Cambridge AS & A Level · Geography 9696 · Notes

Rocks and weathering AS

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What you need to know

By the end of this topic you should be able to:

1. **Describe the nature of tectonic plates and their global pattern**: what a plate is, how oceanic and continental plates differ, where the main plates are and what makes them move.
2. **Describe the types of plate boundary**: divergent (constructive), conservative, and convergent (destructive), including the collision of two continents.
3. **Explain the tectonic processes and the landforms they make**: sea floor spreading, subduction, fold mountain building, ocean ridges, ocean trenches and volcanic island arcs.
4. **Explain the physical (mechanical) weathering processes**: freeze–thaw, heating/cooling, salt crystal growth, pressure release (dilatation) and vegetation root action.
5. **Explain the chemical weathering processes**: hydrolysis, hydration and carbonation.
6. **Explain the general factors that affect the type and rate of weathering** (climate, rock type, rock structure, vegetation and relief) and the **specific factors**, temperature and rainfall, using the **Peltier diagram**.
7. **Explain the slope processes**: the conditions under which each happens and its effects on slopes. Mass movement by **heaves, flows, slides and falls**, and the movement of water and sediment by **rainsplash** and **surface runoff (sheetwash and rills)**.
8. **Explain how human activity can decrease or increase the stability of slopes**, and the strategies that modify slopes to reduce mass movement: **pinning, netting, grading and afforestation**.
9. **Use a case study** of the impacts of human activity on slopes, showing the effect on slope stability, and evaluate attempts to reduce mass movement.

It is examined in Paper 1: a compulsory 10-mark resource question (Question 3) and an optional 30-mark structured question (Question 6).

Understand it

Tectonic plates

The Earth's outer shell, the **lithosphere**, is the crust plus the rigid top of the mantle, about 100 km thick. It is broken into large slabs called **tectonic plates**, which float on the hotter, partly molten and slowly flowing **asthenosphere** beneath. There are seven large plates (Pacific, North American, South American, Eurasian, African, Indo-Australian and Antarctic) and many smaller ones (such as the Nazca, Cocos, Caribbean, Philippine, Arabian and Juan de Fuca plates). They move a few centimetres a year, about as fast as fingernails grow. Most earthquakes, volcanoes and young mountain ranges lie along their edges, the **plate boundaries**, and the ring of boundaries around the Pacific (the "Ring of Fire") holds most of them.

Plates are made of two kinds of crust:

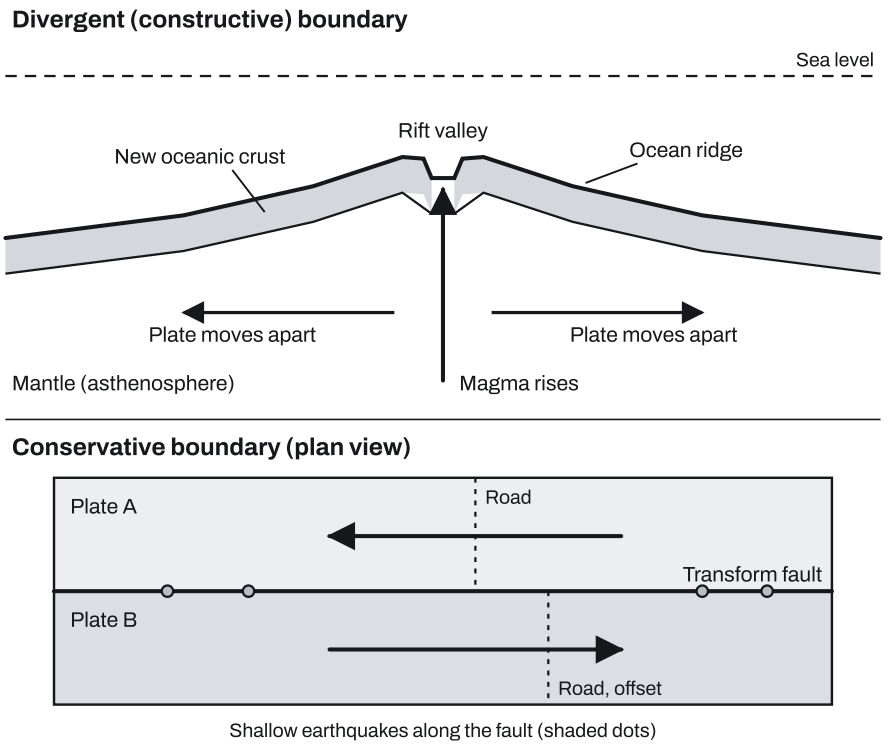
	Oceanic crust	**Continental crust**
Main rock	Basalt (dark, rich in iron and magnesium)	Granite and similar rocks (light, rich in silica)
Density	About 3.0 g/cm^3 (denser)	About 2.7 g/cm^3
Thickness	About 7 km (5–10 km)	About 35 km on average, up to 70 km under mountains
Age	Young: nowhere older than about 200 million years	Old: parts are about 4 billion years old
Fate at a boundary	Can sink (subduct) and be destroyed	Too buoyant to sink; it crumples instead

Say **denser**, not "heavier": a thick continent can weigh more than a thin ocean floor, yet it is less dense.

Why plates move. Three forces work together:

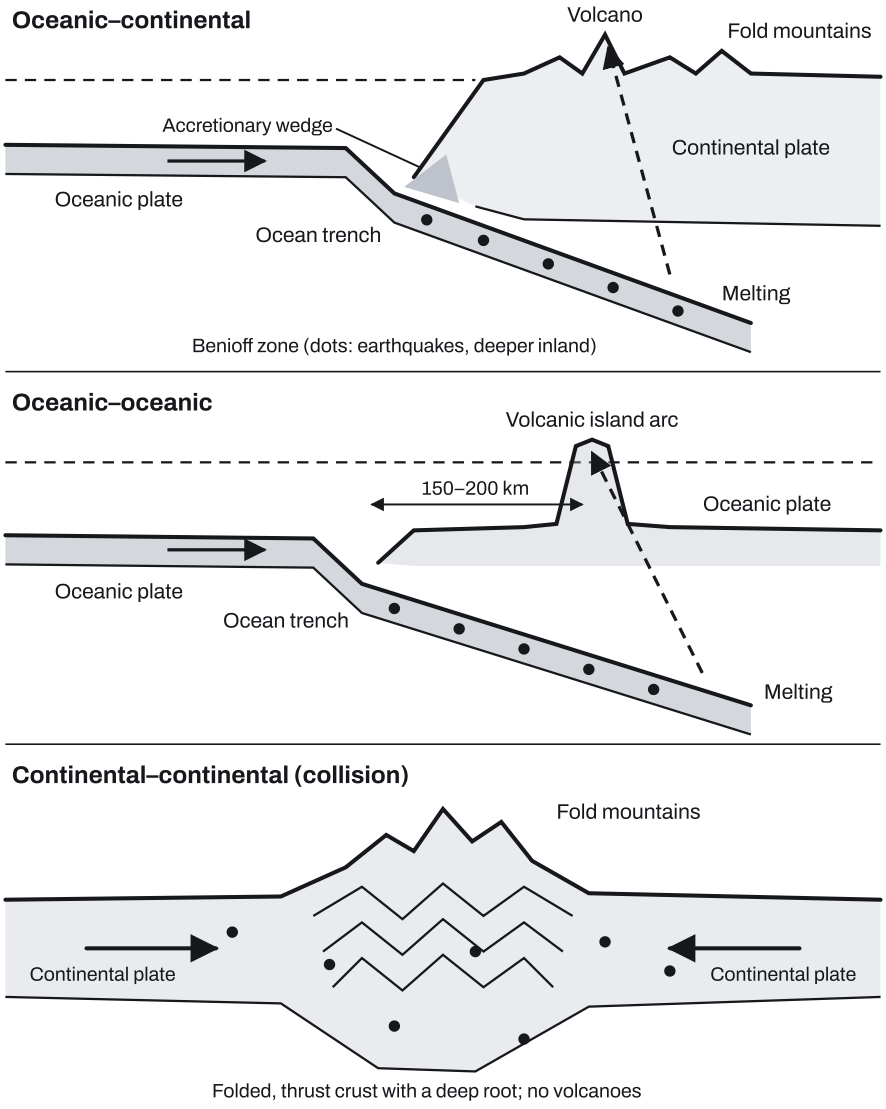
- **Convection currents** in the mantle: heat from the core makes hot mantle rock rise, spread sideways under the plates and sink again as it cools, dragging the plates along.
- **Ridge push**: new crust at an ocean ridge is hot and stands high; as it cools it becomes denser and slides down and away from the ridge.
- **Slab pull**: at a subduction zone, the cold, dense sinking edge of a plate pulls the rest of the plate after it. Today this is thought to be the strongest of the three.

Types of plate boundary



Shallow earthquakes along the fault (shaded dots)

- **Divergent (constructive)**: two plates move **apart**. Magma rises into the gap and new crust is made. Under the oceans this builds **ocean ridges** (the Mid-Atlantic Ridge, with Iceland on top of it); on land it splits a continent along a **rift valley** (the East African Rift). Earthquakes are shallow and mostly small; eruptions are of runny basalt lava from fissures and shield volcanoes.
- **Conservative (transform or passive)**: two plates slide **past** each other, in opposite directions or in the same direction at different speeds. No crust is made or destroyed and there are no volcanoes, but the plates lock, stress builds up and is released in **shallow, often powerful earthquakes**. Example: the San Andreas Fault, California, between the Pacific and North American plates.
- **Convergent (destructive)**: two plates move **towards** each other. If one is oceanic, the denser oceanic plate **subducts** (sinks) under the other, making trenches, volcanoes and fold mountains. If both are continental, neither subducts and they **collide**, making fold mountains only.



Tectonic processes and their landforms

Sea floor spreading happens at divergent boundaries under the ocean. As the plates move apart, the pressure on the mantle beneath falls, so some of it melts. The magma rises into the gap, erupts or cools to form new oceanic crust, and the new crust is carried away on both sides as more is added behind it. So the ocean floor gets **older with distance from the ridge**, in the same pattern on both sides. The Atlantic widens by about 2.5 cm a year in this way.

Ocean ridges are long underwater mountain chains along divergent boundaries, rising 2–3 km above the ocean floor. They stand high because the new rock is **hot and expanded**; it sinks lower as it cools and moves away. Along their crest runs a **rift valley**, where the crust is pulled apart and blocks drop down between faults, and transform faults cut across them at right angles.

Subduction happens where an oceanic plate meets another plate. The denser oceanic plate is forced down, usually at 30–60°, into the mantle. It is pulled by its own weight (slab pull) and helped by convection currents. As it sinks, friction makes earthquakes along a dipping band called the **Benioff zone**: shallow near the trench, deeper further from it, down to about 700 km. At about 100 km down, water driven out of the sinking plate

lowers the melting point of the mantle above it, so rock melts. The magma is less dense than the rock around it, so it rises, collecting in chambers and erupting at the surface as explosive, sticky (andesitic) lava from **composite volcanoes**.

Ocean trenches are long, narrow, steep-sided **V-shaped** troughs in the ocean floor where the subducting plate bends down. They are the deepest places on Earth: the Mariana Trench in the western Pacific is about 11 km deep, and the Peru–Chile Trench runs along the west coast of South America, where the Nazca plate subducts under the South American plate. They are found at **both** oceanic–continental and oceanic–oceanic boundaries, always on the side of the subducting plate. The overriding plate is also dragged down and buckled near the trench. Sediment scraped off the sinking plate piles up against the overriding plate as an **accretionary wedge**.

Volcanic island arcs form where **two oceanic plates** converge. The denser (usually older and colder) plate subducts and melts at depth; the magma rises through the overriding oceanic plate and builds volcanoes on the sea floor, which grow until they break the surface as islands. The islands form a chain about 150–200 km from the trench, on the overriding plate. The chain is **curved** because a boundary drawn on a sphere (the Earth's surface) and the bend of the sinking plate both follow an arc. Examples: the Mariana Islands (Pacific plate under the Philippine plate), the Aleutian Islands of Alaska, and the Lesser Antilles in the Caribbean, including Montserrat. **Hawaii is not an island arc**: it sits in the middle of the Pacific plate over a **hot spot**, a plume of hot mantle, and its islands form a straight line that gets older to the north-west.

Fold mountains form at convergent boundaries:

- **Oceanic–continental**: the edge of the continent is compressed and thickened as the oceanic plate subducts beneath it; sediments from the sea floor and the accretionary wedge are crumpled onto it, and rising magma adds volcanoes. The Andes, with volcanoes such as Cotopaxi, formed this way.
- **Continental–continental (collision)**: once the ocean between two continents has been subducted, the continents meet. Both are too buoyant to sink, so the crust and the sediments between them are **compressed, folded, faulted and thrust** over each other, and pushed up into high mountains with a deep root beneath. The Himalayas are still rising as the Indo-Australian plate pushes north into the Eurasian plate at about 5 cm a year; Mount Everest is 8849 m high. There are **no volcanoes**, because no plate sinks deep enough to melt.

Mountains are **young** (formed in the last 65 million years or so) where the boundary is still active; older ranges such as the Urals mark boundaries that are no longer active.

Earthquake patterns at each boundary, often shown on a figure:

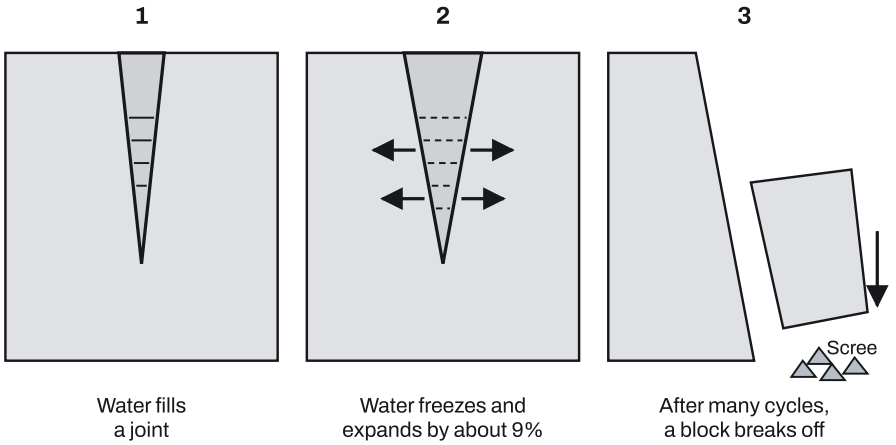
Boundary	Earthquakes
Divergent	Shallow only (under about 30 km), fewest and mostly small, in a narrow band along the ridge
Conservative	Shallow only, many and often strong, along the fault
Convergent with subduction	Shallow near the trench, getting deeper along the Benioff zone, down to about 700 km: the deepest of all

Boundary	Earthquakes
Collision	Many, shallow and some deeper ones spread over a wide zone, because stress builds through the whole thickened, crumpled crust; not as deep as at subduction zones

Weathering

Weathering is the breakdown of rock **in place** (in situ), at or near the Earth's surface, by the weather, plants and chemical reactions. Nothing is carried away by it; that is **erosion**. Weathering is the first step in making soil and in preparing loose material for mass movement and erosion. It is either physical, splitting the rock into smaller pieces of the same material, or chemical, changing the minerals into new substances.

Physical (mechanical) weathering



- **Freeze–thaw (frost shattering)**: water gets into joints, cracks and pores. When it freezes it **expands by about 9%**, putting great pressure on the rock around it. When it thaws, the water seeps deeper into the widened crack, and the next freeze pushes again. After **many repeated cycles** the rock splits and angular pieces break off, piling up as **scree** at the foot of the slope, or as blockfields on flat ground. It needs water, cracks, and temperatures that **swing above and below 0 °C** often, so it is strongest in mountains and cold (periglacial) regions in spring and autumn, such as the Alps and the Lake District, UK. Where it is always frozen, it stops.
- **Heating/cooling (thermal fracture, insolation weathering)**: rock is heated by the sun by day, so it **expands**, and cools at night, so it **contracts**. Rock conducts heat badly, so the outer layer heats and cools more than the inside, and stresses build up between them. The outer layers may peel off in sheets like the layers of an onion: **exfoliation** (onion-skin weathering). In a rock made of different minerals, dark minerals absorb more heat (lower albedo) and expand more than light ones, so grains loosen and crumble out: **granular disintegration**. It is strongest in **hot deserts**, where the daily range of temperature is often 20 °C or more and clear skies let rock cool fast at night; a little moisture speeds it up.
- **Salt crystal growth (salt weathering)**: water containing dissolved salts gets into the pores and cracks of a rock. When the water **evaporates**, salt crystals are left behind and **grow**, pushing on the rock until grains break off. Some salts also swell when they take up water or are heated. It is strongest in **hot deserts**,

where high temperatures cause rapid evaporation and groundwater draws salt to the surface, and on **coasts**, where sea spray supplies salt. It damages buildings and roads too.

- **Pressure release (dilatation, unloading)**: rocks such as granite form deep underground under the huge weight of the rock above. When the overlying rock is removed by erosion, or by melting ice sheets, the **pressure is released** and the rock **expands** upwards. Cracks open **parallel to the surface**, called **sheeting** joints (pseudo-bedding planes), and slabs split away, often leaving rounded domes such as Half Dome in Yosemite, USA. The joints let water in, so other weathering processes speed up.
- **Vegetation root action**: seeds land in cracks, and roots grow into the joints and bedding planes. As the roots thicken they **force the rock apart**, and the crack widens. Roots also hold water against the rock, which helps chemical weathering. (Plants also weather rock chemically: decaying leaves release **organic acids**, and lichens and mosses on rock surfaces break minerals down by **chelation**, where organic compounds bind to metal ions and pull them out of the minerals. This is often called biological weathering.)

Chemical weathering

Chemical weathering needs **water**, and like most chemical reactions it goes faster when it is **warmer**: a rough rule is that the rate doubles for every 10 °C rise in temperature.

- **Hydrolysis**: a reaction between minerals and water, in which hydrogen ions (H^+) in the water replace other ions in the mineral. The best example is **feldspar** in granite, which breaks down into a soft clay, **kaolinite** (china clay), while potassium and silica are carried away in solution. The quartz grains are left loose, so the granite rots into a crumbly mass of sand and clay. It explains the deep weathering of granite in the humid tropics, which can reach tens of metres down, and the china clay of Cornwall, UK.
- **Hydration**: minerals **absorb water** into their structure and **expand**. The swelling puts pressure on the rock around them, which weakens and breaks it apart. Examples: anhydrite takes up water and becomes gypsum; some clay minerals swell when wet and shrink when dry. Hydration often makes minerals easier to attack by other processes.
- **Carbonation**: rainwater dissolves carbon dioxide from the air and soil to form a weak acid, **carbonic acid**. This reacts with **calcium carbonate** in limestone and chalk, forming **calcium bicarbonate (calcium hydrogen carbonate)**, which is soluble and is carried away in solution:

$$\mathrm{CO_2 + H_2O \rightarrow H_2CO_3}$$
$$\mathrm{CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)_2}$$

It widens joints and bedding planes into grikes, leaving blocks (clints) between them: a limestone pavement, as at Malham, UK. Unlike most reactions, carbonation can be **fast in cold climates**, because cold water holds more carbon dioxide; soils rich in decaying plants add even more.

Factors affecting the type and rate of weathering

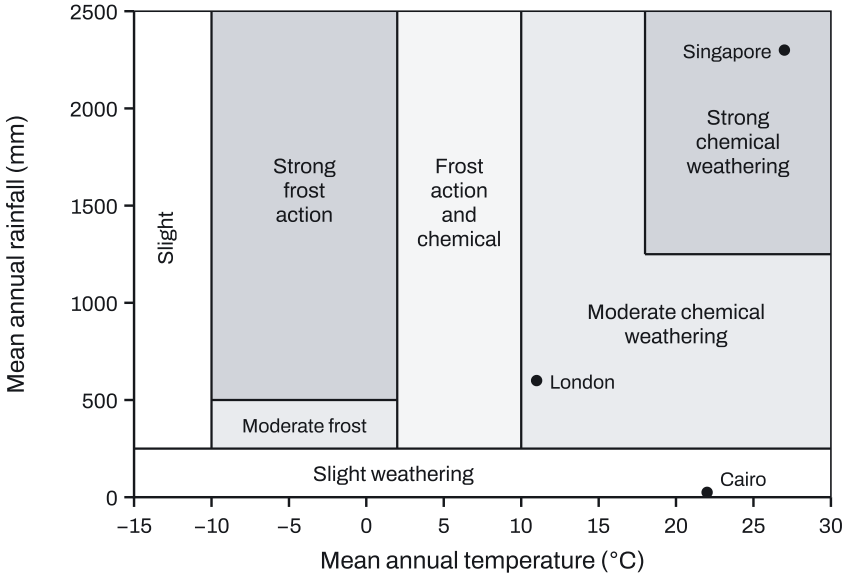
- **Climate**: temperature and rainfall decide which processes can work and how fast (see the Peltier diagram below). Water is needed by every chemical process and by freeze–thaw, salt growth and hydration; warmth speeds up chemical reactions; frequent swings across 0 °C drive freeze–thaw; a large daily range drives

heating/cooling.

- **Rock type (mineral composition)**: decides **which** chemical processes can act. Limestone and chalk (calcium carbonate) are attacked by carbonation; granite's feldspar by hydrolysis, while its quartz hardly weathers at all; basalt's iron-rich minerals weather quickly by hydrolysis and oxidation. Dark rocks absorb more heat for heating/cooling. Grain size matters too: coarse-grained rocks such as granite break down by granular disintegration more easily than fine-grained ones.
- **Rock structure**: **joints**, **bedding planes** and **faults** are lines of weakness that let water, roots and salt in, and they increase the **surface area** that chemical weathering can attack. Closely jointed rock weathers faster than massive rock. **Porosity** and **permeability** decide how much water a rock can hold or let through: porous chalk and sandstone take in water, so freeze–thaw and salt growth work through them. In granite, the spacing of the joints decides the shapes left behind: widely spaced joints leave large rounded blocks such as the tors of Dartmoor, UK.
- **Vegetation**: roots split rocks; plants keep the soil moist; decaying leaves add organic acids and carbon dioxide, so soil water is more acidic than rainwater and chemical weathering under forest is faster. But a thick plant cover also shields rock from big temperature changes, reducing heating/cooling and freeze–thaw.
- **Relief**: on **steep slopes**, weathered material is removed quickly by gravity, so fresh rock is always exposed, and water drains away fast; on **gentle slopes** and flat ground, weathered material stays and deep weathered layers (regolith) build up, holding water for chemical weathering. **Altitude** makes places colder, so freeze–thaw is common on mountains; **aspect** matters too, since sunny slopes have more freeze–thaw cycles and larger temperature swings.
- **Time**: the longer a rock is exposed, the more it is weathered.

The Peltier diagram

The **Peltier diagram** (after the geomorphologist Louis Peltier, 1950) shows which weathering is most likely in a climate from just two numbers: the **mean annual temperature** and the **mean annual rainfall**. The simplified version below uses straight boundaries; the original's are curved, and all boundaries are approximate.



How to read it:

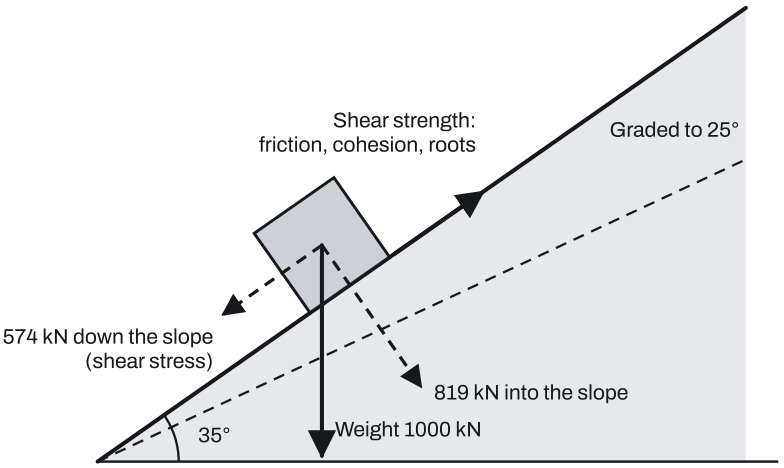
- **Rainfall controls whether much weathering happens at all.** Below about 250 mm a year, there is too little water for chemical weathering or freeze–thaw, so weathering is slight (only heating/cooling and salt growth work), as in Cairo.
- **Temperature controls which type dominates.** In cold climates with enough water, **frost action** (freeze–thaw) dominates, strongest where the mean is a little below 0 °C, so that temperatures cross 0 °C often. In warm, wet climates **chemical weathering** dominates, strongest in the **humid tropics** such as Singapore, where heat and abundant water speed up hydrolysis and carbonation all year. Temperate places such as London have moderate chemical weathering with some frost action in winter.
- **Very cold climates** have slight weathering: water is frozen most of the year and there are few freeze–thaw cycles.

Limits of the diagram, worth a mark in "how far" questions: it uses only **annual means**, so it ignores the **daily range** of temperature (which drives heating/cooling and freeze–thaw), the number of freeze–thaw cycles and the season when rain falls; it says nothing about **rock type, structure, vegetation or relief**; it predicts only the dominant type, not the processes in a particular place; and its boundaries are generalised.

Slope stability: shear stress and shear strength

Every slope is a balance between two forces:

- **Shear stress**: the forces pushing material **down** the slope. Gravity pulls the material's weight straight down; on a slope, part of that weight acts **along** the slope. The steeper the slope, the bigger this part.
- **Shear strength**: the forces **resisting** movement: **friction** between particles and on the surface beneath, **cohesion** (particles sticking together, as in damp clay), and the binding of plant roots.



If W is the weight of the material and θ the slope angle, the part of the weight acting down the slope is $W \sin \theta$. For 1000 kN of material on a 35° slope, $1000 \times \sin 35^\circ = 574$ kN pushes down the slope and $1000 \times \cos 35^\circ = 819$ kN presses into it. Regrading the slope to 25° cuts the downslope part to $1000 \times \sin 25^\circ = 423$ kN, about a quarter less.

Geographers compare the two forces with the **factor of safety**: shear strength ÷ shear stress. Above 1 the slope is stable; below 1 it fails. Material on that 35° slope with a shear strength of 500 kN has a factor of safety of $500 \div 574 = 0.87$, so it fails; regraded to 25°, $500 \div 423 = 1.18$, so it is stable. (Real shear strength also changes a little with the slope, so these are simplified.)

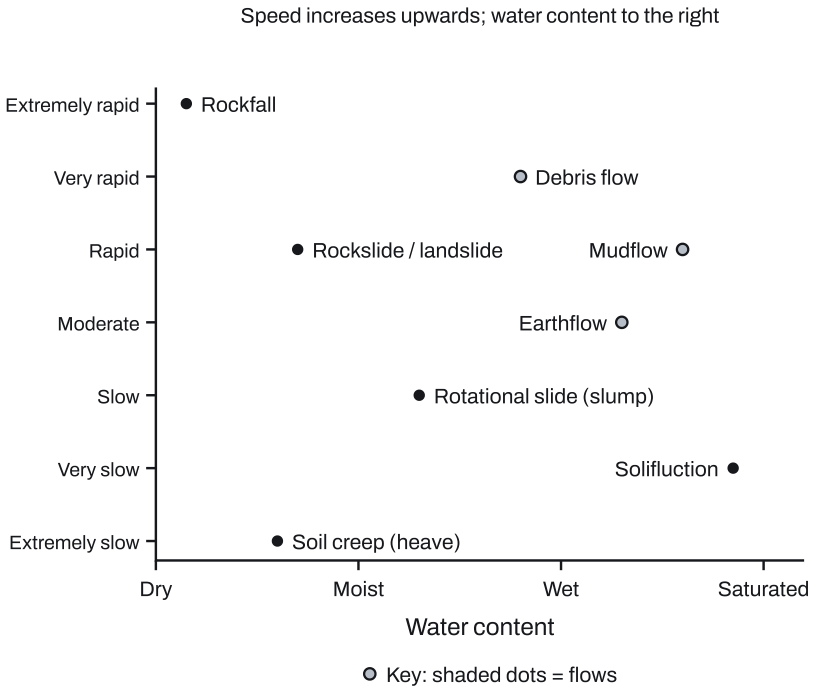
Mass movement happens when shear stress becomes greater than shear strength. Anything that adds stress or removes strength makes a slope less stable:

Increases shear stress	Reduces shear strength
Steepening of the slope, by undercutting at its base (rivers, waves, road cuts)	Water: it raises **pore water pressure**, pushing grains apart and cutting friction and cohesion
Extra weight on the slope: water soaking in, snow, buildings, waste tips	Weathering, which weakens rock along joints and turns it into loose regolith
Vibrations and shaking: earthquakes, traffic, blasting	Removal of vegetation, whose roots bound the soil
Removal of support at the base: erosion, excavation, quarrying	Clays that swell and soften when wet; frozen ground that thaws

Water appears on both sides, which is why most mass movements follow heavy rain or snowmelt. It adds **weight**, raises **pore water pressure** (pushing particles apart so they no longer grip each other), **lubricates** slip planes (bedding planes or the boundary between soil and rock), and can **undercut** a slope where a river or spring erodes its base. A **trigger** (a storm, an earthquake, a road cut) often tips a slope that weathering and steepening have already brought close to failing.

Mass movement: heaves, flows, slides and falls

Mass movement is the movement of weathered material down a slope **under gravity**, as a mass, rather than carried by water, ice or wind. The four types differ in **speed**, **water content** and **how** the material moves.



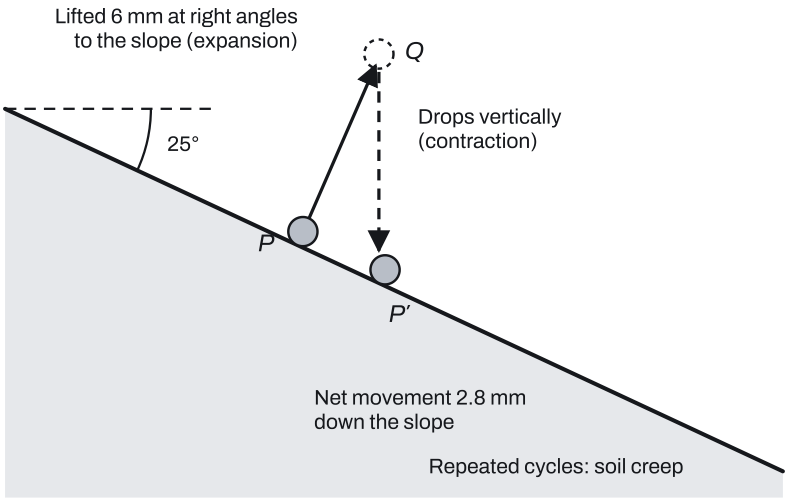
The chart's patterns, often asked about:

- **Flows** need the most water, and from earthflow to mudflow **the wetter, the faster**. **Debris flow** is the exception: drier than both, yet the fastest flow, because it rushes down steep channels carrying coarse debris.
- **Falls** are the fastest and the driest; **soil creep** is the slowest and also dry.
- **Solifluction** is the exception: very wet but very slow, because it moves over frozen ground.
- **Slides** are in the middle for moisture and vary most in speed, from slow slumps to very rapid rockslides.

Heave (soil creep)

Heave is the slowest mass movement, typically less than 1 cm a year. Soil particles are **lifted at right angles to the slope** when the soil **expands**, and **drop straight down** (vertically, under gravity) when it **contracts**. Each cycle moves each particle a tiny distance downslope. The soil expands and contracts by:

- **wetting and drying**: clay soils swell when wet and shrink when dry;
- **freezing and thawing**: ice forms in the soil (sometimes as needle ice, pipkrakes, pushing particles up), then melts;
- **heating and cooling**: the soil expands and contracts slightly.



The geometry: a particle lifted a distance h at right angles to a slope of angle θ and dropped vertically lands $h \tan \theta$ further downslope. Lifted 6 mm on a 25° slope, it moves $6 \times \tan 25^\circ = 2.8$ mm per cycle; steeper slopes move it further. Heave works best in fine soils with many cycles and little vegetation. Its effects: **terracettes** (small steps running across the slope, often trodden by animals), bent tree trunks, tilted fences, posts and walls, and soil piling up behind walls.

Solifluction is a slow flow of saturated soil in cold (periglacial) regions. In summer the top layer thaws, but the ground beneath stays frozen (**permafrost**), so the water cannot drain away; the soaked layer flows slowly downhill even on gentle slopes, forming **lobes** and terraces.

Flows

In a **flow**, the material moves like a thick liquid: particles move **separately within the mass**, so it **deforms internally**, with no single slip plane. Flows happen when fine material (clays and silts) or loose debris becomes **saturated**, usually after heavy or prolonged rain, snowmelt, or an earthquake shaking wet ground. The water adds weight and, above all, raises the **pore water pressure** until the particles are pushed apart, lose cohesion and friction, and move under gravity.

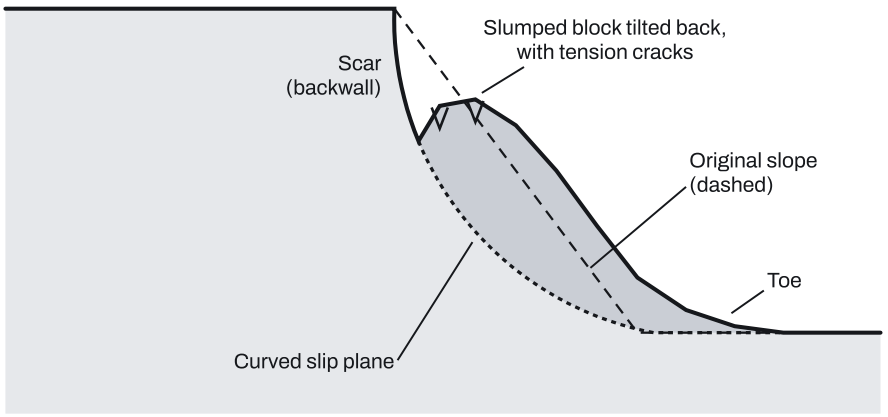
- **Earthflows**: wet clay soils on moderate slopes, moving slowly to moderately fast (metres a day to metres an hour), leaving a scar and a bulging tongue.
- **Mudflows**: very wet, fine material, often in channels; fast (metres a second), they can travel kilometres along valleys. Volcanic mudflows are called **lahars**: in 1985 a lahar from Nevado del Ruiz, Colombia, buried the town of Armero, killing over 20 000 people.
- **Debris flows**: a mixture of water, soil, rock and vegetation moving very fast down steep channels, often after intense rain on steep, unvegetated slopes.

Effects on slopes: a **scar** at the source, a channel or **track**, and a **lobe** or fan of deposits at the base that lowers the slope angle there.

Slides

In a **slide**, a mass of material moves **as a single unit** along a clear **slip plane** (shear plane), with little internal disturbance.

- **Translational (planar) slides**: the mass slides along a straight plane parallel to the surface, such as a **bedding plane** or joint dipping down the slope, or the boundary between soil and the rock beneath. Rockslides and debris slides are fast.
- **Rotational slides (slumps)**: in thick, weak material such as clay, or clay under sandstone or chalk, the material fails along a **curved, concave slip plane** and **rotates backwards** as it slides. Clay is common because it becomes weak when saturated. They are typical of cliffs undercut by the sea, such as the clay cliffs of Dorset and the Isle of Wight, UK.



Features of a rotational slide: a steep, bare, curved **scar** (backwall) at the top; one or more **slumped blocks** with surfaces **tilted back** towards the scar, sometimes forming steps (terraces) if several slips occur; **tension cracks** across the mass; ponds in the back-tilted hollows; and a bulging, irregular **toe** at the base. The slope becomes steeper at the top and gentler at the bottom; vegetation may be destroyed or carried down on the block.

Slides against flows, a common "contrast" question:

	Slide	Flow
How it moves	As one unit, on a slip plane	Particles move separately; the mass deforms internally
Slip plane	Present (planar or curved)	Absent
Water content	Low to moderate; water lubricates the slip plane	High: saturated, high pore water pressure
Material	Rock, or cohesive soil and clay	Fine clays and silts, or loose debris
Speed	Slow (slumps) to very rapid (rockslides)	Moderate (earthflow) to very rapid (debris flow)

	Slide	Flow
Effects	Scar, back-tilted block, tension cracks, toe	Scar, track, lobe or fan of deposits

Falls

In a **fall**, rock (or soil) breaks away from a **very steep or vertical face**, such as a cliff or a road cutting, and drops through the air, bouncing and rolling as it lands. It is the fastest mass movement and needs little water. The rock first has to be loosened, usually by **freeze–thaw**, heating/cooling, root action or pressure release along joints; then a trigger sends it down: **gravity on an overhang**, **undercutting** of the base by waves or a river, **earthquake** shaking, or human activity such as blasting. The fallen pieces collect at the base as **scree** (talus), which builds a slope at about 35°, and the face retreats. Because they come without warning, rockfalls are a danger on mountain roads.

Water and sediment movement on slopes

These are **not** mass movements: the material is carried by water.

- **Rainsplash**: raindrops strike bare soil at speed (up to about 9 m/s for large drops) and dislodge particles, which are thrown up into the air. On a slope, more particles land **downslope** than upslope, so there is a net movement down the slope. It is greatest on **bare** soil, with **intense** rain and **steep** slopes; plant cover and leaf litter absorb the drops' energy and protect the soil.
- **Sheetwash**: when the rain falls faster than the soil can absorb it (its **infiltration capacity** is exceeded), or when the soil is already saturated, water flows over the surface as a thin, **unconcentrated sheet**, carrying fine particles loosened by rainsplash. It needs a smooth surface and enough gradient; it is common on bare, compacted or frozen ground and in semi-arid areas with intense storms.
- **Rills**: as sheetwash flows downhill, small irregularities in the surface gather the water into **threads of concentrated flow**, which erode **small channels** a few centimetres deep, the rills. The flow in a rill is faster and deeper, so it erodes and carries more sediment. Rills can join and deepen into **gullies**. They are most common on bare, steep slopes of soft material, such as newly ploughed fields or construction sites.

Factors that increase all three: high rainfall **intensity** and amount, **bare** ground with little vegetation, **steep** and long slopes, low infiltration (compacted, clay or frozen soils, or soil already wet from earlier rain).

Human activity and slope stability

Activities that decrease stability (by adding stress or removing strength):

- **Undercutting and steepening**: cutting into the base of slopes for roads, railways and buildings removes support, as on mountain roads in Nepal and the Himalayas, where landslides follow road building.
- **Loading**: buildings, waste tips, mine spoil and reservoirs add weight. At **Aberfan**, Wales, in October 1966, a coal-mine waste tip built on a slope with springs beneath it became saturated after heavy rain and flowed downhill into the village, killing 144 people, 116 of them children at the village school.

- **Water**: leaking pipes, septic tanks, irrigation and reservoirs raise pore water pressure. When the Vajont reservoir in Italy was filled, the rising water weakened the valley side; in October 1963 a huge landslide fell into the reservoir and the wave it caused overtopped the dam, killing about 2000 people.
- **Deforestation**: removes the roots that bind the soil and the trees that intercept and take up water.
- **Vibrations**: from traffic, blasting and heavy machinery.

Activities that increase stability: strategies to modify slopes.

- **Pinning** (rock bolting, soil nailing): long steel bars are drilled through the loose or jointed rock or soil into stable rock beneath and fixed with grout. They **anchor** the outer layer to the solid rock, adding strength across potential slip planes. Used against slides and falls on rock faces and cut slopes.
- **Netting**: steel wire mesh is draped and pinned over steep rock faces, or fences of mesh are put up to catch falling rock. It **holds loose material in place** so it cannot fall, or **traps** what does fall before it reaches a road. It is used against rockfalls; it does not stop deep slides. Vegetation can grow through it, adding strength.
- **Grading**: earth is moved to **reduce the slope angle**, cutting the part of the weight acting down the slope (the shear stress), or the slope is cut into **steps (terraces or benches)**, which breaks a long slope into shorter, more stable ones and catches falling debris. It is used against slides and flows on soil slopes, but needs space and can be expensive.
- **Afforestation**: planting trees and other vegetation. **Roots bind** the soil and anchor it to the rock beneath, adding strength; the leaves **intercept** rain, and the plants take up soil water and lose it by **transpiration**, so less water enters the ground, keeping the pore water pressure lower. Cheap and attractive, but trees take years to grow, roots reach only a few metres, so they help only against **shallow** movements, not deep-seated slides, and the weight of large trees can add a little stress.
- **Other methods**: **drainage** (pipes drilled into the slope and channels across it lower the water table and pore water pressure), **shotcrete** (sprayed concrete sealing a rock face so water cannot get into its joints), **retaining walls** and **gabions** (wire cages of rock) supporting the base, sea walls and rock armour that stop undercutting, and **monitoring and warning** systems.

How effective is each? It depends on the **type of movement** (netting suits rockfalls; drainage suits flows and slumps; vegetation suits shallow slides), the **material and depth** of the movement, the **scale and cost** (grading and drainage of a whole hillside are expensive), how long it lasts and how much maintenance it needs, and whether the cause is tackled or only the symptom. Strategies are often **combined**: pins and netting on the same face, drainage with regrading and planting.

Case study: Hong Kong

- **Why slopes are unstable**: Hong Kong is steep and hilly, with about 7.5 million people crowded onto the little flat land and onto slopes cut for buildings and roads. Its granite and volcanic rocks are **deeply weathered** (by hydrolysis in the hot, wet climate) into weak, soil-like material many metres deep. Rainfall averages about 2400 mm a year, most of it in intense rainstorms and typhoons from May to September, which saturate the slopes.

- **Human impacts reducing stability**: cutting and filling slopes for housing and roads steepened them and loaded them with buildings; leaking water pipes added water; in June 1972, landslides after heavy rain killed 67 people at Po Shan Road and 71 at Sau Mau Ping.
- **Attempts to reduce mass movement**: the government set up the Geotechnical Control Office in 1977 (renamed the Geotechnical Engineering Office in 1991) and has since registered and checked about 60 000 man-made slopes. Strategies: **soil nails** (pinning) through slopes, **regrading** of cut slopes, surface and **drainage** channels and pipes, concrete and shotcrete covers, retaining walls, **flexible steel barriers and nets** to catch debris on natural hillsides, **planting** of vegetation on slopes (also for appearance), and a **Landslip Warning System** that uses rain gauges to warn people to stay away from slopes in storms.
- **Evaluation**: deaths from landslides have fallen sharply since the 1970s, and the methods are adapted to each slope (nails and drains for cut slopes, nets for falls from natural hillsides). But the work is costly and never finished: there are many old slopes still to upgrade, natural hillsides cannot all be treated, and extreme rain still sets off many landslides, as on Lantau Island in June 2008. With climate change bringing heavier rainstorms, the risk is managed, not removed. A rich city can afford this; poorer places with the same physical risks often cannot.

Key facts and formulas

There is no formula list in Paper 1, so learn all of these.

Formula	Status
Downslope part of the weight (shear stress) = $W \sin \theta$, for weight W on a slope of angle θ	Learn it
Factor of safety = shear strength ÷ shear stress (above 1: stable; below 1: the slope fails)	Learn it
Carbonation: $\mathrm{CO_2 + H_2O \rightarrow H_2CO_3}$, then $\mathrm{CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)_2}$ (soluble)	Learn it
Hydrolysis of feldspar: feldspar + water (H^+ ions) → kaolinite (clay) + silica and potassium in solution	Learn it
Water expands by about 9% when it freezes	Learn it
Oceanic crust about 3.0 g/cm³ and 5–10 km thick; continental crust about 2.7 g/cm³ and up to 70 km thick	Learn it

Term and meaning	Status
Tectonic plate: a rigid slab of the lithosphere (crust and upper mantle) that moves over the asthenosphere	Learn it
Divergent (constructive) boundary: where two plates move apart and new crust is formed	Learn it

Term and meaning	Status
Conservative boundary: where two plates slide past each other and crust is neither made nor destroyed	Learn it
Convergent (destructive) boundary: where two plates move towards each other and crust is subducted or crumpled	Learn it
Sea floor spreading: the formation of new oceanic crust as plates move apart at an ocean ridge and magma rises to fill the gap	Learn it
Subduction: the sinking of a denser oceanic plate beneath another plate at a convergent boundary, where it melts	Learn it
Benioff zone: the dipping zone of earthquakes along a subducting plate	Learn it
Ocean trench: a long, deep, narrow V-shaped trough in the ocean floor where a plate subducts	Learn it
Ocean ridge: a long underwater mountain chain formed of new, hot crust at a divergent boundary	Learn it
Volcanic island arc: a curved chain of volcanic islands formed where one oceanic plate subducts under another	Learn it
Fold mountains: mountains of folded and thrust crust formed by compression at a convergent boundary	Learn it
Weathering: the breakdown of rock in place by physical, chemical or biological processes	Learn it
Freeze–thaw: water in a crack freezes and expands, pressing on the rock; repeated cycles split it	Learn it
Heating/cooling: daily expansion and contraction of rock by heating and cooling, stressing it until it breaks up	Learn it
Salt crystal growth: salt crystals left in rock pores by evaporating water grow and press on the rock until it breaks	Learn it
Pressure release (dilatation): removal of overlying rock lets the rock below expand, opening joints parallel to the surface	Learn it
Vegetation root action: roots growing into joints widen them and force the rock apart	Learn it
Hydrolysis: a chemical reaction between minerals and water (H^+ ions) that decomposes the minerals, such as feldspar to clay	Learn it
Hydration: minerals absorb water and expand, putting pressure on the rock and breaking it down	Learn it

Term and meaning	Status
Carbonation: carbonic acid in rainwater reacts with calcium carbonate to form soluble calcium bicarbonate, removed in solution	Learn it
Mass movement: the movement of weathered material downslope as a mass under the influence of gravity	Learn it
Heave: slow mass movement in which particles are lifted at right angles to the slope by expansion and drop vertically on contraction	Learn it
Flow: rapid mass movement of saturated material in which particles move within the mass, with no slip plane	Learn it
Slide: mass movement of material as one unit along a slip plane, planar or curved (rotational)	Learn it
Fall: rapid free fall of rock from a steep or vertical face	Learn it
Rainsplash: raindrops dislodging soil particles, with a net movement downslope	Learn it
Sheetwash: unconcentrated surface flow of water in a thin sheet over a slope, once infiltration capacity is exceeded	Learn it
Rills: small, shallow channels cut by concentrated surface flow on a slope	Learn it
Shear stress: the forces acting to move material down a slope	Learn it
Shear strength: the resistance of slope material to movement (friction, cohesion, roots)	Learn it
Pore water pressure: the pressure of water in the spaces between particles, which pushes them apart and reduces shear strength	Learn it

How to do it

We have tagged 60 questions for this topic (2021–2025, all from Paper 1), 54 different (Papers 12 and 13 were the same in June 2022, 2023 and 2024). Every one is a multi-part Question 3 or Question 6, so all 60 mix types and the counts add up to more than 60.

Question type	Questions
Name, state or identify something from a figure	27
Describe or explain a tectonic process or landform	26
Define or explain a mass movement or slope process	25

Question type	Questions
Describe or compare what a figure shows	16
Define or explain a weathering process	16
Explain how climate affects the type and rate of weathering	15
Explain the causes of a mass movement or slope instability	14
Sketch a photograph or draw a labelled diagram	12
Explain strategies that reduce mass movement or make slopes more stable	11
Essay (15 marks): evaluate attempts to reduce mass movement	10
Essay (15 marks): assess a statement about tectonic landforms or plate movement	8
Essay (15 marks): assess which factor most affects weathering	7
Essay (15 marks): assess the main cause of mass movement	5
Explain how rock type and rock structure affect weathering	3

Short parts (2–6 marks) give 1 mark for a simple point and 2 for a developed one; definitions get 2 marks a term. The 8-mark (b) parts are marked in three levels (Level 3, 6–8 marks), and the 15-mark (c) essays in four (Level 4, 12–15 marks).

1. Name, state or identify something from a figure (27 questions)

The first 1-mark part of almost every Question 3.

1. **Read the figure's key, labels and title** and the exact wording ("fastest under the driest conditions", "intermediate rate and wet").
2. **Give the precise term**: rotational slide (slump), rockfall, soil creep, mudflow, freeze–thaw, exfoliation, subduction, divergent boundary. Close alternatives are usually accepted (rockslide, landslide).
3. **Give units** for any number read off (a range of speeds, an area in km^2).

From a mass movement chart like the one in "Understand it": the slowest is **soil creep**; the fastest and driest is **rockfall**; wet and intermediate in speed is often **mudflow** or **earthflow**. From a photo: a curved bare scar with a back-tilted block is a **slump**; angular blocks and scree under a cliff a **rockfall**; concentric peeling layers **exfoliation**; shattered, angular fragments in a cold place **freeze–thaw**. Variants: identify four factors from a written extract (1 mark each: quote them from the extract), estimate the area of a landslide from a map's grid (count squares, with km^2).

2. Describe or explain a tectonic process or landform (26 questions)

Short parts (3–4 marks, 1 per point) and 8-mark (b) parts.

1. **Name the boundary and the plates**: which type, which plates (oceanic or continental), which way they move.

2. **Give the driving mechanism**: convection currents, ridge push, slab pull. It earns a mark in almost every scheme.
3. **Give the process in sequence**, as in "Understand it": subduction → melting in the Benioff zone → magma rises → volcanoes; or plates diverge → magma rises → cools into new crust → ridge.
4. **Name the landform and a real example**: Mid-Atlantic Ridge, Peru–Chile or Mariana Trench, Mariana or Aleutian Islands, Andes, Himalayas, San Andreas Fault.
5. **Draw a labelled cross-section** for 8 marks: it is credited, and an accurate one can carry much of the answer.

For "describe the differences between oceanic and continental plates", give comparative points with numbers: density, thickness, age and rock type. For **island arcs**, say **two oceanic plates** (not oceanic under continental) and keep Hawaii out. For **fold mountains**, cover both the subduction case (Andes) and collision (Himalayas). For an earthquake figure across boundaries, use the table in "Understand it".

3. Define or explain a mass movement or slope process (25 questions)

1. **Definitions (2 marks a term)**: what moves and how fast **(1)**, plus the mechanism or setting **(1)**. Heave: slow, particles raised at right angles to the slope and dropping vertically, by wetting/drying or freezing/thawing. Fall: rapid, from a steep face, often with a trigger. Rainsplash: raindrops dislodge particles, net movement downslope. Sheetwash: unconcentrated flow in a thin sheet once infiltration capacity is exceeded. Rills: small channels of concentrated flow.
2. **Explain a process (8 marks)**: the **conditions** (material, water, slope, climate), the **mechanism** (expansion and contraction, pore water pressure, slip plane), the **speed**, and the **effects on the slope** (terracettes, scar, lobe, toe), with examples.
3. **Contrast parts** (slide against flow): use the comparison table in "Understand it", and write each point as a contrast ("whereas").

Answer only the movement named: if asked about flows, don't write about every mass movement; if asked about heave, cover all three causes, not just freeze–thaw. For "surface movement of sediment", stick to rainsplash, sheetwash and rills (and heave), not deep landslides.

4. Describe or compare what a figure shows (16 questions)

1. **Compare, don't describe separately**: each point links the two or more items ("B has deep earthquakes, whereas A has only shallow ones"). Separate descriptions earn at most 1 mark, and only similarities or only differences at most 3 of 4.
2. **Quote the figure's data or labels** (speeds, depths, names of mass movements): answers that do not name the items lose marks.
3. **Describe only**: no reasons unless the question asks "explain".

For "describe the features" of a slump in a photo or model, describe what is there ("a steep, curved, bare scar at the top"), not just a list of names. For a world map of plate boundaries, fold mountains or volcanoes, describe the distribution: around the Pacific, along continental edges (west of the Americas), in long belts, with named examples and exceptions (the Himalayas have fold mountains without active volcanoes).

5. Define or explain a weathering process (16 questions)

1. **Definitions (2 marks a term)**: the action **(1)**, then how it breaks the rock **(1)**, for example "water in a joint freezes and expands by about 9% (1), and repeated freezing and thawing widens the joint until the rock splits (1)".
2. **"Briefly explain" (3–4 marks)**: the conditions it needs (water, 0 °C swings, a big daily range, salt), the mechanism (expansion, pressure, chemical reaction) and the result (scree, exfoliation, clay, soluble bicarbonate). Name a rock and a place.
3. **In Question 3, tie it to the photo**: concentric layers peeling off point to exfoliation from heating/cooling; angular blocks with scree to freeze–thaw; trees in cracks to root action.

Keep the processes apart: **hydrolysis** (reaction with water; feldspar in granite) is not **hydration** (absorbing water and swelling); **carbonation** acts on limestone and chalk, not granite. Salt crystal growth happens in deserts as well as on coasts. When asked for "one way" vegetation weathers rock, only one is credited: develop root action fully, or organic acids, or chelation.

6. Explain how climate affects the type and rate of weathering (15 questions)

Mostly 8-mark (b) parts: "Explain how temperature (or rainfall, or climate) affects the type and rate of weathering".

1. **Cover both type and rate**, and **both physical and chemical** weathering: full marks need all four.
2. **Temperature**: chemical reactions speed up with heat (roughly double for each 10 °C rise), so the humid tropics have the fastest chemical weathering; swings across 0 °C drive freeze–thaw; large daily ranges in hot deserts drive heating/cooling, exfoliation and granular disintegration; carbonation is the exception, faster in cold water.
3. **Rainfall**: water is needed for every chemical process and for freeze–thaw, salt growth and hydration; more rain means more weathering of all kinds; little rain means slight weathering; acidic rain speeds up carbonation; rain supports plants and so root action and organic acids.
4. **Use the Peltier diagram**: draw or describe it and name the zones with examples (Singapore, London, Cairo, mountains). For "how the Peltier diagram is used", add its **limits**: annual means only, no daily range or seasons, no rock type or relief.

7. Explain the causes of a mass movement or slope instability (14 questions)

1. **Frame every cause as shear stress or shear strength**: "heavy rain saturates the slope, adding weight (more stress) **(1)** and raising pore water pressure, which pushes particles apart and cuts friction (less strength) **(1)**".
2. **Use the resource**: pick the causes that fit what is shown (sea undercutting a cliff, jointed rock, a road at the base, snowmelt in an extract), and quote it.
3. **Develop each cause**: name it **(1)**, then explain how it makes the slope fail **(1)**. A list of causes without explanation scores little.

Causes to choose from: water (weight, pore water pressure, lubrication, undercutting by springs), steep gradient, undercutting by the sea or a river, weathered and jointed rock, weak clay, earthquakes, human loading, cutting, vibrations and deforestation. For "how water influences mass movement" cover weight, pore water pressure, cohesion and lubrication. For "why mass movements move at different rates": water content, slope angle, material, sudden triggers, particle-by-particle (heave) against whole-mass movement (slides), lack of support (falls). For an 8-mark "how human activity causes instability", see the human activity section and Aberfan.

8. Sketch a photograph or draw a labelled diagram (12 questions)

1. **Draw a frame** the shape of the photo and sketch the **main outlines** (skyline, cliff edge, slope, the scar, the slumped mass, the sea), not every detail.
2. **Make it match the photo**: a textbook diagram of an ideal slump earns nothing, and neither do labels for features you cannot see.
3. **Label the features** with the right terms and a short description: scar or backwall, slumped mass, toe, debris, scree, tension cracks, vegetation; for a weathered rock: concentric cracks, the rounded unweathered core, joints, flaking layers, scree. Usually 1–2 marks for the sketch and 2–3 for labels.

For "with the aid of a diagram, describe" a process (freeze–thaw), draw labelled stages like those in "Understand it": without the diagram the maximum is 3 of 4. Annotate the diagram with the process; do not write a separate paragraph underneath instead. For a plate boundary, a labelled cross-section (trench, Benioff zone, volcano, fold mountains, accretionary wedge) is accepted.

9. Explain strategies that reduce mass movement or make slopes more stable (11 questions)

1. **Name the strategy and say what it is (1)**: pinning, netting, grading, afforestation (or drainage, shotcrete, retaining walls, terracing).
2. **Explain how it works in terms of stress and strength (1)**: grading lowers the angle and so the downslope pull of gravity; pins anchor loose rock to stable rock; netting holds loose rock on the face; trees bind soil with roots, intercept rain and take up water by transpiration.
3. **Develop it (1)**: which movement it suits, how well it works, its costs and limits.

When two strategies are named (afforestation **and** grading), explain both: one alone caps an 8-mark answer at Level 2. For "how human activity may increase stability", these strategies are the answer, with an example such as Hong Kong.

10. Essay (15 marks): evaluate attempts to reduce mass movement (10 questions)

Wordings: "evaluate attempts to reduce mass movement", "some strategies are more effective than others", "mass movements can never be effectively reduced", "some types of mass movement are easier to control than others", "how far has human activity increased the stability of slopes" (with a case study).

1. **Introduction**: define mass movement and slope stability (stress against strength), and say what "effective" means: fewer movements, fewer deaths, cost, how long it lasts, what it does to the environment.
2. **Take each strategy in turn**, with how it works, which movement it suits, and evidence from a **named place** (Hong Kong is the example examiners see most).
3. **Weigh them**: netting stops falls but not deep slides; vegetation stops shallow slides but not deep ones; grading and drainage tackle the cause but are expensive and need space; warning systems save lives but do not stop movement.
4. **Bring in the limits**: extreme rain and earthquakes overwhelm defences; cost decides what poorer countries can do; maintenance.
5. **Conclude** with a judgement: effective for some types, places and scales, rarely for all.

Use detailed, located examples throughout: generic answers stop at 6 marks. Keep the case study on **reduction**, not on the causes.

11. Essay (15 marks): assess a statement about tectonic landforms or plate movement (8 questions)

Statement	Weigh it against
The global pattern of plates, or their movement, is explained by subduction	Slab pull (from subduction) against ridge push and convection; divergent and conservative boundaries with no subduction; the nature and density of plates
The type of plate boundary determines the landforms	Match landforms to each boundary; then landforms found at more than one type (trenches, fold mountains, volcanoes) and hot spots found at none
Fold mountains are the main landforms at convergent boundaries	Trenches, island arcs, volcanoes and accretionary wedges where subduction happens; only fold mountains at collisions
Subduction is the most important process in forming tectonic landforms	Sea floor spreading (ridges, rift valleys), collision (Himalayas), transform faulting; hot spots

1. **Introduction**: define the key terms (subduction, the boundary types) and name the landforms.
2. **The case for**: explain subduction (or the named idea) and the landforms it makes, with examples (Andes, Peru–Chile Trench, Mariana Islands).
3. **The case against**: divergent boundaries (Mid-Atlantic Ridge, Iceland, East African Rift), conservative boundaries (San Andreas: few landforms, fault scarps), collision (Himalayas), hot spots (Hawaii), the other driving forces.
4. **Conclude** with a judgement on "how far".

12. Essay (15 marks): assess which factor most affects weathering (7 questions)

The statement names one factor (rainfall, water, temperature, climate, rock type and structure) as the most important, or says "temperature drives physical weathering, rainfall drives chemical".

1. **Introduction**: define weathering, type and rate; list the factors.
2. **Explain the named factor** with processes and named places: for rainfall, every chemical process and freeze–thaw, salt growth and hydration need water; for temperature, reaction rates, freeze–thaw near 0 °C, heating/cooling in deserts. Use the Peltier diagram.
3. **Weigh the others**: the other climate element, rock type (limestone and carbonation, granite and hydrolysis), structure (joints, bedding planes), vegetation, relief and aspect, time, human activity; and the exceptions (heating/cooling needs no water; carbonation is faster in cold water; pressure release is linked to climate only indirectly, through melting ice).
4. **Conclude**: climate usually sets the type and the overall rate, while rock type and structure decide which rocks weather fastest within one climate.

For "temperature for physical, rainfall for chemical", show that **both** matter for **both**: freeze–thaw and salt growth need water; chemical reactions need warmth.

13. Essay (15 marks): assess the main cause of mass movement (5 questions)

The statement names water (or precipitation, or human activity) as the main cause of mass movement or of slopes becoming less stable.

1. **Introduction**: mass movement happens when shear stress exceeds shear strength; gravity is always the force that moves material.
2. **Explain the named cause**: for water, weight, pore water pressure, lubrication and undercutting, with examples (mudflows, Aberfan, Hong Kong storms); for human activity, cutting, loading, deforestation and vibration (Aberfan, Vajont, Himalayan roads).
3. **Weigh the others**: gravity and steep slopes, undercutting by rivers and the sea, weathering, earthquakes, freeze–thaw on rock faces, animals burrowing; water often helps without being the trigger (a rockfall can happen in dry weather).
4. **Conclude** by type of movement and place: water dominates flows and slumps, much less so falls.

14. Explain how rock type and rock structure affect weathering (3 questions)

1. **Rock type (composition)** decides which chemical processes act: limestone and chalk by carbonation; granite by hydrolysis of feldspar while quartz resists; dark basalt absorbs heat and its minerals weather fast. Name the rock and the process each time.
2. **Rock structure** decides how easily water, salt and roots get in, and how much surface is exposed: joints, bedding planes and faults; porosity and permeability; grain size. Freeze–thaw needs cracks or pores; closely jointed rock weathers faster.
3. **Give examples of the results**: limestone pavements (clints and grikes at Malham), granite tors (Dartmoor), deep weathering in the tropics.

Cover **both** type and structure, and both physical and chemical weathering. If the question says only "chemical weathering", keep to chemical processes.

Worked examples

Example 1

Use the mass movement chart in "Understand it".

(a) Name the type of mass movement shown that is slow and has a moderate water content. **[1]**

(b) Compare slides and flows on the chart. **[3]**

(c) Explain why a mudflow moves much faster than soil creep. **[4]**

(a) Rotational slide (slump) **(1)**.

(b)

- Flows (earthflow, mudflow, debris flow) have higher water contents than slides (rockslide, rotational slide) **(1)**.
- Both cover a wide range of speeds: slides from slow (slump) to rapid (rockslide), whereas flows range from moderate (earthflow) to very rapid (debris flow) **(1)**.
- From earthflow to mudflow, speed rises with water content, but the debris flow is drier and yet the fastest flow; among slides, the drier rockslide is faster than the slump **(1)**.

(c)

- A mudflow is saturated: water raises the pore water pressure, pushing the particles apart so they lose friction and cohesion **(1)**, and the whole mass moves like a liquid under gravity **(1)**.
- Soil creep moves particle by particle: each is raised at right angles to the slope by expansion and drops vertically on contraction, moving only a tiny distance each cycle **(1)**, and cycles of wetting and drying or freezing and thawing are slow, so movement is less than 1 cm a year **(1)**.

Example 2

(a) (i) Define the weathering terms 'hydrolysis' and 'vegetation root action'. **[4]** (ii) Explain how a conservative plate boundary differs from a divergent plate boundary. **[3]**

(i) Hydrolysis is a chemical reaction between the minerals in a rock and water (its hydrogen ions) **(1)**, which decomposes them, for example turning the feldspar in granite into kaolinite clay **(1)**. Vegetation root action is the growth of plant roots into joints and cracks in rock **(1)**; as the roots thicken they force the rock apart and widen the cracks **(1)**.

(ii) At a divergent boundary the plates move apart and new crust forms as magma rises into the gap, whereas at a conservative boundary the plates slide past each other and no crust is made or destroyed **(1)**. Divergent boundaries have volcanic activity (fissure eruptions, ocean ridges), whereas conservative boundaries have none **(1)**. Both have only shallow earthquakes, but at conservative boundaries they are more frequent and stronger, because the plates lock and then slip suddenly, as on the San Andreas Fault **(1)**.

Example 3

Explain the formation of ocean trenches and fold mountains at convergent plate boundaries. **[8]**

At a convergent boundary two plates move towards each other, driven by slab pull, ridge push and convection currents in the mantle.

Ocean trenches form where an oceanic plate meets another plate. Oceanic crust is denser (about 3.0 g/cm^3) than continental crust (about 2.7 g/cm^3), so where the Nazca plate meets the South American plate, the Nazca plate is forced down into the mantle: it subducts. Where it bends downwards it pulls the ocean floor into a long, narrow, steep-sided trough, the Peru–Chile Trench, about 8 km deep. Where two oceanic plates meet, the older, colder and denser one subducts, forming trenches such as the Mariana Trench (about 11 km deep). Friction along the sinking plate causes earthquakes in the Benioff zone, shallow near the trench and deeper inland.

Fold mountains form where the crust is compressed. At the Andes, the edge of the South American plate is squeezed and thickened by the subducting plate, and sediments scraped off the ocean floor are crumpled onto it as an accretionary wedge; magma from the melting plate rises to form volcanoes along the range. Where two continental plates meet, as India meets Eurasia, neither is dense enough to subduct, so the crust and the sediments between them are folded, faulted and thrust upwards into the Himalayas, which are still rising, with no volcanoes.

A labelled cross-section of each boundary (trench, Benioff zone, volcano, folds) would support the answer.

Level 3 (6–8 marks): both landforms explained in sequence, the driving forces, the difference between subduction and collision, and named examples.

Example 4

'Grading is the most effective strategy for reducing mass movement.' With the aid of examples, how far do you agree with this statement? **[15]**

Introduction. Mass movement happens when the shear stress on a slope exceeds its shear strength. Grading reduces the slope angle, and so the stress; other strategies, such as pinning, netting, afforestation and drainage, add strength or reduce water. "Most effective" can mean preventing the most movements, saving the most lives, costing the least or lasting longest.

For. Grading tackles one of the main causes directly: lowering a slope from 35° to 25° cuts the part of the weight acting down the slope by about a quarter. It works for slides and flows in soil and weathered rock, and cutting a slope into benches also catches falling debris. In Hong Kong, regrading of cut slopes, combined with

drainage, was central to the slope upgrading programme that followed the 1972 disasters, and deaths from landslides have since fallen sharply.

Against. Grading needs space and moves large amounts of material: on crowded slopes like Hong Kong's, buildings sit at the top and bottom, so soil nails (pinning), retaining walls and drainage are often used instead. It does little for rockfalls from steep faces, where netting and rock bolts work better, as on mountain roads. Where water is the cause, as in mudflows after heavy rain, drainage reduces pore water pressure more directly. Afforestation is cheaper and better for the environment, binding soil and reducing water, though it protects only against shallow movements. Grading can even make things worse if the removed material is dumped where it loads another slope, as with spoil from road building in Nepal. And no strategy stops very large events: the 1963 Vajont landslide was deep-seated, set off by the reservoir's water, and no regrading of the surface could have held it.

Conclusion. Grading is very effective for shallow slides and flows on soil slopes where there is space, but it is not the most effective in every case: the best strategy depends on the type of movement, the material, the space and the money available. In practice, as in Hong Kong, combinations of grading, pinning, netting, drainage and vegetation work best, so the statement is only partly true.

Level 4 (12–15 marks): what "effective" means, each strategy weighed against the type of movement with located examples, and a judgement on "how far".

Common mistakes

- **Confusing hydrolysis and hydration**, or linking carbonation to granite. Hydrolysis is a reaction (feldspar to clay); hydration is absorbing water and swelling; carbonation attacks limestone and chalk.
- **Saying oceanic plates are heavier.** They are denser; weight depends on thickness too.
- **Linking volcanic island arcs to oceanic–continental subduction, or to hot spots such as Hawaii.** Island arcs need two oceanic plates.
- **Confusing conservative and constructive boundaries.** Conservative: plates slide past; constructive: plates move apart.
- **Linking ocean ridges to destructive boundaries**, or leaving out the driving mechanism (ridge push, slab pull, convection).
- **Writing about all mass movements when the question names one** (flows only, heave only), or explaining heave by freeze–thaw alone.
- **Mixing up mass movement with movement by water**: rainsplash and sheetwash are not mass movements, and deep landslides are not surface sediment movement.
- **Listing causes without explaining them.** "The slope is steep" earns little; say how it increases shear stress.
- **Describing instead of comparing**, or describing two items separately when the question says "compare" or "contrast".
- **Sketching a textbook diagram instead of the photo**, labelling features that are not visible, or writing an explanation under a diagram instead of labelling it.

- **Forgetting the rate**: questions on factors or climate ask about type and rate; many answers cover only type.
- **Generic essays**: naming a country where pinning was used is not an example; use detailed, located case studies such as Hong Kong.
- **Defining an ocean trench by describing it**, rather than saying what it is and how it forms.

How to get the marks

- **Develop each point.** In short parts, a simple point earns 1 and a developed point (cause → process → result) earns 2.
- **Define** = the term's precise meaning plus its qualifier, 2 marks each. **Describe** = what it is or what the figure shows, with detail and data. **Explain** = reasons and processes. **Suggest** = apply what you know to an unfamiliar resource. **Compare/Contrast** = linked statements of similarity and difference. **Briefly** = a few well-chosen points.
- **Use the resource** in Question 3: quote the figure's labels, values and features, and tie explanations to what it shows.
- **Stress and strength.** Every slope answer is stronger framed as increased shear stress or reduced shear strength.
- **Diagrams earn credit** when they are labelled and annotated with processes: plate boundary cross-sections, freeze–thaw stages, the Peltier diagram, a rotational slide, heave.
- **Name real places**: Mid-Atlantic Ridge, Peru–Chile Trench, Mariana Islands, Himalayas, San Andreas Fault, Malham, Dartmoor, Hong Kong, Aberfan.
- **8-mark (b) parts** are levelled: Level 3 (6–8) needs clear explanation of every part of the question (both strategies, both type and rate, both processes), with examples or a labelled diagram.
- **15-mark essays** are levelled: Level 4 (12–15) needs a thorough, balanced assessment with located examples built in and a clear judgement. With no examples the maximum is 6.

Quick check

1. Define the weathering terms 'carbonation' and 'pressure release (dilatation)'.
2. In a soil on a 30° slope, a particle is lifted 4 mm at right angles to the slope and drops vertically. Calculate how far it moves downslope. Then work out how much 50 cm^3 of water expands by when it freezes.
3. Slope material weighing 800 kN rests on a 30° slope with a shear strength of 360 kN. Calculate the shear stress and the factor of safety, and say whether the slope fails. Repeat after grading the slope to 20°.
4. Using the Peltier diagram, name the main type of weathering for places with these climates: (a) 24 °C and 1600 mm; (b) –4 °C and 700 mm; (c) 20 °C and 150 mm.
5. Explain why volcanic island arcs are curved, and why Hawaii is not one.

Answers

1. Carbonation is the reaction of carbonic acid (carbon dioxide dissolved in rainwater) with calcium carbonate in limestone or chalk, forming soluble calcium bicarbonate, which is removed in solution. Pressure release is the expansion of rock when the overlying rock is removed by erosion, which opens joints parallel to the surface (sheeting) along which slabs split off.
2. $4 \times \tan 30^\circ = 2.3$ mm downslope. Water expands by about 9%: $50 \times 0.09 = 4.5$ cm³, to 54.5 cm³.
3. At 30°: shear stress $800 \times \sin 30^\circ = 400$ kN, factor of safety $360 \div 400 = 0.9$, below 1, so it fails. At 20°: $800 \times \sin 20^\circ = 273.6$ kN, factor of safety $360 \div 273.6 = 1.32$, above 1, so it is stable.
4. (a) Strong chemical weathering (hot and wet, as in the humid tropics). (b) Strong frost action (freeze–thaw), cold with enough water. (c) Slight weathering, because it is too dry.
5. The arc follows the curve of the subduction zone: a boundary on the surface of a sphere, where a plate bends down into the mantle, traces an arc, so the volcanoes above the sinking plate do too. Hawaii is in the middle of the Pacific plate, far from any boundary; it formed over a hot spot (a plume of hot mantle), not by subduction, and its islands lie in a straight line that gets older to the north-west as the plate moves over the plume.

Past questions to try

- **9696/12/O/N/25 Q6**: heave and fall, ocean ridges, human causes of slope instability, and an essay on temperature and rainfall in weathering.
- **9696/13/M/J/24 Q6**: subduction and conservative boundaries, island arcs, afforestation and grading, and an essay on climate and weathering.
- **9696/11/M/J/25 Q3**: factors in a written account of a mass movement, how they caused it, and one way to reduce mass movement.
- **9696/12/O/N/24 Q3**: a model of a rotational slide: name it, describe its features, and explain heave.