the soil from the beating rain and bind it with roots, which is the heart of the soil-conservation work in the Kondoa area.

Examiner's Note

Part (a) wants true productivity factors; part (b) carries the weight and must grade the three erosion forms by severity, then pair two real control measures. Naming Kondoa anchors the answer.

False Confidence Alert

It is wrong to treat all soil erosion as natural; over much of Tanzania it follows human acts, the clearing of vegetation, overgrazing and ploughing up and down a slope, so conservation must change those practices, not merely blame the rain.

Question 50

The hydrological cycle is the continuous circulation of water between the oceans, the atmosphere and the land, driven by solar energy and gravity, so that water is transferred but never lost.

1) **Closed system:** Globally the cycle is a closed system; no water enters from space and almost none escapes, so the total volume stays fixed even though the Indian Ocean off Tanga loses water to the air daily.

2) **Solar energy as the driver:** The Sun supplies the heat that evaporates water from the surface of Lake Victoria, lifting it into the atmosphere against gravity and powering the whole circulation.

3) **Gravity as the return force:** Gravity pulls precipitation back to the ground and moves rivers such as the Rufiji downhill to the sea, so water raised by the Sun is always returned to the oceans.

4) **Transfers between stores:** Water passes from the ocean store to the air by evaporation, to the land by precipitation, and back through runoff, so any store may gain or lose but the sum is unchanged.

5) **Inputs balance outputs:** Over a long period the rain falling on the Tanzanian land surface is balanced by evaporation and river discharge leaving it, keeping each store in long term equilibrium.

6) **Recycling of the same water:** Because the cycle has no beginning or end, the water vapour condensing over the Uluguru Mountains is recycled water that has passed through the cycle countless times before.

Examiner's Note

Command word is explain, so marks reward the mechanism of transfer and the closed nature of the system, not a mere list of processes. The discriminator is naming the Sun and gravity as the two drivers.

Question 51

(a) Evaporation is the change of water from liquid to vapour from an open water or soil surface, whereas evapotranspiration is the combined loss by evaporation plus transpiration from plants, as over the Kilombero floodplain where both the water and the rice crop release vapour.

(b)

1) **Temperature:** Higher air and surface temperature gives water molecules more energy to escape, so the sunlit pan at Dodoma evaporated faster than the shaded one.

2) **Humidity of the air:** Dry air can absorb more vapour, so evaporation is rapid over the dry interior near Dodoma but slows when the air is already near saturation.

3) **Wind:** Wind sweeps saturated air away and replaces it with drier air, so the windy pan kept losing water while still air over the shaded pan became saturated and evaporation stalled.

4) **Surface area exposed:** A larger or more disturbed surface exposes more water to the air, which is why a broad shallow water body such as Lake Eyasi loses water quickly relative to its volume.

Examiner's Note

Part (a) marks lie in the plant component that separates the two terms; part (b) rewards linking each named factor to its effect on rate. Weak scripts define the terms but never tie factors to the pans.

False Confidence Alert

Many candidates treat evaporation and evapotranspiration as the same thing. They are not; evapotranspiration includes transpiration from vegetation, so a forested catchment loses more water than a bare one of equal size even at the same temperature.

Question 52

Precipitation forms when moist air is cooled to its dew point so that vapour condenses around nuclei and the droplets grow heavy enough to fall; the way the air is lifted gives three main types.

1) **Convectional rainfall:** Intense surface heating makes air rise, expand and cool, condensing into towering cumulonimbus that bring afternoon thunderstorms, as on the hot interior plains around Tabora.

2) **Orographic or relief rainfall:** Moist air forced to rise over a highland barrier cools and condenses on the windward side, giving the heavy rain on the windward slopes of Mount Kilimanjaro.

3) **The rain shadow:** Having lost its moisture, the descending air on the leeward side warms and dries, producing the dry rain shadow scrub near Same.

4) **Cyclonic or frontal rainfall:** When a warm air mass meets a cooler one the lighter warm air is forced to rise along the front, cools and yields steady rain, as in the coastal disturbances reaching Mtwara.

5) **Role of the dew point:** In every type the air must be cooled to its dew point before condensation begins, so rainfall depends on both moisture supply and a cooling mechanism.

6) **Role of condensation nuclei:** Tiny particles such as dust and salt give surfaces on which vapour condenses, so coastal air at Dar es Salaam rich in salt nuclei condenses readily.

Examiner's Note

The command is explain, so each type must show the lifting and cooling mechanism, not just a name. Marks split evenly across the three types; the discriminator is the rain shadow on the leeward side.

Question 53

Surface runoff is generated when rainfall arrives faster than the ground can absorb it; the balance between infiltration and runoff is controlled by several factors of the surface and the storm.

1) **Slope of the land:** On steep slopes water flows away before it can soak in, so the steep hillsides of the Kondoa erosion area shed runoff quickly, whereas gentle land allows infiltration.

2) **Vegetation cover:** Plants intercept rain, slow its flow and open the soil with roots, so the wooded slope near Kondoa soaks up water while the bare overgrazed slope sheds it at once.

3) **Infiltration capacity of the soil:** A porous sandy soil takes in water rapidly, but a crusted or clay soil has a low infiltration capacity, forcing most rain to run off as on the trampled hillside.

4) **Antecedent soil moisture:** If the soil is already saturated from earlier rain it can absorb little more, so late season storms on wet ground in the Kilombero valley produce far more runoff.

5) **Underlying geology:** Permeable rock such as the limestone near Tanga lets water percolate to groundwater, while impermeable basement rock forces water to remain at the surface and run off.

6) **Rainfall intensity:** A short violent downpour delivers water faster than any soil can infiltrate, so the intense storms of the Kondoa area generate immediate muddy runoff regardless of soil type.

Examiner's Note

Command is explain, so each factor must state its effect on the infiltration to runoff balance. Marks reward the named factor plus mechanism; the strongest scripts contrast the bare and wooded slopes.

Question 54

(a) The borehole reveals the two main groundwater zones separated by the water table.

Zone of aeration: The upper dry crumbly material is the zone of aeration, where pore spaces hold both air and some water but are not fully filled, lying above the water table near Dodoma.

Zone of saturation: Below this lies the zone of saturation, where every pore space is completely filled with water, shown by the dripping saturated sand the drill brought up.

The water table: The water table is the upper surface of the zone of saturation, the level below which the ground is permanently waterlogged, and it rises in the wet season on the Dodoma plains.

(b)

Aquifer: An aquifer is a rock both porous and permeable so it can store and transmit water freely, for example the sandstones that supply boreholes in parts of the coastal belt near Dar es Salaam.

Aquiclude: An aquiclude is a rock that holds water in its pores but is too impermeable to transmit it usefully, such as a clay layer that traps water above it in the interior basins.

Aquifuge: An aquifuge is a rock with neither pore space nor cracks, so it can neither hold nor pass water, for example unfractured granite of the basement near Dodoma.

Examiner's Note

Part (a) marks lie in defining the water table as the top of the saturation zone; part (b) rewards the store and transmit distinction. The discriminator is correctly separating aquiclude from aquifuge.

False Confidence Alert

Candidates often confuse porosity with permeability and so cannot tell an aquiclude from an aquifuge. A clay is porous yet nearly impermeable, so it stores water but will not yield it; permeability, not pore space alone, decides whether a rock can supply a well.

Question 55

An artesian basin allows groundwater to be held under pressure so that water rises on its own; springs by contrast occur where the water table meets the ground surface.

1) **A synclinal or basin structure:** The permeable rock must be folded into a saucer or syncline so that its edges rise higher than its centre, trapping water that collects in the dip.

2) **Confining impermeable layers:** The aquifer must be sandwiched between an impermeable layer above and below so the water cannot escape upward and is held under hydrostatic pressure.

3) **An exposed intake area:** The upturned edge of the aquifer must outcrop in a wetter, higher zone where rain can recharge it, supplying the head of water that drives the pressure.

4) **The artesian well:** When a well is bored through the upper confining layer the water, under pressure from the higher intake, rises to the surface unaided, as in some confined coastal aquifers near the Tanzanian coast.

5) **Formation of a spring:** A spring forms where the water table is cut by the land surface, for example along a valley side, so groundwater flows out naturally at the point of contact.

6) **Geological control of springs:** Springs commonly emerge at the junction of permeable rock over impermeable rock on the flanks of highlands such as the Usambara Mountains, where water perched above the barrier escapes.

Examiner's Note

The command is explain, so marks reward the pressure conditions, not a labelled sketch alone. The discriminator is the exposed intake area higher than the well that creates the artesian head.

Question 56

Drainage patterns are the plan arrangement of streams in a basin, and it is the rock and relief structure that determines how each pattern develops.

1) **Dendritic pattern:** On rocks of uniform resistance with no strong structural control, streams branch freely like a tree, as on the broad uniform basement plains of central Tanzania around Tabora.

2) **Trellis pattern:** Where hard and soft rocks alternate in parallel folded ridges, main rivers follow the soft outcrops and tributaries join at right angles, as in dissected fold country.

3) **Rectangular pattern:** Where rock is crossed by two sets of joints or faults meeting at right angles, streams follow the lines of weakness and bend sharply, giving a rectangular network.

4) **Radial pattern:** On a dome or isolated volcanic cone the slope leads water outward in all directions, so streams radiate from the summit, as on the flanks of Mount Kilimanjaro.

5) **Centripetal pattern:** Where relief forms an enclosed basin, streams converge inward toward the lowest point, as the drainage flowing inward toward Lake Eyasi in its closed depression.

6) **Annular pattern:** On an eroded dome of concentric hard and soft rings, streams pick out the weak rings and curve around the structure, producing a ring like annular pattern.

Examiner's Note

The command explain demands the structural cause of each pattern, not just its shape. Marks reward pattern plus the controlling structure or relief, with the strongest scripts naming a real example.

Question 57

(a) A river and its basin form the basic unit of surface drainage.

Drainage basin: A drainage basin is the whole area of land drained by a river and its tributaries, for example the vast Rufiji basin that gathers water from much of southern Tanzania.

Watershed: A watershed or divide is the higher ground, often a ridge line, that separates one drainage basin from the next and directs rain into one basin or the other.

(b)

Perennial regime: A perennial river flows all year because rainfall or groundwater keeps it supplied even in the dry season, as the Pangani sustained by highland rains and springs.

Intermittent regime: An intermittent river flows only in the wet season and dries up when the water table falls below its bed, as stretches of the Great Ruaha that dry to sand.

Ephemeral regime: An ephemeral stream flows only briefly during and just after a storm, typical of the seasonal sand rivers of the dry central and northern lowlands.

Examiner's Note

Part (a) marks reward the basin as an area and the watershed as the dividing high ground; part (b) rewards each regime tied to its climatic cause. The discriminator is separating intermittent from ephemeral flow.

False Confidence Alert

A watershed is not the river or the valley floor; it is the high ground between basins. Candidates who define it as the river itself lose easy marks because the divide directs water away from itself into two separate basins.

Question 58

Lakes may be classified by the process that created their basins, and Tanzania offers an example of almost every type.

1) **Tectonic rift faulting:** Crustal tension drops a block of land between parallel faults to form a long deep basin, producing the rift lake of Lake Tanganyika in its narrow steep sided trough.
2) **Downwarping:** A broad gentle sagging of the crust between the rift arms creates a shallow basin, as the wide saucer that holds Lake Victoria.
3) **Vulcanicity:** Volcanic activity forms basins where a crater or caldera holds water or where lava dams a valley, as the crater lakes among the Momela lakes near Arusha.
4) **Erosion:** Erosional hollows scoured by ice or by deflation can hold water, as the shallow seasonal soda water of Lake Eyasi occupying a fault and deflation hollow.
5) **Deposition:** Deposition can cut off water bodies, as a meandering river abandons a bend to leave an ox bow lake on the floodplain of the lower Rufiji.
6) **Damming by man:** Artificial barrages impound rivers to form reservoirs, as the Mtera and Nyumba ya Mungu reservoirs built across the Great Ruaha and Pangani systems.

Examiner's Note

The command classify demands grouping by process with a clear cause for each basin. Marks reward process plus a correctly matched example; the discriminator is separating rift faulting from downwarping.

Question 59

(a) Wetlands take several forms depending on water and vegetation.

Swamp: A swamp is a permanently or seasonally waterlogged area dominated by tall reeds, grasses and trees rooted in mineral rich water, as in the seasonally flooded Kilombero valley.

Bog: A bog is a waterlogged area fed mainly by rainwater, acidic and low in nutrients, where the vegetation is dominated by mosses and the dead matter accumulates as peat.

(b)

1) **Drainage for farmland:** Wetlands are dug out and drained to win land for crops, so the spreading rice and sugar schemes are draining and shrinking the Kilombero floodplain.
2) **Overgrazing:** Large herds driven onto the wetland in the dry season trample the soil and strip the vegetation, degrading grazing wetlands such as parts of the Usangu plains.
3) **Pollution:** Fertilisers, pesticides and sediment washed from surrounding farms poison the water and choke the wetland, threatening the fisheries of the Malagarasi wetlands.
4) **Siltation from upstream erosion:** Soil eroded from cleared catchments is carried in and deposited, raising the bed and smothering the natural habitat of the floodplain.

Examiner's Note

Part (a) marks lie in the rainwater fed, peaty, acidic nature of a bog; part (b) rewards each named threat with its mechanism. Weak scripts merely list threats without explaining the damage.

Question 60

The salinity of sea water, the mass of dissolved salts it carries, varies from place to place, and the water itself is kept in constant motion by three agents.

1) **Evaporation:** Strong evaporation removes water but leaves the salt behind, so the hot tropical surface of the open Indian Ocean off Tanga becomes more saline.
2) **Fresh water inflow from rivers:** Rivers pour in fresh water that dilutes the sea, so salinity is lowered near the mouth of the Rufiji where its discharge mixes with the ocean.
3) **Rainfall:** Heavy rain adds fresh water directly to the surface and lowers salinity, so persistently wet coasts are less saline than dry evaporating ones.
4) **Mixing by currents and inflow:** Currents and the free exchange of an open coast mix saltier and fresher water toward an average, while enclosed seas with little exchange become more extreme.
5) **Movement by waves:** Wind blowing over the surface drives waves, an oscillation that chiefly transfers energy and stirs the surface along the Dar es Salaam shore.
6) **Movement by tides:** The gravitational pull of the Moon and Sun raises the regular rise and fall of tides, flooding and draining the creeks and mangroves of the Tanga coast twice daily.
7) **Movement by currents:** Steady horizontal flows of water driven by prevailing winds form currents, such as the warm current that washes the East African coast and moderates its climate.

Examiner's Note

The command explain demands the effect of each factor on salt concentration plus the agent behind each movement. Marks reward cause and effect; the discriminator is naming all three agents of movement.

ESSAY SOLUTIONS

Question 61

Continental drift is the theory that the continents were once joined as one great landmass, Pangaea, which later broke apart so that its fragments drifted slowly to the positions they hold today. Wegener gathered support for the idea from the shape of the continents, from their rocks and structures, and from the fossils and ancient climates recorded in them.

The fit of the continents. The Atlantic coast of South America fits the coast of Africa like two pieces of a jig-saw, and the match becomes almost exact when the continents are joined along the edge of the continental shelf rather than the present shoreline. Because the shelf is the true edge of a continent, so close a fit over thousands of kilometres cannot be the work of chance, and it points to the two having once formed a single block.

Continuity of rocks across the ocean. Rocks of the same type, age and structure are found facing one another on opposite shores, so that the ancient blocks of eastern Brazil match those of West Africa. Such a match of whole rock provinces shows that the rocks formed as one body and were later torn apart, for it is most unlikely that identical rocks would form separately on either side of a wide ocean.

Truncated mountain chains. Old fold-mountain belts run to the coast of one continent and stop abruptly, then continue on another continent across the ocean, as the Cape ranges of South Africa reappear as the Sierras of Argentina. The ranges must therefore have been folded as one continuous belt before the continents drifted apart, the drift splitting a single chain in two.

Matching fossils of land species. Identical fossils of land animals and plants, among them Mesosaurus, Lystrosaurus and the Glossopteris flora, occur on continents now separated by oceans. Since a freshwater reptile cannot swim across salt water and a heavy-seeded fern cannot blow across an ocean, these organisms must have lived on one connected land that has since broken up and drifted apart.

Ancient glaciation of tropical lands. Glacial deposits and ice-scratched rock pavements of Permo-Carboniferous age are found today in tropical Brazil, central Africa, India and Australia, where no ice could possibly form now. Their presence shows that these lands once lay together in high, cold latitudes near the South Pole and have since drifted to the warm latitudes they occupy today.

Coal in polar regions. Thick coal seams, which form only from lush vegetation in warm, wet climates, are found beneath the ice of Antarctica. This is impossible in the present polar position, so Antarctica must once have lain in warm low latitudes and drifted to the pole, once more showing that the continents change their position over geological time.

Alignment of mineral and ore belts. Belts of valuable minerals and ores in West Africa line up exactly with similar belts in eastern Brazil when the two continents are reassembled. Because such belts form only in particular geological settings, their continuity across the join shows that they were created as single belts before the continent split and the Atlantic opened between them.

Apparent wandering of the poles. The fossil magnetism frozen into rocks of different ages points to former magnetic poles that appear to have wandered, and each continent yields a different wander path. Since there can have been only one pole at any one time, it must be the continents, and not the poles, that have moved, which is powerful evidence for drift.

Reassembly into a single ice sheet. When the southern continents are fitted back together along their shelves, the scattered patches of ancient glaciation join into one continuous ice cap, and the directions in which the ice once flowed radiate neatly outward from its centre. Such an orderly picture, impossible in the present scatter of continents, confirms that they were formerly united.

Taken together these independent evidences, drawn from very different branches of geology, all point the same way, and although Wegener could not at first explain how the continents moved, his theory was later confirmed by sea-floor spreading and plate tectonics and is accepted today.

Examiner's Note

The stem asks for eight points, so any eight of those above earn full marks; the candidate should choose the eight they can develop most fully. Each must be argued, not merely listed, and **a sketch of the fit of the continents** adds credit.

False Confidence Alert

Listing the evidence as bare names, fit, fossils, rocks and climate, scores very little. Each point must be turned into an argument that the feature is impossible unless the continents were once joined.

Question 62

Continental drift held that the continents had moved across the globe from a former supercontinent. Although the evidence Wegener offered was strong, the theory was resisted for half a century, chiefly because its mechanism was missing, and it was accepted only when later discoveries on the ocean floor supplied that mechanism, vindicating at last the matching coasts of Africa and South America that Wegener had pointed to.

No mechanism was offered. Wegener could not say what force was strong enough to move whole continents, and his suggestion that they ploughed through the solid ocean floor was shown to be physically impossible. Without a believable mechanism the scientific world had no way to accept that continents could move, and so dismissed the idea however good the other evidence was.

It contradicted the fixed-earth belief. The accepted view of the time was that the continents and oceans were permanent and had never changed their places. A theory claiming that continents wandered across the globe overturned this settled belief, and such a sweeping challenge naturally met deep resistance from established geologists.

Wegener was regarded as an outsider. Wegener was trained as a meteorologist and astronomer rather than as a geologist, so the geological establishment did not easily trust his reading of their own evidence. His standing as an outsider made it easier for leading geologists to set his ideas aside without serious testing.

Some of his details were wrong. Wegener overestimated the speed of drift and proposed forces, such as the pull of the tides, that could not do the work. These errors in detail gave his critics an easy target, and by attacking the weak parts they felt justified in rejecting the whole theory.

Discovery of the mid-ocean ridges. After the Second World War the mapping of the sea floor revealed a continuous system of ridges running through every ocean. This showed that the ocean floor was far from being a fixed, dead surface, and hinted that it might be the very place where the movement of the Earth's surface was taking place.

Sea-floor spreading supplied the mechanism. Harry Hess proposed that new crust forms at the ridges and spreads outward, carrying the continents on top like cargo. This at last supplied the missing force that Wegener had lacked, for the continents no longer needed to plough through the floor but were carried passively upon it.

Magnetic stripes proved spreading. The discovery of symmetrical bands of normal and reversed magnetism on either side of the ridges confirmed that the floor really was spreading, and even allowed its rate to be measured. This turned drift from an untestable idea into a measured, provable process and silenced much of the doubt.

Earthquake and volcano belts mapped the plates. Narrow worldwide belts of earthquakes and volcanoes were found to outline the edges of rigid plates. This revealed the plates themselves and showed that drift was only one part of the wider working of plate tectonics, within which the whole theory now made sense.

Palaeomagnetism confirmed the movement. The apparent wandering of the magnetic poles recorded in rocks of different ages could be explained only if the continents had moved beneath a single fixed pole. This independent line of evidence completed the proof and removed the last reasonable grounds for rejecting drift.

The theory was therefore rejected not because its evidence was weak but because its mechanism was missing and it challenged a settled belief; once sea-floor spreading and palaeomagnetism supplied that mechanism, drift was absorbed into plate tectonics and accepted as established fact.

Examiner's Note

Examine requires both sides, why the theory failed and why it later succeeded, so the candidate should select eight points balanced between rejection and vindication. The missing-mechanism point is central and should not be left out.

Question 63

Pangaea was the single supercontinent that existed about 250 million years ago, surrounded by one great ocean called Panthalassa. It split first into two and then into the present continents along lines that opened as new oceans, and the main stages of that break-up may be traced as follows.

Splitting into Laurasia and Gondwana. Pangaea first divided along an east-west seaway, the Tethys, into a northern mass called Laurasia and a southern mass called Gondwana. This first split separated the future continents of the north, North America and Eurasia, from those of the south, and set the pattern for all that followed.

Opening of the central Atlantic. North America then began to pull away from Africa as the central Atlantic Ocean started to open between them. This was the first of the great new oceans of the break-up, and its steady widening carried the Americas slowly away from the Old World.

Break-up of Gondwana. The southern mass, Gondwana, split as South America, Africa, India, Antarctica and Australia began to move apart from one another. As they separated, the South Atlantic opened between South America and Africa and the Indian Ocean opened to the east, dividing lands that had shared the same fossils and glaciation.

India's rapid northward drift. India broke away from the side of Africa and Antarctica and drifted rapidly northward across the Tethys Sea towards Asia. Its long, fast journey across the closing ocean would in time bring it into violent collision with the Asian mainland.

Separation of Australia and Antarctica. Australia parted from Antarctica and moved north towards warmer latitudes, while Antarctica was left isolated over the South Pole. There it became covered by the ice cap it still carries, completing the southern pattern of the break-up.

Collision of India with Asia. India finally collided with Asia, closing the Tethys Sea and crumpling its thick floor sediments upward into the Himalayas. Because the two continents are still pushing together, these mountains are rising even now, showing the break-up is not yet finished.

Opening of the East African Rift. Most recently, Africa itself has begun to split along the East African Rift, where the Nubian and Somali plates are pulling apart. This is the youngest stage of all and may, in time, open a new ocean through the heart of the continent.

Arrival at the present positions. Continued sea-floor spreading has carried all the fragments to the positions they occupy today, where they are still drifting a few centimetres a year. The map of the world is therefore only a snapshot of a break-up that is still going on.

The break-up therefore moved in clear stages, from one supercontinent to two and then to many, each separation marked by a new and widening ocean, a process that has not ended but continues today in the rifting of East Africa.

Examiner's Note

Account for asks for the sequence and the reason at each stage, not merely a list of continents; six well-ordered stages, each naming the ocean or mountain produced, earn full marks, and a sketch of Pangaea splitting helps. Select any six.

False Confidence Alert

Writing only that Pangaea broke into seven continents, with no order and no oceans named, scores poorly. The marks lie in the sequence and in naming the ocean or mountain belt produced at each split.

Question 64

Sea-floor spreading, proposed by Harry Hess, is the process by which new oceanic crust is created at the mid-ocean ridges and moves outward on both sides, so widening the ocean. The process itself and the evidence that confirms it can be set out in turn as follows.

Rising magma at the ridge. Beneath a mid-ocean ridge hot mantle rises towards the surface, and as the pressure on it falls it begins to melt. The molten rock wells up into the crack that runs along the crest of the ridge, ready to form new crust along the line where the plates are parting.

Creation of new crust. The rising magma cools and solidifies against the edges of the parting plates to form fresh basaltic crust along the ridge axis. In this way new ocean floor is added continuously at the ridge, exactly along the line where the two plates pull away from each other.

Outward movement on both sides. As yet more magma rises, the crust already formed is pushed aside, so the floor moves steadily away from the ridge on both flanks like two conveyor belts running in opposite directions. The ocean therefore grows wider as the two halves of its floor are carried apart, which is how the Atlantic is widening and slowly carrying Africa away from South America.

Recycling of old crust at trenches. Far from the ridge the old, cold and dense crust sinks back into the mantle at the deep ocean trenches, where it is melted and destroyed. Because crust is destroyed at the trenches at about the rate it forms at the ridges, the Earth as a whole does not grow, and the floor is constantly recycled.

Evidence from the age of the floor. The youngest rocks of the ocean floor lie along the ridge and grow steadily older with distance away from it on either side. This orderly increase in age is exactly what the process predicts, since the rock furthest from the ridge formed first and has travelled longest.

Evidence from the symmetry of the floor. The pattern of ages and rocks on one side of the ridge is a mirror image of the pattern on the other side. Such symmetry can only arise if new floor forms along the central axis and then spreads outward equally in both directions.

Evidence from the magnetic stripes. As the new basalt cools it records the direction of the Earth's magnetic field, and because that field reverses from time to time the floor preserves parallel stripes of normal and reversed magnetism. These stripes match exactly on the two sides of the ridge, providing the clearest single proof of spreading.

Evidence from sediment and age limits. The layer of sediment on the floor is thinnest at the ridge and thickens steadily outward, since the ridge crust is youngest and has had least time to gather it. Moreover no ocean floor is older than about 200 million years, far younger than the continents, because the older floor has all been recycled at the trenches.

Sea-floor spreading thus shows the ocean floor to be young and active, created at the ridges and destroyed at the trenches, and its symmetrical ages and matching magnetic stripes give the clearest proof of it, supplying at the same time the very mechanism that continental drift had lacked.

Examiner's Note

Separate the process, the first four points, from the evidence, the rest, and select eight in all. The magnetic-reversal stripe is the strongest single point and must be fully explained, not just named.

Question 65

Continental drift had failed to convince the scientific world because Wegener could not explain how the continents move. Sea-floor spreading, by showing that the ocean floor itself moves and carries the continents upon it, supplied that missing mechanism and so confirmed drift, as the following points show.

It identified the moving force. Spreading showed that the rise of hot mantle and the creation of new crust at the ridges drive the floor steadily outward. This was the very force that Wegener had searched for in vain, and its discovery removed the central objection that there was no engine to move the continents.

The continents ride passively. Wegener had wrongly imagined the continents ploughing their way through the solid ocean floor, which was physically impossible. Spreading showed instead that the continents sit on top of the moving plates and are carried along like cargo, which disposed of his impossible idea and made movement believable.

It explained the widening Atlantic. Spreading at the Mid-Atlantic Ridge adds new floor along the centre of the ocean and so steadily widens it, carrying the Americas away from Europe and Africa. Here was drift actually happening and being measured, no longer a guess about the distant past but a process going on today.

The magnetic stripes measured the drift. The width and pattern of the magnetic stripes on the ocean floor gave both the rate and the direction of the spreading. This turned drift from an untestable claim into a measured, dated process, giving it the firm numerical support that Wegener's theory had never had.

It fitted the fossil and rock evidence. Spreading explained at once why facing coasts share the same rocks and fossils, since these lands lay together before the ocean between them opened. The old evidence that Wegener had gathered now made perfect sense within the new picture of a spreading floor.

It grew into plate tectonics. Spreading at the ridges, combined with the sinking of crust at the trenches, led directly to the full theory of plate tectonics. Within this larger theory continental drift is simply one natural result of plate movement, so the once-rejected idea became part of accepted science.

It explained the youth of the ocean floor. The surprising youth of all ocean floor, a puzzle before, followed naturally from spreading, since the floor is forever being made at the ridges and destroyed at the trenches. This success added further weight to the case for drift.

It revived a rejected theory. By removing the one fatal objection, the lack of a mechanism, spreading converted a theory that had been dismissed for fifty years into one accepted across the world. In this sense it truly rescued the work of Wegener.

Sea-floor spreading therefore supplied the moving force, the measurement and the wider framework that drift had lacked, so the statement is fully justified, for it rescued Wegener's theory and confirmed it as part of plate tectonics.

Examiner's Note

The hinge of the answer is the missing mechanism, so every selected point should connect back to how spreading completed or proved drift. Select any six.

Question 66

A plate boundary is the line along which two of the Earth's rigid plates meet. There are three main types, divergent, convergent and transform, and the convergent type takes more than one form; each prints its own family of landforms upon the surface, as set out below.

Divergent margins beneath the ocean. Where two plates move apart on the floor of an ocean, hot magma rises to fill the gap and builds a long submarine mountain chain, the mid-ocean ridge, such as the Mid-Atlantic Ridge. The ridge is flanked by young volcanic crust and split along its crest by the central rift where the plates part.

Divergent margins on land. Where a continent is pulled apart, the crust is stretched and broken, and the central strip sinks between parallel faults to form a rift valley. Volcanoes grow along the cracks, as in the East African Rift, where Ol Doinyo Lengai and the rift lakes lie on the sunken floor between steep scarps.

Ocean-to-continent convergence: the trench. Where an oceanic plate meets a continental one, the denser oceanic plate bends downward and dives beneath the lighter continent at a subduction zone. This downward plunge forms a long, deep ocean trench just offshore, marking the line where the plate begins its descent into the mantle.

Ocean-to-continent convergence: fold mountains. As the ocean plate sinks, the thick pile of sediments along the edge of the continent, together with its leading edge, is crumpled and thrust upward into a chain of fold mountains running parallel to the trench, as the Andes rise above the Peru-Chile trench.

Ocean-to-continent convergence: volcanoes. The descending plate melts at depth, and the magma so formed rises through the overriding continent to feed a line of explosive volcanoes set back behind the trench. These volcanoes, often violent because the magma is sticky and gas-rich, complete the family of landforms above a subduction zone.

Ocean-to-ocean convergence. Where two oceanic plates meet, the older and denser of the two sinks beneath the other, again forming a trench. The magma that rises from the sinking plate builds a curved chain of volcanic islands on the floor of the sea, an island arc such as Japan or the islands of the western Pacific.

Continent-to-continent collision. Where two continents meet, neither is dense enough to sink, so the crust between them is crushed and piled up into very high fold mountains. The Himalayas, raised by the collision of India with Asia, are the great example, and such ranges carry no volcanoes because no plate descends to be melted.

Transform margins. Where two plates simply slide past one another, crust is neither created nor destroyed, so there are no volcanoes and no mountains of this origin. Instead the rocks lock, strain builds and is released as severe earthquakes, as along the San Andreas Fault of California.

The Tanzanian case. Tanzania lies on a divergent margin, where the African plate is splitting into the Nubian and Somali plates. This is why the country shows rift valleys, steep escarpments, deep and soda lakes and active volcanoes, rather than the trenches and fold mountains of a convergent margin.

Each type of boundary therefore prints its own signature upon the land, ridges and rifts where plates part, trenches, fold mountains and volcanoes where they meet, and earthquakes where they slide past, which is exactly why these features are concentrated in narrow belts along the plate edges.

Examiner's Note

Eight points are required and convergence has three cases, so spread the selection across all the margin types and pair each with a real example. **Clear labelled cross-sections of the boundaries** carry the construction marks.

False Confidence Alert

A common error is to give volcanoes to every boundary. Transform margins produce earthquakes but no volcanoes, and continent-to-continent collision builds mountains without volcanoes; the type of margin decides which landforms appear.

Question 67

The movement of the plates is powered by heat escaping from the deep interior of the Earth, which sets the solid mantle slowly into motion and drives the plates by three connected forces. The chain from the source of the heat to the motion of the plates may be explained as follows.

The source of the heat. Heat is produced within the Earth by the decay of radioactive elements such as uranium, and is added to by heat left over from the planet's fiery formation. This great store of internal heat must slowly escape towards the surface, and it is the escape of this heat that ultimately drives all plate movement.

Mantle convection currents. The escaping heat sets up slow convection cells in the solid but slowly flowing mantle. Hot, less dense rock rises towards the surface, spreads sideways beneath the plates, then cools, becomes denser and sinks once more, forming a closed loop that turns over very slowly through millions of years.

Plates dragged by the currents. The plates rest upon the moving upper limb of these convection cells, and as that limb spreads sideways it drags the plate along with it. In this way the plate is carried slowly across the surface like cargo riding on a very slow conveyor belt.

Ridge push. At a mid-ocean ridge the newly formed crust stands high and hot, and as it cools and slides down the gentle slope of the ridge under its own weight it presses outward on the rest of the plate. This gravitational push from the ridge helps to drive the plate away from the spreading axis.

Slab pull. Where the cold, dense edge of an old plate sinks into the mantle at a trench, its great weight hangs down and pulls the rest of the plate along behind it. This pull is now thought to be the strongest of the three forces, which is why plates with a sinking edge move fastest.

The forces act together. Convection, ridge push and slab pull do not act alone but work together as one system, the relative strength of each varying from plate to plate. Their combined action opens oceans at the ridges, closes them at the trenches, and is slowly widening the East African Rift.

The slowness of the motion. Because the solid mantle can creep only extremely slowly, the plates move just a few centimetres in a year, about the speed at which fingernails grow. The forces are nonetheless vast, for they move whole continents, but the motion is far too slow to be felt.

The driving mechanism is therefore the escape of the Earth's internal heat through mantle convection, helped by ridge push and slab pull, a system of forces great enough to move continents yet so slow that the movement passes unseen.

Examiner's Note

Select any six, but trace the chain from the heat source through convection to the push-and-pull forces; naming convection without its energy source limits the marks. **A labelled convection-cell diagram** earns credit.

Question 68

Plate tectonics is the theory that the Earth's outer shell is broken into rigid plates which move slowly over the mantle and interact along their edges. It is called a unifying theory because, with one set of ideas, it explains a wide range of features that were once treated as separate and unconnected, as the following assessment shows.

It explains the distribution of earthquakes. Earthquakes are not scattered at random but are concentrated in narrow belts along the plate edges, where plates grind past or sink beneath one another. Plate tectonics explains this worldwide pattern at a stroke, since it is at the plate margins that the strain needed to cause earthquakes is built and released.

It explains the distribution of volcanoes. The world's volcanoes likewise follow the plate edges, lying along the divergent ridges and the subduction zones. Because plate tectonics shows where magma is generated, by melting at subduction zones and by upwelling at ridges, it accounts directly for where volcanoes are found.

It explains the great fold mountains. The major mountain ranges lie in long belts along convergent margins, where crust is crumpled by the collision of plates. Plate tectonics explains both why mountains form in belts rather than singly and why they stand where they do, as with the Andes and the Himalayas.

It explains the ocean basins. The mid-ocean ridges, the deep trenches and the surprising youth of the ocean floor are all explained by the creation of crust at ridges and its destruction at trenches. A whole set of puzzling features of the ocean floor thus follows from a single idea.

It confirms and contains continental drift. The slow movement of the plates carries the continents with them, so Wegener's drift becomes simply one outcome of plate motion. A theory once rejected is thereby absorbed and explained, a clear sign of the unifying power of plate tectonics.

It explains the spread of rocks and fossils. The matching rocks and fossils found on continents now separated by oceans follow naturally from their having been joined before the plates carried them apart. The theory therefore ties together evidence from biology and from geology within one framework.

It accounts for many mineral and energy belts. Many ores and fuels form in particular plate settings, such as the metals of subduction zones and the oil of sediment-filled rifts and margins. Plate tectonics thus even helps to explain where these economically important deposits are found.

A limitation: features within plates. The theory is weaker in explaining features that lie far from any plate edge, such as the hot-spot volcanoes of Hawaii in the middle of the Pacific plate. These require the further idea of fixed mantle plumes, which the basic theory does not by itself supply.

A limitation: the deep driving force. The exact balance of the forces that drive the plates, and the precise pattern of convection in the mantle, are still debated by scientists. The theory is therefore complete in its description of what happens at the surface but not in every detail of why.

On balance the claim is well justified, for plate tectonics explains earthquakes, volcanoes, mountains, ocean basins and drift within a single framework; the few features it cannot fully explain are exceptions that refine rather than overturn it, so it rightly remains the great unifying theory of the Earth sciences.

Examiner's Note

Assess means weigh the strengths against the limitations and reach a verdict, so a strong answer selects mostly strengths, includes at least one limitation, and ends with a clear judgement. Eight points in all.

Question 69

Isostasy is the state of balance in which the lighter crust floats upon the denser mantle, each part of the crust standing at a height fixed by its thickness and density. When that balance is disturbed by the adding or removing of a load, the crust slowly rises or sinks to restore it, a movement called isostatic adjustment, explained below.

The crust floats on the mantle. The crust is made of lighter rock than the mantle beneath it, so it floats upon the mantle much as a block of wood floats on water. The thicker and lighter blocks of crust ride higher and stand up as continents and mountains, while the thinner, denser ocean crust sits lower and is covered by the seas.

Mountains have deep roots. Because a floating block sits mostly below the surface, a high mountain range must have a deep root of crust projecting down into the mantle to support its great height. Just as an iceberg shows only a small part above the water, the visible height of a mountain is balanced by a far greater hidden root below.

Loading depresses the crust. When a heavy load is added to the crust, such as a great ice sheet or a thick pile of sediment, the extra weight presses the crust downward into the yielding mantle. The land surface therefore sinks, exactly as a raft settles lower in the water when cargo is placed upon it.

Unloading causes uplift. When the load is later removed, by the melting of the ice or the wearing away of the mountains, the crust is set free to rise again and slowly floats back upward to recover its balance. This upward recovery is the most clearly seen form of isostatic adjustment.

Post-glacial rebound. Scandinavia and northern Canada, which were pressed down by thick ice sheets during the last Ice Age, are still rising today thousands of years after that ice melted. This continuing uplift is clear proof of isostatic recovery, the land slowly returning to the level its lightened crust now demands.

Erosion, rebound and sediment loading. As rivers strip rock from highlands such as the East African plateau, the lightened crust rises in response, so the mountains wear down far more slowly than erosion alone would suggest. In the opposite way, the great weight of sediment dumped in a delta or basin slowly presses the floor beneath it downward.

The adjustment is slow. Because the solid mantle can flow only very slowly, the rising or sinking of the crust takes thousands of years to be completed. This is why lands once buried under Ice-Age ice are rising even now, long after the ice itself has gone.

Isostasy therefore keeps the crust in a floating balance upon the mantle, and isostatic adjustment is the slow rise or fall by which that balance is restored whenever ice, sediment or erosion changes the load, as the continuing uplift of the once-glaciated lands clearly shows.

Examiner's Note

Define isostasy and use the iceberg analogy first, then select any six adjustments, pairing the loading and the unloading cases. The slow flow of the mantle is the point that explains why uplift still continues today.

False Confidence Alert

Isostasy is not the same as plate tectonics. Isostasy is the vertical balancing of the crust under changing loads, whereas plate tectonics is the horizontal movement of the plates; confusing the two loses marks.

Question 70

The East African Rift System is a long trough of sunken land bordered by faults, stretching from the Red Sea through Tanzania towards Mozambique. It is forming where the African plate is slowly splitting apart, and its many features can be accounted for as the products of plate divergence in the following way.

Splitting of the African plate. East Africa lies where the great African plate is dividing into two smaller plates, the Nubian plate to the west and the Somali plate to the east. The rift marks the line along which this splitting is taking place, a divergent plate boundary running across dry land rather than beneath the sea.

A rising mantle plume. Beneath East Africa a plume of unusually hot mantle rises towards the surface, heating the crust above it. This rising heat provides the energy that lifts and weakens the crust and sets the whole process of rifting in motion.

Doming and stretching of the crust. The heat of the plume lifts the crust into a broad upward dome and at the same time stretches and thins it. As the crust is stretched it is placed under strong tension, the pulling-apart force that prepares it to break.

Normal faulting. Unable to withstand the tension, the stretched crust snaps along a series of parallel normal faults that run the length of the rift. These great faults form the framework of the rift and define the steep walls that border it.

Subsidence of the graben floor. Between the parallel faults the central block of crust slips downward to form a graben, the flat floor of the rift valley, while the blocks on either side stand high as the rift shoulders. This sinking produces the characteristic deep, steep-sided trough.

Formation of the rift lakes. Water gathers on the sunken floor to form lakes, among them long deep lakes such as Lake Tanganyika lying in the deepest troughs, and shallow soda lakes such as Natron and Eyasi where evaporation is strong. The lakes thus owe their shape and depth directly to the faulting.

Volcanic activity. Magma from the hot mantle rises along the deep faults and erupts at the surface, building volcanoes such as Ol Doinyo Lengai, Kilimanjaro and Meru, and the lavas that dam some of the lakes. Such volcanic activity is a sure sign of the thinning and splitting of the crust below.

Two branches around a stable block. The rift divides into an eastern, volcanic branch and a western branch marked by deep lakes, the two arms enclosing the old and rigid block of crust beneath Lake Victoria. This block has resisted the splitting, forcing the rift to pass around it on either side.

An ocean in the making. If the splitting continues, the floor of the rift will eventually drop below sea level and the sea will flood in, creating a new ocean as is already beginning in the Afar region to the north. The rift is therefore regarded as an ocean in its earliest stage.

The East African Rift System is therefore the surface expression of a continent being torn apart by plate divergence, its lakes, escarpments and volcanoes all the products of the doming, tension and faulting that accompany the splitting of the African plate, a process that may one day make Tanzania the shore of a new ocean.

Examiner's Note

The stem demands the divergence mechanism, so the marked points are the doming, tension, faulting and subsidence, with the lakes and volcanoes following as results; eight points anchored with Tanzanian examples score best.

Question 71

The Earth is not a collection of separate parts but a single system in which four great spheres, the atmosphere, hydrosphere, lithosphere and biosphere, continuously exchange energy and matter. To justify this view, one must show how each sphere depends on and feeds the others so that no part can be understood in isolation.

The atmosphere supplies gases to life and rock. The gaseous envelope provides the oxygen for animal respiration, the carbon dioxide for plant photosynthesis and the rainfall that weathers rock, so the air directly sustains both the biosphere and the lithosphere over lands such as Dodoma in central Tanzania.

The hydrosphere stores and moves heat and water. All the water of oceans, rivers and lakes such as Lake Victoria stores solar heat and circulates moisture, evaporating into the atmosphere and returning as rain to soak the soils and feed living things across the system.

The lithosphere provides the platform and minerals. The solid rocky shell forms the surface on which water collects and life grows and releases the mineral nutrients that plants need, so the rocky plains around Tabora become the foundation for soils, vegetation and farming.

The biosphere links the spheres through life processes. Living things bind the spheres together by drawing gases from the air, water from the ground and minerals from the rock, as the miombo woodlands of Tanzania exchange oxygen and carbon dioxide with the atmosphere every day.

Energy flows from the Sun through every sphere. Incoming solar radiation drives winds in the atmosphere, evaporation in the hydrosphere, weathering in the lithosphere and growth in the biosphere, so a single energy source ties all four spheres into one working system across East Africa.

Matter is recycled among the spheres. The same water, carbon and nitrogen pass repeatedly between air, water, rock and life through cycles such as the water cycle over Lake Victoria, showing that the spheres share a common stock of materials.

The Earth is open for energy but closed for matter. Solar energy enters and heat escapes to space while almost no matter is gained or lost, so the planet behaves as one closed store of materials energised from outside, a defining property of a single system.

A change in one sphere affects the others. Because the spheres are linked, deforestation in the lithosphere alters the carbon balance of the atmosphere and the rainfall of a region, as forest loss in Tanzania can change local climate and river flow.

Feedback keeps the whole system adjusting. The spheres respond to one another so that a warming atmosphere melts ice in the hydrosphere on Kilimanjaro, which lowers surface albedo and feeds back on temperature, proving the parts act together as one system.

Human activity now acts as a sphere-wide force. People draw on every sphere at once, taking water, clearing land and changing the air over Tanzania, which only makes sense if the Earth is understood as one interconnected system rather than separate compartments.

Because each sphere supplies, receives from and responds to the others through shared flows of energy and matter, the Earth can only be understood as one integrated system. The constant exchange and feedback among the four spheres fully justify treating the planet as a single working machine.

Examiner's Note

The question asks for eight points; any eight earn full marks. Strong answers prove the integration through cross-sphere linkages rather than describing each sphere on its own.

Question 72

The roughly spherical shape of the Earth is one of the most firmly established facts of geography, supported by observation, exploration and modern technology. To examine this, one must gather the different lines of evidence that together leave no doubt about the planet form.

The circular horizon at sea. From a ship or a high point over the Indian Ocean near Dar es Salaam the horizon always appears as a circle, and a circular outline in every direction is the view one obtains only from the surface of a sphere.

Ships disappearing hull first. As a vessel sails away from the Tanzanian coast its hull vanishes over the horizon before its mast, which can only happen if the sea surface curves away, indicating a curved and spherical Earth.

The circular shadow in a lunar eclipse. During a lunar eclipse the Earth casts a shadow on the Moon whose edge is always curved, and only a sphere throws a circular shadow from every angle, proving the planet is round.

Changing altitude of stars with latitude. As a traveller moves from the Equator near Tanzania towards higher latitudes the heights of stars and constellations change, which is explained by the observer moving over a curved surface.

Circumnavigation of the globe. Explorers and modern flights can set out in one direction and return to the starting point without turning back, a journey possible only on the surface of a sphere.

Photographs from space. Satellites and astronauts have photographed the Earth directly and it appears as a sphere, providing the clearest modern proof of its rounded shape.

Sunrise and sunset at different times. The Sun rises earlier in eastern places than western ones, so as eastern Tanzania greets the dawn other longitudes are still dark, which fits a rotating sphere rather than a flat surface.

The curved path of long-distance flights. Aircraft and shipping follow great-circle routes that look curved on a flat map, and these shortest paths over a globe confirm that the Earth surface is spherical.

Taken together, the circular horizon, the manner in which ships vanish, the round eclipse shadow, circumnavigation and direct photography form an overwhelming case. These independent observations all converge on the conclusion that the Earth is a sphere.

Examiner's Note

The question asks for six points; any six earn full marks. The strongest scripts explain why each observation requires curvature rather than simply listing the proofs.

Question 73

The temperature of any place is not fixed by latitude alone but by a combination of factors that together decide how much heat it receives and retains. To account for the hotness or coldness of a place, one must examine each of these controls and how it raises or lowers temperature.

Latitude and the angle of the Sun. Near the Equator the Sun is high so its rays strike steeply and concentrate heat over a small area, while towards the poles the slanting beam spreads over a wider area and crosses more atmosphere, making low-latitude Dar es Salaam hotter than higher-latitude lands.

Altitude above sea level. Temperature falls with height at about 6.5 degrees per kilometre because the dense lower air is warmed from the ground upward, so the highland town of Mbeya in the Southern Highlands is markedly cooler than lowland Dar es Salaam at a similar latitude.

Distance from the sea or continentality. Water heats and cools slowly while land heats and cools quickly, so coastal places like Dar es Salaam have a small temperature range while interior Dodoma swings between hot days and cold nights.

Warm and cold ocean currents. Currents carry the temperature of distant waters to a coast, so the warm Indian Ocean keeps the Tanzanian coast mild all year, whereas the cold Benguela Current chills the coast of Namibia in southern Africa.

Cloud cover. By day thick cloud reflects incoming radiation and lowers temperature, while by night it traps outgoing heat and keeps temperature up, so cloudy coastal nights stay warm but clear nights in Dodoma turn cold.

Prevailing winds. Winds bring the temperature of the region they blow from, so a wind off the warm ocean warms the coast while a wind off a hot dry interior raises temperatures inland around Tabora.

Aspect or the direction a slope faces. Slopes facing the Sun receive more direct radiation and grow warmer than shaded slopes, so the sunward sides of hills in the Southern Highlands are warmer than their shaded sides.

Nature of the surface and its albedo. Bright surfaces such as the snow of Kilimanjaro reflect most insolation and stay cold, while dark surfaces such as water and bare soil absorb it and warm strongly, so surface colour controls local heating.

Length of day. The longer the Sun stays above the horizon the more heat a place gains, so longer days deliver more insolation and warmer conditions than short ones for any given location.

Cloudless skies and the season. The position of the overhead Sun shifts with the season, so a place is hottest when the Sun is most nearly overhead, as the Tanzanian interior warms most when the noon Sun is high.

The hotness or coldness of a place is therefore the combined result of latitude, altitude, nearness to the sea, currents, cloud, wind, aspect and surface. No single factor acts alone, and it is their interaction that explains why Dar es Salaam is warm and Mbeya is cool.

Examiner's Note

The question asks for eight points; any eight earn full marks. Top answers explain the mechanism of each factor with a contrasting example rather than merely naming it.

Question 74

It is a common observation that mountains and high air are colder than the lowlands beneath them, even close to the Equator. To explain this decrease of temperature with height one must examine how the atmosphere is heated and how its properties change upward.

The air is heated from the ground upward. The atmosphere is largely transparent to incoming sunlight, so it is the surface that absorbs the radiation and then warms the air above it, meaning the air is hottest near the ground and cooler higher up over places like Dodoma.

Air density decreases with height. Air becomes thinner with altitude, so there are fewer molecules to absorb and hold heat, and the thin air on the upper slopes of Kilimanjaro retains far less warmth than the dense lowland air.

Air pressure falls and rising air expands. Pressure decreases with height, so air that rises expands into the lower pressure and cools as its energy is spread through a larger volume, a process that chills ascending air over the Southern Highlands.

Distance from the heated surface. The higher one goes the further one is from the warm ground that is the main heat source, so the supply of heat to the air weakens steadily with altitude.

Loss of long-wave radiation to space. The upper air more readily radiates its heat outward to space and is less warmed by the long-wave radiation from the surface, so it cools, especially at night over the highlands.

Reduced water vapour and greenhouse warming aloft. Most water vapour, a key greenhouse gas, lies in the lower air, so the drier upper troposphere traps less outgoing heat and stays cold above Tanzania.

The average environmental lapse rate. In the troposphere temperature falls on average by about 6.5 degrees per kilometre, which is why a station on a high Tanzanian mountain is far colder than one at sea level on the same latitude.

Reduced dust and absorbing particles. The lower air carries most of the dust and aerosols that absorb radiation, so the cleaner upper air absorbs less and remains cooler than the surface layer.

The fall of temperature with height arises because the air is warmed from the surface upward while density, pressure, water vapour and dust all decrease aloft. These combined effects, summed up in the lapse rate, explain why the high air over Tanzania is cold even near the Equator.

Examiner's Note

The question asks for six points; any six earn full marks. The discriminator is the surface-upward heating idea, not the false claim that height brings one nearer the Sun.

False Confidence Alert

Weaker scripts argue that high places are colder because they are closer to the Sun; this fails because the few kilometres gained are trivial against the vast distance to the Sun, and the real reason is that air is heated from the ground.

Question 75

Coastal places are well known for their gentle, even temperatures compared with the extremes of the interior. To account for this moderating effect of the sea one must examine the special way in which water gains, stores and releases heat.

Water heats and cools more slowly than land. The sea has a high heat capacity, warming and cooling slowly, while land warms and cools quickly, so the Indian Ocean keeps the air over coastal Dar es Salaam far steadier than the air over inland Dodoma.

Heat is mixed through a great depth of water. Sunlight penetrates and currents stir the sea so that heat is spread through a deep layer, preventing the surface from becoming very hot or very cold and keeping the Tanzanian coast mild.

Land and sea breezes moderate coastal temperature. By day a cool sea breeze blows onshore to lower temperatures and by night a land breeze blows offshore, so the daily swing at the coast is small compared with the interior.

Small annual and daily temperature range. Because of the slow response of water, coastal Dar es Salaam shows only a small difference between its hottest and coldest periods, unlike the wide swings of continental Dodoma.

Higher humidity reduces the temperature range. The sea supplies abundant water vapour to coastal air, and this moisture absorbs and releases heat slowly while clouds reduce both heating and cooling, smoothing temperatures along the coast.

Warm currents keep the coast mild. The warm waters of the Indian Ocean wash the Tanzanian coast and keep its air mild throughout the year, whereas a cold current would have chilled it as the Benguela does in Namibia.

Continentality produces extremes inland. Far from the sea there is no such buffering, so interior stations like Dodoma and Tabora experience hot days and cold nights, highlighting the moderating role of the ocean by contrast.

Cloud and onshore air limit night cooling. Moist onshore air and coastal cloud trap outgoing heat at night, so coastal nights in Dar es Salaam remain warm while clear interior nights turn cold.

The sea moderates coastal temperatures because water warms and cools slowly, mixes heat through depth, supplies moisture and generates breezes. These effects keep Dar es Salaam mild and even, in sharp contrast with the extremes of interior Dodoma.

Examiner's Note

The question asks for six points; any six earn full marks. Strong answers contrast a coastal and an interior place to demonstrate continentality rather than merely defining it.

Question 76

When solar radiation reaches the Earth it is partly reflected and partly absorbed, and the balance between the two governs how surfaces and the planet heat up. To assess the importance of reflection, absorption and albedo, one must show how they share out incoming energy and shape both local and global temperatures.

Albedo decides how much radiation is reflected. Albedo is the fraction of insolation a surface reflects, so a high-albedo surface returns most sunlight to the sky while a low-albedo surface returns little, directly setting how much energy each place keeps, as between snow and water on and around Kilimanjaro.

Fresh snow reflects almost all radiation. Fresh snow has an albedo of about 85 percent, reflecting most of the sunlight and absorbing very little, which is why the ice cap of Kilimanjaro stays near freezing even under the equatorial Sun.

Deserts reflect a moderate share. Desert surfaces have an albedo near 40 percent, reflecting a fair amount yet absorbing enough to grow very hot by day, as in the dry, sparsely vegetated lands around Dodoma.

Grass and vegetation absorb most radiation. Grass has an albedo of about 25 percent, so vegetated surfaces absorb most of the radiation and warm moderately, as on the grazing plains of the Tanzanian interior.

Water and dark soil absorb nearly all radiation. Water and dark soil have an albedo under 10 percent, absorbing almost all the radiation reaching them, so Lake Victoria stores great quantities of heat and warms steadily.

Absorbed radiation is converted into heat. The portion of radiation that is not reflected is absorbed and turned into heat that warms the surface and the air above it, so low-albedo surfaces become local sources of warmth across the country.

Reflection and scattering form planetary albedo. Clouds, gases and bright surfaces together reflect about a third of incoming radiation back to space, and this planetary albedo is a major term in the global radiation balance and heat budget.

Albedo feedback can amplify climate change. When ice melts it exposes darker land or water of lower albedo that absorbs more heat and causes further warming, so the retreat of the Kilimanjaro ice can reinforce local warming through this feedback.

Surface colour governs local microclimate. Because dark surfaces heat strongly and bright ones stay cool, the colour of the ground shapes local temperatures, so a tarred road in Dar es Salaam grows far hotter than a snowfield of equal exposure.

Scattering returns some radiation before it lands. Tiny molecules and dust scatter part of the incoming beam in all directions, returning some to space and softening the light reaching the ground, adding to the reflective losses in the balance.

Reflection, absorption and albedo together decide how incoming radiation is divided between heat gained and energy lost, controlling both local temperatures and the planetary heat budget. The contrast between reflective Kilimanjaro snow and absorbent Lake Victoria shows just how decisive these processes are.

Examiner's Note

The question asks for eight points; any eight earn full marks. The strongest answers quote albedo values with named surfaces and reach the albedo-feedback idea.

Question 77

The colours of the sky are not painted on but result from the way air scatters sunlight of different wavelengths. To explain the blue daytime sky and the red sunset, one must follow how light is scattered as it passes through the atmosphere.

Sunlight is a mixture of all colours. White sunlight reaching Tabora is made up of light of many wavelengths from violet and blue through to red, and these colours behave differently when they meet the air.

Air molecules scatter light. Gas molecules and fine particles in the atmosphere redirect incoming light in all directions, a process called scattering that sends light to us even from parts of the sky away from the Sun.

Rayleigh scattering favours short wavelengths. The smallest molecules scatter short blue wavelengths far more strongly than long red ones, a selective process named Rayleigh scattering that picks out the blue from the beam.

Scattered blue light fills the daytime sky. Because blue is scattered in every direction across the sky over Tabora, the whole daytime sky glows with this scattered blue light, which is why it appears blue overhead.

Sunset light travels a longer path. At sunset the Sun is low and its light slants through a much thicker layer of air over Lake Victoria, so most of the blue is scattered out long before the light reaches the eye.

Surviving red light colours the sunset. After the blue has been scattered away, mainly the long red and orange wavelengths survive the long path and reach the observer, so the setting Sun and the sky around it glow red.

Dust deepens the sunset colours. Extra dust and smoke in the evening air scatter still more of the short wavelengths, so a dusty sky over the interior can give especially deep red and orange sunsets.

The same scattering reddens sunrise. At sunrise the geometry is the same, with light again crossing a long path of air, so dawn over the Tanzanian coast can also glow red for the same reason as sunset.

The blue day and the red sunset both arise from Rayleigh scattering, which removes blue light most strongly. Overhead this scattered blue fills the sky, while along the long evening path the blue is lost and only red survives, colouring the sunset over Lake Victoria.

Examiner's Note

The question asks for six points; any six earn full marks. The discriminator is the longer path at sunset, not a vague claim that the Sun changes colour.

False Confidence Alert

A frequent mistake is to say the sky is blue because it reflects the sea or that the Sun itself turns red; in fact the colours come from selective scattering of light by air, and the sky is blue even over dry inland Tabora.

Question 78

Although the Sun pours energy onto the Earth continuously, the planet has not steadily heated up over the long term, which shows that gains and losses of energy are balanced. To explain this, one must trace the incoming and outgoing flows of radiation and the way they are kept equal.

Incoming short-wave solar radiation. The Earth gains energy chiefly as short-wave radiation from the Sun, most intense in the tropics where overhead Sun pours heat onto places such as Dar es Salaam, and this is the only major input to the budget.

Reflection by clouds and bright surfaces. About a third of the incoming radiation is reflected straight back to space by clouds, gases and bright surfaces such as the snow of Kilimanjaro, a loss known as the planetary albedo.

Scattering and atmospheric losses. Some incoming radiation is scattered by air molecules and dust back to space, so not all the energy that arrives reaches and heats the ground, adding to the reflective losses.

Absorption by the surface and atmosphere. The radiation that is neither reflected nor scattered is absorbed by the land, the seas such as Lake Victoria and the atmosphere, where it is converted into heat that warms the planet.

Outgoing long-wave radiation from the Earth. The warmed Earth re-radiates energy as long-wave infrared heat back towards space, and this outgoing stream is the main way the planet loses the energy it has gained.

Greenhouse gases delay the loss of heat. Carbon dioxide, methane and water vapour absorb much of the outgoing long-wave radiation and re-emit it in all directions, slowing its escape and keeping the surface warmer than it would otherwise be over Tanzania.

Balance of energy gained against energy lost. Over the course of a year the energy absorbed from the Sun is matched almost exactly by the energy radiated to space, so the global average temperature stays nearly constant from one year to the next.

Horizontal transfer evens out surplus and deficit. The tropics receive more energy than they lose while the poles lose more than they gain, and winds and ocean currents carry surplus heat from the Equator polewards, balancing the budget across latitudes.

Evaporation and condensation move latent heat. Heat absorbed when water evaporates from the warm Indian Ocean is carried upward and released when the vapour condenses into cloud, redistributing energy through the atmosphere as part of the balance.

Feedbacks keep the system near equilibrium. If the Earth warms, it radiates more strongly to space, and if it cools it radiates less, so the system naturally tends back towards balance and a steady average temperature.

The global heat budget is maintained because the short-wave energy absorbed from the Sun is balanced over the year by long-wave radiation lost to space, with reflection, greenhouse trapping and heat transfer adjusting the flows. This equilibrium is why the average temperature of the Earth stays nearly steady.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is distinguishing short-wave gains from long-wave losses and showing how they are equalised.

Question 79

The greenhouse effect is the natural warming of the Earth by gases that trap part of the outgoing heat, and it is essential to making the planet habitable. To explain and assess it, one must show how the effect works and weigh its benefits against its dangers when intensified.

Short-wave radiation reaches the surface. Incoming short-wave solar radiation passes fairly freely through the atmosphere and is absorbed by the land and seas, warming the surface of the Earth over places such as Tabora.

The warmed surface radiates long-wave heat. The heated surface re-radiates energy as long-wave infrared radiation back towards space, and it is this outgoing heat that the greenhouse gases are able to capture.

Greenhouse gases absorb the outgoing heat. Gases such as carbon dioxide, methane and water vapour absorb much of the outgoing long-wave radiation instead of letting it escape directly to space.

Heat is re-radiated back to the surface. These gases re-emit the absorbed heat in all directions, including downward, so the lower atmosphere and surface are kept warmer than they would be without the effect.

It makes the Earth habitable. Without this natural warming the average surface temperature would fall well below freezing, so the greenhouse effect is what allows crops to grow and people to live across Tanzania.

It supports the water cycle and agriculture. By keeping temperatures mild the effect maintains liquid water, evaporation and rainfall that sustain rivers, lakes and the farming on which Tabora depends.

An enhanced effect causes global warming. When human activity adds extra greenhouse gases, more heat is trapped and the planet warms too much, melting the ice of Kilimanjaro and disturbing rainfall, which is the harmful side of the effect.

Balance is the key to its importance. A moderate greenhouse effect is vital and beneficial while an excessive one is dangerous, so its importance lies in keeping the right balance of gases in the atmosphere.

The greenhouse effect is therefore a natural and essential process that traps outgoing heat and keeps the Earth warm enough for life and farming. Its importance is double-edged, for it makes the planet habitable yet becomes a threat when human activity strengthens it too far.

Examiner's Note

The question asks for six points; any six earn full marks. The best scripts assess both the life-giving benefit and the danger of an enhanced effect rather than treating the greenhouse effect as wholly bad.

False Confidence Alert

Many candidates treat the greenhouse effect as entirely harmful; this loses marks because the natural effect is essential for life, and only its human-enhanced excess is the problem.

Question 80

Climate change is the long-term shift in the average state of the climate, driven both by natural forces that have always operated and by recent human activity. To examine its causes, one must separate the natural drivers from the human ones and show how each alters the global energy balance.

Volcanic eruptions as a natural cause. Major eruptions throw vast quantities of ash and sulphur gases high into the atmosphere where they block incoming sunlight and cool the climate for months or years, a well-known natural cause of climate change.

Variations in the Earth orbit. Slow cyclical changes in the shape of the orbit and the tilt and wobble of the axis alter how much insolation different parts of the Earth receive, driving the ice ages over tens of thousands of years.

Changes in solar output. The energy given out by the Sun varies over time, and periods of weaker or stronger output cool or warm the planet, contributing to natural climate change independent of human action.

Natural changes in greenhouse gases. Over geological time the natural release and absorption of carbon dioxide by oceans, rocks and life has raised and lowered global temperatures long before humans appeared.

Burning of fossil fuels as a human cause. The burning of coal, oil and gas in industry, transport and power generation releases large amounts of carbon dioxide that strengthen the greenhouse effect, the leading human cause of present warming.

Deforestation as a human cause. Clearing forests for farming and settlement, as in parts of Tanzania, removes trees that absorb carbon dioxide and releases stored carbon, adding to the greenhouse gases in the air.

Industrial and agricultural emissions. Factories, cement making and farming release carbon dioxide, methane and other gases, so the growth of industry and livestock keeping in East Africa adds further to global warming.

Land use change and urban growth. Replacing vegetation with bare ground, roads and buildings, as around expanding Dar es Salaam, alters surface albedo and local heat and contributes to changing climate.

Release of methane from various sources. Methane from livestock, rice fields, wetlands and decaying waste is a powerful greenhouse gas, so both natural wetlands and human agriculture across the region add to warming.

Pollution and aerosols with mixed effects. Human emissions of dust and aerosols can both cool the air by reflecting sunlight and warm it as soot, showing that human activity affects climate in several competing ways.

Climate change therefore springs from natural causes such as volcanic activity, orbital change and solar variation alongside human causes such as fossil-fuel burning and deforestation. While natural forces have always acted, it is the rapid human additions of greenhouse gases that explain the swift warming behind the retreat of the Kilimanjaro ice.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is keeping natural and human causes clearly separate while linking each to the energy balance.

Question 81

The effects of climate change reach far beyond a simple rise in temperature, touching ice, water, land, life and human livelihoods. To assess these effects, one must examine how the warming climate reshapes both the natural environment and the lives of people.

Retreat of glaciers and mountain ice. Warming melts mountain ice, and the once extensive ice cap of Kilimanjaro has shrunk dramatically, reducing the meltwater that feeds streams and threatening the tourism it supports.

Rise in global sea level. Melting ice and the expansion of warming seawater raise sea level, so the low-lying coast around Dar es Salaam faces flooding, erosion and the loss of land to the Indian Ocean.

More frequent and severe droughts. Higher temperatures and shifting rainfall bring longer and harsher droughts, damaging farming and water supplies in the interior around Dodoma and Tabora.

Disruption of rainfall and farming. Changes in the timing and amount of rain make harvests unreliable, so farmers across Tanzania struggle to plan planting, threatening food security.

Increased flooding and extreme weather. A warmer atmosphere holds more moisture and can produce heavier downpours, so floods become more common and destructive in towns and farmland alike.

Loss of biodiversity and habitats. Shifting temperature and rainfall stress plants and animals, so species in Tanzanian forests and wetlands may decline or move as their habitats change.

Spread of diseases. Warming can extend the range of disease carriers such as mosquitoes into new highland areas, raising the risk of malaria in parts of the Southern Highlands once too cool for it.

Threat to water resources. Reduced glacier melt and erratic rainfall lower the flow of rivers and the level of lakes, straining water supply for towns, farms and hydropower in the region.

Pressure on coastal settlements and economy. Sea-level rise and saltwater intrusion damage homes, ports and farmland along the coast, forcing costly defence or relocation in cities such as Dar es Salaam.

Migration and conflict over resources. As land, water and pasture become scarce, people may be forced to move, raising the risk of competition and conflict over the remaining resources in affected parts of Africa.

Climate change therefore produces wide-ranging effects, from melting glaciers and rising seas to drought, disease and displacement. The shrinking snows of Kilimanjaro and the threatened coast of Dar es Salaam show that these effects are already reshaping both the physical and the human environment of Tanzania.

Examiner's Note

The question asks for eight points; any eight earn full marks. Strong answers cover both physical and human effects and anchor them in named Tanzanian examples.

Question 82

Because much of present climate change is driven by human activity, people also hold the means to slow it and to soften its impacts. To address this, one must propose measures that cut greenhouse gas emissions and others that help communities cope with the changes already underway.

Reducing the burning of fossil fuels. Cutting the use of coal, oil and petrol in industry and transport lowers carbon dioxide emissions, so encouraging fuel efficiency and cleaner engines in cities like Dar es Salaam directly attacks the main human cause.

Developing renewable energy sources. Generating power from the Sun, wind, water and geothermal heat replaces fossil fuels with clean sources, and Tanzania can expand its solar and hydropower to reduce emissions.

Afforestation and protecting forests. Planting trees and protecting existing woodland absorbs carbon dioxide from the air, so reforestation programmes across Tanzania both store carbon and restore the environment.

Promoting energy-efficient technology. Using efficient stoves, lighting and appliances reduces the energy and fuel needed, cutting emissions from homes and industries throughout the country.

Public education and awareness. Teaching people about the causes of climate change encourages habits such as avoiding open burning and saving energy, building wide support for action in towns and villages.

Improving farming and water management. Drought-resistant crops, efficient irrigation and water harvesting help communities in Dodoma and the interior cope with erratic rainfall and protect food supplies.

Enforcing environmental laws and agreements. Setting and enforcing emission standards and joining international agreements commits governments and industries to cut greenhouse gases, strengthening the global response.

Reducing and managing waste. Recycling, reusing materials and properly managing waste cut the methane released from dumps and the energy used in making new goods, lowering emissions in growing cities.

Climate change and its effects can therefore be reduced by cutting fossil-fuel use, expanding renewable energy, planting trees, educating the public and adapting farming. Combining such measures offers Tanzania the best chance of slowing the warming and easing the droughts that threaten Dodoma.

Examiner's Note

The question asks for six points; any six earn full marks. The strongest scripts balance mitigation that cuts emissions with adaptation that helps people cope.

Question 83

The atmosphere is a mixture of gases in fairly fixed proportions, each of which plays a part in supporting life and shaping the environment. To explain its composition and usefulness, one must identify the main gases, their proportions and the role each performs.

Nitrogen, about 78 percent. Nitrogen is the most abundant gas, forming more than three quarters of the air, and although unreactive it is converted through the nitrogen cycle into compounds that plants need to grow on lands such as those around Tabora.

Oxygen, about 21 percent. Oxygen forms about a fifth of the atmosphere and is essential for the respiration of humans, animals and plants and for the burning of fuels, making it the gas on which animal life depends.

Argon and other inert gases. Argon makes up most of the remaining one percent as an inert gas with little chemical effect, together with traces of other noble gases that complete the permanent mixture.

Carbon dioxide, a small but vital share. Carbon dioxide is present in a small proportion yet is essential for plant photosynthesis and is the chief greenhouse gas that helps keep the Earth warm enough for life over Tanzania.

Water vapour, a variable constituent. Water vapour varies greatly from place to place, being plentiful over coastal Dar es Salaam and scarce over the dry interior, and it controls humidity, cloud and rainfall.

Ozone in the upper atmosphere. Ozone is a trace gas concentrated in the stratosphere where it absorbs harmful ultraviolet radiation, shielding life at the surface from its damaging effects.

Dust and aerosols. Fine solid particles of dust, smoke and salt, though tiny in amount, provide the surfaces on which water vapour condenses to form cloud and rain across the country.

The mixture supports weather and life. Together these gases give the atmosphere the properties that sustain breathing, photosynthesis, the greenhouse warmth and the weather on which all life in Tanzania depends.

The atmosphere is therefore composed mainly of nitrogen and oxygen with smaller amounts of argon, carbon dioxide, water vapour, ozone and dust, each with its own use. This balanced mixture supplies the gases for life, drives photosynthesis and weather, and shields the surface from harmful radiation.

Examiner's Note

The question asks for six points; any six earn full marks. The discriminator is pairing each gas with its correct proportion and a stated usefulness rather than listing gases alone.

Question 84

The atmosphere is not uniform but is divided into layers that differ in temperature, composition and behaviour from the surface upward. To explain its vertical structure, one must describe each layer in turn and the features that distinguish it.

The troposphere as the lowest layer. The troposphere lies next to the surface and contains most of the air, water vapour and dust, and nearly all weather occurs here, with temperature falling at about 6.5 degrees per kilometre over places such as Dodoma.

The tropopause boundary. At the top of the troposphere lies the tropopause, where the fall of temperature halts, marking the ceiling above which ordinary weather largely ceases.

The stratosphere and its warming. Above the tropopause the stratosphere shows temperature rising with height because the ozone layer within it absorbs ultraviolet radiation, and its calm, stable air is favoured by high-flying aircraft.

The ozone layer in the stratosphere. Within the stratosphere a concentration of ozone absorbs most of the harmful ultraviolet radiation from the Sun, shielding life at the surface across Tanzania from its damaging effects.

The stratopause boundary. The stratopause marks the top of the stratosphere where the temperature stops rising, separating it from the layer above.

The mesosphere and falling temperature. In the mesosphere temperature falls again to the lowest values found in the atmosphere, and most meteors entering from space burn up in this layer.

The thermosphere or ionosphere. Here temperature rises steeply as the very thin air absorbs intense solar radiation, and its electrically charged particles reflect radio waves, aiding long-distance communication.

The exosphere merging into space. The outermost exosphere has extremely thin air whose molecules gradually escape into outer space, so the atmosphere fades away rather than ending at a sharp boundary.

The pattern of alternating temperature. Taken together the layers alternate, cooling in the troposphere, warming in the stratosphere, cooling in the mesosphere and warming in the thermosphere, a pattern set by where radiation is absorbed.

Decreasing density and pressure throughout. Through every layer the air grows thinner and pressure falls with height, so the dense lower air over Tanzania gives way steadily to the near-vacuum of the upper atmosphere.

The atmosphere is therefore built of distinct layers, the troposphere, stratosphere, mesosphere, thermosphere and exosphere, each with its own temperature behaviour and features. This layered structure, with the protective ozone in the stratosphere, governs weather, shields life and explains why the air fades gradually into space.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is naming the layers in order with their correct temperature trend and quoting the lapse rate.

Question 85

The belief that the sky ends in a solid ceiling is a common misconception, for the atmosphere simply thins away into space, while high above lies the ozone layer that shields life yet is now under threat. To address this, one must correct the misconception and then examine the importance and depletion of ozone.

The air thins gradually with height. The atmosphere is a mixture of gases held by gravity whose density decreases steadily upward, so above Tabora there is no level at which the air suddenly stops to form a roof.

There is no solid boundary to the sky. Because the gases simply become sparser with altitude until they merge into the vacuum of space in the exosphere, there is no surface or ceiling that could mark an end to the sky.

The blue dome is only scattered light. What looks like a solid blue dome is merely sunlight scattered by air molecules, an optical effect rather than a physical lid, so the apparent ceiling is an illusion seen from below.

The ozone layer shields life from ultraviolet. High in the stratosphere a layer of ozone absorbs most of the Sun harmful ultraviolet radiation, protecting people in Tanzania from skin cancer, eye damage and harm to crops and marine life.

Chlorofluorocarbons destroy ozone. Chlorofluorocarbons released from old refrigerators, air conditioners and aerosol sprays rise to the stratosphere where ultraviolet light frees chlorine atoms that break apart many ozone molecules each.

Ozone depletion increases ultraviolet at the surface. As the layer thins, more harmful ultraviolet radiation reaches the ground, raising the risk of skin cancer and crop damage, a danger felt most strongly nearer the poles but of global concern.

International action to protect the ozone. Because the threat is shared, nations have agreed to phase out the gases that destroy ozone, allowing the layer slowly to recover and showing how the misconception of an empty, harmless sky is mistaken.

The atmosphere is a continuous, active envelope. Far from being a fixed dome, the sky is a deep, working envelope of gases whose upper layers protect and regulate life, which is why understanding its true structure matters.

The sky has no end because the air thins gradually into space and the blue dome is only scattered light. Far above lies the precious ozone layer that shields life yet is depleted by chlorofluorocarbons, proving that the sky is a deep, active envelope rather than a solid roof.

Examiner's Note

The question asks for six points; any six earn full marks. The discriminator is explaining why no boundary exists rather than asserting it, and naming chlorine as the agent of ozone loss.

False Confidence Alert

A common error is to claim that high mountains or aircraft reach the end of the sky; this fails because the air thins continuously with no edge, and what appears to be a ceiling is only scattered sunlight.

Question 86

Air pollution is the release of harmful gases and particles into the atmosphere by human activity, and it threatens health, the environment and the climate. To examine it, one must identify the activities responsible and set against each the measures that can bring it under control.

Burning of fossil fuels by vehicles. Motor vehicles burning petrol and diesel release carbon monoxide, nitrogen oxides and soot, so the heavy and growing traffic of Dar es Salaam is a leading source of the haze over the city; cleaner engines and better public transport reduce it.

Emissions from industries and factories. Factories and power stations burning fuel release sulphur dioxide, smoke and toxic gases into the air, and fitting filters and enforcing emission standards can greatly cut these industrial emissions in urban Tanzania.

Domestic burning of wood and charcoal. The widespread use of firewood and charcoal for cooking fills homes and town air with smoke and fine particles, so promoting cleaner stoves, gas and electricity reduces this household pollution across the country.

Open burning of waste and bush. Burning rubbish in the open and setting fire to bush release smoke and harmful gases, and proper waste collection, recycling and bans on open burning help control this source in growing towns.

Agricultural emissions and dust. Farming releases methane and ammonia and stirs dust into the air, so improved farming practices and the planting of trees and grass to bind the soil reduce these emissions.

Use of chlorofluorocarbons and aerosols. Gases from old refrigerators and aerosol sprays pollute the air and damage the ozone layer, so replacing them with safer substitutes and phasing them out by law tackles this hidden form of pollution.

Planting trees as a control measure. Trees absorb carbon dioxide and trap dust, so urban tree planting and the protection of green spaces around Dar es Salaam help clean the air and offset emissions.

Public education and enforcement of laws. Teaching people the dangers of air pollution and enforcing environmental laws encourages cleaner behaviour and holds polluters to account, supporting all the other control measures.

Air pollution in Tanzania springs mainly from vehicle and industrial emissions, domestic and open burning and harmful gases, but each can be controlled through cleaner energy, emission treatment, tree planting, education and law. Pairing every source with its remedy offers the surest way to clear the haze over cities like Dar es Salaam.

Examiner's Note

The question asks for six points; any six earn full marks. Strong scripts pair each polluting activity with a matching, practical control measure.

Question 87

The biogeochemical cycles are the natural pathways along which carbon, oxygen and nitrogen move between the air, water, rock and living things. To explain how they link the four spheres, one must trace these cycles and show how each carries matter from one sphere to another so that the spheres act as one system.

Carbon moves from atmosphere to biosphere. In photosynthesis plants take carbon dioxide from the air and build it into their tissues, so the carbon of the atmosphere passes into the biosphere as the trees of the Tanzanian woodlands around Tabora grow.

Carbon returns through respiration and decay. Living things release carbon dioxide back to the atmosphere through respiration, and when they die decay returns more, completing a loop between the biosphere and the air.

Carbon is stored in the lithosphere. Over long ages carbon is locked into the lithosphere as it forms rocks such as limestone and the fossil fuels, linking the biosphere and atmosphere to the solid Earth beneath.

The ocean acts as a carbon sink. The hydrosphere absorbs great amounts of carbon dioxide from the air, so the waters of the Indian Ocean around Mafia act as a carbon sink, tying the atmosphere to the hydrosphere.

Oxygen cycles between life and the air. Photosynthesis releases oxygen into the atmosphere while respiration and burning consume it, so the oxygen cycle constantly links the biosphere with the air over Tanzania.

Nitrogen is fixed from air into the soil. Although the air is rich in nitrogen, living things cannot use it directly until bacteria in the soil and roots fix it into usable compounds, linking the atmosphere to the biosphere and lithosphere.

Nitrogen returns to the atmosphere. Other bacteria break down nitrogen compounds in the soil and release nitrogen gas back to the air, completing the nitrogen cycle between the lithosphere, biosphere and atmosphere.

Water carries materials between spheres. The water cycle dissolves and transports carbon, nitrogen and minerals as it moves through the spheres, so rain over Lake Victoria carries dissolved matter from air to land to water.

Weathering links rock to water and life. The weathering of rock in the lithosphere releases minerals into the soil and water that plants and animals need, linking the solid Earth to the biosphere and hydrosphere.

The cycles show the Earth as one system. Because each cycle moves matter from sphere to sphere and back, the carbon, oxygen and nitrogen cycles bind the atmosphere, hydrosphere, lithosphere and biosphere into a single interconnected system.

The biogeochemical cycles therefore weave the four spheres together by carrying carbon, oxygen and nitrogen continuously between air, water, rock and life. The journey of carbon from the air into a tree near Tabora, and on to the rocks beneath the Indian Ocean, shows that the spheres function as one integrated system.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is showing each transfer crossing between named spheres rather than describing one cycle in isolation.

Question 88

Endogenic forces are the internal forces that originate within the earth and act upon the crust from below, deriving their energy from sources deep inside the planet. Through diastrophism, the large scale deformation of the crust, they raise mountains, sink basins and tilt continents, providing the very relief upon which the external agents then work. Far from being passive, the earth interior is still active, and the following points show how these internal forces shape the land.

Energy from radioactivity. A major source of endogenic energy is the heat released by the radioactive decay of minerals such as uranium, thorium and potassium deep within the earth. This heat keeps the mantle hot and mobile, driving the convection currents that move crustal plates. Because this heat is continuously produced, the earth remains internally active, and the movements it powers, such as those along the East African Rift, are ongoing rather than finished events.

Primordial heat of the earth. A second source is the primordial heat trapped since the earth first formed from the gravitational collapse and compression of matter. This original heat, slowly escaping from the deep interior, adds to the energy that drives crustal movement. Its steady loss helps maintain the

temperature differences that keep the interior churning, sustaining the forces that lift and fracture the crust over millions of years.

Influence of earth rotation. The rotation of the earth and the stresses it sets up in the spinning, layered body contribute, in a minor way, to the forces acting on the crust. Rotational forces help shape the broad pattern of crustal stress and the slight equatorial bulge of the planet. Although smaller than the thermal sources, rotation is part of the internal energy budget that distinguishes endogenic from purely external forces.

Diastrophism deforms the crust. Diastrophism is the general term for the bending, breaking and warping of crustal rocks by these internal forces. It is the master process through which the energy of the interior is expressed at the surface. Without diastrophism there would be no mountains, rift valleys or plateaus for rivers and wind to attack, as seen in the faulted blocks of the Usambara Mountains in Tanzania.

Orogenic movements raise mountains. Orogenic, or mountain building, movements are horizontal compressive or tensional forces that fold and fracture the crust into mountain ranges. They created the great fold mountains of the world and, by faulting, the block mountains of East Africa such as the Pare and Uluguru ranges in Tanzania. These uplands are entirely the work of internal forces, supplying the high ground that external agents later wear down.

Epeirogenic movements lift continents. Epeirogenic movements are broad vertical uplifts or downward sinkings affecting large parts of a continent without intense folding. The general uplift of the East African plateau is an example, raising vast areas thousands of metres above sea level. Such uplift steepens rivers and renews their cutting power, showing how internal movement directly governs the work of external agents.

Warping shapes wide basins. Warping is the gentle up bending or down bending of extensive areas of the crust. Downwarping creates shallow basins, while upwarping raises domes and swells. The basin occupied by Lake Victoria in Tanzania was formed by the downwarping of the land between the two arms of the rift, a feature no river could have produced, again pointing to internal control of relief.

Internal and external forces work together. The relief of any landscape is the joint product of internal forces that build it up and external forces that wear it down. Internal forces provide the raw relief, the mountains, rifts and plateaus, and external agents then sculpture the detail. In Tanzania the rift highlands raised by faulting are now being dissected by rivers, proving that the two sets of forces are partners, not rivals.

Continuing activity of the interior. Modern earthquakes and active volcanoes are direct evidence that endogenic forces are still at work today. The 2016 Kagera earthquake and the eruptions of Ol Doinyo Lengai in Tanzania show energy still being released from within. This ongoing activity confirms that the earth is dynamic and that internal forces remain a present, not merely a past, shaper of the surface.

It is therefore clear that the earth surface is not the work of external agents alone. Endogenic forces, powered by radioactivity, primordial heat and rotation and expressed through diastrophism, build the very relief that rivers, wind and waves go on to modify. The two groups of forces act together, and any account that ignores the internal forces is incomplete.

Examiner's Note

The question asks for eight points; any eight earn full marks. Strong scripts will show internal and external forces as partners rather than treating endogenic action as a finished, ancient event.

Question 89

An earthquake is a sudden shaking of part of the earth crust caused by the rapid release of stored energy along a line of weakness. Two earthquakes of similar size can cause very different amounts of damage, because destructiveness depends not on energy alone but on a combination of physical and human factors. The Kagera event of 2016 showed how, in one district, some places suffered heavily while others escaped. The factors that determine how destructive an earthquake will be are explained below.

Magnitude of the earthquake. Magnitude measures the amount of energy released at the focus, recorded on the Richter scale. The greater the magnitude, the more powerful the ground shaking and the wider the area affected. The Kagera quake of about magnitude 5.9 was moderate, causing serious but localised damage; a magnitude 8 event would have released vastly more energy and devastated a far larger region.

Depth of the focus. The depth at which the rocks rupture strongly affects damage at the surface. A shallow focus delivers its energy close to the ground, producing violent shaking directly above, whereas a deep focus loses much of its energy before the waves reach the surface. The shallow focus of the Kagera earthquake helped explain the heavy local damage in and around Bukoba.

Distance from the epicentre. Shaking is strongest at the epicentre, the point on the surface above the focus, and weakens with distance as the waves spread out and lose energy. Settlements close to the Kagera epicentre suffered most, while towns far away felt only mild tremors. This is why damage forms rings of decreasing severity around the epicentre.

Nature of the local geology and ground. The type of ground on which a place stands greatly affects how much it shakes. Solid bedrock transmits the waves with little amplification, but soft, water saturated sediments shake violently and may even liquefy. Buildings near the lakeshore on soft ground suffered more than those on firm rock the same distance from the Kagera epicentre.

Quality of building construction. Strongly built, well designed structures resist shaking far better than weak ones. Poorly built houses of unreinforced brick or block, common in parts of Bukoba in 2016, cracked and collapsed, while sturdier, properly engineered buildings remained standing. Construction quality is often the difference between life and death in a moderate earthquake.

Time of day and population density. The number of casualties depends partly on when the quake strikes and how many people are present. A tremor during busy working or market hours in a crowded town causes more deaths than one at a quiet time in a thinly peopled area. The densely settled town of Bukoba suffered casualties partly because of its concentration of people.

Secondary effects such as tsunamis and fires. Much destruction comes not from the shaking itself but from what it triggers. Undersea quakes generate tsunamis, like the 2004 Indian Ocean tsunami that struck the East African coast including parts of Tanzania, while on land tremors set off fires, landslides and floods from broken dams, multiplying the damage well beyond the initial shock.

Duration of the shaking. The longer the ground continues to shake, the more likely buildings are to fail, as repeated stress weakens walls and foundations. A brief jolt may crack a structure, but prolonged shaking can bring it down entirely. Earthquakes that release energy over many seconds therefore tend to be more destructive than those that pass quickly.

Level of preparedness and warning. Communities that are prepared, with earthquake resistant buildings, public education and emergency plans, suffer far fewer losses than unprepared ones. The relatively limited preparedness in the Kagera region in 2016 contributed to the damage and casualties, whereas drilled and well equipped populations elsewhere survive similar quakes with lighter losses.

The destructiveness of an earthquake is therefore the outcome of many factors acting together, ranging from natural ones such as magnitude, depth and ground conditions to human ones such as building quality, population density and preparedness. The contrast in damage across the Kagera region in 2016 shows clearly that two places shaken by the same earthquake can suffer very differently, and that reducing the human factors offers the best hope of cutting future losses.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is treating destructiveness as a combination of physical and human factors, not magnitude alone.

Question 90

Earthquakes are among the most sudden and dangerous of natural hazards, yet science has developed reliable ways of detecting, recording and measuring them, and societies have devised precautions to limit

their toll. From the seismograph that records the faintest tremor to the building codes that keep walls standing, a combination of instruments and planning reduces the loss of life. The following points describe how earthquakes are studied and how their effects can be guarded against.

Detection by the seismograph. An earthquake is detected and recorded by an instrument called a seismograph, which senses the vibrations passing through the ground. A heavy weight remains nearly still through inertia while the frame moves with the earth, and a pen or sensor traces the movement onto a record called a seismogram. Networks of seismographs across the world, including stations in East Africa, register every significant tremor.

Recording the seismic waves. The seismogram shows the arrival of the different seismic waves in order, the fast primary (P) waves first, then the slower secondary (S) waves, and finally the surface waves. By measuring the time gap between the P and S wave arrivals, scientists can work out how far away the earthquake occurred. Combining records from three or more stations fixes the position of the epicentre.

Measuring magnitude on the Richter scale. The magnitude, or energy released, is measured on the Richter scale as a single number derived from the size of the recorded waves. The scale is logarithmic, so each whole step represents about thirty times more energy. The Kagera earthquake of about magnitude 5.9 thus released far more energy than a magnitude 4 tremor, and magnitude allows different earthquakes to be compared on one consistent measure.

Measuring intensity on the Mercalli scale. Intensity, the strength of shaking and the damage felt at a place, is graded on the Modified Mercalli scale in Roman numerals from I to XII. Unlike magnitude, intensity varies from place to place for a single earthquake, being higher near the epicentre and on soft ground. Mapping intensity helps identify which areas suffered most and need the greatest relief and rebuilding.

Recognising natural warning signs. Certain signs may precede an earthquake or its tsunami, and recognising them saves lives. Unusual animal behaviour, small foreshocks, changes in well water levels and, before a tsunami, a sudden retreat of the sea exposing the shore, can all serve as warnings. Communities along the Tanzanian coast that understand the receding sea sign can flee to high ground before the wave arrives, as the 2004 event taught.

Constructing earthquake resistant buildings. A key precaution is to design and build structures that can withstand shaking. Reinforced frames, firm foundations, light roofs and flexible joints allow a building to sway without collapsing. Enforcing building codes in towns such as Bukoba would reduce the kind of collapse of weak brick houses that caused deaths in the 2016 Kagera earthquake.

Planning land use and settlement. Damage can be limited by controlling where and how people build. Avoiding construction on soft, water logged ground that amplifies shaking, keeping clear of steep slopes liable to landslide, and siting vital buildings such as hospitals on firm rock all reduce risk. Coastal settlements can be set back from low lying shores most exposed to tsunamis.

Public education and emergency preparedness. Teaching people what to do, to take cover during shaking and to move quickly to open or high ground afterwards, greatly cuts casualties. Emergency plans, trained rescue teams, stored supplies and rehearsed evacuation routes prepare a community to respond. Such preparedness, still developing in much of Tanzania, is the cheapest and most effective protection of all.

Locating earthquakes with three stations. The exact position of an earthquake is fixed by combining records from at least three seismograph stations. From each station the distance to the earthquake is found from the P and S wave time gap, and circles of that radius are drawn around each station on a map; the single point where the three circles cross marks the epicentre. This triangulation lets scientists pinpoint events anywhere, including those off the East African coast.

Building tsunami warning systems. For coastal communities, a further precaution is a tsunami warning system of sea floor pressure sensors and ocean buoys that detect the passage of a tsunami and send alerts to threatened shores. After the 2004 Indian Ocean disaster that struck the East African coast, an Indian

Ocean warning network was set up, giving low lying Tanzanian coastal settlements precious minutes to evacuate to higher ground.

Earthquakes cannot be prevented or precisely predicted, but they can be detected and measured with great accuracy through the seismograph and the Richter and Mercalli scales, and their dangers can be sharply reduced. By heeding warning signs, building strongly, planning settlement wisely and preparing the public, a coastal community such as those in Tanzania can survive even powerful earthquakes and tsunamis with far smaller losses.

Examiner's Note

The question asks for eight points; any eight earn full marks. Reward candidates who keep measurement (magnitude versus intensity, instruments) distinct from precautions, and who use a relevant Tanzanian example.

Question 91

An earthquake, the sudden shaking of part of the crust as stored energy is released, produces a wide range of effects. Some are destructive and felt at once, others reshape the land over time, and a few even bring benefits. To judge an earthquake fairly one must look at its effects on both the physical landscape and human society. The following points discuss these effects, drawing on Tanzanian and East African experience.

Destruction of property and infrastructure. The most immediate effect is the collapse of buildings, roads, bridges and water and power lines as the ground shakes. Weak structures fail first, as happened to many houses in Bukoba during the 2016 Kagera earthquake. Such destruction disrupts daily life, damages the economy and may take years and great expense to repair.

Loss of life and injury. Earthquakes kill and injure people, mainly through the collapse of buildings onto those inside and from triggered hazards such as fires and landslides. The Kagera quake of 2016 caused deaths and many injuries in north western Tanzania. Casualties are heaviest where buildings are weak and people are densely concentrated at the time of the shock.

Changes to the land surface. Shaking and fault movement can crack, raise or drop the ground, opening fissures and shifting the level of the land along the fault line. Over time repeated earthquakes help build the fault scarps and displaced blocks of regions such as the East African Rift. Thus earthquakes are agents that slowly reshape the relief of the land.

Triggering of landslides and ground failure. On steep or unstable slopes the shaking dislodges masses of rock and soil, sending landslides downhill, while on soft, water saturated ground the soil may liquefy and flow. These secondary movements bury fields, block roads and rivers and can be more destructive than the shaking itself, especially in hilly and lakeshore districts.

Generation of tsunamis. When a strong earthquake displaces the sea floor, it can generate a tsunami, a series of huge waves that race across the ocean and flood the coast. The 2004 Indian Ocean tsunami reached the East African shore, including parts of the Tanzanian coast, drowning people and damaging fishing communities far from the earthquake itself.

Disruption of services and the economy. Earthquakes cut off essential services and damage the economy. Broken water mains, fallen power lines, blocked roads and wrecked communications leave survivors without water, electricity or transport, while shops, offices and factories are halted. The damage to Bukoba in 2016 disrupted trade and services in the town and cost a great deal to repair, setting back the local economy.

Social and psychological effects. Beyond the physical damage, earthquakes leave deep social and psychological scars. Survivors may be left homeless, families separated and communities traumatised by the sudden loss of life and property, and the fear of further tremors lingers long after. After the Kagera earthquake many people in north western Tanzania were displaced and shaken, needing shelter and lasting support.

Some beneficial effects. Not all effects are harmful. Earthquakes expose deep rocks and minerals at the surface, help create the rift troughs that hold valuable lakes, and the study of their waves has revealed the structure of the earth interior. The deep rift lakes of Tanzania, ultimately linked to the same crustal movements, support fishing and transport.

The effects of an earthquake are therefore varied, ranging from the immediate destruction of property and loss of life to the slow reshaping of the landscape and even a few benefits. While the harmful effects dominate human concern, a full account must recognise that the same crustal forces also build the relief and resources on which people depend, as the rift lakes of Tanzania show.

Examiner's Note

The question asks for six points; any six earn full marks. The discriminator is covering both physical and human effects, and noting that not all effects are negative.

Question 92

Vulcanicity is the process by which molten magma moves into or onto the crust, cooling to form a variety of landforms. Where the magma solidifies below the surface it produces intrusive features, later exposed by erosion, and where it reaches the surface it builds extrusive features. Together these create much of the volcanic scenery of Tanzania and the world. The chief intrusive and extrusive features are explained in the points that follow.

Batholith. A batholith is a very large mass of igneous rock that solidifies deep within the crust from a great body of magma. It forms the cores of many old mountain ranges and is exposed only after long erosion strips away the rock above it. Such deep seated granite masses underlie parts of the Tanzanian basement and form prominent domed inselbergs where laid bare.

Sill. A sill is a sheet of magma that forces its way along the bedding planes of existing rocks and cools as a layer lying parallel to them. Being made of hard igneous rock, it often stands out as a resistant ledge or step when the softer surrounding rocks are worn away. Sills are common where layered sedimentary rocks have been invaded by molten material.

Dyke. A dyke is a sheet of magma that cuts across the bedding of the rocks it intrudes, cooling as a near vertical wall. When the softer host rock is eroded, the resistant dyke may stand up as a wall like ridge across the landscape. Dykes frequently occur in swarms radiating from volcanic centres.

Laccolith and lopolith. A laccolith is a dome shaped intrusion that pushes up the overlying rocks into an arch as viscous magma collects beneath them, while a lopolith is the opposite, a saucer shaped intrusion that sags downward. Both form where magma spreads between rock layers, the laccolith doming the surface and the lopolith creating a basin in the strata.

Phacolith. A phacolith is a lens shaped intrusion that forms in the crest of an anticline or the trough of a syncline in already folded rocks. The magma collects in these natural hollows of the fold and solidifies there. Phacoliths therefore record both folding and intrusion, and like other intrusions are revealed only by erosion of the overlying rock.

Composite and shield cones. When magma reaches the surface it builds volcanic cones. A composite cone is tall and steep, built of alternating layers of viscous lava and ash, such as Mount Meru in Tanzania, while a shield cone is low and broad, built of fluid basic lava that spreads widely, a form underlying the broad base of Kilimanjaro. The lava type controls the shape of the cone.

Crater and caldera. At the summit of many cones is a crater, a funnel shaped hollow marking the vent, as on the active Ol Doinyo Lengai. A caldera is a far larger basin formed when the summit collapses into an emptied magma chamber after a great eruption. The Ngorongoro Caldera in Tanzania is a world famous example, its huge floor now teeming with wildlife.

Geysers and fumaroles. Where hot rock heats underground water, the steam and water may escape at the surface as geysers, which spout jets of hot water, or fumaroles, which release only steam and volcanic

gases. These minor extrusive features occur in geothermally active areas such as around Lake Natron and the Rungwe volcanic field in southern Tanzania.

Ash and cinder cones. Where eruptions are explosive but build only from loose material, the ash, cinders and small fragments thrown into the air pile up around the vent to form a small, steep sided ash and cinder cone. Such cones are often found as parasitic cones on the flanks of larger volcanoes, as around the Rungwe volcanic area in southern Tanzania, and rarely grow very large.

Lava plateaus. Where very fluid basic lava escapes not from a single vent but from long fissures, it floods out over wide areas and cools into vast, level sheets that build up a lava plateau. Repeated outpourings raise broad, flat uplands of solidified lava, and such fissure fed volcanic deposits contribute to parts of the high plateau surfaces of the East African volcanic regions.

Vulcanicity therefore produces a rich variety of landforms, the intrusive batholiths, sills, dykes, laccoliths, lopoliths and phacoliths that form below ground and emerge through erosion, and the extrusive cones, craters, calderas, geysers and fumaroles built at the surface. From the granite domes of the basement to the great caldera of Ngorongoro, these features give Tanzania some of the most striking scenery in Africa.

Examiner's Note

The question asks for eight points; any eight earn full marks. The clear discriminator is keeping intrusive features (below surface, exposed by erosion) distinct from extrusive features (built at the surface), each with a real example.

Question 93

Vulcanicity, the movement of magma into and onto the crust, leaves deep marks on both the land and the lives of those who dwell near volcanoes. Its effects are double edged, bringing fertile soils, energy and revenue on the one hand and destruction and danger on the other. To weigh its true value one must set the benefits against the costs. The following points evaluate the positive and negative effects of vulcanicity, with reference to Tanzania.

Fertile volcanic soils. When lava and volcanic ash weather, they release minerals that form deep, fertile soils ideal for agriculture. The slopes of Kilimanjaro and Meru in Tanzania carry rich volcanic soils that support intensive farming of coffee, bananas and maize. These soils sustain dense rural populations and make volcanic highlands among the most productive farmland in the country.

Geothermal energy and hot springs. Heat from magma near the surface warms underground water, which can be tapped for geothermal electricity and provides hot springs. The Ngozi and Songwe areas of the Rungwe volcanic field in southern Tanzania are under exploration for geothermal power. Such energy is clean and renewable and could reduce the country dependence on other power sources.

Tourism and scenic value. Volcanic landforms create spectacular scenery that attracts visitors and earns foreign exchange. Kilimanjaro, the great Ngorongoro Caldera and the active Ol Doinyo Lengai draw thousands of climbers and tourists to Tanzania each year. This tourism supports hotels, guides and local crafts, bringing income and employment to the surrounding communities.

Mineral resources. Volcanic activity and its associated processes concentrate valuable minerals and materials. The soda ash of Lake Natron, building stone from volcanic rock and various other deposits in the volcanic zones of Tanzania provide raw materials for industry and trade. These resources add to the economic worth of volcanic regions.

Destruction by eruptions and gases. Against these gains stand serious dangers. Lava flows, falls of ash and clouds of poisonous volcanic gas can bury farmland, destroy property and harm health. Eruptions of Ol Doinyo Lengai have covered nearby Maasai grazing land with ash, while volcanic gases threaten both people and livestock close to active vents.

Earthquakes and unstable, steep land. Volcanic activity also triggers tremors and builds steep, often unstable slopes prone to landslides. Living and farming on high volcanic ground is therefore risky, and the shaking that accompanies the rise of magma can damage buildings. These hazards offset some of the benefits that draw people to volcanic regions in the first place.

Water supply and orographic rainfall. High volcanic mountains intercept moist winds and force them to rise, cool and shed rain, so they attract heavy rainfall and act as water towers. Mount Kilimanjaro and Meru in Tanzania feed springs and rivers that supply water to the drier lowlands around them, making volcanic highlands a valuable source of water for farming and settlement.

New land and building materials. Vulcanicity also creates new land and useful materials. Solidified lava forms fresh rock surfaces, while volcanic ash, pumice and hard volcanic stone provide building materials and aggregate for construction. In the volcanic districts of northern Tanzania such rock is quarried for building, adding a further economic benefit to volcanic activity.

On balance, vulcanicity is both a blessing and a threat. Its fertile soils, geothermal energy, tourist appeal and minerals bring great benefit to Tanzania, yet its eruptions, gases, tremors and unstable slopes carry real danger. Whether the benefits outweigh the costs depends on careful planning and preparedness, but the dense, prosperous settlement on slopes such as Kilimanjaro shows that, for many, the gains are judged worth the risk.

Examiner's Note

The question asks for six points; any six earn full marks. The command word is evaluate, so the strongest scripts weigh benefits against dangers and reach a judgement rather than merely listing effects.

Question 94

Volcanoes do not all erupt in the same way, and the form of the cone they build reflects the way they erupt. The chief control is the nature of the magma, especially its silica content, which decides whether it is fluid or sticky and whether gas escapes quietly or explosively. Other factors, such as the amount of gas and the presence of water, also play a part. The following points account for the different types of eruption and their resulting cones, with Tanzanian examples.

Control by the type of magma. The single most important control is the silica content of the magma. Basic magma is low in silica, hot and very fluid, so gas escapes easily and eruptions are gentle, whereas acidic magma is high in silica, cooler and sticky, trapping gas until it bursts out violently. The behaviour of a volcano therefore depends largely on which kind of magma feeds it.

Quiet or effusive eruptions. Where the magma is basic and fluid, eruptions are quiet, with lava flowing freely from the vent and spreading far before it cools. Little ash is thrown out and explosions are rare. The fluid lava characteristic of shield type activity, seen in the broad lava base of Kilimanjaro, produces this gentle, effusive style of eruption.

Explosive eruptions. Where the magma is acidic and viscous, gas cannot escape and pressure builds until the volcano erupts violently, hurling out ash, cinders and blocks and sometimes destroying part of the cone. Such explosive activity is far more dangerous, and the more viscous lavas of Tanzanian composite volcanoes such as Meru reflect this style.

Shield cones from fluid lava. Quiet eruptions of fluid basic lava build shield cones, which are low, broad and gently sloping because the lava spreads widely before solidifying. These cones cover large areas yet rise gently. The broad lower form of Kilimanjaro illustrates how fluid lava produces a wide, gently sloping volcanic mountain.

Composite cones from mixed eruptions. Volcanoes that erupt alternately with lava flows and explosions of ash build composite, or strato, cones. These are tall and steep, made of many layers of lava and ash, as in Mount Meru near Arusha. Their steep, symmetrical form comes from the piling up of viscous lava and fragments around the vent.

Ash and cinder cones and special lavas. Highly explosive but smaller eruptions throw out loose ash and cinders that pile into small, steep ash and cinder cones, often as parasitic cones on larger volcanoes around the Rungwe field. Ol Doinyo Lengai is unusual in erupting rare cool carbonatite lava, showing how special magma chemistry can produce an exceptional style of eruption and cone.

Influence of dissolved gas. The amount of gas dissolved in the magma also controls the eruption. Gas rich magma erupts more violently, since the trapped gas expands suddenly and blasts the lava into fragments, while gas poor magma erupts more quietly. The build up and sudden escape of gas helps explain why some Tanzanian volcanic vents erupt with explosive force and others release lava gently.

Role of groundwater and depth of vent. Where rising magma meets groundwater or a water table, the water flashes instantly into steam and greatly increases the violence of the eruption, blasting out shattered rock and ash. The depth and shape of the vent also matter, since a narrow, blocked vent builds up pressure for an explosive burst, while an open vent allows quieter, steadier outflow of lava.

The contrast between a gently erupting volcano and one that blows its summit apart is therefore explained chiefly by the nature of the magma, fluid basic magma giving quiet eruptions and broad shield cones, viscous acidic magma giving violent eruptions and steep composite or ash cones. Tanzanian volcanoes, from the broad base of Kilimanjaro to the explosive composite of Meru and the unusual Ol Doinyo Lengai, display this whole range.

Examiner's Note

The question asks for six points; any six earn full marks. The discriminator is linking eruption style to magma type and then to cone shape, supported by named Tanzanian volcanoes.

False Confidence Alert

Some candidates state that fluid basic lava gives the most violent eruptions because it moves fast. This is wrong; it is the sticky acidic lava that traps gas and erupts explosively, while fluid basic lava erupts quietly and flows far.

Question 95

Faulting is the fracturing of crustal rocks along planes of weakness, accompanied by the movement of the blocks on either side, in response to tension or compression within the crust. In East Africa this process has operated on a vast scale to produce the East African Rift System, a great series of faults running for thousands of kilometres and creating dramatic relief. The process of faulting and the chief landforms and features of the rift system are explained below.

The process of faulting. Faulting occurs when stresses within the crust exceed the strength of the rocks, which then break along a fault plane and the blocks shift relative to one another. Tension pulls the crust apart, while compression pushes it together. The East African Rift was formed mainly by tension as the crust was stretched and arched up, then split along great faults, allowing central blocks to sink.

Types of faults. Several kinds of fault exist. A normal fault forms by tension, with one block slipping down relative to the other; a reverse fault forms by compression, with one block pushed up over the other; a tear or transform fault involves horizontal sliding; and a step fault is a series of parallel faults dropping the land in stages. The rift owes its trough chiefly to normal and step faulting.

Rift valley or graben. Where a central block sinks between two roughly parallel sets of faults as the crust is stretched, a long, narrow, steep sided trough called a rift valley or graben is formed. The East African Rift is the world finest example, and its western arm in Tanzania holds the deep trough occupied by Lake Tanganyika.

Horst or block mountains. A horst, or block mountain, is an upstanding block left high either by being pushed up between faults or by the sinking of the land on either side. In Tanzania the Usambara, Pare and Uluguru Mountains are fault blocks of this kind, rising steeply above the surrounding country and giving the region much of its highland relief.

Fault scarps and tilted blocks. A fault scarp is the steep cliff or slope marking the exposed face of a fault where one block stands above another, and many such scarps form the walls of the rift. Where faulting lifts one edge of a block more than the other, a tilted block results, with one steep and one gentle slope, features common along the rift shoulders.

The eastern (volcanic) branch. The rift divides into two arms. The eastern branch passes through northern Tanzania and is marked by intense volcanic activity and shallow soda lakes. Volcanoes such as Ol Doinyo Lengai and soda lakes such as Natron and Eyasi lie along it, giving this branch its distinctive volcanic and saline character.

The western (deep lake) branch. The western branch runs along the western edge of Tanzania and is marked by very deep, steep sided troughs holding deep fresh water lakes, with less volcanic activity. Lake Tanganyika, among the deepest lakes on earth, and Lake Nyasa fill this branch, providing fisheries, fresh water and transport for the surrounding peoples.

Indirect effects on drainage. Faulting also reshapes rivers in indirect ways. Uplift along a fault reversed the Kagera River, which now flows eastward into Lake Victoria, while rivers crossing fault scarps plunge over them as waterfalls and rapids. Downwarping between the two arms of the rift also created the broad basin holding Lake Victoria, altering the whole drainage of the region.

Formation of the rift by crustal doming. Before the rift split open, the crust was first arched upward into a broad dome by heat and pressure rising from the mantle below. This doming stretched and weakened the crust until it cracked along great faults and the crown of the dome collapsed to form the trough. The high, faulted shoulders that flank the East African Rift in Tanzania are the remains of this uparched crust.

Economic significance of the rift. The features formed by faulting are of great value to the people of Tanzania. The deep rift lakes Tanganyika and Nyasa provide fisheries, fresh water and transport, the volcanic eastern branch offers fertile soils and geothermal energy, and the dramatic scenery of the rift and its lakes draws tourists. Thus faulting has shaped not only the land but also the economy of the region.

The East African Rift System is therefore a magnificent product of faulting, in which the stretching and fracturing of the crust have created rift valleys, block mountains, fault scarps and tilted blocks, and have controlled the pattern of lakes and rivers. From the deep western trough of Lake Tanganyika to the volcanic eastern branch with its soda lakes, the rift gives Tanzania and East Africa some of the most remarkable relief on the planet.

Examiner's Note

The question asks for eight points; any eight earn full marks. Reward clear separation of the faulting process, the resulting landforms and the two contrasting branches, each anchored to a named Tanzanian feature.

Question 96

Faulting, the fracturing and displacement of crustal blocks along fault planes, can produce both upstanding and sunken landforms depending on how the blocks move. Block mountains stand high while rift valleys lie low, yet both arise from the same fracturing of the crust under tension or compression. Understanding how opposite forms come from one process is central to physical geography. The following points explain the formation of block mountains and rift valleys, with Tanzanian examples.

Faulting under tension. When the crust is subjected to tension, it is stretched and pulled apart until it fractures along normal faults. Along these faults the blocks are free to move vertically. Tension is the main force behind the East African Rift, where the crust was stretched and arched before breaking, setting the stage for both the sinking of troughs and the standing up of blocks.

Formation of a rift valley by subsidence. A rift valley, or graben, forms when a central block sinks downward between two roughly parallel sets of normal faults as the crust is stretched apart. The down dropped block becomes a long, narrow, steep sided trough. The western arm of the East African Rift in Tanzania, occupied by the deep Lake Tanganyika, was formed in just this way.

Formation of a block mountain by uplift. A block mountain, or horst, forms in the opposite manner, when a central block stands high either because it is pushed up between two faults or because the blocks on either side sink away from it. The result is an upstanding, steep sided upland. The Usambara, Pare and Uluguru Mountains of Tanzania are block mountains of this kind.

The role of compression. Block mountains may also be raised by compression, when the crust is squeezed and one block is forced up between reverse faults. Whether by uplift between faults or by the sinking of neighbouring land, the essential point is that the block ends up standing above its surroundings, giving the steep edged relief typical of horsts.

Associated fault scarps. Both block mountains and rift valleys are bordered by fault scarps, the steep cliffs marking the faces of the faults. The walls of a rift valley and the steep edges of a block mountain are such scarps. These cliffs, seen along the rift near Lake Nyasa and around the Tanzanian block mountains, are a clear sign of the faulting that formed them.

Contrasting relief from one process. The key lesson is that the same process of faulting produces opposite landforms according to the direction of block movement. Where the central block sinks, a rift valley results; where it stands high, a block mountain results. The juxtaposition of the sunken rift troughs and the upstanding ranges of Tanzania shows both outcomes of one set of forces.

The compression theory of rift formation. One explanation holds that rift valleys form by compression rather than tension. When the crust is squeezed from the sides, two reverse faults may develop and the central block is pushed down and held between the overhanging walls, while the side blocks ride up. By this view the bordering blocks become block mountains and the wedged central block becomes the rift floor, again giving opposite landforms from one set of movements.

Modification by erosion and deposition. Once formed, both landforms are altered by external agents. The steep scarps of block mountains are gradually worn back and gullied by erosion, while sediment washed off the highlands and volcanic ash fill the floor of the rift valley. The flat, sediment covered floors of the East African rift troughs in Tanzania show how deposition smooths the original faulted relief over time.

Block mountains and rift valleys are therefore complementary products of faulting, the one formed where a block is left standing high and the other where a block sinks low between faults. The block mountains such as the Usambara and the rift valley holding Lake Tanganyika in Tanzania demonstrate how a single process, controlled by the direction of crustal movement, can carve such strikingly opposite relief.

Examiner's Note

The question asks for six points; any six earn full marks. The discriminator is showing that one process yields opposite landforms through the direction of block movement, backed by named examples.

Question 97

The East African Rift System is not only a spectacular feature of the landscape but also a major influence on the economy and daily life of Tanzania. The faulting that created it has produced lakes, highlands, minerals and scenery that the people use in many ways, although it also brings certain difficulties. To judge its true significance one must look at its varied benefits and drawbacks. The following points discuss the significance of the rift system to Tanzania.

Deep lakes for fishing and water. The rift faulting created the deep lakes of the western branch, Tanganyika and Nyasa, which are among the deepest in the world. These lakes provide rich fisheries that feed and employ many people, as well as fresh water for domestic and other uses. They are a vital resource for the communities along their shores in western and southern Tanzania.

Water transport and trade. The long rift lakes serve as natural highways for boats and ships, linking Tanzania with neighbouring countries across Lake Tanganyika and Lake Nyasa. This cheap water transport carries people and goods where roads are few, supporting trade and contact between regions and across international borders along the rift.

Geothermal and hydroelectric energy. The volcanic activity of the eastern rift offers geothermal energy potential, as in the Rungwe area, while the steep relief and rivers associated with the rift provide sites for hydroelectric power. These energy resources, linked directly to rift processes, can support industry and lighting in Tanzania.

Tourism and scenic attractions. The rift contains some of Tanzania finest tourist attractions, including the Ngorongoro Caldera, the rift lakes and the volcanoes along the eastern branch. The flamingo filled soda lakes such as Natron, the game rich rift floor and the dramatic scarps draw many visitors, earning foreign exchange and supporting jobs in tourism.

Minerals and fertile land. The rift zone yields valuable resources such as the soda ash of Lake Natron and the fertile volcanic soils of the eastern branch highlands. These soils support productive farming, while the minerals provide raw materials for industry and export, adding to the economic value of the rift region.

Difficulties posed by the rift. The rift also brings challenges. Its steep scarps hinder the building of roads and railways, the soda lakes are useless for drinking, earthquakes such as those along the rift threaten settlements, and the deep troughs can isolate communities. These drawbacks must be set against the many benefits the rift provides.

Wildlife habitats and conservation. The rift has created varied habitats that support abundant wildlife, from the flamingos of the soda lakes to the game of the rift floor. The Ngorongoro Caldera and the rift lakes such as Natron and Manyara shelter rich animal life and form important conservation areas in Tanzania, which both protect biodiversity and underpin the wildlife tourism on which the country depends.

Scientific and educational value. The East African Rift is of great scientific and educational importance, for it is one of the best places on earth to study how continents split apart. Its faults, volcanoes and lakes attract researchers and students, and the rift deposits have yielded famous discoveries about early human origins, as at Olduvai Gorge in northern Tanzania, giving the region worldwide academic significance.

The East African Rift System is therefore of great significance to Tanzania, supplying fisheries, water, transport, energy, minerals, fertile soils and a thriving tourist industry, even though its scarps, soda lakes and earthquakes pose real difficulties. On balance its lakes, scenery and resources make it one of the country greatest natural assets, fully justifying the view that it is far more than mere scenery.

Examiner's Note

The question asks for six points; any six earn full marks. The command word is discuss, so credit a balanced treatment that weighs the rift benefits against its drawbacks, with named examples.

Question 98

Folding is the bending of layers of crustal rock into waves by compressional forces acting horizontally, the rocks being squeezed without breaking. It is responsible for some of the greatest mountain ranges on earth, although Tanzania, lying on a stable ancient block, has no young fold mountains of its own and one must look to other parts of Africa for examples. The process of folding and the landforms it produces are explained in the points below.

The process of folding. Folding takes place when horizontal compressional forces squeeze layers of rock from opposite sides. If the rocks are pliable, they bend rather than break, forming a series of arches and troughs. These forces arise mainly where crustal plates move together, crumpling the rocks caught between them into folds over very long periods of time.

Anticlines and synclines. The two basic parts of a fold are the anticline and the syncline. An anticline is the up arched part of the fold, where the rock layers bend upward and the limbs dip away from the crest. A syncline is the down sagging part, where the layers bend downward and the limbs dip towards the trough. A folded region is a succession of anticlines and synclines.

Limbs and axis of a fold. Each fold has limbs and an axis. The limbs are the two sloping sides of the fold, shared between neighbouring anticlines and synclines, while the axis is the central line about which the layers are bent. The angle and direction in which the limbs dip describe the shape of the fold and indicate the strength and direction of the compression.

Simple and asymmetrical folds. A simple, or symmetrical, fold has its two limbs dipping away from the axis at roughly equal angles, formed by moderate compression from both sides. An asymmetrical fold has

one limb steeper than the other because compression was stronger from one side. These are the gentler folds, formed where the squeezing forces are not extreme.

Overfolds and recumbent folds. Stronger compression pushes a fold over so that one limb is bent across the other, both limbs dipping the same way, forming an overfold. Still greater compression presses the fold almost horizontal to form a recumbent fold, in which the axis lies nearly flat. These tightly compressed folds are typical of the cores of great mountain ranges.

Nappes. Where a recumbent fold is pushed so far that it shears and the rocks slide forward over those in front along a thrust plane, a nappe is formed. Nappes represent the most intense folding, often combined with faulting, and great sheets of rock may be carried many kilometres. They occur in the heavily compressed Atlas Mountains of north Africa.

Young fold mountains. Folding on a great scale builds fold mountains, the highest ranges on earth. Young fold mountains, formed comparatively recently, are high, rugged and still rising, with sharp peaks; the Alps of Europe and the Himalaya of Asia are the outstanding examples. Their great height reflects the recent and powerful compression that raised them.

Old fold mountains and the African case. Old fold mountains were folded long ago and have since been worn down to lower, rounded ranges. In Africa the Cape Ranges of South Africa and the Atlas Mountains of north west Africa are fold mountains, since Tanzania itself, resting on a stable ancient block, has no young fold mountains. These African ranges illustrate folding for students in Tanzania.

Cause of folding in plate movement. The compressional forces that fold the rocks arise mainly where two crustal plates move towards each other. As the plates converge, the sediments lying in the basin between them are squeezed and crumpled upward into folds, and the great fold mountains rise along the line of collision. The Himalaya, for example, were folded where one great plate pushed against another.

Synclinal valleys and anticlinal ridges. Folding also shapes valleys and ridges. In many folded regions the upfolded anticlines stand out as ridges and the downfolded synclines form valleys between them, though prolonged erosion can later reverse this. The alternating ridges and valleys of an eroded fold belt, as seen in the old Cape Ranges of South Africa, show how folding controls the detailed pattern of relief.

Folding therefore bends rock layers into anticlines and synclines and, with increasing compression, into asymmetrical, over, recumbent and nappe structures, ultimately raising the great fold mountains of the world. Because Tanzania lies on a stable ancient block, it has no young fold mountains, and the Cape Ranges and Atlas of Africa, along with the Alps and Himalaya, serve as the chief examples of this process.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is showing folds of increasing intensity and recognising that Tanzania lacks young fold mountains, so African or world examples are needed.

Question 99

Fold mountains are ranges built by the bending of rock layers under compression, but they differ greatly in appearance according to their age. Young fold mountains are high and rugged, while old fold mountains have been worn down to lower, gentler forms. Comparing the two reveals how time and erosion reshape even the mightiest ranges. Since Tanzania has no fold mountains of its own, examples are drawn from elsewhere in Africa and the world. The following points compare young and old fold mountains.

Age of formation. Young fold mountains were formed comparatively recently in the earth history and are geologically youthful, whereas old fold mountains were folded in far more distant ages. The Himalaya and Alps are young, formed within the last few tens of millions of years, while the Cape Ranges of South Africa and the Atlas of north Africa are much older, having been folded long before.

Height and relief. Young fold mountains are very high, with great elevation and bold relief, while old fold mountains are much lower because erosion has reduced them over time. The towering Himalaya rise far above the lower, more subdued Cape Ranges, whose summits have been worn down through long ages of denudation since they were first folded.

Sharpness of the peaks. The peaks of young fold mountains are sharp, jagged and rugged, reflecting recent uplift and active erosion, whereas those of old fold mountains are rounded and smoothed by prolonged weathering and erosion. The serrated crests of the Himalaya contrast with the gentler, rounded outlines of the old Cape Ranges.

State of uplift and activity. Young fold mountains are often still rising and tectonically active, with frequent earthquakes, while old fold mountains are stable and no longer being uplifted. The Himalaya are still growing and earthquake prone, whereas the ancient Cape Ranges are quiet and stable, their building forces long since spent.

Degree of erosion. Young fold mountains have suffered relatively little erosion and retain much of their original folded structure, while old fold mountains have been deeply eroded so that their cores and resistant beds stand out as ridges. The deep dissection of the old Atlas and Cape Ranges exposes their inner structure far more than in the youthful Himalaya.

Folding structure preserved. In young fold mountains the folds are fresh and clearly displayed in the high ranges, whereas in old fold mountains long erosion has stripped away much of the original cover, leaving the harder folded rocks as parallel ridges and valleys. The ridge and valley pattern of the old Cape Ranges illustrates this, contrasting with the bolder folds of the young ranges.

Continuity and extent of the ranges. Young fold mountains usually form long, continuous and clearly defined chains, since they have not yet been broken up by erosion, whereas old fold mountains are often broken, discontinuous and reduced to isolated remnants. The unbroken sweep of the young Himalaya contrasts with the fragmented, isolated character of the old Cape Ranges and Atlas of Africa, worn apart over long ages.

Snow cover and drainage. Because young fold mountains rise so high, their summits reach above the snow line and bear permanent snow and glaciers that feed great rivers, while the lower old fold mountains seldom carry snow. The snowfields of the towering Himalaya feed mighty rivers, whereas the modest old Cape Ranges of South Africa, worn low, stand well below the snow line and support only smaller streams.

Young and old fold mountains therefore differ chiefly in age, height, sharpness of peaks, activity and degree of erosion, the young Himalaya and Alps standing high and rugged and still rising, the old Cape Ranges and Atlas of Africa worn low and rounded and now stable. The contrast shows how time and erosion gradually transform even the greatest fold mountains, a lesson drawn from ranges outside Tanzania, which has none of its own.

Examiner's Note

The question asks for six points; any six earn full marks. The discriminator is a genuine point by point comparison rather than two separate descriptions, with African and world examples since Tanzania lacks fold mountains.

Question 100

Endogenic processes, the internal forces of vulcanicity, faulting, folding and broad earth movements, have played the leading part in building the landscape of Tanzania and in setting the stage for human life. They have raised mountains, cut deep troughs, formed lakes and laid down fertile soils, and these in turn govern where and how people farm, settle, fish and earn a living. The following points examine how these internal processes have shaped both the relief and the human activities of the country.

Building the highland relief. Faulting and vulcanicity together have raised much of the high ground of Tanzania. Block mountains such as the Usambara, Pare and Uluguru ranges were lifted by faulting, while volcanoes such as Kilimanjaro and Meru were built by eruption. These highlands give the country its varied, often cool relief and break the monotony of the surrounding plateau and plains.

Creating the great rift troughs and lakes. Faulting on a vast scale produced the East African Rift and its lakes. The western arm holds the deep lakes Tanganyika and Nyasa, while the eastern arm holds the soda lakes Natron and Eyasi. These troughs and lakes are among the most striking features of the Tanzanian landscape and a direct product of internal forces stretching the crust.

Forming volcanic landforms. Vulcanicity has created a wealth of volcanic landforms, from the great Ngorongoro Caldera and the active cone of Ol Doinyo Lengai to the dormant peaks of Kilimanjaro and Meru and the Rungwe volcanic field. These features give northern and southern Tanzania scenery found in few other places and form the basis of important national parks.

Producing fertile volcanic soils for farming. The weathering of lava and ash has produced deep, fertile volcanic soils, especially on the slopes of Kilimanjaro and Meru and in the rift highlands. These soils support intensive farming of coffee, bananas, tea and maize, so the most productive agriculture of the country is concentrated on land created by volcanic activity.

Controlling the pattern of settlement. The relief and soils built by endogenic forces strongly influence where people live. The cool, fertile, well watered volcanic and fault highlands attract dense settlement, as around Kilimanjaro and in the Southern Highlands, while the hot, dry rift floors and arid plains are thinly peopled. Internal forces thus help shape the human map of Tanzania.

Supporting fishing and water transport. The deep rift lakes formed by faulting provide rich fisheries and serve as natural waterways. Lake Tanganyika and Lake Nyasa supply fish that feed and employ many people and carry boats linking Tanzania with its neighbours. These activities depend entirely on the troughs that internal forces created for the water to fill.

Providing energy, minerals and tourism. Endogenic processes also supply resources and revenue. The volcanic Rungwe area offers geothermal energy potential, Lake Natron yields soda ash, and the volcanoes, caldera and rift lakes draw tourists from around the world. Kilimanjaro and Ngorongoro alone earn large amounts of foreign exchange, all founded on landforms made by internal forces.

Posing hazards to human life. The same internal forces that build the landscape also threaten it. Earthquakes such as the 2016 Kagera event damage towns, volcanic eruptions and gases endanger nearby communities, and the steep slopes raised by faulting and vulcanicity are prone to landslides. People in these regions must live with the hazards that accompany the benefits of an active earth.

Influencing climate and vegetation. The relief raised by endogenic forces controls local climate and vegetation. The high volcanic and block mountains intercept rain bearing winds and create cool, wet highlands clothed in forest, while the rift floors lie in hot, dry rain shadows with savanna and scrub. The contrast between the moist forested slopes of Kilimanjaro and the dry rift floor below it shows this influence clearly.

Guiding transport and communication routes. The relief built by internal forces also governs where roads, railways and towns can be placed. Steep fault scarps and deep rift troughs obstruct movement and force routes to wind around or through gaps, while the lakes serve as waterways. The need to cross the rugged faulted and volcanic terrain of Tanzania has shaped the pattern of its transport links and the siting of its settlements.

Endogenic processes have therefore shaped almost everything distinctive about Tanzania, raising its mountains and volcanoes, cutting its rift troughs and lakes, and laying down its fertile soils, while at the same time governing settlement, farming, fishing, energy, tourism and the hazards people face. From the snow capped summit of Kilimanjaro to the deep waters of Lake Tanganyika, the landscape and the life it supports are, above all, the work of forces operating within the earth.

Examiner's Note

The question asks for eight points; any eight earn full marks. The command word is examine, so each point should link a landform to a human consequence; the discriminator is connecting relief to activity rather than describing relief alone.

Question 101

Mechanical or physical weathering is the breakdown of rock into smaller fragments by physical stress alone, without any change in its chemical composition. It works through several distinct processes, each applying a different stress, and together they prepare the loose material on which erosion and mass wasting then act. The chief processes can be examined as follows.

Exfoliation. Exfoliation is the peeling of rock in curved shells like the layers of an onion. Daily heating makes the outer skin of the rock expand more than the cool interior, and night cooling makes it contract, so the surface layer cracks and flakes away. Over time this rounds the rock into a dome. The bare granite domes near Dodoma show exfoliation clearly.

Insolation weathering. Insolation weathering acts on rocks made of several minerals in places of fierce heat. Each mineral expands and contracts by a different amount as the rock heats by day and cools sharply by night, so the grains pull against one another until the rock crumbles grain by grain. It is strongest in hot deserts such as the Sahara, where day and night temperatures differ greatly.

Frost action. Frost action, or freeze-thaw, works where temperatures cross freezing point. Water seeps into cracks and pores, and on freezing it expands by about a tenth, prising the rock apart with great force; on thawing the water seeps deeper and the cycle repeats. It shatters the high summit rocks of Kilimanjaro, where it freezes by night and thaws by day.

Salt crystallisation. Salt crystallisation breaks rock in dry and coastal places. Salty water enters the pores of the rock, and when the water evaporates the salt crystals it leaves behind grow and exert pressure that pushes the grains apart, crumbling the surface. It weakens porous rock along the Tanga coast, where sea spray supplies the salt.

Pressure release. Pressure release affects rock that formed deep underground under heavy load. When the overlying rock is stripped away by erosion, the buried rock is freed of its weight and expands upward, cracking into curved sheets parallel to the new surface. This jointing helps form and expose the bare granite domes of the central plateau of Tanzania.

Wetting and drying. Wetting and drying weathers clay-rich rocks in places of marked wet and dry seasons. The clay minerals swell as they take up water in the rains and shrink as they dry out, and the repeated swelling and shrinking flakes the surface and opens cracks. It works on clay-bearing rocks during the alternating seasons of much of Tanzania.

Biological mechanical action. Living things also break rock physically. The roots of trees grow into joints and widen them as they thicken, splitting the rock apart, while burrowing animals loosen and shift material. Tree roots prising open the jointed rock of the forested Usambara slopes show this mechanical work of life.

Action of running and freezing water in cracks. Beyond freezing, water repeatedly entering and leaving cracks weakens the rock by easing fragments loose and flushing them out, so the cracks widen with each wetting. On steep slopes this loosening readies fragments for removal and prepares the way for the chemical attack that follows.

Outcome of mechanical weathering. Taken together these processes shatter solid rock into loose debris and greatly increase the surface area exposed. This opens the way for chemical weathering to work faster and supplies the loose material that gravity and rivers can then carry off, so mechanical weathering is the first stage of denudation.

In conclusion, mechanical weathering breaks rock by physical stresses alone, through exfoliation, insolation, frost action, salt crystallisation, pressure release and the action of plants and water, with the type that dominates depending on the local climate. By reducing solid rock to loose fragments it prepares the ground for chemical decay and for erosion, and so begins the wearing down of the land.

Examiner's Note

The question asks for eight points; any eight earn full marks. The strongest scripts give the actual physical stress behind each process, not just its name, and tie each to a climate where it is active.

Question 102

Chemical weathering is the decay of rock through chemical reactions, usually involving water, oxygen and carbon dioxide, which alter the minerals of the rock into new and weaker substances. Unlike mechanical weathering it changes the very composition of the rock, and it is most active in warm, moist conditions. Its main processes can be explained as follows.

Carbonation. Carbonation acts on limestone and other calcareous rocks. Rainwater absorbs carbon dioxide from the air and soil to form a weak carbonic acid, which reacts with the calcium carbonate of the rock to make soluble calcium bicarbonate that is then washed away. This is the process that dissolves the limestone of the Amboni caves near Tanga into their underground chambers.

Hydrolysis. Hydrolysis is the reaction of water with minerals in the rock, most importantly the feldspar in granite. The feldspar is changed into soft clay minerals, so the once-hard granite loses its strength and rots from within into a crumbly mass. Hydrolysis rots the feldspar-rich granites of central Tanzania, leaving behind clay and loose quartz grains.

Oxidation. Oxidation is the reaction of oxygen, usually dissolved in water, with iron minerals in the rock. The iron is turned into reddish-brown iron oxides, much like the rusting of iron, and these crumble easily and stain the rock. Oxidation reddens and weakens the iron-bearing rocks of the Tanzanian interior, leaving rust-coloured weathered surfaces.

Hydration. Hydration is the taking up of water into the structure of certain minerals, which makes them swell. The swelling sets up internal stress that flakes the rock surface and opens it to further decay, and it also speeds other reactions. Hydration prepares rock surfaces for decay in the humid coastal belt of Tanzania, where moisture is plentiful.

Solution. Solution is the direct dissolving of soluble minerals, such as rock salt and parts of limestone, in water. The dissolved material is carried away unseen in the water, leaving hollows and weakening the remaining rock. Solution removes soluble minerals along parts of the limestone country near Tanga, helping widen joints and passages.

Control by climate. The speed of chemical weathering depends strongly on climate. Heat speeds chemical reactions and abundant water provides the medium for them, so chemical weathering is fastest in warm, wet regions and slow in cold or dry ones. The warm and humid coast and lake regions of Tanzania therefore weather chemically far faster than the dry interior.

Role of water and biological acids. Water is essential to nearly every reaction, and living things add to it. Decaying plants release organic acids into the soil water, and these acids attack minerals more strongly than rain alone. Beneath the forests of the Usambara Mountains such acids speed the chemical decay of the underlying rock.

Deepening of the weathering profile. Where chemical weathering works long and deep it rots the rock far below the surface into a thick mantle of soft, decayed material called regolith. This deep weathered layer is common in the warm humid parts of Tanzania and supplies the parent material from which soils form.

Outcome of chemical weathering. Chemical weathering turns hard rock into soft, often clay-rich material that is easily removed, and it works hand in hand with mechanical weathering, which exposes fresh surfaces for it to attack. Together they reduce rock to the loose mantle that erosion and mass wasting carry away, advancing denudation.

In conclusion, chemical weathering decays rock by carbonation, hydrolysis, oxidation, hydration and solution, all favoured by warmth and moisture, and so it dominates in the humid parts of Tanzania. By turning solid rock into soft and soluble material it both shapes distinctive scenery, such as karst, and prepares the ground for soil formation and for further denudation.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is naming the reaction and the mineral it attacks, for example carbonation on limestone and hydrolysis on feldspar, rather than vague decay.

Question 103

Weathering does not act at the same speed or in the same way everywhere. Its type and rate are governed by several factors, chief among them the climate, the nature of the rock and the cover of plants and soil.

Examining these factors shows why some rocks decay quickly while others endure, and they can be set out as follows.

Temperature. Temperature controls both the kind and the speed of weathering. High temperatures speed chemical reactions, so chemical weathering dominates in hot regions, while large daily ranges of temperature drive mechanical weathering such as insolation weathering. The fierce day-to-night swings of desert areas such as the Sahara favour mechanical breakdown over chemical decay.

Moisture and rainfall. Water is needed for almost all chemical weathering and for frost action, so the amount of moisture is decisive. Where rainfall is heavy and steady chemical weathering is rapid and deep, while dry areas weather slowly. The warm and wet coastal belt of Tanzania weathers far faster and deeper than the dry central interior.

Rock type and chemical composition. The minerals making up a rock decide how it reacts. Rocks rich in soluble or reactive minerals, such as the calcium carbonate of limestone, weather quickly by chemical means, while quartz-rich rocks resist. The limestone near Tanga dissolves into caves while neighbouring resistant rocks stand firm.

Rock structure: joints and bedding. The cracks, joints and bedding planes in a rock give water a way in. A well-jointed rock offers many surfaces for attack and weathers fast, while a massive unjointed rock resists because water cannot penetrate. The heavily jointed limestone of the Amboni area weathers rapidly along its many joints.

Vegetation cover. Plants influence weathering in two opposite ways. Their roots prise rock apart mechanically and their decaying remains release acids that speed chemical attack, yet a dense plant cover also shields the rock and holds moisture against it. The forested slopes of the Usambara Mountains show both the protecting and the decaying effects of vegetation.

Slope and drainage. The angle of the land and how freely water drains affect weathering. On gentle, poorly drained ground water lingers in contact with the rock and chemical weathering is intense, while on steep slopes water and debris are quickly removed, exposing fresh rock. Gentle, moist lowlands therefore weather more deeply than steep, free-draining hillsides.

Length of exposure and time. Weathering is gradual, so the longer a rock surface is exposed the more deeply it is weathered. Ancient land surfaces such as the long-stable plateaus of central Tanzania carry deep weathered mantles, while newly exposed rock is only lightly altered.

Surface area and particle size. The more surface a rock exposes, the faster it weathers, because reactions occur on surfaces. Mechanical weathering that shatters rock into many fragments greatly increases the surface area, so chemical weathering then proceeds much faster, showing how the two kinds assist each other.

Combined working of the factors. These factors act together rather than alone. A warm wet climate acting on a jointed soluble rock under acid-producing vegetation gives the fastest weathering of all, while a cold dry climate on massive resistant rock gives the slowest, so the local scenery reflects their combined balance.

In conclusion, the type and rate of weathering are controlled chiefly by climate, by the composition and structure of the rock, and by vegetation, slope and time. Because these vary from place to place, weathering differs across Tanzania from the deep chemical decay of the humid coast to the slow mechanical breakdown of the dry interior, and so it shapes the land at different speeds in different regions.

Examiner's Note

The question asks for eight points; any eight earn full marks. The strongest answers explain how each factor changes the type as well as the rate of weathering and support the point with a contrasting Tanzanian setting.

Question 104

Mass wasting is the downslope movement of weathered rock and soil under the direct pull of gravity, without a carrying agent such as a river. It ranges from movements so slow they can hardly be seen to

sudden and destructive collapses, and the types differ in their speed and in the way the material moves. They can be examined as follows.

Soil creep. Soil creep is the slowest form of mass wasting, in which soil moves downhill only a little each year. Wetting and drying, heating and cooling and the trampling of animals nudge each grain slightly downslope, and over years the whole soil layer shifts. It shows in tilted fence posts and curved tree trunks on the cultivated slopes around Lushoto.

Solifluction. Solifluction is the slow flow of water-logged soil over a firm or frozen layer beneath. The surface soil becomes saturated and lobes of it ooze downslope. Though typical of cold regions, a similar slow flow of saturated soil occurs on gentle waterlogged slopes in the Tanzanian highlands during the long rains.

Mudflow. A mudflow is a rapid downhill flow of soil so soaked with water that it behaves like a thick liquid. Heavy rain saturates the slope until it loses all strength and pours downward, carrying everything before it. The mudflow that buried homes at Lwandai in Lushoto in 2022 is a clear Tanzanian example.

Slump. A slump is the downward and outward slipping of a mass of material along a curved surface, so that the slipped block rotates and tilts backward. It is common where soft material rests on a weak base that has been soaked or undercut. The deeply weathered slopes of the Tukuyu area are prone to slumping.

Rockfall. A rockfall is the sudden free fall of loose rock from a steep cliff or slope. Weathering, especially frost and the prising of roots, loosens blocks until they break free and crash down, collecting as scree at the foot. Rockfalls occur on the steep rocky faces of the Usambara Mountains.

Rockslide. A rockslide is the rapid sliding of a large mass of rock down a slope, often along a bedding plane or joint that dips downhill. When the rock is undercut or lubricated by water the mass slides as a unit. Such slides have struck the steep slopes of the Hanang area.

Landslide. A landslide is the swift collapse and downslope movement of a large mass of rock and soil together. It is triggered when heavy rain, undercutting or a tremor finally overcomes the strength of the slope. The Hanang landslides destroyed farmland and homes when saturated steep slopes gave way.

Control by water, slope and vegetation. Across all these types the decisive controls are the steepness of the slope, the amount of water in the material and the cover of plants binding it. Steep, saturated and bare slopes move most readily, which is why clearing forest for farming on the steep wet slopes of the highlands so often ends in slides.

Importance and prevention. Mass wasting matters because it destroys farmland, blocks roads and buries settlements, as at Lwandai. It can be reduced by keeping a cover of trees and grass, by terracing and draining the slopes and by avoiding building on unstable ground, so that human action does not turn a steep slope into a disaster.

In conclusion, mass wasting ranges from the imperceptible creep of soil to the sudden rush of mudflows, slumps, rockfalls, rockslides and landslides, differing mainly in speed and water content. In the steep and rainy Tanzanian highlands such as Lushoto and Hanang it is a real hazard, and protecting the vegetation cover and draining the slopes are the surest defences against it.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is separating the slow movements, creep and solifluction, from the rapid ones, and naming a real Tanzanian slope failure such as Lwandai or Hanang.

Question 105

Mass wasting, the movement of rock and soil downslope under gravity, results from a combination of natural conditions and human actions that together overcome the strength holding a slope in place. Understanding its causes is the key to controlling it, and the causes and the matching measures can be assessed as follows.

Steepness of slope. The steeper a slope, the greater the downhill component of gravity acting on its material, so steep slopes are far more likely to fail than gentle ones. The abrupt slopes of the Usambara and

Hanang highlands are therefore especially prone to movement, and building or farming on them must be approached with great care.

Heavy and prolonged rainfall. Water is the commonest trigger of mass wasting. Prolonged rain soaks the soil, adds weight and reduces the friction between grains until the slope flows or slides. The long rains that saturated the slopes at Lwandai in Lushoto in 2022 set off a destructive mudflow there.

Nature of the slope material. Loose, deeply weathered and clay-rich material moves far more easily than solid rock, especially when wet, because it has little internal strength. The thick weathered mantle of the Tukuyu area slumps readily once it is soaked, while firmer rock nearby stays in place.

Removal of vegetation. Plant roots bind the soil and draw water out of it, so clearing the forest for farms and settlement removes the slope's anchor and leaves it free to slip. The clearing of forest on the steep slopes around Lushoto for cultivation has made landslides there more frequent.

Undercutting of slopes. When the base of a slope is cut away, by a river, by waves or by road and house construction, the mass above loses its support and collapses. Careless road cuttings across the steep mountain slopes of Tanzania often start slides by removing the toe of the slope.

Earth tremors. Vibration from earthquakes along the East African Rift can jolt loose material past its balance and set rockfalls and landslides moving on already steep ground. A tremor acting on a saturated steep slope is enough to trigger sudden failure.

Control by maintaining vegetation. Because bare slopes fail most easily, the surest control is to keep and replant a cover of trees and grass whose roots bind the soil and remove water. Protecting the remaining forest on the Usambara slopes guards both the land and the people below it.

Control by terracing and drainage. Cutting slopes into level terraces reduces their effective steepness and slows runoff, while drains carry water away before it can saturate the soil. Terracing the farmed highland slopes of Tanzania reduces both soil erosion and the risk of slides.

Control by wise land use and avoidance. Some slopes are too steep or unstable to build on safely, so the wisest measure is to map the dangerous ground and keep settlement off it, and to avoid undercutting slopes during construction. Had homes at Lwandai stood clear of the unstable slope, the loss of life would have been less.

In conclusion, mass wasting is caused by steep slopes, heavy rain, weak material, the loss of vegetation, undercutting and tremors, and many of these are worsened by human action. It can be controlled by keeping a vegetation cover, terracing and draining the slopes, and avoiding building on unstable ground, as the disaster at Lwandai in Lushoto so clearly teaches.

Examiner's Note

The question asks for eight points; any eight earn full marks. The command word assess invites a balance of natural and human causes, and each cause should be paired in spirit with a control. Lwandai is the precedent worth naming.

Question 106

In hot deserts, where there is little water or vegetation to hold the surface, the wind becomes the chief agent of erosion. It works by deflation, the lifting of loose material, and by abrasion, the scouring of rock with the sand it carries, and these produce a range of distinctive landforms. Since Tanzania has no true hot desert, the Sahara and Namib provide the examples, explained as follows.

Deflation hollow. A deflation hollow is a shallow basin scooped out where the wind lifts and removes loose dry sand and dust. As the fine material is blown away the surface is lowered, sometimes until damp or coarse material is reached that the wind cannot move. Such hollows are common on the sandy floors of the Sahara.

Ventifact. A ventifact is a pebble or stone whose exposed faces have been smoothed and faceted by sandblasting. The wind drives sand against the windward side and polishes it flat, and if the wind shifts or

the stone is turned, several smooth faces meeting in sharp edges are cut. Ventifacts litter the stony surfaces of the Sahara.

Zeugen. Zeugen are tabular masses of rock standing above the desert floor, formed where a hard rock layer caps a softer one. Wind abrasion, strongest near the ground, eats away the soft rock faster and undercuts the hard cap, leaving ridges with narrow necks and broad tops separated by furrows in the Sahara.

Yardang. Yardangs are sharp parallel ridges aligned with the wind, formed where bands of hard and soft rock stand on end. The wind etches out the soft bands into grooves and leaves the hard bands upstanding as keel-like ridges, much like the hull of a boat, across exposed parts of the Sahara.

Pedestal rock. A pedestal or mushroom rock is a mass standing on a narrow stem. Because abrasion is concentrated near the ground where the sand load is greatest, the base is worn thinner than the top, leaving a broad cap perched on a slender pedestal, a striking sight in the Sahara.

Inselberg. An inselberg is an isolated steep-sided hill of resistant rock rising abruptly from a worn desert plain. While the surrounding softer rock has been stripped away by wind and water over long ages, the hard mass survives as an island of rock. Inselbergs rise from the plains of the Namib and the Sahara.

Process of deflation. Deflation underlies several of these forms. By steadily lifting and carrying off the loose fine material, the wind lowers the surface, exposes pebbles as a protective lag of stones, and creates the hollows; without this removal of debris the abrasional forms could not be laid bare. It is most effective where the surface is dry and bare.

Process of abrasion. Abrasion shapes the standing rock. The wind, armed with sand, scours and grinds the rock surfaces, cutting them back fastest near the ground where the sand is densest. This sandblasting carves the zeugen, yardangs, pedestals and ventifacts, etching out the weaker rock and leaving the stronger upstanding.

Control by rock resistance and wind. Which form develops depends on the arrangement and hardness of the rock and on the direction of the prevailing wind. Hard layers over soft give zeugen, vertical bands give yardangs, and a steady wind direction aligns the ridges, so the desert sculpture records both the rock structure and the wind regime.

In conclusion, wind erosion in hot deserts works by deflation and abrasion to produce deflation hollows, ventifacts, zeugen, yardangs, pedestal rocks and inselbergs. Their form depends on the hardness and arrangement of the rock and on the prevailing wind, and because Tanzania has no true hot desert these features are best illustrated from the Sahara and the Namib.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is explaining the process, deflation or abrasion, behind each form, and correctly using Saharan or Namib examples rather than inventing a Tanzanian desert.

Question 107

Wind erodes only while it has the energy to carry its load, and where that energy falls the sand and dust are laid down to build depositional landforms. The coarse sand settles near its source as dunes of various shapes, while the finest dust travels far before it falls as loess. As Tanzania has no true hot desert, the Sahara and Namib provide the examples, explained as follows.

Why the wind deposits. The wind drops its load whenever its speed falls and it can no longer carry the grains. This happens when the wind meets an obstacle, slows in a hollow or simply weakens, so the heaviest grains settle first and the finest last. The sorting that results separates coarse dune sand near the source from fine dust carried far away.

Formation of dunes in general. Dunes form where moving sand meets an obstacle or a rough patch that slows the wind, so sand accumulates. The dune grows with a gentle windward slope up which sand is pushed and a steep leeward slope down which it slips, and it migrates slowly downwind as grains move from front to back. The Sahara and Namib carry vast dune fields.

Barchan dune. A barchan is a crescent-shaped dune that forms on a firm surface where sand is limited and the wind blows steadily from one direction. Its horns point downwind because the thinner edges move faster than the thick centre, and the whole dune creeps forward. Barchans are the classic isolated dunes of the Sahara.

Seif dune. A seif is a long, sharp-crested ridge of sand lying roughly parallel to the prevailing wind. It forms where sand is more plentiful and the wind blows mainly from one direction with occasional cross winds that shape the long sword-like ridge. Seif dunes run for kilometres across parts of the Sahara.

Transverse dune. A transverse dune is a long ridge lying at right angles to the wind, formed where sand is abundant and the wind is steady. The ridges line up like waves across the wind, with a gentle windward and a steep leeward face. Transverse dunes cover sand seas in the Sahara and Namib where sand is plentiful.

Migration of dunes. Dunes are rarely still. Sand is blown up the gentle windward slope, spills over the crest and slips down the steep leeward slope, so the dune advances downwind grain by grain. This migration can bury oases, roads and fields, a real difficulty at the desert margins of the Sahara.

Loess deposits. The finest dust lifted by the wind is carried far beyond the desert before it settles in a thick, fertile, yellowish cover called loess. Because it is fine and well sorted it makes deep, easily worked soils where it falls. Extensive loess lies downwind of the great deserts of Asia, derived from desert dust.

Sorting of wind deposits. Wind deposits are well sorted by size because the wind separates grains by weight as it loses energy. Coarse sand is dropped first to build dunes near the source, while fine silt travels on to form loess far away, so a clear sorting from coarse to fine marks the path of the wind.

Significance of wind deposition. Wind deposition both threatens and rewards. Moving dunes bury useful land and block routes at the desert edge, yet loess forms some of the most fertile soils on Earth. The contrast shows that the same depositing wind can be a hazard in one place and a gift in another.

In conclusion, the wind deposits its load wherever it loses energy, building barchan, seif and transverse dunes from coarse sand near the source and spreading fine loess far downwind. The shape of a dune reflects the sand supply and the steadiness of the wind, and since Tanzania lacks a true hot desert these features are drawn from the Sahara and Namib.

Examiner's Note

The question asks for eight points; any eight earn full marks. The strongest answers link dune shape to sand supply and wind direction and keep the examples in the Sahara or Namib, since Tanzania has no hot desert.

Question 108

Although deserts are dry for most of the year, the rare storms that do fall send water rushing over bare ground that has no plants or soil to hold it back, so the runoff is sudden and powerful. This running water both erodes and deposits, producing landforms that owe nothing to the wind. They can be accounted for as follows.

Rills and gullies. When a desert storm breaks, water runs at once over the bare unprotected surface and scores it into small channels called rills. Where the runoff is concentrated these deepen and widen into larger steep-sided gullies. Such dissection of bare slopes is common across the arid lands of the Sahara.

Wadi. A wadi is a steep-sided, normally dry desert valley cut by occasional floods. During a storm a torrent rushes down it, deepening and widening the channel by hydraulic action and abrasion, then drains away and leaves the valley dry for months. Wadis form a branching network across the Sahara.

Sheet wash and pediment. After heavy rain water may spread as a thin sheet across the gentle slope at the foot of desert highlands rather than gathering into channels. This sheet wash planes the rock into a smooth, gently sloping surface called a pediment that fringes the mountain front in many desert areas.

Mesa and butte. Where a hard caprock protects softer rock beneath, running water and weathering wear back the surrounding land and leave flat-topped remnants. A broad flat-topped hill is a mesa, and as it is reduced further it becomes a smaller steep-sided butte. Mesas and buttes stand above the plains of arid regions.

Alluvial fan. Where a flooded channel emerges from the steep highlands onto the flatter plain, the water slows, loses energy and drops its load. The sediment spreads out into a fan-shaped mound called an alluvial fan, broadening away from the point where the channel leaves the hills, a common form at desert mountain fronts.

Bajada. Where many alluvial fans grow side by side along the foot of a mountain range and merge into one another, they form a continuous gently sloping apron of sediment called a bajada that skirts the base of the highlands in desert basins.

Playa. Floodwater draining into a closed desert basin cannot escape and forms a shallow temporary lake. When the lake dries out under the desert heat it leaves a flat floor often crusted with salt, called a playa, on the floors of enclosed arid basins.

Role of flash floods. The key to all these forms is the flash flood. Rain falls on baked, bare ground that cannot soak it up, so almost all of it runs off at once with great erosive force, doing more work in a few hours than the wind does in years. This explains why running water shapes so much desert scenery despite the dryness.

Sorting of deposited material. As the floodwater slows on the plain it drops its coarsest load first and its finest last, so alluvial fans are coarse near the hills and finer toward the basin, and the playa floor is the finest of all. This sorting records the falling energy of the water as it spreads out and dies away.

In conclusion, running water in hot deserts, acting chiefly through sudden flash floods on bare ground, cuts rills, gullies, wadis and pediments and builds alluvial fans, bajadas and playas, with mesas and buttes left as worn remnants. Water and not wind shapes much of the boldest desert scenery, here illustrated from the Sahara.

Examiner's Note

The question asks for eight points; any eight earn full marks. Make clear that water, not wind, is the agent, and separate the erosional forms such as the wadi from the depositional forms such as the bajada.

Question 109

The work of running water in a desert can be divided into two contrasting parts. In the highlands and on the slopes water erodes, cutting and stripping the land, while on the plains and in the basins it deposits, building up new surfaces from the load it can no longer carry. Distinguishing these two kinds of work makes the desert scenery clear, and they can be set out as follows.

Erosion by gullying. On the bare desert slopes the storm runoff erodes by scoring the surface into rills and then into deep gullies. With no plants to slow it, the water concentrates and cuts down quickly, dissecting the slopes into a rough channelled surface, as on the slopes of the arid Sahara.

Erosion by wadi cutting. Water erodes vigorously along the desert valleys, deepening and widening them into steep-sided wadis during floods. The force of the torrent and the rock it carries grind the channel down, so the wadi is essentially a water-cut valley, branching across the Sahara.

Erosion leaving mesas and buttes. Where a hard caprock shields softer rock, water and weathering strip away the unprotected land around it and leave flat-topped erosional remnants. A larger remnant is a mesa and a smaller one a butte, both witnesses to how much rock the water has removed from arid plateaus.

Erosion forming the pediment. Sheet wash spreading from the highland front planes the rock into a smooth gently sloping pediment. This is an erosional surface, cut across the rock by running water as it spreads thinly from the hills, fringing desert mountain ranges.

Deposition forming alluvial fans. Where a flooded channel leaves the steep hills for the flatter plain it loses energy and drops its load in a fan-shaped heap. The alluvial fan is therefore a depositional form, built up rather than cut down, at the mountain fronts of desert basins.

Deposition forming bajadas. As neighbouring alluvial fans grow and merge along a mountain base they build a continuous depositional apron called a bajada. Like the fans that compose it, the bajada is made of laid-down sediment, marking where the water spread and died on the plain.

Deposition forming playas. In closed basins floodwater gathers into a temporary lake and then evaporates, leaving behind the fine sediment and salt it carried as a flat playa floor. This is a depositional and evaporational surface, the lowest and finest-grained part of the desert basin.

Link between erosion and deposition. The two kinds of work are joined, for the material eroded from the highlands by gully and wadi is exactly the material deposited on the plain as fans, bajadas and playas. The water carries the waste from the high ground where it erodes to the low ground where it deposits, so one process feeds the other.

Control by gradient and energy. Whether water erodes or deposits at a given place depends on its energy, which falls as the gradient flattens. On the steep highland the fast water erodes, while on the gentle plain the slowing water deposits, so the change from cutting to building follows the change in slope across the desert.

In conclusion, the running water of a desert erodes on the highlands and slopes to cut rills, wadis, pediments, mesas and buttes, and deposits on the plains and basins to build alluvial fans, bajadas and playas. The same water shifts from eroding to depositing as the gradient flattens, and the two kinds of work are best illustrated from the Sahara, since Tanzania has no true hot desert.

Examiner's Note

The question asks for eight points; any eight earn full marks. The command word distinguish requires a clear split between erosional and depositional forms, and the best answers explain that falling gradient and energy decide which occurs.

Question 110

Karst is the distinctive scenery that develops on thick, well-jointed limestone in a moist climate. Because limestone is dissolved by rainwater charged with carbon dioxide, through the process of carbonation, water acting along the joints both at the surface and underground produces a remarkable set of landforms. These can be accounted for, with Tanzanian reference to the Amboni area near Tanga, as follows.

The basis: carbonation of limestone. All karst features stem from one process. Rainwater absorbs carbon dioxide to form a weak carbonic acid, which reacts with the calcium carbonate of the limestone to form soluble calcium bicarbonate that is washed away. Because limestone is jointed, this solution works fastest along the joints, opening them out. The limestone near Tanga is dissolved in just this way.

Clints and grikes. On a bare limestone surface, solution widens the vertical joints into deep open grooves called grikes, leaving the blocks of rock between them upstanding as clints. The result is a bare, ridged limestone pavement crossed by a grid of grooves, formed wherever bare jointed limestone is exposed.

Dolines. A doline is a funnel-shaped surface hollow. It forms either where solution is concentrated at a joint intersection and slowly enlarges the opening, or where the roof of a cave below collapses into the void. Dolines are the basic enclosed depressions of karst country.

Uvalas. Where several neighbouring dolines continue to enlarge and eventually run together, they merge into a single larger and more irregular depression called an uvala, marking an advanced stage of surface solution.

Poljes. A polje is a very large, flat-floored, steep-sided depression, far bigger than an uvala. It forms by long-continued solution and the merging of many hollows, sometimes guided by the rock structure, and its broad floor may be flooded in the wet season.

Caves. Underground, water sinking along the joints and bedding planes dissolves the limestone into long horizontal passages and chambers called caves. As more rock is removed the caves enlarge into systems running deep into the hillside, as at the Amboni caves near Tanga.

Stalactites and stalagmites. Within the caves, water dripping from the roof loses carbon dioxide and deposits a little calcium carbonate with each drop. Hanging icicles of carbonate called stalactites grow down from the roof, and rounded mounds called stalagmites build up from the floor where the drops land, decorating the Amboni caves.

Pillars. Where a growing stalactite and the stalagmite beneath it continue to grow until they meet and fuse, they form a continuous column or pillar of calcium carbonate joining the cave floor to its roof, the final stage of cave decoration.

Underground drainage. A further mark of karst is that surface streams often vanish down the joints and dolines into the rock and flow underground through the cave systems, reappearing as springs lower down. This loss of surface water explains the dry valleys and bare appearance of many karst landscapes.

In conclusion, karst scenery is the work of carbonation dissolving jointed limestone, producing surface features such as clints and grikes, dolines, uvalas and poljes, and underground features such as caves, stalactites, stalagmites and pillars, with much of the drainage running underground. The Amboni caves near Tanga show this limestone scenery within Tanzania.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is grounding every feature in carbonation along joints and keeping the dissolved forms, such as caves, distinct from the deposited forms, such as stalactites. Amboni is the Tanzanian anchor.

Question 111

A river is the most important agent of denudation in humid lands, and it does three linked kinds of work as it flows. It erodes by wearing away its bed and banks, transports the loosened material downstream, and deposits it where its energy falls. Each kind of work is carried out by several distinct processes, which can be explained as follows.

Hydraulic action. Hydraulic action is erosion by the sheer force of moving water. The current pushes into cracks in the bed and banks, compresses the air trapped there and, as the water passes, the air expands and loosens the rock, which is then plucked away. It is powerful in the strong flood flows of the Rufiji.

Abrasion. Abrasion is erosion by the load the river carries. The sand and stones swept along are used as tools to scour and grind the bed and banks, deepening and widening the channel and smoothing the rock. Abrasion is the chief means by which a river cuts down into its bed.

Attrition. Attrition is the wearing down of the load itself. As the transported stones knock against one another and against the bed they break and gradually become smaller, smoother and more rounded the further they travel, which is why pebbles downstream are rounder than those upstream.

Solution in erosion. Solution is the chemical erosion of soluble rock. Where the river crosses limestone or other soluble rock, the water dissolves the minerals and carries them away unseen, slowly enlarging the channel, as along limestone stretches of the Pangani.

Transport by traction and saltation. The river moves its load along the bed in two ways. The largest boulders are rolled and dragged along the bed by the current, called traction, while smaller stones and coarse sand are bounced along in a series of hops, called saltation, both requiring strong flow.

Transport by suspension and solution. The river also carries finer material within the water. Fine clay and silt are held up in the moving water and carried along in suspension, giving the Rufiji its brown flood colour, while dissolved minerals are carried invisibly in solution as a chemical load.

Vertical, lateral and headward erosion. The direction of erosion changes along the course. In the upper course the river cuts mainly downward by vertical erosion, in the middle and lower course it cuts sideways by lateral erosion as it meanders, and at its source it eats backward by headward erosion, lengthening the valley upstream.

Deposition. Deposition occurs when the river loses energy and can no longer carry its load, so the material settles out. The coarsest is dropped first and the finest last, and deposition is greatest where the river slows, on entering a lake or the sea, on the inside of bends and on flooding its plain, as the Rufiji deposits its delta.

Balance of the three kinds of work. Erosion, transport and deposition go on together but in changing proportion along the river. Erosion dominates in the steep upper course, transport in the middle, and deposition in the gentle lower course, so the work the river does at any point depends on its energy there.

In conclusion, a river erodes by hydraulic action, abrasion, attrition and solution, transports its load by traction, saltation, suspension and solution, and deposits when its energy falls. These kinds of work change in proportion along the course, dominating in turn from source to mouth, as the long course of the Rufiji from highland to delta shows.

Examiner's Note

The question asks for eight points; any eight earn full marks. The strongest answers keep erosion, transport and deposition clearly separate and explain the mechanism of each named process rather than merely listing the terms.

Question 112

The pattern that a river system makes on the land is not random but is guided largely by the underlying rock and the shape of the relief. The hardness, arrangement and structure of the rocks, together with the slope of the land, decide where rivers can cut and how they branch. These controls can be examined as follows.

Initial slope of the land. The first control is the slope down which water flows. Rivers run from high to low ground, so the original slope of a newly uplifted or tilted surface sets the main direction of flow. On a simple uniform slope the rivers run straight down it as parallel consequent streams, following the lie of the land.

Dendritic pattern on uniform rock. Where the underlying rock is of uniform hardness and offers no special lines of weakness, the river and its tributaries branch freely in all directions like the veins of a leaf, forming a dendritic pattern. This tree-like branching reflects rock that is the same in every direction.

Trellis pattern on alternating rock. Where bands of hard and soft rock lie side by side, the main rivers cut along the soft bands and the tributaries join them at right angles after crossing the hard bands, producing a rectangular trellis pattern. This pattern reflects the alternation of resistant and weak rocks.

Control by rock hardness. The hardness of the rock decides where a river can most easily cut its valley. A river erodes the soft rock quickly and is held up by hard rock, so valleys follow the belts of weak rock while ridges stand on the resistant rock, guiding the whole drainage along the lines of least resistance.

Control by joints and faults. Lines of weakness such as joints and faults give a river ready-made paths to follow, for the rock there is more easily eroded. Rivers therefore often run along fault lines and major joints, and a strongly faulted area may show drainage aligned with the faults, as along parts of the East African Rift.

Radial pattern on a dome or cone. Where the relief is a dome or a volcanic cone, the rivers run outward in all directions down its flanks from the high centre, forming a radial pattern. The streams draining outward from the slopes of Kilimanjaro show this control of pattern by a conical relief.

Influence of the Rift relief. The bold relief of the Rift strongly guides Tanzania's drainage. Some rivers drain inward to the floor of the Rift and its lakes, while others drain outward to the sea, and the steep fault scarps divide the flow, so the great trough sorts the rivers into those running to the interior basins and those running to the ocean.

Superimposed and antecedent drainage. Sometimes a river keeps a course that ignores the present rock structure because it was set on an earlier cover since stripped away, or because it cut down as fast as the land rose. Such superimposed or antecedent rivers cross hard ridges in deep valleys, showing that the present pattern can record an earlier history.

Combined control of rock and relief. In practice the pattern reflects rock and relief working together. The slope sets the first direction, the arrangement of hard and soft rock guides the branching, and faults and domes add their own patterns, so the drainage map is a faithful record of the geology and shape of the land beneath.

In conclusion, rock and relief together control the development of drainage patterns, the slope setting the first direction and the hardness, arrangement and structure of the rocks producing dendritic, trellis, radial

and fault-guided patterns. As the radial streams of Kilimanjaro and the Rift-guided rivers of Tanzania show, a drainage pattern is a map of the geology beneath it.

Examiner's Note

The question asks for eight points; any eight earn full marks. The strongest answers name specific patterns and tie each to a rock or relief control, with a Tanzanian example such as Kilimanjaro or the Rift.

Question 113

A river does different work in different parts of its course, and the landforms it makes record that change. In the upper course it cuts downward through steep ground, while in the middle course it begins to swing sideways across gentler land. The chief landforms of these two sections can be explained, with Tanzanian reference to rivers such as the Pangani and Rufiji, as follows.

V-shaped valley. In the upper course the river has steep gradient and energy and cuts mainly downward by vertical erosion, while weathering and runoff wear back the sides. The result is a narrow, deep valley with a V-shaped cross profile. The upper Pangani in its highland section shows such a valley.

Interlocking spurs. In the upper course the young river is not strong enough to cut through the spurs of high ground in its path, so it winds between them. Projecting ridges from each side jut into the valley and overlap when seen from along it, and these are called interlocking spurs.

Waterfall. Where a band of hard rock crosses the channel above softer rock, the river wears the soft rock away faster, undercuts the hard band and leaves a step over which the water plunges as a waterfall. The retreat of the hard band upstream may leave a gorge below the fall.

Gorge. A gorge is a deep, steep-sided, narrow valley. It forms where rapid vertical erosion cuts down faster than the sides can be worn back, as in hard rock or where a waterfall retreats upstream, leaving a sheer-walled valley behind it.

Rapids. Rapids form where the river crosses bands of harder and softer rock that wear unevenly, or where the gradient steepens, so the bed becomes uneven and the water rushes turbulently over and between the resistant patches without forming a single clear fall.

Meander. As the river reaches gentler ground in the middle course, it begins to swing from side to side. On the outer bank of each bend the faster flow erodes and undercuts the bank, while on the inner bank the slower flow deposits sediment, so the channel develops sweeping bends called meanders, well shown on the lower Rufiji.

River cliff and slip-off slope. Each meander has two contrasting banks. The undercut outer bank is steep and is called a river cliff, while the inner bank, where deposition builds a gentle bank of sand and shingle, is called a slip-off slope. Together they show erosion and deposition at work within a single bend.

Widening of the valley. In the middle course lateral erosion becomes more important than vertical erosion, so the river widens its valley as it swings across it. The valley floor broadens and the once steep V opens out, beginning the flat floor that the flood plain will occupy downstream.

Transition from upper to middle course. The change from upper to middle course is a change from downcutting to sideways cutting as the gradient eases. The narrow V-valleys, gorges and waterfalls of the steep upper course give way to the meanders and widening valley of the gentler middle course, recording the fall in gradient along the river.

In conclusion, the upper course of a river, with its steep gradient and vertical erosion, produces V-shaped valleys, interlocking spurs, waterfalls, gorges and rapids, while the middle course, where lateral erosion grows, produces meanders with their river cliffs and slip-off slopes in a widening valley. The Pangani and Rufiji illustrate this change of work down their courses.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is linking each landform to vertical erosion in the upper course or lateral erosion in the middle course, and explaining hard-over-soft rock for the waterfall.

Question 114

In its lower course a river flows over gentle, almost level ground, its gradient slight and its load large, so its dominant work is no longer erosion but deposition. As it loses energy it lays down the material it can no longer carry, building a series of distinctive landforms. These can be explained, with Tanzanian reference to the Rufiji, as follows.

Flood plain. A flood plain is the wide, flat floor of the lower valley, built of alluvium. When the river overflows in flood, the water spreads out, slows and drops its load over the valley floor, and repeated floods build a deep layer of fertile sediment. The lower Rufiji is bordered by a broad flood plain.

Natural levees. Natural levees are raised banks along the sides of the channel. During a flood the river slows abruptly as it leaves its channel, so it drops its coarsest load first right at the channel edge, and over many floods these deposits build up into ridges flanking the river, sometimes raising the channel above the plain.

Meanders and their migration. On the gentle lower course the river swings in broad meanders, eroding the outer banks and depositing on the inner banks, so the bends grow and slowly migrate across the flood plain. This migration helps to plane the valley floor flat and to widen the flood plain on the lower Rufiji.

Ox-bow lakes. As a meander loop grows, its narrow neck is gradually narrowed by erosion until, often in a flood, the river cuts through it and takes the shorter straight course. The abandoned loop is sealed off by deposition at its ends and left as a curved ox-bow lake on the flood plain.

Braided channel. Where the river carries more load than it can move and the banks are easily eroded, it splits around banks of its own deposited sediment into many shifting channels separated by islands of sand and gravel. This braided pattern develops where deposition is heavy and the load is coarse.

Deltas. Where the river meets the still water of a lake or the sea it slows sharply and deposits its load at the mouth. If the sea is calm and cannot remove the sediment fast enough, the deposits build out into new land called a delta. The Rufiji has built a large arcuate delta where it enters the Indian Ocean.

Distributaries. The sediment deposited in a delta blocks and divides the river, forcing it to split into many smaller branches called distributaries that carry the water across the delta to the sea. These shifting channels spread the load over the whole delta surface, as on the Rufiji delta.

Backswamps and the rich plain. Behind the levees, in the lower parts of the flood plain, floodwater lingers and fine mud settles to form marshy backswamps. The whole flood plain and delta, renewed by fresh alluvium at each flood, become highly fertile, which is why the lower Rufiji supports intensive farming.

Control by loss of energy. All these landforms share one cause, the loss of the river's energy on gentle ground. As the gradient flattens and the river slows or meets standing water, it can no longer carry its load and deposits it, so the lower course is essentially a zone of building rather than cutting.

In conclusion, the lower course of a river, where the gradient is gentle and energy is lost, is a zone of deposition that builds flood plains, natural levees, ox-bow lakes, braided channels and deltas with their distributaries. The Rufiji, with its broad flood plain and its arcuate delta on the Indian Ocean coast, shows this depositional work clearly.

Examiner's Note

The question asks for eight points; any eight earn full marks. The strongest answers tie every landform to the loss of energy on gentle ground and name the Rufiji arcuate delta, distinguishing levees, ox-bows and braiding clearly.

Question 115

Meanders and ox-bow lakes are among the most striking landforms of the middle and lower course of a river, where the gradient is gentle and the river swings freely across its valley floor. They arise from the way erosion and deposition act unequally on the two banks of a bend, and their formation can be accounted for, with reference to the lower Rufiji, as follows.

Beginning of bends. Meanders begin where the flow of the river is first turned to one side, by an obstacle, an unequal bank or the natural swinging of the current. Once the water swings against one bank it is set on a winding path, and the bend, once started, tends to grow rather than straighten.

Faster flow on the outer bank. On the outside of a bend the water flows fastest and deepest, because it has the longer path and the current is thrown outward. This swift, deep water has the most energy and attacks the outer bank strongly, so erosion is concentrated there.

Erosion of the outer bank. The fast water on the outer bank erodes it by hydraulic action and abrasion, undercutting it so that it becomes a steep river cliff. The continual wearing of the outer bank pushes the bend outward and is what makes the meander grow and migrate across the valley.

Slower flow on the inner bank. On the inside of the bend the water is shallow and slow, because it has the shorter path and less energy. Unable to carry all its load at this low speed, the river drops sand and shingle on the inner bank, building a gentle slip-off slope of deposited material.

Deposition on the inner bank. The deposition on the inner bank balances the erosion on the outer bank, so as the outer bank retreats the inner bank builds outward. In this way the channel keeps its width but the whole bend shifts sideways, and the meander becomes more pronounced over time.

Growth of the meander loop. As erosion continues on the outer bank and deposition on the inner, the bend grows into a wide loop with only a narrow neck of land between the approaching sides. The river swings ever more widely across its flood plain, as the broad meanders of the lower Rufiji show.

Cutting through the neck. When the loop has grown so far that only a narrow neck of land separates the two arms, a flood gives the river the energy to cut straight across the neck. The river then takes this shorter, steeper course and abandons the long way round the loop.

Formation of the ox-bow lake. Once the river flows across the neck, deposition builds up banks of sediment that seal off the ends of the abandoned loop, cutting it off from the main channel. The loop is left as a separate, curved, crescent-shaped body of water called an ox-bow lake on the flood plain.

Decay of the ox-bow lake. Cut off from the flowing river, the ox-bow lake receives no fresh water and is fed only by floods and rain. It gradually silts up with sediment and is invaded by plants, becoming a marshy crescent and finally a faint curved scar on the flood plain, marking where the river once ran.

In conclusion, meanders form because the fast water on the outer bank of a bend erodes while the slow water on the inner bank deposits, so the bend grows and migrates; when the loop is finally cut off across its neck it is sealed into an ox-bow lake that slowly silts up. The broad meanders and ox-bows of the lower Rufiji illustrate the whole sequence.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is explaining the unequal flow, fast and erosive outside, slow and depositing inside, and showing the neck being cut through to seal the ox-bow, not merely describing the shapes.

Question 116

River rejuvenation is the renewal of a river's power of vertical erosion, so that a river which had nearly worn its valley down to a gentle grade begins to cut downward into its bed once more. It is caused by changes that increase the river's energy or lower its base level, and it leaves a recognisable set of landforms. These can be explained, with reference to the uplifted Rift margins of Tanzania, as follows.

Meaning of rejuvenation. Rejuvenation means the renewed downcutting of a river. A river that has graded its profile to a smooth curve and is mainly meandering and depositing is given fresh energy and begins again to erode vertically into its bed, as if it had become young a second time, hence the name.

Cause: uplift of the land. Rejuvenation is commonly caused by uplift of the land. When the land over which a river flows is raised, the gradient of the river is steepened and it gains energy, so it begins to cut down to restore its graded profile. The uplift along the margins of the East African Rift has rejuvenated rivers flowing there.

Cause: fall in sea level. A fall in sea level also rejuvenates a river. Because the sea is the base level below which a river cannot cut, a fall in sea level lowers that base, leaving the river above its new grade, so it cuts down toward the lower sea level, beginning at the mouth and working upstream.

Cause: increase in discharge or capture. A river may also be rejuvenated by a lasting increase in its volume of water, for example through a wetter climate or by capturing another river's headwaters, which gives it more energy to erode. The added water lets it cut its bed deeper than before.

Knick-point. The renewed downcutting begins at the mouth or the new base level and works upstream, so there is a sharp break of slope, often marked by rapids or a small waterfall, where the new steep profile meets the old gentle one. This break is called a knick-point, and it slowly retreats upstream.

River terraces. When a rejuvenated river cuts down below its old flood plain, parts of that former plain are left as flat benches, called river terraces, standing above the new channel on the valley sides. Paired terraces on both sides mark the level of the abandoned flood plain.

Incised meanders. Where a meandering river is rejuvenated, it cuts its existing bends downward into the rock while keeping their looping plan, producing deep, winding, steep-sided valleys called incised meanders. These show that the river was meandering on a plain before it was given new energy to cut down.

Rejuvenated valley within a valley. Rejuvenation often produces a small, fresh, steep-sided valley cut into the floor of the older, wider valley, giving a valley-within-a-valley form. The narrow new trench marks the renewed downcutting, while the broad older valley above records the river's earlier graded stage.

Evidence of rejuvenation in the landscape. Together, knick-points, terraces and incised meanders are read as evidence that a river has been rejuvenated. Where these features appear along a river, as on parts of the uplifted Tanzanian interior, they tell of past uplift of the land or a fall in sea level that renewed the river's downcutting.

In conclusion, river rejuvenation is the renewal of downcutting caused chiefly by uplift of the land or a fall in sea level, and it leaves knick-points, river terraces, incised meanders and valleys within valleys as its signature. Where these features occur, as along the uplifted margins of the East African Rift in Tanzania, they record the renewed energy of the river.

Examiner's Note

The question asks for eight points; any eight earn full marks. The strongest answers tie each landform to renewed downcutting and give a correct cause, uplift or falling sea level, treating capture only as a contributing cause here.

Question 117

The sea shapes the coast through the work of waves, which both wear it away and build it up. Destructive waves, with strong backwash, erode the headlands into bold landforms, while constructive waves, with strong swash, and the sideways movement of longshore drift, build up gentler depositional forms. These features matter to human life, and they can be explained, with reference to the Tanzanian coast, as follows.

Cliff and wave-cut platform. Destructive waves attack the foot of high ground between the tide marks, undercutting it by hydraulic action and abrasion to form a notch. The rock above collapses and the cliff retreats inland, leaving a gently sloping rocky bench, the wave-cut platform, at its base, as on rocky parts of the Tanga coast.

Caves. Waves pick out lines of weakness, such as joints and faults, in a headland and erode them faster than the surrounding rock. The repeated pounding hollows out the weakness into a cave at the base of the cliff, enlarging it as erosion continues along the line of weakness.

Arch. Where a cave is cut right through a narrow headland, or where two caves on opposite sides meet, the opening passes through the headland to form a natural arch. The sea flows beneath the arch while the rock bridge stands above, as off parts of the Dar es Salaam coast.

Stack and stump. When the roof of an arch is weakened and collapses, the seaward part of the headland is left as an isolated pillar of rock standing offshore, called a stack. Continued wave attack wears the stack down until only a low remnant, a stump, is left, often covered at high tide.

Blowhole. Where a cave is enlarged upward along a joint until it reaches the cliff top, the waves entering the cave force air and spray up through the opening. This opening is a blowhole, through which spray is thrown into the air during high seas, a striking sight on rocky coasts.

Beach. Constructive waves, whose strong swash pushes material up the shore and whose weak backwash leaves it there, pile up sand and shingle between the tide marks to build a beach. The broad sands of Nungwi in Zanzibar and of Bagamoyo are beaches built in this way.

Spit. Longshore drift carries sand and shingle along the coast, and where the coastline turns or a river mouth interrupts it, the material is deposited beyond the bend as a long ridge growing out into the open water, called a spit, often with a curved or hooked end shaped by changing winds.

Bar, tombolo and lagoon. Where a spit grows right across a bay it becomes a bar, cutting off a lagoon of quiet water behind it, and where deposited sand links an offshore island to the mainland it forms a tombolo. These show longshore drift building the coast outward into new land.

Control by wave type and rock. Whether the coast is eroded or built up depends on the waves and the rock. Destructive waves on hard, jointed headlands produce cliffs, caves, arches and stacks, while constructive waves and abundant sand in sheltered bays produce beaches, spits and bars, so the coast shows both kinds of work side by side.

In conclusion, wave erosion by destructive waves produces cliffs, wave-cut platforms, caves, arches, stacks, stumps and blowholes, while wave deposition by constructive waves and longshore drift builds beaches, spits, bars and tombolos. These coastal landforms, well shown along the Tanzanian coast at Tanga, Dar es Salaam and Zanzibar, are of real significance to human life.

Examiner's Note

The question asks for eight points; any eight earn full marks. Keep erosional and depositional forms distinct, explain the wave process behind each, and use Tanzanian coastal examples.

Question 118

Much of the building work of the sea is done by longshore drift, the steady movement of beach material along the coast by waves that strike the shore at an angle. This sideways transport feeds sand and shingle along the coastline and lays it down to build a family of depositional landforms. The process and its landforms can be explained, with reference to the Tanzanian coast, as follows.

The process of longshore drift. Waves usually approach the shore at an angle, driven by the prevailing wind. The swash carries sand and shingle up the beach at that angle, but the backwash drains straight back down the slope under gravity. Each wave therefore moves the material a little along the beach, and over time it travels a long way in a zigzag path.

Swash and backwash. The drift depends on the difference between swash and backwash. The swash, running up the beach at an angle, carries material along the shore, while the straight backwash returns it seaward; the net effect of many waves is a steady sideways movement of the beach material in the direction the waves are driving.

Building of beaches. Where longshore drift brings more material than it removes, it builds and maintains beaches of sand and shingle along the shore. The beaches of Bagamoyo and Nungwi in Zanzibar are nourished by the sand carried along the coast, and a beach is starved if the drift is interrupted.

Formation of a spit. Where the coastline turns or a river mouth breaks it, the drift continues in its old direction and deposits its load beyond the bend as a long ridge of sand growing out into the open water. This ridge attached at one end to the land is a spit, often with a curved end shaped by changing winds.

Formation of a bar. Where a spit grows right across the mouth of a bay or inlet, joining one headland to another, it forms a bar. The bar encloses the water behind it and seals off the bay from the open sea, recording the continued work of the drift across the bay.

Formation of a lagoon. Behind a bar the cut-off body of quiet, sheltered salt or brackish water is called a lagoon. Sheltered from the waves, the lagoon gradually fills with fine sediment and may in time become a marsh, marking where open water once lay behind the depositional ridge.

Formation of a tombolo. Where longshore drift builds a ridge of sand or shingle out from the coast until it reaches and joins an offshore island to the mainland, the connecting bar is called a tombolo. The island is thus tied to the land by the deposited material, a clear sign of strong drift.

Effect of interrupting the drift. Because the drift moves material along the coast, anything that blocks it, such as a harbour wall or groyne, traps sand on the upstream side and starves the coast downstream. This both widens the beach in one place and causes erosion in another, a matter of real concern in managing the Dar es Salaam coast.

Importance of drift landforms. The landforms built by longshore drift are valuable to people. Beaches and spits draw tourists and protect the coast behind them from wave attack, while lagoons provide sheltered water, so understanding and managing the drift is important for coastal communities such as those of Zanzibar and Bagamoyo.

In conclusion, longshore drift is the angled movement of beach material along the coast by swash and backwash, and it builds beaches, spits, bars with their lagoons, and tombolos. Because interrupting the drift starves the coast downstream, as can happen along the Dar es Salaam coast, understanding it is essential for protecting beaches such as those of Nungwi and Bagamoyo.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is explaining the angled swash and straight backwash that drive the drift, then linking each landform, spit, bar, lagoon and tombolo, to that sideways transport.

Question 119

The level of the sea against the land changes on two very different time scales. Day to day the tides raise and lower the water through the pull of the Moon and Sun, while over far longer spans the general level of the sea itself, or of the land, rises or falls, drowning or exposing the coast. Both kinds of change and their effects can be examined as follows.

Cause of tides. Tides are the regular rise and fall of the sea caused chiefly by the gravitational pull of the Moon, with the Sun adding a smaller pull. The Moon draws the water toward it into a bulge, and as the Earth rotates beneath this bulge most coasts experience two high and two low tides each day.

Spring tides. Spring tides are tides of large range, with very high high-water and very low low-water. They occur at new and full Moon, when the Sun and Moon are in line and their gravitational pulls combine, producing the strongest tidal pull and the greatest difference between high and low water.

Neap tides. Neap tides are tides of small range, with lower high-water and higher low-water. They occur near the half Moon, when the Sun and Moon pull at right angles to each other so that their forces partly cancel, giving the weakest tidal pull and the smallest tidal range.

Effects of tides on the coast. Tides decide how much of the shore is exposed to wave attack, spreading erosion over the zone between high and low water and producing the wide wave-cut platforms there. They

also drive currents that move sediment, flush estuaries and govern the daily life of fishing and shipping along the coast.

Eustatic change of sea level. A eustatic change is a worldwide rise or fall of the sea itself. It occurs chiefly when water is locked into growing ice sheets, lowering the sea, or released as they melt, raising it, and because it affects the whole ocean it changes the level on all coasts together.

Isostatic change of sea level. An isostatic change is a rise or fall of the land relative to the sea. It occurs, for example, when the land rises slowly after the great weight of an ice sheet is removed, and because it affects only that region it changes the relative sea level locally rather than worldwide.

Submergent coasts. Where the relative sea level rises, the coast is drowned and becomes a submergent coast. The sea floods the lower valleys to form winding inlets called rias, drowns deep glaciated valleys to form fiords, and floods river mouths to form broad estuaries, all marking a rise of the sea over the land.

Emergent coasts. Where the relative sea level falls, the coast emerges and becomes an emergent coast. Former beaches and wave-cut platforms are lifted above the present sea as raised beaches, and old sea cliffs are stranded inland as relict cliffs, all marking a fall of the sea relative to the land.

Evidence and significance of sea-level change. Raised beaches and relict cliffs are read as evidence of past emergence, while drowned valleys and submerged forests show past submergence. Such changes matter today because a rising sea threatens low coasts and islands, a real concern for the low-lying Tanzanian coast and the islands of Zanzibar and Mafia.

In conclusion, tides are the daily rise and fall of the sea caused by the Moon and Sun, ranging from large spring tides to small neap tides, while changes of sea level may be eustatic, affecting the whole ocean, or isostatic, affecting the land in one region, producing submergent coasts such as rias and emergent coasts such as raised beaches. Both shape the coast and matter to the low-lying shores of Tanzania.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is keeping two distinctions clear, spring versus neap tides, and eustatic versus isostatic change, and matching submergent and emergent forms to a rise or fall of relative sea level.

Question 120

Coral reefs are ridges of limestone built in warm tropical seas by tiny animals called coral polyps, whose hard skeletons accumulate over time. They can grow only where conditions suit the living polyps, and they take several forms whose origin has been explained by the subsidence theory of Charles Darwin. The conditions, types and origin can be explained, with reference to the reefs of Zanzibar and Mafia, as follows.

Warm water. Coral polyps need warm water, generally above about twenty degrees Celsius, so reefs are confined to the tropical seas. The warm waters of the western Indian Ocean off Tanzania provide the temperature that allows the reefs of Zanzibar and Mafia to flourish.

Shallow water. The polyps depend on tiny plants living within them that need sunlight, so coral grows only in shallow, well-lit water down to a few tens of metres. Reefs therefore form on shallow shelves and around islands, as on the shallow banks around Mafia, and cannot grow in deep water.

Clear water free of sediment. Coral needs clear water, because mud and silt settling on the polyps smother and kill them and cloud the water the inner plants need for light. Reefs are therefore poorly developed off muddy river mouths, such as near the Rufiji delta, and thrive in the clear water away from such sediment.

Salty, well-oxygenated water. Coral polyps need water of normal sea salinity and plenty of dissolved oxygen, so reefs avoid places where fresh river water dilutes the sea or the water is stagnant. The clean, salty, wave-washed water around the offshore islands of Tanzania suits them well.

Fringing reef. A fringing reef is a coral platform built directly against or close to the shore of the mainland or an island, with little or no lagoon between. Fringing reefs grow along parts of the shores of Zanzibar and the East African coast where the conditions are right.

Barrier reef. A barrier reef lies further out from the coast and is separated from it by a wide, deeper lagoon. It runs parallel to the coast as a broad ridge, with the lagoon of quieter water lying between the reef and the land.

Atoll. An atoll is a roughly circular or horseshoe-shaped coral reef enclosing a central lagoon, with no land in the middle other than low coral islets. It rises from the sea apparently far from any mainland, surrounding only its lagoon.

Darwin subsidence theory. Darwin explained the three types as stages of one process. A fringing reef first grows around a volcanic island; as the island slowly subsides, the coral grows upward and outward to keep near the surface, so the reef becomes a barrier reef separated by a lagoon; when the island sinks entirely beneath the sea, the upward-growing reef is left as an atoll surrounding only a lagoon.

Significance of coral reefs. Coral reefs are of great value. They shelter the coast from wave attack, provide rich fishing grounds and nurseries for fish, and draw many tourists, so the reefs of Zanzibar and Mafia support both the protection of the coast and the livelihoods of coastal people.

In conclusion, coral reefs grow only in warm, shallow, clear, salty and well-oxygenated tropical water, and they take the form of fringing reefs, barrier reefs and atolls, which Darwin explained as successive stages of reef growth around a subsiding island. The reefs of Zanzibar and Mafia show these conditions and forms and are of real value to the Tanzanian coast.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is giving the reason behind each growth condition, not just listing them, and explaining Darwin's subsidence theory as the link between fringing, barrier and atoll reefs.

Question 121

The landforms of the coast and the coral reefs that fringe it are not mere scenery, for they shape the lives and livelihoods of the people who dwell beside the sea. Their value, and also the problems they bring, can be assessed, with reference to the Tanzanian coast and its reefs, as follows.

Beaches and tourism. Wide sandy beaches built by constructive waves are a major attraction for visitors, supporting hotels, transport and employment. The beaches of Nungwi in Zanzibar and of Bagamoyo draw many tourists, so this coastal landform is an important source of income and work for the people.

Reefs as fishing grounds. Coral reefs are among the richest fishing grounds in the sea, for they shelter and feed great numbers of fish and other sea creatures. The reefs around Mafia and Zanzibar provide fish that feed coastal families and supply local markets, making them vital to food and livelihood.

Reefs and beaches as coastal protection. Reefs and beaches absorb and break the force of the waves before they reach the shore, protecting the land behind from erosion and flooding. The reefs off Mafia and Zanzibar shield the coast and its settlements, so that their loss would expose the shore to far stronger attack by the sea.

Bays and natural harbours. Drowned valleys and sheltered bays make fine natural harbours where ships can lie safe from the open sea. The deep, sheltered harbour at Dar es Salaam, formed where the sea entered a lowland, is the chief port of Tanzania and the gateway for its trade.

Lagoons and sheltered water. The quiet water of lagoons enclosed behind bars and reefs provides safe places for small boats, for fishing and for activities such as seaweed farming. Sheltered lagoon waters along the Zanzibar coast support seaweed growing, an important local industry.

Salt and other coastal resources. Flat coastal areas and lagoons are used to make salt by evaporating seawater in shallow pans, and reefs and beaches yield lime, sand and building material. Such resources along the Tanga and coastal belt provide raw materials and income for local communities.

Hazards of the coast. Coastal landforms also bring dangers. Cliffs retreat as waves undercut them, threatening buildings near the edge, and low coasts and islands are easily flooded by storms and a rising sea. The low-lying parts of the Tanzanian coast and the islands are vulnerable to such flooding.

Threats to reefs from human activity. Reefs are easily harmed by people, through pollution, sediment from cleared land, and destructive fishing. Damage to the reefs off the Tanzanian coast reduces the fish catch and removes the natural breakwater, so careless use of the coast destroys the very things that sustain it.

Need for careful management. Because the coast both sustains and endangers life, it must be managed with care. Protecting reefs and beaches, controlling building near cliffs and planning for a rising sea allow the people of the Tanzanian coast to keep the benefits while reducing the dangers, balancing use against conservation.

In conclusion, coastal landforms and coral reefs are of great significance to human life, providing tourism, fishing, coastal protection, harbours, sheltered water and resources, while also posing hazards of cliff retreat and flooding. The coast of Tanzania, with the reefs of Mafia and Zanzibar and the harbour of Dar es Salaam, must be used wisely so that its benefits endure.

Examiner's Note

The question asks for eight points; any eight earn full marks. The command word assess invites both benefits and hazards, each tied to a named coastal landform and a Tanzanian example.

Question 122

A rock is a natural aggregate of one or more minerals, built almost entirely from a short list of elements led by oxygen and silicon. Because rocks differ in origin, chemistry and age, geologists do not classify them in one way but in several, and the task is not as tidy as it first seems.

Classification by mode of formation. The first and broadest basis sorts rocks by how they came to be, giving the igneous rocks from cooled magma, the sedimentary rocks from settled sediment, and the metamorphic rocks from altered older rock. This scheme is the most useful because origin governs nearly every other property, so the molten birth of the Dodoma granite at once tells us it is crystalline, unbedded and fossil-free.

Classification by chemical composition. Within the igneous family rocks are sorted by their chemistry, chiefly by how much silica they contain, into acidic or felsic rocks rich in silica, basic or mafic rocks poor in it, and ultrabasic rocks poorer still. This basis explains why the silica-rich Dodoma granite is pale and light while the silica-poor Rungwe basalt is dark and heavy, so chemistry is read straight from colour and density.

Classification by age. The third basis orders rocks in time, from the oldest to the youngest, using both the relative order of the beds and the absolute age in years. This places the ancient basement granite of Dodoma far below the young volcanic rock of the rift, and it lets a geologist speak of a Precambrian rock or a Tertiary rock with a clear meaning.

One rock named under all three. The three bases do not compete but describe the same rock from different sides, so a single specimen carries three labels at once. The one Dodoma granite is igneous by origin, acidic by chemistry and Precambrian by age, which shows that the schemes are complementary rather than rival ways of filing the same object.

The difficulty of mixed and borderline rocks. The neat scheme is strained by rocks that sit on a boundary, such as a coarse rock whose chemistry lies between acidic and basic, or a partly altered rock caught between sedimentary and metamorphic. Such borderline rocks must be placed by judgement, which shows the classes are convenient divisions of a continuous range, not sharp natural boxes.

The difficulty of weathered and disguised rock. A rock met in the field is often weathered, stained or coated, so its true texture and minerals are hidden and it is easily misnamed. A deeply rotted granite in the humid Usambara may look like a soft sedimentary rock, so a fresh, unweathered surface must be found before the rock can be safely classified.

The difficulty of needing the laboratory. Some distinctions cannot be made by eye at all, for the exact silica content or the absolute age can be fixed only by chemical analysis or radiometric dating in a

laboratory. The field geologist mapping the Dodoma basement can give a relative order easily, but the age in years waits on equipment far from the outcrop.

The value of classifying rocks despite this. For all its difficulties the work is worth doing, because a named and dated rock tells the geologist where to expect ore, water or building stone and how the ground will behave. It is by classifying its rocks that a nation learns where its Tanzanite, its limestone and its coal are likely to lie, so the scheme repays the trouble it costs.

The bases reinforce one another. Used together the three bases give a fuller picture than any one alone, since origin, chemistry and age each fix part of a rock's story. A rock named igneous, acidic and Precambrian is far better understood than one merely called granite, which is why the careful geologist always reads all three.

Rocks are therefore classified by mode of formation, by chemical composition and by age, three complementary schemes that describe the same rock from different sides. The task is made awkward by borderline, weathered and laboratory-dependent cases, yet it remains the first and most rewarding step in reading the solid earth, as the search for Tanzania's own mineral wealth shows.

Examiner's Note

The question asks for eight points; any eight earn full marks. Examine wants both the bases and their difficulties, so a strong answer weighs the neat scheme against the messy reality of real rock.

Question 123

Igneous rock forms from the cooling and solidification of molten material, its very name coming from the Latin ignis, meaning fire. Because the place and rate of cooling differ from rock to rock, igneous rocks are classified both by where the molten material solidified and by the texture that the cooling left behind, two schemes that together tell the rock's history.

Intrusive rock that cooled at depth. Where magma cools and solidifies below the surface the rock is called intrusive or plutonic, trapped within the crust. Because the surrounding rock holds the heat in, cooling is very slow, as in the great body of granite beneath Dodoma that solidified deep underground long before erosion laid it bare.

Extrusive rock that cooled at the surface. Where the molten material reaches the surface as lava and solidifies there the rock is called extrusive or volcanic. Exposed to the air or water it loses its heat quickly, as in the basalt poured out by the volcanoes of the Rungwe field, so the place of cooling sets the whole contrast that follows.

The further split of intrusive rock. Intrusive rock is itself divided by depth into deep-seated plutonic rock, which cooled very slowly far down, and shallow hypabyssal rock, which solidified in cracks and sheets near the surface and so cooled at a middle rate. This shows that the mode-of-formation scheme grades smoothly from deep to surface rather than jumping between two states.

Coarse texture from slow cooling. Slow cooling at depth gives crystals long enough to grow large, so the rock is coarse-grained or phaneritic, with crystals plainly visible to the eye. The Dodoma granite, with its clear grains of quartz, feldspar and mica, is coarse precisely because it cooled slowly underground, so texture records the rate of cooling.

Fine texture from fast cooling. Rapid cooling at the surface gives the crystals no time to grow, so the rock is fine-grained or aphanitic, its crystals too small to see. The Rungwe basalt is fine for this reason, and the same magma, cooled at two depths, would give a coarse and a fine rock, which proves texture depends on cooling rate and not on chemistry alone.

Porphyritic texture from two-stage cooling. Where magma first cools slowly at depth and then is erupted to finish cooling fast at the surface, large early crystals end up set in a fine later groundmass, a mixed texture called porphyritic. This two-sized texture is itself a record, telling the geologist that the rock cooled in two stages in two different places.

Glassy texture from instant chilling. Where lava is chilled so suddenly that no crystals can form at all the rock sets as a natural glass, as in the dark, shiny obsidian. The complete absence of crystals shows the most extreme and rapid cooling of all, the very opposite of the slow-grown Dodoma granite.

Vesicular texture from trapped gas. Where gas-charged lava cools so fast that escaping bubbles are frozen in place the rock is full of holes and is vesicular, as in the light, frothy pumice that can float on water. The holes record both rapid surface cooling and the violent escape of gas, adding yet another page to the texture story.

The two schemes read together. Mode of formation and texture are not rivals but two readings of the same cooling history, the first naming where the rock solidified and the second recording how fast. A coarse intrusive Dodoma granite and a fine extrusive Rungwe basalt are each consistent in both schemes, so used together they let the geologist reconstruct the rock's birth.

Igneous rocks are therefore classified by their mode of formation, into intrusive and extrusive with the intrusive split again by depth, and by texture, from coarse through porphyritic and glassy to vesicular. Both schemes ultimately record the rate and place of cooling, so the slow-cooled Dodoma granite and the fast-cooled Rungwe basalt can be read straight from the rock itself.

Examiner's Note

The question asks for eight points; any eight earn full marks. The thread that wins the top band is that texture records cooling rate, so every point should connect to the speed and place of cooling.

False Confidence Alert

A common error is to classify igneous rock by hardness or colour alone. Hardness does not separate it from quartzite, and colour reflects chemistry, not mode of formation, so the safe keys are the crystalline grain, the lack of strata, the lack of fossils and the texture left by cooling.

Question 124

Igneous rock forms when molten material from within the Earth cools and solidifies, and because the early crust was once wholly molten it is regarded as the first or primary rock of the planet. From this primacy comes the claim that it is the mother rock, the parent from which the sedimentary and metamorphic families are ultimately derived.

The formation of magma. Igneous rock begins with magma, molten rock generated within the crust and upper mantle by a rise in temperature, a fall in pressure or the addition of water that lowers the melting point. This molten material is the raw stock of the whole family, gathering in chambers such as the one that fed the Dodoma granite before it ever cooled.

Cooling and solidification. As the magma loses heat its minerals crystallise and lock together into solid rock, the rate of cooling fixing the size of the crystals. Slow cooling at depth gave the coarse Dodoma granite while fast cooling at the surface gave the fine Rungwe basalt, but in both the rock formed simply by the freezing of a melt.

Igneous rock as the first rock. Because the newborn Earth was a molten body, the first solid crust to form had to be igneous, cooled from that global melt. There was as yet no sediment to settle and no older rock to alter, so igneous rock necessarily came first and every later rock had to be made, directly or indirectly, from it.

It is the source of sediment. Sedimentary rock is built from fragments and dissolved matter weathered from pre-existing rock, and the ultimate source of that material is igneous rock broken down at the surface. The sand that may one day become a Karoo sandstone began as grains weathered from a granite, so the sedimentary family traces back to an igneous parent.

It is a source of metamorphic rock. Metamorphic rock is older rock recrystallised by heat and pressure, and that older rock is very often igneous, so a granite buried and altered becomes gneiss. In this way the metamorphic family too can descend directly from igneous rock, strengthening the parent claim.

It supplies the chief crustal minerals. The minerals that make up most of the crust, the quartz, feldspars and ferromagnesian minerals, crystallise first from cooling magma, so igneous rock is the original source of the very minerals the other rocks are later built from. The quartz grains of a sandstone and the clay of a shale alike began as minerals grown in an igneous body such as the Dodoma granite, which deepens the sense in which it is the parent.

It makes up the bulk of the crust. Beneath the thin skin of sedimentary rock the great mass of the crust, and the whole of the deep crust under Tanzania, is igneous and metamorphic rock derived from it. Because igneous rock and its altered products form the solid foundation on which everything else rests, it is the parent not only in time but in sheer volume, supporting the claim from a second direction.

The qualification: the cycle is a loop, not a line. Yet the title of sole mother must be qualified, for the rock cycle is an endless loop in which sedimentary and metamorphic rock are themselves melted to make new magma. The granite of today may be made from yesterday's sediment, so igneous rock is both ancestor and descendant, and the three families are interdependent rather than ranked from one parent.

Igneous rock forms by the cooling of magma and, because the first crust was molten, it was genuinely the first rock and the ultimate source of the sediment and the altered rock that followed. To that extent the title of mother rock is deserved, but only with the reminder that the rock cycle is a loop, so igneous rock is renewed from the very families it is said to parent.

Examiner's Note

The question asks for six points; any six earn full marks. Account for needs the how of formation, while assess needs a verdict, so the strong answer grants the parent claim and then qualifies it with the loop of the cycle.

Question 125

Sedimentary rock forms at the Earth's surface as sediment accumulates in layers and is compacted and cemented into stone, and though it is only a thin skin it covers most of the land. Because it forms from such varied material, the family supplies both the raw stuff of industry and much of the fuel a developing nation burns, a double worth that makes it indispensable to a developing nation.

Limestone as the raw material of cement. Calcareous limestone, formed from the shells and skeletons of sea life, is burnt and ground to make cement, the basic material of all modern building. The limestone worked at Wazo Hill near Dar es Salaam and at Tanga feeds the cement that builds the nation's roads, bridges and houses, so this single sedimentary rock underpins the whole construction industry.

Coal as a source of energy. Carbonaceous coal, formed from plant matter buried and compressed in ancient swamps, burns to release stored energy for power and industry. The coalfields of Kiwira and Ngaka in the southern highlands hold reserves that can drive electricity generation and fuel factories, making this sedimentary rock a direct source of energy.

Natural gas held in sedimentary basins. The natural gas that now lights Tanzanian homes and runs power stations is trapped within porous sedimentary rock, sealed beneath impermeable beds. The gas of Songo-Songo and Mnazi Bay is won from such sedimentary reservoirs, so the family supplies not only solid fuel but the cleaner gas that is reshaping the nation's energy.

Sandstone and clay as building and ceramic materials. Arenaceous sandstone is quarried as building and paving stone, while the fine argillaceous clays are dug for bricks, tiles and pottery. These common sedimentary materials supply the everyday construction trade across the country, from the village brick kiln to the town builder, showing the family's reach beyond the famous deposits.

Evaporites as industrial chemicals. The chemically formed sedimentary rocks, rock salt and gypsum, are raw materials for the chemical and building trades, salt for food and industry and gypsum for plaster and as a cement additive. Won from evaporating brines, these rocks add another industrial use to the sedimentary list.

Limestone and phosphate as raw materials for fertiliser. Beyond cement, limestone is crushed to lime to sweeten acid farmland, and sedimentary phosphate rock such as that of Minjingu near Lake Manyara is

processed into fertiliser. These uses tie the sedimentary family directly to the productivity of the nation's agriculture.

Diatomite and other special deposits. The sedimentary family also yields special-purpose materials such as diatomite, the siliceous remains of microscopic algae, used as a filter and a fine abrasive, and limestone burnt to lime for the sugar and steel industries. These less obvious products widen the industrial reach of the family still further, so that even minor sedimentary deposits earn their keep in manufacturing.

Sedimentary rock as a store and aquifer. Because it is porous and permeable, sedimentary rock both holds the oil and gas of the world and stores groundwater in aquifers tapped by wells. This storage role, impossible in dense crystalline rock, is itself a resource, supplying water to dry districts and holding the very fuels already named.

The economic argument in sum. Taken together these uses show that the sedimentary family is at once the quarry and the fuel store of a developing economy, supplying cement, building stone, fertiliser and chemicals on the one side and coal and gas on the other. The claim is therefore well supported, for from Wazo Hill cement to Kiwira coal the nation's building and power both rest on sedimentary rock.

Sedimentary rocks are therefore both an industrial raw material and a source of energy, the first through the limestone, sandstone, clay and evaporites that build and supply industry, the second through the coal and natural gas that power it. With Wazo Hill cement, Kiwira and Ngaka coal and Songo-Songo gas all drawn from this one family, the claim of the 2021 paper is fully justified.

Examiner's Note

The question asks for eight points; any eight earn full marks. Support means defend the claim, so the marks lie in tying each named Tanzanian deposit to either a raw-material use or an energy use, keeping both halves of the claim in view.

Question 126

Sedimentary rock forms by the slow settling of sediment in layers at the surface, followed by its compaction and cementation into stone. The gentle, low-temperature way in which it forms gives it a set of characteristics, strata, fossils and a soft, porous body, that set it apart from the crystalline families and explain why it alone keeps the record of the past.

It is built in strata. Because sediment settles bed upon bed, sedimentary rock is layered into strata, each bed marking a fresh pulse of deposition. These layers are seen plainly in the bedded limestone of Tanga, and because the lowest bed was laid first they preserve the order of events in time, which the unbedded igneous rocks cannot.

It may contain fossils. As sediment settles quietly over the remains of plants and animals it buries and preserves them as fossils, a thing possible only at the low temperatures of surface deposition. The shells locked in the Tanga limestone are such fossils, and because the heat of magma and metamorphism destroys any remains, only sedimentary rock can hold them.

It is mostly soft, porous and permeable. Held together only by compaction and cement rather than by interlocking crystals, sedimentary rock is generally softer and full of pore spaces, so water can pass through it. This porosity, absent in dense granite, lets the rock store groundwater, oil and gas, and is itself a clue to its settled origin.

Its grains record the surroundings of deposition. The size, shape and sorting of the grains record the conditions in which they settled, so a well-rounded, well-sorted sandstone tells of a windblown desert while a fine mud tells of still water. The rock thus carries a picture of the ancient surroundings, a record the molten igneous rocks never received.

Why the other families cannot keep the record. Igneous rock forms from a melt hot enough to destroy any fossil and is built of interlocking crystals with no bedding, while metamorphic rock is recrystallised by heat and pressure that wipe out or distort any fossils and original layers. Neither, therefore, can preserve the delicate record that quiet sedimentation lays down.

Its bedding planes record breaks in time. The surfaces between the beds, the bedding planes, themselves record pauses, changes and even long gaps in deposition, so the rock preserves not just the layers but the rhythm of time. An unconformity within a Tanzanian basin marks a whole chapter of erosion, a thing the structureless igneous rock could never record.

It forms over a vast span and so spans history. Because sediment has settled somewhere on Earth in nearly every age, the sedimentary cover taken as a whole spans almost the entire history of the planet, layer recording age upon age. The igneous and metamorphic rocks record only the moments of melting or alteration, so only the continuous sedimentary record can act as a calendar of the past.

Why this record matters. Because sedimentary rock alone keeps fossils, ordered strata and the signs of past surroundings, it is the chief archive of the history of life and of the changing face of the Earth, and at the same time the host of coal, oil, gas and groundwater. The geologist reading the beds of a Tanzanian basin is therefore reading both the planet's past and its buried wealth.

The characteristics of sedimentary rock, its strata, its fossils and its soft, porous body, all flow from its quiet, low-temperature origin at the surface. It is exactly this gentle birth that the fiery igneous and the crushed metamorphic rocks lack, which is why sedimentary rock alone preserves the fossil and economic record, as the fossil-rich limestone of Tanga shows.

Examiner's Note

The question asks for six points; any six earn full marks. Account for the characteristics, then turn the question on the contrast, so the discriminator is explaining why heat and recrystallisation deny the other families this record.

Question 127

Metamorphic rock is an older igneous or sedimentary rock whose minerals and texture have been changed in the solid state, without melting, by heat, pressure and chemically active fluids. The agents that drive the change and the way they act decide both the kind of metamorphism and whether the new rock comes out banded or plain, as a comparison of gneiss and marble shows.

Heat as the master agent. Heat is taken as the master agent of metamorphism because it can act alone, driving the recrystallisation of the minerals into new and often larger crystals. Where the heat of a rising magma bakes the rock around it, as it bakes limestone into marble at a contact zone, the change is brought about by heat with no need of pressure.

Pressure as a shaping agent. Pressure, whether the even squeeze of deep burial or the directed push of mountain-building, compacts the rock and, when directed, flattens and aligns its minerals. This alignment is the very thing that will later give a rock its banding, so pressure both densifies the rock and shapes its grain.

Chemically active fluids. Hot fluids moving through the rock carry ions in and out and so change its chemical make-up, helping new minerals to grow that could not form from the original chemistry alone. These fluids speed the whole change and explain why some metamorphic rocks gain minerals their parent never held.

Dynamic metamorphism. Where directed pressure acts chiefly along a fault or shear zone, grinding and recrystallising the rock under stress, the change is dynamic metamorphism. It is driven by movement and pressure rather than by heat, and is found along the great fracture zones of the basement.

Thermal or contact metamorphism. Where heat from an igneous intrusion bakes the surrounding rock, the change is thermal or contact metamorphism, strongest next to the magma and fading outward. This is the process that turns the limestone of a contact aureole into marble, a change of heat without directed pressure.

Thermo-dynamic or regional metamorphism. Where great heat and great directed pressure act together over wide areas during mountain-building, the change is thermo-dynamic or regional metamorphism, the most widespread kind. It is this combined attack that produced the schists and gneisses of the ancient Usambara basement over vast tracts of country.

Metasomatic metamorphism by fluids. Where the chief agent is chemically active fluid soaking through the rock and altering its very chemistry, the change is metasomatic metamorphism, in which new minerals grow as ions are carried in and out. This fluid-driven change explains how some altered rocks of the mineralised basement gained metallic minerals their parent rock never held, which is why such zones are searched for ore.

Foliated rock from directed pressure. Where directed pressure aligns the new minerals into parallel sheets or bands the rock is foliated, splitting easily along the banding, as in slate from shale, then schist, then coarsely banded gneiss. The stripes of the gneiss are therefore the direct record of the directed pressure that formed it.

Non-foliated rock from heat without directed pressure. Where the change is driven by heat with little directed pressure, no alignment forms and the rock comes out plain and even-grained, as limestone becomes marble and sandstone becomes quartzite. The plain marble is unbanded precisely because it grew under heat rather than under directed squeeze, which is the very contrast the class had to explain.

Metamorphism is therefore the work of heat, pressure and chemically active fluids, acting in dynamic, thermal and regional settings to remake an older rock in the solid state. Whether the product is banded or plain turns on directed pressure, so the striped gneiss of the Usambara basement records that pressure while the plain marble records heat alone.

Examiner's Note

The question asks for eight points; any eight earn full marks. The hinge is that foliation comes from directed pressure, so the answer must tie the banded-versus-plain contrast to whether pressure was directed, not merely to heat.

False Confidence Alert

It is a mistake to say metamorphism melts the rock; melting would make it igneous. The change is in the solid state, the minerals recrystallising while the rock stays solid, which is exactly why fossils and original features are distorted rather than wiped out by melting.

Question 128

The rock cycle is the model by which the three rock families, igneous, sedimentary and metamorphic, are continually converted into one another, driven by the Earth's internal heat below and the hydrological cycle above. The teacher's claim that it has no true beginning or end goes to the heart of the model, and to judge it the cycle itself must first be traced.

Magma and the making of igneous rock. The familiar starting point is molten magma, which cools and solidifies into igneous rock, the primary crystalline rock. The slow-cooled Dodoma granite formed in just this way, and because the early crust was wholly molten the igneous rock is conventionally taken as the first rock of the cycle.

Weathering into sediment. Exposed at the surface, any rock is attacked by weathering and its fragments are carried off by rivers, ice and wind. The hard Dodoma granite is in this way reduced to loose sand and clay, which is the sediment from which the next family will be built, showing the surface processes at work in the cycle.

Compaction into sedimentary rock. The sediment settles in layers in a basin, is buried, compacted and cemented, and becomes sedimentary rock. The granite-derived sand may thus end as a bed of sandstone in a basin like the Karoo, so material has passed from the igneous family into the sedimentary family without any new matter being created.

Heat and pressure make metamorphic rock. Where igneous or sedimentary rock is buried deep and met by heat and directed pressure it recrystallises in the solid state into metamorphic rock. The sandstone becomes quartzite and the granite becomes gneiss, so the cycle carries rock into the third family by the internal heat of the Earth.

Melting returns rock to magma. Carried still deeper, any rock may be heated until it melts back into magma, which on cooling forms fresh igneous rock. This melting closes the loop and returns the path to its starting point, which is the core of the teacher's claim that the process never truly ends.

The short-cuts that skip a stage. The cycle is not forced through every stage in turn, for a rock may take a short-cut, so igneous rock carried straight to depth may become metamorphic without ever being sediment, and a metamorphic rock may be weathered straight into sediment. These short-cuts make the model a web of paths rather than a single fixed ring.

Two engines keep it turning. The cycle is kept turning by two tireless engines, the Earth's internal heat that drives melting and metamorphism from below, and the hydrological cycle and weathering that break and move rock at the surface. Because neither engine shows any sign of stopping, the conversions go on without pause, which supports the teacher's claim.

Why igneous rock is taken as the first rock. Although the loop has no true beginning once it is running, the igneous rock is taken as the conventional starting point because the newborn Earth was wholly molten and the first solid crust had to cool from that melt. There was then no sediment to settle and no older rock to alter, so the very first rock of all was necessarily igneous, as the ancient crystalline core of the Tanzania Craton reflects.

Assessing the claim. The claim is largely sound, for the loop has no fixed first rock once it is turning and no natural end while the engines run, so in a working sense rock formation is endless. Yet strictly the Earth itself had a beginning, when the molten planet first cooled, and will one day lose its internal heat, so the process is endless only within the long life of an active planet, not for all time.

The rock cycle therefore converts igneous, sedimentary and metamorphic rock endlessly into one another, driven from below by internal heat and from above by the water cycle, and threaded through with short-cuts that skip a stage. The teacher's claim is justified for as long as the Earth stays active, so the Dodoma granite is neither the first nor the last rock but one passing stage in a turning wheel.

Examiner's Note

The question asks for eight points; any eight earn full marks. Assess needs a verdict, so credit the endless loop and its short-cuts, then add the qualification that the planet itself began and will cool, to reach the top band.

Question 129

The age of a rock may be read in two quite different ways, relatively, by placing rocks in order from oldest to youngest, and absolutely, by fixing the age in years. The relative method rests on a set of stratigraphic laws and the breaks between beds, while the absolute method rests on the steady decay of radioactive elements, and the working geologist uses both.

The law of superposition. Relative dating begins with the law of superposition, that in a pile of undisturbed beds each layer is younger than the one beneath it, so the lowest bed is the oldest. Read together with original horizontality, which states that beds are first laid down flat, this lets the geologist order an undisturbed sequence at a glance.

Cross-cutting relationships. Where a fault or an igneous intrusion cuts across existing beds, the cut must be younger than the rock it cuts, since the rock had to exist before it could be broken or intruded. A granite dyke slicing the Dodoma basement is thus younger than the rock around it, which extends relative dating to disturbed ground.

Included fragments. Where one rock contains fragments of another, the fragments must be older than the rock that encloses them, since they had to exist first to be caught up. A xenolith of older rock trapped within a granite is therefore the elder of the two, giving another rule of relative order.

Fossil succession and correlation. Because life has changed steadily through time, each span of the past has its own assemblage of fossils, so beds carrying the same fossils are of the same age even when far apart. This law of fossil succession lets the geologist match the beds of one basin with those of another and so order rocks across whole regions.

Index fossils as precise time markers. Certain short-lived, widespread fossils, such as the trilobites and graptolites of the early Palaeozoic, are used as index fossils that pin a bed to a narrow span of time. Because such a species lived only briefly but spread widely, finding it in a bed fixes that bed's relative age sharply, giving relative dating much of its precision.

Unconformities as gaps in the record. An unconformity is a buried surface of erosion that marks a long gap in the record, where deposition stopped, the rocks were worn down, and deposition later resumed. Recognising an angular unconformity, in which tilted older beds are overlain by flat younger ones, tells the geologist that a whole chapter of time is missing from the pile.

Radioactive decay and absolute dating. Absolute dating rests on the fact that a radioactive element decays into a stable product at a fixed rate, measured by its half-life, the time for half of it to decay. By measuring how much parent and product a mineral now holds, the geologist calculates the years since the mineral formed, turning relative order into real dates.

Uranium-to-lead dating of old rock. For the oldest rocks the decay of uranium to lead is used, because its half-life of about four and a half billion years matches the great age of the basement. This clock dates the ancient crystalline rocks of the Dodoma basement and the Tanzania Craton in billions of years, far beyond the reach of any other method.

Carbon-14 dating of young material. For recent once-living material the decay of carbon-14 is used, but its short half-life of about five and a half thousand years exhausts the clock within some seventy thousand years. It therefore dates wood, charcoal and bone from the recent past, such as the remains at the prehistoric site of Olduvai, and is useless for ancient rock.

Relative dating, through superposition, cross-cutting, inclusions, fossil succession and unconformities, orders the rocks of the Dodoma basement from oldest to youngest, while absolute dating, through uranium-to-lead and carbon-14, fixes their ages in years. The two are complementary, the first giving the order and the second the dates, so the geologist needs both to read the full history of the ground.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is matching each clock to its time range, uranium for ancient rock and carbon-14 for recent material, and showing relative and absolute methods as complementary, not rival.

False Confidence Alert

A frequent error is to claim carbon-14 can date rocks or dinosaur bones millions of years old. Its half-life is far too short, so it is reserved for recent organic material, while ancient rock is dated by long-lived clocks such as uranium to lead.

Question 130

The geological time scale is the calendar of Earth history, dividing the vast span since the planet formed into a nested ladder of eons, eras, periods and epochs, each boundary marked by a great change in the rock or fossil record. Built from both relative and absolute dating, it lets the geologist place any rock or event in its true position in time, and its uses are many.

The nested divisions of the scale. The scale is built of units within units, the longest being eons, divided into eras, these into periods and the periods into epochs. This nesting lets the geologist speak as broadly or as finely as the evidence allows, from a whole eon down to a single epoch, giving a common language for the age of any rock.

The eras defined by their life. The familiar eras are named and bounded by the life that dominated each, the Palaeozoic of ancient life and the early invertebrates and fishes, the Mesozoic of the reptiles and the dinosaurs, and the Cainozoic of the mammals and finally of humankind, all preceded by the long Precambrian of simple life. Each great boundary marks a mass change in the fossils, so the scale is at once a record of time and of the history of life.

It is built from dating methods. The scale is not guessed but constructed, its order fixed by relative dating, such as superposition and fossil succession, and its dates in years fixed by radiometric dating. The position of a Tanzanian basement rock on the scale therefore rests on the same uranium-to-lead clock that dates the rock itself, so the calendar is grounded in evidence.

Its use in dating mountain-building and events. Because the scale orders events in time, the geologist can date the great episodes of mountain-building, rifting and volcanism and set them in sequence. The opening of the East African Rift can thus be placed late in the Cainozoic, which lets its history be told in step with the rest of the Earth's.

Its use in finding and correlating resources. Many ores, coals and oils form only in rocks of particular ages, so knowing the age of a bed guides the search for them and lets the geologist correlate the bearing beds from place to place. A coal-bearing horizon of one age in the southern basins can be traced and sought elsewhere by its position on the scale, of direct economic value.

Its use as a record of the history of life. Because each era is bounded by great changes in the fossils, the scale is at the same time a record of the evolution and the mass extinctions of life, from the first simple cells through the age of reptiles to the rise of mammals and humankind. The early human remains of Olduvai can thus be set in their true place near the end of the scale, joining the story of the rocks to the story of life.

It gives a common language across the world. The same divisions are used by geologists everywhere, so a rock called Jurassic in Tanzania means exactly what it means in Europe or America. This shared calendar lets workers compare and combine their findings worldwide, which is why the scale is as much a tool of communication as of dating.

Its weaknesses. The scale is not perfect, for its boundaries are sometimes drawn where the fossil record is incomplete, and the very oldest, fossil-poor Precambrian is hard to subdivide finely. Its dates also carry a margin of error and are refined as methods improve, so the geologist must treat it as a working framework rather than an exact and final calendar.

The geological time scale is therefore a nested ladder of eons, eras, periods and epochs, bounded by changes in life and dated by relative and absolute methods together. For the working geologist it is indispensable, dating events, ordering Earth history and guiding the search for resources, yet it must be used with awareness of its gaps, as the difficulty of dividing the Precambrian basement of Tanzania shows.

Examiner's Note

The question asks for six points; any six earn full marks. Examine wants both the structure and a weighing of its usefulness, so include at least one weakness and tie a use to a Tanzanian example for the top band.

Question 131

Soil formation, or pedogenesis, is the slow turning of solid parent rock into a layered, living soil, and it is governed not by one cause but by five factors acting together, parent material, climate, relief, living organisms and time. Their joint working explains why the same rock can give a deep, rich soil in one place and a thin, poor one in another, as the contrast between Kilimanjaro and Kondoa shows.

Parent material starts the soil. Pedogenesis begins as weathering breaks the parent rock into regolith, the loose mantle of broken rock from which soil develops, and the parent rock sets the early texture and supplies the mineral nutrients. The mafic volcanic rock of Kilimanjaro weathers to a rich, fertile soil, while a quartzite, almost pure silica, yields a thin and barren one.

Climate is often the leading factor. Climate is commonly the dominant factor, for warmth speeds the chemical weathering of the rock and rainfall both deepens the soil and washes minerals down through it by leaching. The hot, wet conditions of the highlands form deep soils far faster than the dry climate of central Dodoma, so two soils on the same rock may differ entirely with climate.

Relief governs depth and drainage. Relief, or slope, controls how much of the weathered material can stay in place and how freely water drains. On the steep slopes of the Uluguru highlands the soil is washed

off as fast as it forms and stays thin and dry, while on the gentle valley floors deep, moist soils gather, so the same hillside carries different soils top and bottom.

Living organisms build the soil. Plants, animals and microbes turn broken rock into living soil, for plant litter rots into humus, roots open the ground and release acids, and burrowing animals mix the layers. The dense forest litter of the Usambara highlands builds a dark, fertile, well-structured topsoil that bare rock could never form.

Time matures the soil. Soil deepens and develops its layers only slowly, so a thin, immature soil grows over centuries into a mature, well-horizoned profile. A young soil on a fresh lava flow has barely begun, while the soils of the long-stable plateau surfaces are deep and fully developed, showing that time is itself a factor.

Human activity as a modern agent. Within the factor of living organisms, human activity has become a powerful modern agent, building soil through manuring, terracing and careful tillage, or destroying it through clearing, overgrazing and careless ploughing. The terraced, manured plots of Kilimanjaro stay deep and fertile, while the cleared slopes of Kondoa have lost their soil to erosion.

Parent rock chemistry sets the early fertility. Beyond supplying the grains, the chemistry of the parent rock sets how fertile the young soil will be, for mafic rock rich in iron, magnesium and bases weathers to a richer soil than felsic rock of nearly pure silica. The basic volcanic rock of Kilimanjaro gives a naturally fertile soil, while a granite or quartzite yields a poor and sandy one, so the rock chosen as parent matters as much as how it weathers.

The factors act together, not alone. No factor works in isolation, so the soil that finally forms is the joint product of all five, and a change in any one alters the result. The deep, fertile soil of Kilimanjaro owes itself to rich parent ash, a warm wet climate, gentle middle slopes, lush vegetation and long undisturbed time, all acting at once.

Why the same rock gives different soils. Because the five factors vary from place to place, identical parent rock can yield very different soils, which is why a basalt gives a deep soil on a gentle, wet, forested, long-stable Kilimanjaro slope but a thin one on a steep, dry, bare and recently exposed surface. The soil records the whole local combination, not the rock alone.

A soil is therefore a function of parent material, climate, relief, living organisms and time, working together upon a weathering parent rock, with human activity now a powerful agent among them. Because these factors vary from place to place, the same rock gives the deep, rich soils of Kilimanjaro in one setting and the thin, eroded soils of Kondoa in another, so the soil is the signature of all five at once.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is showing the factors act together, with climate often leading, rather than listing them singly, and naming a Tanzanian soil for the contrast.

False Confidence Alert

A common slip is to treat soil formation as nothing more than weathering. Weathering only breaks the rock into regolith; soil forms when climate, organisms, relief and time then act on that regolith over long periods, so weathering is one stage of pedogenesis, not the whole of it.

Question 132

A soil profile is the sequence of layers, or horizons, seen in a vertical section from the surface down to the bedrock, each layer differing in colour, texture and content. The horizons are not separate creations but the work of water and organisms moving material down through the soil over long time, so the profile is best read as the record of those processes at work.

The O horizon of surface litter. At the very top lies the O horizon, the layer of fresh and partly rotted plant litter resting on the soil surface. Under the forest of the Rungwe highlands this litter is thick, and as it decays it is the raw material from which the humus of the topsoil below is made.

The A horizon, the topsoil. Beneath it lies the A horizon, the dark, humus-rich topsoil where roots, soil animals and microbes are most active and where most plant growth takes place. Its dark colour comes from the humus mixed through it, and it is the most fertile and the most worked layer of the Rungwe soil.

The B horizon, the subsoil. Below the topsoil lies the B horizon, or subsoil, the zone of accumulation where clay, iron and other material washed down from above are deposited. It is therefore denser, often more brightly coloured and less fertile than the A horizon, and its content is matter that the topsoil has lost.

The C and R horizons at the base. At the base lies the C horizon, the weathered and broken parent rock, or regolith, from which the whole soil developed, and beneath it the unweathered solid bedrock of the R horizon. A Rungwe soil grades down through broken volcanic rock into the solid lava or basement beneath.

Leaching. Leaching is the washing of soluble minerals dissolved out of the upper soil and carried down by percolating rainwater. In the wet highlands leaching strips nutrients from the topsoil and lowers its fertility, which is why heavily leached soils need careful management to stay productive.

Eluviation and illuviation. Eluviation is the washing-out of fine clay and particles from the A horizon, and illuviation is their deposition in the B horizon below. Together these paired processes move solid fine material from topsoil to subsoil, which is exactly why the B horizon of the profile is clay-rich and dense.

Humification. Humification is the breakdown by soil organisms of dead plant and animal matter into dark, sticky humus, which gathers in the A horizon. Humus gives the topsoil its dark colour, binds it into a crumb structure that holds water and air, and slowly releases nutrients, so it is central to the fertility of the surface layer.

Laterisation in the wet tropics. Under hot, wet tropical conditions a complex process called laterisation strips away the silica and bases by intense leaching and leaves the soil enriched in iron and aluminium oxides, giving the red, often hard laterite soils. Many of the leached upland soils of Tanzania are reddened in this way, which shows how a strong climate can drive a profile far from the chemistry of its parent rock.

The profile as the record of the processes. Read together, the horizons are the visible record of these processes, the dark A horizon the work of humification, the depleted upper soil the work of leaching and eluviation, and the enriched B horizon the work of illuviation. The Rungwe profile is therefore not a set of accidents but the orderly outcome of water and life moving material down through the soil over long time.

A soil profile is therefore an ordered set of horizons, from the litter of the O horizon through the humus-rich A and the enriched B to the broken parent rock of the C and the bedrock of the R. Each layer is the work of leaching, eluviation, illuviation and humification moving material downward over long time, so the Rungwe pit reads as the written history of those processes.

Examiner's Note

The question asks for eight points; any eight earn full marks. The marks lie in linking each process to the named horizon it builds, so a labelled profile sketch earns the construction marks and the top band needs cause tied to layer.

Question 133

The productivity of a soil is its capacity to support healthy plant growth and yield good crops, and it is not fixed by any single quality but by several physical, chemical and biological factors together. To assess a soil, each of these must be weighed, for a soil strong in one may be ruined by a weakness in another, as the contrast between the rich soils of Rungwe and a worn-out field shows.

Supply of plant nutrients. The first factor is the store of plant nutrients, the nitrogen, phosphorus, potassium and other elements that crops draw from the soil. The well-supplied volcanic soils of Rungwe carry heavy harvests, while a nutrient-poor or heavily leached soil starves the crop however well it is worked, so the nutrient store is fundamental.

Humus and organic matter. The amount of humus and organic matter is a second factor, for humus stores and releases nutrients, binds the soil into a workable crumb structure and holds moisture. A dark,

humus-rich Rungwe topsoil is therefore far more productive than a pale soil from which the organic matter has been lost or burnt away.

Soil texture and structure. Texture, the mix of sand, silt and clay, and structure, the way the grains are bound into crumbs, govern how a soil holds water, air and roots. A balanced loam with a good crumb structure is ideal, while a heavy clay waterlogs and a loose sand dries out, so both texture and structure must be judged.

Soil depth. The depth of soil decides how far roots can reach and how much water and nutrient they can tap. A deep soil on a gentle Rungwe slope gives roots a large reservoir, while the thin soil of a steep, eroded hillside limits the crop no matter how rich its surface, so depth is a key measure.

Moisture and drainage. A steady supply of moisture, neither too little nor too much, is essential, and this depends on rainfall, water-holding capacity and drainage. A soil that holds enough water through the growing season yet drains away the excess is productive, while a droughty or a waterlogged soil is not, so the water balance must be weighed.

Soil reaction, the acidity or alkalinity. The reaction of the soil, whether acid, neutral or alkaline, controls how freely nutrients dissolve and become available to plants. A soil that is too acid, as some leached highland soils become, or too alkaline locks up nutrients and limits growth, so a near-neutral reaction is part of a productive soil.

Soil organisms and biological activity. An active population of soil organisms, from earthworms to bacteria and fungi, keeps the soil productive by breaking down litter, recycling nutrients and improving structure. A biologically lively soil renews its own fertility, while a soil poisoned or exhausted of its life declines, so biological activity is a real factor to assess.

Relief and the position of the land. The slope and position of the land affect productivity, for a gentle, well-placed site holds its soil, drains freely and is easy to work, while a steep or hollow site loses soil or waterlogs. The gentle middle slopes of Kilimanjaro both keep a deep soil and drain it well, so relief is weighed alongside the qualities of the soil itself.

Freedom from salinity and erosion. Finally a productive soil must be free of the damage of salinity and erosion, for a build-up of salts poisons crops and the loss of the topsoil strips away the fertile layer. The gullied, eroded fields near Kondoa have lost their productive topsoil, showing that even a once-rich soil fails if its best layer is washed away.

The productivity of a soil must therefore be assessed across many factors at once, its nutrients and humus, its texture, depth and moisture, its reaction and its living organisms, and its freedom from salt and erosion. Because a single weakness can undo many strengths, the deep, rich, well-managed soils of Rungwe outyield a thin or worn-out field, so all the factors must be weighed together.

Examiner's Note

The question asks for eight points; any eight earn full marks. Examine means weigh the factors, so the discriminator is showing that one weakness can undo many strengths, and tying productivity to a named Tanzanian soil.

False Confidence Alert

It is wrong to judge a soil productive on nutrients alone. A rich but waterlogged, shallow, strongly acid or eroding soil still fails, so productivity is the balance of physical, chemical and biological factors together, not the reading of any single one.

Question 134

Soil erosion is the removal of the fertile topsoil from the land faster than it can be replaced, chiefly by running water and wind. It springs from both natural forces and human activities working together, and because it strips the very layer on which farming depends, its causes and its cure are matters of national concern, as the scarred slopes of Kondoa show.

Natural cause: heavy and intense rainfall. A leading natural cause is heavy, intense rainfall, for a violent downpour strikes the bare soil hard, loosens the grains and washes them away in sheets and channels. The fierce seasonal storms of semi-arid central Tanzania fall on thinly covered ground and drive much of the erosion of the Kondoa hills.

Natural cause: steep slopes. Steep slopes are a second natural cause, for on a sharp gradient water runs off fast and with great force, carrying the soil with it rather than soaking in. The steep hillsides of the Uluguru and Kondoa country shed their soil far more readily than gentle land, so relief itself drives the loss.

Natural cause: sparse natural vegetation. A naturally thin or seasonal vegetation cover is a third cause, for where the ground is bare for part of the year the soil is left exposed to rain and wind. The dry-season bareness of the semi-arid centre leaves the soil unprotected just when the first heavy rains arrive, so nature itself can expose the land.

Human cause: clearing of vegetation. The chief human cause is the clearing of the protecting vegetation for farmland, firewood and timber, which strips away the cover that shielded and bound the soil. The felling and burning of the woodland on the Kondoa slopes laid the soil bare to the rain and turned a slow natural loss into rapid erosion.

Human cause: overgrazing and overcultivation. Overgrazing by too many cattle and the overcultivation of the land without rest both destroy the plant cover and break down the soil structure. The heavy herds of the Kondoa district once stripped the grass and trampled the ground, leaving a bare, loosened surface that the rains carried away in gullies.

Human cause: poor farming methods. Poor farming methods, above all ploughing up and down the slope instead of along the contour, cut channels that guide the runoff straight downhill and speed the wash. Such careless tillage turns each furrow into a drain, so the way the land is worked can either save the soil or destroy it.

Wind erosion on bared dry land. In the drier districts a further agent is the wind, which lifts and carries away the fine, loose topsoil once the protecting cover has gone, a loss that is part natural and part the work of overclearing. The bared, overgrazed plains of semi-arid central Tanzania lose soil to the wind in the dry season, showing that erosion is not by water alone and that human clearing again magnifies a natural force.

Conservation by terracing and contour methods. The land is conserved by cutting steep slopes into level terraces and by ploughing and planting along the contour, both of which hold back the runoff and let it soak in rather than rush downhill. Such measures, applied in the long campaign to heal the Kondoa slopes, sharply reduce the wash on cultivated hillsides.

Conservation by cover crops and afforestation. The soil is further protected by keeping the ground under cover crops and grass and by planting trees, which shield it from the beating rain and bind it with their roots. The replanting of trees and the restoring of grass cover were the heart of the recovery of the Kondoa area, showing that conservation works by restoring the cover that clearing removed.

Soil erosion is therefore the product of natural forces, heavy rain, steep slopes and thin cover, working together with human acts, the clearing of vegetation, overgrazing and careless tillage, the second often turning the first into a crisis. It is conserved by terracing, contour methods, cover crops and afforestation, so the healing of the gullied Kondoa slopes shows that what human carelessness began, careful management can repair.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is balancing natural and human causes and showing human acts magnify the natural, then pairing the cure to the cause.

Question 135

The hydrological cycle is the endless circulation of water between the oceans, the atmosphere and the land, driven by solar energy and returned by gravity. Although water moves ceaselessly, the global cycle is closed, so the same finite quantity is recycled rather than created, and the student's claim cannot stand.

Solar energy lifts water from the surface. The Sun heats open water and evaporates it from the Indian Ocean off Dar es Salaam and from Lake Victoria. This raises water as invisible vapour against gravity, beginning the upward limb of the cycle and supplying the atmospheric store.

Transpiration adds water from vegetation. Plants draw water from the soil and release it as vapour from their leaves. Over the forests of the Uluguru Mountains transpiration adds large quantities of moisture to the air, so vegetation as well as open water feeds the atmospheric store.

Condensation forms clouds in the atmosphere. As moist air rises it cools to its dew point and the vapour condenses around nuclei into cloud droplets. This transfer moves water from vapour into visible cloud over the Tanzanian highlands without any being added or lost.

Precipitation returns water to the surface. When droplets grow heavy enough, gravity returns them as rain over the catchment of the Rufiji. Precipitation is the chief input to the land store, but it is merely water the cycle had earlier lifted from the oceans, not new water.

Infiltration and percolation recharge groundwater. Part of the rain soaks in and percolates downward to the water table, recharging the groundwater store beneath the Dodoma plains. This water is held temporarily before it moves on, transferring water between stores rather than removing it.

Runoff and rivers return water to the sea. Water that does not infiltrate flows overland into rivers such as the Pangani and the Great Ruaha, which carry it back to the Indian Ocean. This completes the return limb so water raised from the ocean is delivered back to it.

The global cycle is a closed system. Across the whole Earth no significant water enters from space and almost none escapes the atmosphere. Because outside inputs are effectively nil, the total volume is fixed, and the cycle simply redistributes it among ocean, atmosphere and land.

Inputs and outputs of each store balance over time. For any store the long term gains balance the losses; the rain falling on the Tanzanian land surface is offset by evaporation and river discharge leaving it. This dynamic equilibrium keeps each store and the whole system steady.

Water is recycled, not manufactured. Because the cycle has neither beginning nor end, the same molecules pass through it again and again. The rain over Morogoro today is water that has evaporated, condensed and fallen countless times, which is why the global store stays constant.

The hydrological cycle therefore moves water endlessly but creates none. Since it is a closed system in which the inputs and outputs of each store balance over time, the Earth neither gains nor loses water, and the student's belief that constant rain means a growing supply is mistaken.

Examiner's Note

The question asks for eight points; any eight earn full marks. The strongest scripts pin the constancy to the closed system and balanced stores rather than merely listing the processes in order.

Question 136

Within a single drainage basin the hydrological cycle operates as a local system whose inputs, stores, transfers and outputs are finely balanced. Human activities such as clearing forest, paving land, draining wetlands and damming rivers alter these elements, so the basin's water moves and is stored differently from its natural state.

Deforestation reduces interception. When forest is cleared, as on the slopes above the Kondoa lowlands, rain that leaves would have caught now strikes the ground directly. Less is intercepted and evaporated back, so a greater share reaches the soil at once and overland flow increases.

Loss of vegetation increases runoff and erosion. Without roots and litter to slow it, water runs off bare ground rapidly, as in the gullied Kondoa erosion area. Runoff rises sharply, the soil is stripped, and the natural transfer to infiltration is replaced by flashy surface flow.

Reduced infiltration lowers groundwater recharge. Because more water runs off, less percolates downward, so the groundwater store beneath a cleared catchment is recharged more slowly. Wells and dry season springs that depend on this store may weaken, cutting the base flow of rivers.

Urban surfaces seal the ground. Roads, roofs and concrete in growing cities such as Dar es Salaam are impermeable. They cut infiltration to almost nothing and shed rain straight into drains, raising peak flows and causing the rapid urban flooding seen after heavy storms.

Wetland drainage removes natural storage. Wetlands such as the Kilombero floodplain store water and release it slowly. When they are drained for rice and sugar, this natural reservoir is lost, so floods downstream become higher and the dry season flow lower.

Dams alter river regime and evaporation. Reservoirs such as Mtera and Nyumba ya Mungu hold back flow and spread water over a wide surface. They even out the regime downstream but expose a large area to intense evaporation, increasing losses from the basin store.

Irrigation increases evapotranspiration. Diverting river water onto fields, as in the Usangu and Kilombero schemes, spreads it where crops and soil evaporate it rapidly. Much of this leaves the basin as vapour instead of returning to the river, reducing downstream discharge.

Over abstraction lowers the water table. Pumping groundwater for towns and farms faster than it is recharged draws the water table down, as around heavily used boreholes near Dodoma. Springs may fail and the ground may no longer feed rivers, disturbing the natural store.

Pollution degrades the quality of basin water. Sewage, farm chemicals and sediment entering rivers and lakes do not change the quantity of water but degrade the store, as nutrient inflow threatens parts of Lake Victoria. The cycle still turns, but the usable water is diminished.

Human activity does not stop the hydrological cycle, but it redistributes water within the basin, shifting the balance from infiltration and storage toward rapid runoff and evaporation loss while degrading quality. Sound catchment management, by conserving forest and wetland, is therefore the key to keeping a basin's water cycle in balance.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is showing the direction of change in each element of the basin system, not merely listing harmful activities.

Question 137

Evaporation is the change of water from liquid to vapour from an open surface, while evapotranspiration adds the transpiration of plants. The rate of loss is governed by the state of the air, the nature of the surface and the vegetation upon it, which together explain why the interior reservoir loses more than the coastal one.

Temperature of air and surface. Heat gives water molecules the energy to escape as vapour. The hot interior around Dodoma reaches high daytime temperatures, so its reservoir evaporates faster than a cooler water body, because warmer water sheds molecules more readily.

Humidity of the overlying air. Dry air can absorb much more vapour before it is saturated. The dry interior air takes up water rapidly, whereas the humid coastal air near Dar es Salaam is often near saturation, so it accepts little more and evaporation is slow.

Wind speed. Wind sweeps moist air away from the surface and replaces it with drier air, keeping evaporation going. The breezy open interior around Dodoma loses water steadily, while in still air a saturated layer forms and slows further loss.

Area and depth of the water surface. A wide shallow water body exposes a large surface relative to its volume, so it loses water quickly, as the shallow soda water of Lake Eyasi. A deep narrow lake exposes less surface for its volume and loses proportionally less.

Amount of sunshine and cloud. Clear skies over the interior allow strong insolation that drives rapid evaporation, whereas the cloudier coast at Dar es Salaam receives less direct energy. The energy supply at the surface therefore sets an upper limit on the rate of loss.

Availability of water at the surface. Evaporation needs water present; this distinguishes potential from actual evapotranspiration. Over a full reservoir the supply is unlimited, but over dry interior soil between rains the actual loss falls far below the potential.

Type and density of vegetation. Transpiring plants raise total loss above open water evaporation. A dense crop such as the rice of the Kilombero floodplain transpires heavily, so a vegetated surface there can lose more water than bare ground of equal area.

Salinity of the water. Dissolved salts lower the rate at which water molecules escape. The highly saline water of Lake Natron evaporates a little more slowly than fresh water at the same temperature, because the salts hold the molecules more tightly.

Nature and colour of the surface. A dark surface absorbs more heat and warms faster, raising evaporation, while a pale surface stays cooler. Bare dark soil in the interior near Dodoma heats strongly and dries quickly compared with a lighter or shaded surface.

The rate of evaporation and evapotranspiration is thus set chiefly by the temperature, humidity and movement of the air, the energy received, and the surface and its vegetation. Because the dry interior combines high heat, low humidity, clear skies and steady wind, its reservoir loses far more water than the humid coast.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is the potential against actual distinction, which separates places with water available from places where supply, not energy, is the limit.

Question 138

Precipitation forms when air is cooled to its dew point so that vapour condenses and the droplets grow heavy enough to fall under gravity. The way the air is forced to rise and cool gives rise to convectional, orographic and cyclonic rainfall, and to other forms of condensation at the surface, each favoured by particular conditions.

The basic requirement of cooling to dew point. All precipitation begins with moist air being cooled until it is saturated. Without a supply of moisture and a mechanism to cool it, no rain can form, which is why both a moisture source and a lifting process are needed over any Tanzanian district.

The role of condensation nuclei. Water vapour condenses on tiny particles of dust, smoke or salt. The salt rich air of the coast at Dar es Salaam supplies abundant nuclei, so droplets form readily, whereas very clean air condenses less easily even when cooled.

Convectional rainfall. Intense surface heating makes air rise, expand and cool rapidly, building towering cumulonimbus. This gives the heavy afternoon thunderstorms of the hot interior plains around Tabora, typically in the early wet season afternoons.

Conditions favouring convectional rain. Convectional rain needs strong insolation and a moist, unstable lower atmosphere. It is therefore most common over heated interiors such as central Tanzania in the hot season and near the Equator, where surface heating is reliably strong.

Orographic or relief rainfall. Moist air forced to climb a highland barrier cools and condenses on the windward side. The windward slopes of Mount Kilimanjaro and the Uluguru Mountains receive heavy relief rain as the rising air sheds its moisture.

The rain shadow on the leeward side. Having lost moisture on the ascent, the air descends the far slope, warms and dries, creating a rain shadow. This is why the leeward country near Same is dry scrub although it lies close to well watered slopes.

Cyclonic or frontal rainfall. Where a warm air mass meets a cooler one, the lighter warm air is forced to rise along the front, cools and yields prolonged steady rain. Such frontal disturbances bring widespread rain to coastal districts such as Mtwara.

Surface condensation forms of dew, frost, fog and mist. When the ground cools at night, air in contact with it may cool to dew point, depositing dew, or frost on cold highland nights, while cooling of a moist layer forms fog and mist, as the morning mists of the Southern Highlands.

The influence of relief and air mass on distribution. These processes shape rainfall distribution; windward highlands are wet, interior plains have seasonal convectional rain, and rain shadows are dry. Relief and the source of the air together explain the uneven pattern across Tanzania.

The main types of precipitation therefore differ in the way air is lifted and cooled: convectional by surface heating, orographic by highland barriers, and cyclonic by fronts, with dew, frost and fog forming by surface cooling. Each is favoured by particular conditions of heat, moisture and relief, which together govern where rain falls.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is naming the lifting and cooling mechanism behind each type rather than describing the resulting weather.

Question 139

The distribution of rainfall over a country is controlled by the supply of moisture to the air and by the mechanisms that lift and cool it. In Tanzania, distance from moisture sources, relief, prevailing winds, water bodies and pressure systems combine to produce a sharp contrast between wet highlands and dry interior plains.

Distance from the sea and moisture source. Air loses moisture as it travels inland, so coastal districts such as Tanga receive ample rain while the far interior is drier. The reliable supply of moist air to the coast explains its higher and more dependable rainfall.

Relief and altitude. Highlands force moist air to rise, cool and shed orographic rain, so the windward slopes of Mount Kilimanjaro and the Southern Highlands are very wet. Low plateau surfaces lack this forced uplift and therefore receive far less rain.

Rain shadow effect. Land sheltered behind a highland barrier lies in a rain shadow where descending air is dry. The lee of the northern highlands near Same is dry scrub, showing how relief can both raise and reduce rainfall over short distances.

Prevailing winds and the monsoons. The seasonal reversal of the monsoon winds governs when and where moist air arrives. The wetter season comes when winds blow onshore from the Indian Ocean, while offshore or continental air brings dry conditions to much of the country.

The Inter Tropical Convergence Zone. The migration of the ITCZ brings a belt of convergence and rising air across the country, giving the main rains as it passes. Areas it crosses twice may have two rainy seasons, while its timing sets the rhythm of wet and dry seasons.

Large water bodies and lake effect. Great lakes add moisture to passing air and trigger local rain. The Lake Victoria basin around Bukoba is among the wettest parts of Tanzania because the lake feeds moisture and convection to the air around it.

Continentality of the interior. The far interior plateau around Dodoma is remote from any moisture source and is heated strongly. Air reaching it is already dry, so rainfall is low and unreliable, the hallmark of a continental interior climate.

Ocean currents along the coast. The warm current washing the East African coast warms the overlying air and encourages it to hold and release moisture onshore. This supports the relatively high coastal rainfall compared with coasts cooled by cold currents elsewhere.

Vegetation and local feedback. Well vegetated highlands recycle moisture through transpiration and encourage further rainfall, while sparsely vegetated plains return little. This feedback tends to reinforce the contrast between the wet highlands and the dry interior.

The uneven distribution of rainfall therefore results from the interplay of distance from moisture sources, relief, prevailing winds, the ITCZ, large lakes and ocean currents. Where these favour the supply and uplift of moist air the land is wet, as on the highland and lake margins, while the sheltered interior remains dry.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is linking each factor to either moisture supply or the uplift mechanism, supported by a contrasting Tanzanian location.

Question 140

Surface runoff is the water that flows over the ground after rain that the surface cannot absorb. Whether rainfall becomes runoff or soaks in to feed base flow depends on the slope, the surface cover, the soil and rock, the state of the ground and the storm itself, which together explain the contrast between the bare and forested slopes.

Gradient of the slope. On steep land water flows downhill before it can infiltrate, so runoff is rapid and erosive on the steep hillsides of the Kondoa area. Gentle slopes hold water long enough for it to soak in, so they generate far less surface flow.

Vegetation cover and interception. A plant canopy intercepts rain and slows its fall, while roots open the soil and litter holds water. A wooded slope in the Kondoa area soaks up the storm, whereas the bare overgrazed slope, stripped of cover, sheds water and soil at once.

Infiltration capacity of the soil. Soils differ in how fast they admit water; a porous sandy soil absorbs rain readily, but a crusted or compacted soil has a low capacity. Trampling by livestock on the Kondoa hillsides seals the surface, lowering capacity and forcing rain to run off.

Antecedent soil moisture. Soil already wet from earlier rain can absorb little more, so further rain runs off. Late in the rainy season the saturated ground of the Kilombero valley produces much more runoff from the same storm than dry ground would.

Underlying geology and permeability. Permeable rock such as the coastal limestone near Tanga lets water percolate to groundwater and reduces runoff. Impermeable basement rock keeps water at the surface, so catchments on such rock are prone to rapid runoff and flooding.

Rainfall intensity. A short violent downpour delivers water faster than any soil can infiltrate, so runoff is immediate regardless of soil. The intense convectional storms of the interior therefore produce flash runoff even where the soil would absorb gentle rain.

Rainfall duration and totals. Prolonged rain eventually fills the soil store, after which all further rain runs off. A long wet spell over the Rufiji catchment saturates the basin and swells the river, raising the proportion of rainfall that becomes runoff.

Land use and human activity. Clearing, cultivation along slopes and urban paving raise runoff by reducing infiltration. The sealed surfaces of Dar es Salaam shed almost all rain into drains, causing the rapid urban flooding that bare or built land produces.

Drainage density and basin shape. A dense network of channels and a compact basin collect runoff quickly and deliver a sharp flood peak. In the closely dissected Kondoa catchments water concentrates fast, whereas a long thin basin spreads the flow over time.

The generation of surface runoff is therefore controlled by the slope, the vegetation and land use, the soil and rock, the antecedent moisture and the character of the rainfall. Because the bare overgrazed slope

combines compacted soil and no cover, it sheds storm water at once, while the forest slope absorbs and slowly releases it.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is distinguishing storm factors such as intensity from surface factors such as cover and soil, each tied to its effect on the runoff balance.

Question 141

Groundwater is the water held beneath the surface in the pore spaces and cracks of rock and soil. Its occurrence is organised into zones above and below the water table, and although every soil and rock has pore spaces holding water, the amount varies from place to place for reasons of rock, relief and supply.

The zone of aeration. Below the surface lies a zone in which pore spaces hold both air and some water but are not full. The dry crumbly material the Dodoma borehole first passed through is this zone, where water is held loosely and can move downward under gravity.

The zone of saturation. Beneath the zone of aeration every pore space is completely filled with water. The dripping saturated sand the drill struck on the Dodoma plains marks this zone, the true groundwater store from which wells draw their supply.

The water table as the dividing surface. The water table is the upper surface of the zone of saturation, below which the ground is permanently waterlogged. Its depth varies between sites and seasons, which is why boreholes strike water at different depths across the Dodoma plains.

Porosity determines how much water can be held. Porosity is the proportion of pore space in a rock, and it sets the volume that can be stored. The well sorted sandstones near Dar es Salaam have many pores and hold much water, whereas the dense basement granite of central Tanzania has few, so storage varies with rock type.

Permeability determines how water moves and collects. Permeability is the ease with which water passes through a rock. The permeable coastal sands near Tanga both store and transmit water freely, while a clay layer holds water yet barely transmits it, so recharge and the gathering of water differ from place to place.

Nature of the underlying rock. Where the bedrock is porous and permeable, as in parts of the coastal sedimentary belt near Dar es Salaam, abundant groundwater collects. Over the impermeable basement that underlies much of central Tanzania, pore water is scarce, explaining the wide variation.

Relief and the depth to the water table. Beneath valleys the water table lies near the surface and groundwater is plentiful, while beneath hills it lies deep. So on the Dodoma plains a borehole in a low lying site strikes water sooner than one on higher ground nearby.

Recharge from rainfall and rivers. Groundwater is replenished where rain infiltrates or rivers lose water to the ground. A well watered, well vegetated catchment recharges its store generously, whereas a dry, sealed or steeply sloping area recharges little, so supply varies with input.

Discharge through springs, wells and evaporation. Groundwater is lost where springs flow, wells are pumped and shallow water tables evaporate. Heavy abstraction around Dodoma or strong evaporation lowers the store and the water table locally, further altering how much pore water remains.

Groundwater therefore occurs in a zone of aeration above a zone of saturation, divided by the water table. The amount held in the pores varies because porosity and permeability differ between rocks, relief sets the depth to water, and recharge and discharge differ between places, exactly as the examiners noted that every rock holds water but in differing amounts.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is separating porosity from permeability and using both to explain why pore water varies spatially.

Question 142

Groundwater reaches the surface either where the water table is exposed, as at a spring, or where confined water is held under pressure, as in an artesian basin. The structure of the rocks decides which conditions occur, and the resulting supplies are of great value to settlement and farming in dry areas of Tanzania.

A basin or synclinal structure for artesian water. An artesian supply requires the permeable aquifer to be folded into a saucer or syncline so its edges stand higher than its centre. Water gathered in the dip is then held with its edges above the lowest point, the first condition for natural flow.

Confining layers above and below the aquifer. The aquifer must lie between impermeable layers that seal it, so the water cannot escape upward and is held under hydrostatic pressure. Without this confinement the water would simply rise to the water table and no pressure would build.

An exposed intake area at higher ground. The upturned edge of the aquifer must outcrop in a higher, wetter zone where rain can enter and recharge it. This raised intake supplies the head of water whose weight drives the pressure felt lower down in the basin.

The artesian well. When a bore is sunk through the upper confining layer, the confined water, pressed by the higher intake, rises to the surface unaided. Such self flowing supplies are valuable where they occur in confined coastal and basin aquifers because they need no pumping.

Springs where the water table meets the surface. Where the land surface cuts the water table, groundwater flows out as a spring. Springs emerge along valley sides and at the foot of highlands such as the Usambara Mountains, providing reliable clean water for nearby villages.

Ordinary wells in unconfined aquifers. In an unconfined aquifer a well must be dug or bored below the water table and the water lifted out. Across the Dodoma plains shallow wells and boreholes tap such groundwater, but their yield depends on the depth and richness of the local aquifer.

Reliable dry season water supply. Groundwater is replenished in the wet season but can be drawn in the dry season when rivers shrink. It therefore gives interior settlements and livestock around Dodoma and the semi arid central plateau a dependable supply when surface water has failed.

Support for irrigation and livestock. Boreholes and wells allow small scale irrigation and watering of herds far from any river, opening dry rangelands such as the Maasai Steppe and parts of central Tanzania to settlement and farming that surface water alone could not sustain.

Risks of over abstraction and pollution. If water is pumped faster than the aquifer is recharged the water table falls, springs fail and the supply may not be replaced, while seepage of waste can pollute it. Around heavily used boreholes near Dodoma the water table has fallen, showing groundwater must be used within the limit of its recharge.

Artesian basins arise from a confined aquifer in a syncline fed by a higher intake, while springs and ordinary wells tap groundwater where the water table is reached. These supplies are of great value, giving dry interior Tanzania reliable water for people, livestock and irrigation, provided abstraction is kept within the rate of natural recharge.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is the three structural conditions for artesian flow, kept distinct from the ordinary spring and well supplies.

Question 143

A drainage pattern is the plan arrangement of the streams in a basin, and it is the rock and relief structure that determines how each pattern develops. Differences in rock resistance, in the lines of weakness and in the shape of the land guide where streams cut their courses and so create the recognisable patterns.

Dendritic pattern on uniform rock. Where rocks are of fairly uniform resistance and offer no strong structural guide, streams branch freely in a tree like network. The broad uniform basement plains of central Tanzania around Tabora carry such dendritic drainage, the streams following the general slope.

Trellis pattern on folded rocks. Where hard and soft rocks alternate in parallel folded ridges, the main rivers run along the weak outcrops and short tributaries join at right angles. In the folded and faulted ridges of the Usambara Mountains this trellis pattern reveals the underlying parallel structure.

Rectangular pattern on jointed rock. Where rock is crossed by two sets of joints or faults meeting at right angles, streams exploit these lines of weakness and bend sharply. On the heavily jointed basement granite around Dodoma the rectangular pattern is a direct print of the joint and fault structure.

Radial pattern on domes and cones. On an isolated dome or volcanic cone the surface slopes outward in every direction, so streams radiate from the summit. The flanks of Mount Kilimanjaro show this radial pattern, the streams obeying the conical relief.

Centripetal pattern in enclosed basins. Where relief forms a closed depression, streams flow inward toward the lowest point instead of out to the sea. The drainage converging inward toward Lake Eyasi in its fault and deflation basin is centripetal, controlled by the enclosing relief.

Annular pattern on an eroded dome. When a dome is worn down to expose concentric rings of hard and soft rock, streams follow the weak rings and curve around the structure. The resulting ring like annular pattern again reflects the arrangement of the underlying rocks.

Consequent and subsequent streams and structure. The first streams to follow the original slope are consequent, while subsequent streams later develop along lines of weak rock such as a fault or soft band. Their interplay along the structure builds the trellis and rectangular forms of the fold country.

Antecedent and superimposed drainage. Some rivers keep a course that predates the present structure: an antecedent river cuts down as the land rises across its path, while a superimposed river imposes a pattern inherited from rocks now removed. Both seem to defy the visible structure.

Relief and slope as the overall guide. Beyond rock structure, the general slope of the land sets the direction in which water gathers and flows. The regional tilt toward the Indian Ocean guides the great rivers such as the Rufiji eastward, framing the local patterns within the broad relief.

Drainage patterns are therefore the surface expression of the rocks and relief beneath them: uniform rock gives dendritic drainage, folded and jointed rock gives trellis and rectangular forms, and domes and basins give radial, annular and centripetal patterns. Exactly as the examiners observed, it is the structure of rock and relief that determines how each pattern develops.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is naming the controlling structure or relief behind each pattern, not merely describing the pattern's shape.

Question 144

A drainage system describes how the streams of an area relate to the rock structure and to the history of the land. Streams may develop in step with the existing structure or may inherit a course from an earlier surface, and these origins explain why some rivers obey the rocks while others appear to ignore them.

Consequent streams. Consequent streams are the first to form, flowing in the direction of the original slope. As the regional surface tilts toward the Indian Ocean, master rivers such as the Rufiji follow that slope eastward, their courses a direct consequence of the initial relief.

Subsequent streams. Subsequent streams develop later along lines of weakness, picking out a fault or a band of soft rock at an angle to the consequent stream. Tributaries that have eaten headward along faulted weaknesses in the Tanzanian basement extend the network along the structure.

Obsequent streams. Obsequent streams flow opposite to the original consequent slope, often down a steep scarp face toward a subsequent valley. Short steep streams draining the inward facing scarps of the rift shoulders near Lake Tanganyika illustrate this back slope drainage.

Resequent streams. Resequent streams flow in the same direction as the original consequent slope but develop later, at a lower level, after further dissection. On the dissected plateau surfaces of central Tanzania they reinforce the original drainage direction on the new surface.

Antecedent drainage. An antecedent river already existed before the land was uplifted across its path, and it kept its course by cutting down as fast as the ground rose. Where rivers such as the Pangani cross rising ground in steep gorges, the course seems to defy the structure.

Superimposed drainage. A superimposed river developed its pattern on an upper cover of rock since eroded away, letting the river cut down and impose that inherited pattern on quite different rocks beneath. It therefore crosses hard ridges without regard to the present structure.

Accordant drainage that obeys structure. Where streams have adjusted fully to the rocks, the pattern is accordant: rivers follow the soft outcrops and avoid the hard ones. Across the uniform basement plains around Tabora the drainage closely reflects the underlying geology in this mature condition.

Discordant drainage that ignores structure. Antecedent and superimposed rivers produce discordant drainage that cuts across the structure. Where the Pangani slices through resistant ground in a gorge, this is the field clue that a river is older than, or inherited above, the rocks it now crosses.

The role of base level and uplift. Changes in base level and episodes of uplift renew the cutting power of rivers and allow resequent and antecedent forms to develop. Regional uplift along the East African plateau has rejuvenated rivers, helping to explain gorges and incised courses.

The drainage systems of an area thus range from consequent, subsequent, obsequent and resequent streams that develop in relation to slope and structure, to antecedent and superimposed rivers that inherit older courses. Recognising whether drainage is accordant or discordant reveals how far the rivers have adjusted to the rocks and how the land has evolved.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is the accordant against discordant contrast, especially distinguishing antecedent from superimposed drainage by their origin.

Question 145

The regime of a river is the pattern of its discharge through the year, ranging from perennial flow that lasts all year, through intermittent flow that ceases in the dry season, to ephemeral flow that follows single storms. This is governed by the climate, the catchment and the stores that feed the channel, which explain why the Pangani flows always while the Great Ruaha may dry to sand.

Seasonal distribution of rainfall. A river's flow reflects when and how much rain falls on its basin. Where rain comes in a short wet season, as over much of the Great Ruaha catchment, discharge is high in the rains and falls away sharply in the long dry season.

Reliability of the rainfall source. A catchment fed by reliable highland rain keeps flowing all year, giving a perennial regime. The Pangani draws on the dependable rains of Kilimanjaro and the northern highlands, so it remains a perennial river even in the dry months.

Contribution of groundwater base flow. Where a permeable catchment stores water and releases it slowly, base flow sustains the river between storms. The Pangani, fed by springs and base flow from the Kilimanjaro highlands, stays perennial, whereas a river over impermeable rock with little storage may dry up.

Evaporation losses in the dry season. High temperatures in the dry season evaporate water from the channel and the catchment. In the hot Ruaha lowlands intense evaporation helps to dry stretches of the bed to sand, deepening the seasonal contrast in flow.

Melting of snow and ice on high mountains. On the highest mountains seasonal melt adds to flow in the warmer months. The streams rising on the glaciated summit of Kilimanjaro receive a small contribution from melt that helps to maintain dry season flow in their upper courses.

Geology and permeability of the basin. An impermeable basement catchment sheds rain quickly and stores little, so its rivers rise and fall sharply with the rains, as in much of the Great Ruaha basin. A permeable catchment stores water and evens out the flow into a steadier regime.

Vegetation cover of the catchment. A well vegetated catchment slows runoff, encourages infiltration and feeds base flow, smoothing the regime. A cleared catchment such as parts of the Usangu plains sheds water rapidly in the rains and dries quickly afterwards, sharpening the swing.

Human abstraction and storage. Diversions for irrigation and dams alter the natural regime. Heavy abstraction in the Usangu wetlands upstream has reduced dry season flow in the Great Ruaha, while reservoirs such as Mtera even out the discharge passed downstream.

Size and shape of the drainage basin. A large basin gathers water from many sources and tends to flow more steadily, while a small basin responds quickly to single storms. The huge Rufiji basin draws on many tributaries and flows the year round, whereas small interior catchments may flow only after a storm.

The regime of a river is therefore set by the seasonality and reliability of its rainfall, the base flow from groundwater, evaporation, the geology and vegetation of its basin, and human use. Because the Pangani enjoys reliable highland supply and base flow it is perennial, while the Great Ruaha, drained by seasonal rain, use and evaporation, falls to an intermittent regime.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is connecting the named factors to the perennial, intermittent and ephemeral classes rather than describing one river in isolation.

Question 146

A lake is a body of water occupying a hollow in the land surface, and they are best classified by the process that created their basins. Tanzania, lying across the East African Rift, offers basins formed by earth movement, by vulcanicity, by erosion, by deposition and by human activity, illustrating almost every mode.

Tectonic rift faulting. Tension in the crust drops a long block of land between parallel faults to form a deep narrow trough. Lake Tanganyika occupies such a rift, which gives it great depth and steep straight sides, the classic form of a tectonic rift lake.

Downwarping of the crust. A broad gentle sag of the crust between the two arms of the rift creates a shallow saucer shaped basin. Lake Victoria lies in such a downwarp, which is why it is enormous in area yet shallow compared with the rift lakes.

Faulting and a separate rift trough. A second arm of the rift holds Lake Nyasa in a deep faulted trough, while the smaller Lake Rukwa lies in a shallower fault depression. These confirm that crustal movement is the dominant lake forming process in Tanzania.

Vulcanicity forming crater and caldera lakes. Volcanic activity creates basins where water fills a crater or caldera. The crater lakes among the Momela lakes near Arusha sit in old volcanic hollows, and a caldera may hold a deep circular lake where its floor lies below the water table.

Lava damming of valleys. A lava flow can block a valley and pond the river behind it to form a lake. Such volcanic damming has created lake basins in the volcanic highlands of northern Tanzania, where flows have crossed and blocked drainage lines.

Erosion forming hollows. Erosional hollows, scoured by deflation or by other agents, may hold water. The shallow seasonal water of Lake Eyasi occupies a basin formed by faulting combined with deflation in a dry hollow, partly an erosional origin.

Deposition forming ox bow lakes and lagoons. Deposition can cut off bodies of water; a meandering river abandons a loop to leave an ox bow lake, as on the floodplain of the lower Rufiji, while coastal deposition can seal off a lagoon behind a bar on the Indian Ocean shore.

Classification by water chemistry. Lakes may also be grouped by their water as fresh or saline; freshwater lakes such as Victoria and Tanganyika have an outlet, whereas closed basins with no outlet and high evaporation become soda lakes, as Lake Natron and Lake Eyasi.

Man made reservoirs. People dam rivers to impound water for power and irrigation, creating artificial lakes. The Mtera reservoir on the Great Ruaha and the Nyumba ya Mungu reservoir on the Pangani are large man made lakes, a deliberate human mode of formation.

The lakes of Tanzania can therefore be classified by their mode of formation into tectonic rift and downwarp lakes, volcanic crater and lava dammed lakes, erosional and depositional lakes, and man made reservoirs, with a further division by chemistry into fresh and soda lakes. This variety reflects the country's position across the dynamic East African Rift, exactly as the examiners required.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is grouping by clear process with a correctly matched lake, especially separating rift faulting from downwarping.

Question 147

Lakes are among Tanzania's most valuable natural resources, supplying water, food, transport, power and rainfall to surrounding regions. Yet the same lakes face mounting pressures from pollution, invasive species, falling levels and overuse, so their value must be weighed against the threats that endanger them.

Source of water for domestic and farm use. Lakes supply water for towns, livestock and irrigation. Lake Victoria provides domestic and agricultural water for the densely settled regions around its shores, sustaining cities such as Mwanza and the farming of the lake basin.

Fisheries and food supply. Lakes are rich fishing grounds that feed people and provide income. The Nile perch and tilapia fisheries of Lake Victoria support a large fishing and export industry, while Lake Tanganyika yields the valuable *dagaa* sardine catch.

Transport and communication. Large lakes serve as natural highways for ferries and cargo. Lake Victoria and Lake Tanganyika carry passenger and goods traffic between lakeside ports, linking regions that roads reach only with difficulty.

Hydro electric power generation. Rivers and reservoirs linked to lake systems generate electricity. The Mtera reservoir on the Great Ruaha supports hydro power for the national grid, and lake fed rivers are central to Tanzania's electricity supply.

Influence on local climate and rainfall. Great lakes add moisture to passing air and encourage rainfall on their margins. The Lake Victoria basin around Bukoba is among the wettest parts of the country because the lake feeds moisture and convection to the surrounding land.

Tourism and biodiversity. Lakes attract tourists and shelter unique wildlife. The soda water of Lake Natron is a key breeding ground for flamingos, and the rift lakes harbour many endemic fish species, drawing visitors and supporting conservation value.

Pollution from towns and farms. Sewage, industrial waste and farm chemicals drain into lakes and degrade their water. Nutrient rich runoff entering Lake Victoria has caused algal growth and falling oxygen, harming fish and the people who depend on the lake.

Invasive species and weed infestation. Introduced plants and animals can upset the lake ecosystem. The water hyacinth has choked bays of Lake Victoria, blocking landing sites and starving the water of oxygen, while the introduced Nile perch altered its native fish community.

Falling levels, siltation and over fishing. Drought, abstraction and silt washed from eroded catchments lower lake levels and smother habitats, while over fishing depletes the stocks. Together these reduce the catch and the storage of lakes such as Victoria and Rukwa, threatening their long term value.

Lakes are therefore of immense importance to Tanzania, providing water, food, transport, power, rainfall and tourism, but they are increasingly threatened by pollution, invasive weeds, over fishing and falling

levels. Protecting catchments and controlling pollution and harvesting are essential if these resources are to keep serving the nation.

Examiner's Note

The question asks for eight points; any eight earn full marks. As an assess question the strongest scripts balance several uses against several threats rather than dwelling only on one side.

Question 148

Wetlands are areas of land that are permanently or seasonally waterlogged, including the marshes and swamps of floodplains and the bogs and fens of wetter highlands. They are of great ecological and economic value, yet across Tanzania they face mounting threats.

Water storage and flood control. Wetlands act as natural sponges, soaking up flood water and releasing it slowly. The Kilombero floodplain stores the rains and feeds the river through the dry season, reducing downstream flooding and sustaining flow when rivers would otherwise fall.

Fisheries and food supply. Shallow wetland waters are rich breeding grounds for fish that feed local communities. The Malagarasi and Kilombero wetlands support important fisheries, providing protein and income to the people living along their margins.

Grazing and farming land. Wetland margins offer fertile soil and dry season pasture. Herders bring cattle to graze the Usangu and Kilombero plains as the surrounding land dries, and the moist alluvial soils support rice and other crops.

Biodiversity and wildlife habitat. Wetlands shelter a great variety of plants, birds and animals. The Kilombero valley is a refuge for waterbirds and for rare large mammals, while soda wetlands such as Lake Natron host vast flamingo breeding colonies.

Water purification and recharge. By trapping sediment and absorbing nutrients, wetlands cleanse the water passing through them and allow some to recharge groundwater. This natural filtering improves the quality of water reaching rivers and lakes downstream.

Drainage for agriculture as a threat. Wetlands are dug out and drained to win land for crops, the chief threat of all. The spreading rice and sugar schemes are draining and shrinking the Kilombero floodplain, destroying its natural functions.

Pollution and siltation. Fertilisers, pesticides and eroded soil washed from surrounding farmland poison and choke the wetland. Such inflow degrades the water of the Malagarasi wetlands and smothers the habitat on which the fisheries depend.

Overgrazing and burning. Too many livestock trample the soil and strip the vegetation, while repeated burning destroys the wetland plants. Heavy grazing on parts of the Usangu plains degrades the wetland and exposes the soil to erosion.

Over abstraction and upstream dams. Diverting water for irrigation and holding it behind dams reduces the flooding that the wetland needs. Heavy abstraction upstream has dried parts of the Usangu wetland, shrinking the very floods that maintain its life.

Wetlands are therefore of great value, storing water, supporting fisheries and grazing, sheltering wildlife and cleansing water, yet they are gravely threatened by drainage, pollution, overgrazing and over abstraction. As the examiners stressed, safeguarding wetlands such as Kilombero against these threats is vital for both people and the environment.

Examiner's Note

The question asks for eight points; any eight earn full marks. The strongest scripts give roughly balanced attention to value and threats and explain the mechanism of each threat.

Question 149

Ocean water is in constant motion, expressed as waves that break on the shore, tides that rise and fall, and currents that flow steadily across the sea. This movement is driven by the winds, the gravitational pull of the Moon and Sun, and differences within the water itself, all of which keep the sea off the Tanzanian coast in perpetual motion.

Wind blowing over the surface. Wind dragging across the sea transfers energy to the surface and is the chief driver of waves and surface currents. The steady monsoon winds over the Indian Ocean raise the waves that break along the Dar es Salaam shore and help drive the coastal currents.

Gravitational pull of the Moon and Sun. The pull of the Moon, aided by the Sun, draws the ocean into bulges that sweep round the Earth as tides. This is why the sea at Tanga rises and falls twice each day, flooding and draining the creeks and mangroves on the tide.

Spring and neap tidal variation. When the Moon and Sun pull in line their combined force gives high spring tides, but when they pull at right angles the weaker neap tides result. This alternation changes the height and reach of the tide along the Tanga coast through the month.

Differences in water temperature. Warm water is less dense and tends to flow toward and over colder, denser water, setting up movement. Contrasts between the warm tropical surface water of the Indian Ocean and cooler water at depth drive part of the ocean's circulation.

Differences in salinity and density. Saltier water is denser and sinks beneath fresher water, while fresher water spreads on top. These density contrasts, alongside temperature, drive deep and slow movements of water within the ocean as part of the wider circulation.

Prevailing winds driving major currents. The planetary wind belts push the surface water into great steady currents. The monsoon driven circulation of the Indian Ocean steers warm water along the East African coast, producing the persistent coastal current felt off Tanzania.

Deflection by the rotation of the Earth. The Earth's rotation deflects moving water, to the right in the northern hemisphere and to the left in the southern, through the Coriolis effect. This turning helps to organise the currents into large circulating systems rather than straight flows.

Shape of coastlines and the sea floor. Coastlines, channels and the relief of the sea bed guide and concentrate moving water. The configuration of the East African coast and its offshore channels steers the currents and shapes how the tide enters the bays and creeks around Tanga.

Underwater disturbances generating waves. Submarine earthquakes and landslides can suddenly displace water and send out large waves. Although rare, such disturbances in the Indian Ocean can move great volumes of water and reach the Tanzanian coast, a further cause of ocean movement.

The movement of ocean water is therefore driven chiefly by the wind, which raises waves and surface currents, by the gravitational pull of the Moon and Sun, which causes the tides, and by differences of temperature and salinity, guided by the Earth's rotation and the shape of the basin. Together these keep the sea along the Tanga coast in ceaseless motion, exactly as the examiners required.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is separating the three forms of movement, waves, tides and currents, and naming the distinct force behind each.

Question 150

Global winds and ocean currents work together to redistribute heat and moisture around the Earth, and their effect on the temperature and rainfall of coastlands is profound. Warm and cold currents, steered by the planetary winds, warm or cool the air above them and encourage or suppress rainfall on the coasts they wash.

Currents transfer heat between latitudes. Ocean currents carry warmth from the tropics toward higher latitudes and cold water toward the Equator. This transfer moderates the temperature of the coasts they pass, spreading the Sun's unevenly received heat more evenly around the globe.

Warm currents raise coastal temperatures. A warm current warms the air above it, so the coast it washes is mild. The warm current along the East African coast keeps the shore at Tanga and Dar es Salaam warm and equable throughout the year, with a small annual range.

Warm currents encourage rainfall. Air over a warm current is heated, holds more moisture and rises readily, so onshore winds bring rain. The warm water off the East African coast supplies moist, unstable air that contributes to the relatively high rainfall of the coastal belt.

Cold currents lower coastal temperatures. A cold current chills the air above it, cooling the coast it borders. The cold Benguela current off south west Africa keeps that coast distinctly cool for its latitude, in sharp contrast to the warm East African shore.

Cold currents suppress rainfall and cause aridity. Air over a cold current is cooled from below, becomes stable and resists rising, so little rain falls and coastal deserts form. The cold current off south west Africa helps create the arid Namib coast, showing how currents can dry a coastland.

Winds carry the maritime influence inland. The effect of a current is felt on land only where winds blow onshore. The onshore monsoon winds carry the warmth and moisture of the warm Indian Ocean current onto the East African coast, while offshore winds would leave the land dry.

Cold currents and coastal fog. Where warm moist air drifts over a cold current it is chilled to its dew point, forming advection fog rather than rain. Such fog is common over cold current coasts such as the Namib, delivering moisture as fog while true rainfall remains very low.

The monsoon reversal and seasonal rainfall. The seasonal reversal of the monsoon winds over the Indian Ocean changes the direction of moisture flow, giving the East African coast its wet and dry seasons. The wetter season comes when winds blow onshore from the warm ocean.

Combined effect on coastal climate type. Where warm currents and onshore winds coincide, the coast is warm and wet, as in East Africa; where cold currents and stable air coincide, the coast is cool and dry, as in south west Africa. The pairing of wind and current shapes the whole coastal climate.

Global winds and ocean currents therefore govern coastal climate by transferring heat and moisture: warm currents with onshore winds make coasts warm and wet, as on the East African shore, while cold currents with stable air make coasts cool and dry, as in south west Africa. As the examiners required, it is the partnership of wind and current that decides the temperature and rainfall of a coastland.

Examiner's Note

The question asks for eight points; any eight earn full marks. The discriminator is the contrast between warm and cold current coasts and the insistence that winds must blow onshore for the current's effect to reach the land.

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