Cambridge AS & A Level · Geography 9696 · Notes

Hot arid and semi-arid environments A2

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Read first: Atmosphere and weather, Rocks and weathering, Hydrology and fluvial geomorphology

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What you need to know

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

1. **Describe where hot arid and semi-arid environments are found** (their global distribution) and their **climatic characteristics**.
2. **Define aridity** and **explain its causes**: **pressure and wind systems**, **ocean currents** and the **rain shadow effect**.
3. **Explain the key features of these climates**: why they are **high wind energy environments**, and their **diurnal and seasonal variations** in temperature and precipitation.
4. **Explain the weathering processes** of deserts, **thermal fracture**, **exfoliation**, **salt weathering** and **chemical weathering**, and their effects.
5. **Explain how wind erodes, transports and deposits**: **corrasion (abrasion)**, **deflation**, **traction**, **saltation** and **suspension**.
6. **Explain how water erodes, transports and deposits**: the **hydrological regime** of dryland streams, **episodic rainfall**, **sheet floods** and **flash floods**.
7. **Explain the characteristic landforms**: **sand dunes**, wind-sculptured rocks (**yardangs**, **zeugen**), **wadis**, **alluvial fans**, **arroyos**, **pediments**, and the **piedmont zone** (**bajadas**, **playas**, **salt lakes**, **inselbergs**).
8. **Weigh the relative roles of wind (aeolian) and water (fluvial) processes**, using the **evidence for past climate change** (the Pleistocene **pluvials**) and the part **past processes** played in forming today's landforms.
9. **Explain the vegetation**: low **biomass productivity** (with low **biodiversity**, **limited nutrient cycling** and **fragility**), and how plants are adapted to **extreme temperatures** and to **physical** and **physiological drought**.
10. **Explain the soil processes**, above all the **upward capillary movement** of water and minerals (**salinisation**).
11. **Explain desertification**: how **natural and human factors** degrade the soils and vegetation of semi-arid environments.
12. **Know a case study** of **either a hot arid or a semi-arid environment**: the **problems of managing it sustainably**, and an **evaluation of attempted or possible solutions**.

It is one of the options in Paper 3 (Advanced physical geography options), where you answer two options. For this option you answer Question 10 (10 marks: a describe part and an explain part, built on a figure) and one essay, Question 11 or Question 12 (20 marks). Read the notes on atmosphere and weather (pressure belts, the Hadley cell, lapse rates), rocks and weathering (weathering processes) and hydrology and fluvial geomorphology (hydrographs, sediment transport) first.

Understand it

What "arid" and "semi-arid" mean

Aridity is a **lasting shortage of water**: an area is arid when, year after year, far more water could evaporate than falls as rain. It is a property of the **climate**. Don't confuse it with **drought** (a temporary shortage below an area's normal rainfall, which can happen anywhere) or with **desertification** (the degradation of land, see below): examiners report answers that mix them up.

Two ways to define the types:

- **By rainfall**: **hot arid** (hot desert) areas get **under about 250 mm** of rain a year; **semi-arid** areas get **about 250–500 mm**. "Hot" means warm all year, with mean annual temperatures above about 18 °C.
- **By an aridity index**: rainfall P divided by **potential evapotranspiration** PET (how much water could evaporate and transpire if it were available). Since PET in hot deserts is often 2000 mm a year or more, even 250 mm is a small fraction of it. The bands are in Key facts.

Where they are

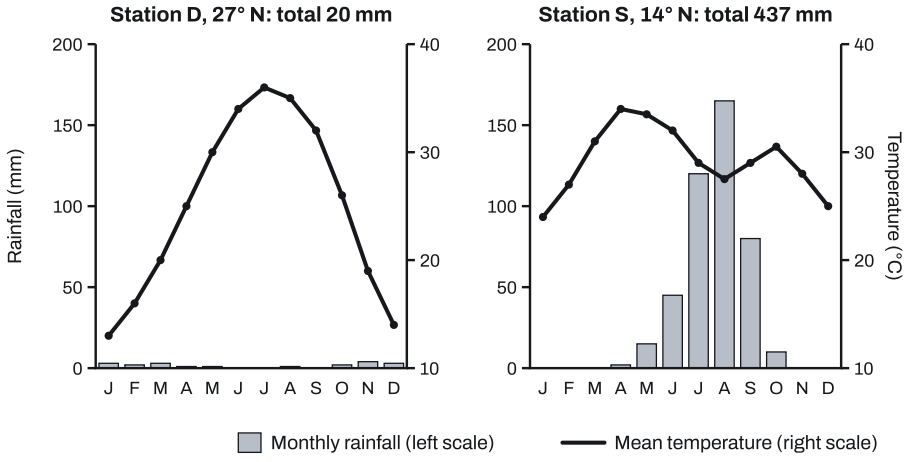
Arid and semi-arid lands, hot and cold, together cover about a third of the world's land.

- **Hot deserts** lie mainly **between about 15° and 30° N and S**, on the **western sides of continents** and in **continental interiors**: the **Sahara** (the largest, about 9 million km²) and its continuation through **Arabia** to the **Thar** of north-west India and Pakistan; the **Namib** and **Kalahari** in southern Africa; the **Atacama** in Chile and Peru; the **Sonoran**, **Mojave** and **Chihuahuan** deserts of the south-western USA and Mexico; and the deserts of **central and western Australia** (about 70% of Australia is arid or semi-arid).
- **Semi-arid areas** mostly form **transition zones round the arid cores**: on the **equator side**, the **Sahel** south of the Sahara and the margins of the Kalahari; on the **poleward side**, the edges of the Mediterranean (Morocco, Tunisia, southern Spain), the Middle East, southern Australia and northern Mexico. They also cover large **inland** areas (much of Botswana, interior Australia).
- **The overall pattern**: **two broken, roughly east–west bands** either side of the equator, centred near the **tropics**, widest in **Africa** and **Australia**, wider over land interiors than along coasts, with very little **on the equator** or **poleward of about 35°** (deserts there, such as the Gobi and Patagonia, are **cold** deserts).
- **Exceptions**: semi-arid and arid areas close to the equator, in **north-east Brazil** (the sertão) and the **Horn of Africa** (Somalia, northern Kenya), caused by local winds blowing parallel to the coast and by sinking air.

Climatic characteristics

	Hot arid	Semi-arid
Annual rainfall	Under about 250 mm; some coastal deserts under 20 mm (Arica, Atacama, under 1 mm)	About 250–500 mm
Seasonality of rain	No reliable season; a few storms a year, and some years none	A **short rainy season**: in summer on the equator side (from the ITCZ), in winter on the poleward side (from mid-latitude depressions)
Rainfall variability	Extreme: the coefficient of variation is often **over 40%**	High: often **20–40%**
Temperature	Very hot summers (monthly means 30–37 °C, daily maxima over 40 °C), mild winters (10–15 °C)	Hot all year near the tropics (20–35 °C); hottest **before** the rains
Diurnal range	Very large, often **15–25 °C**, sometimes more	Large in the dry season, smaller in the wet season
Humidity and cloud	Very low; clear skies most days	Low in the dry season; cumulonimbus in the wet season

Extremes: **Death Valley**, California, holds the highest air temperature on record, 56.7 °C in July 1913; **Aswan**, Egypt, gets about 1 mm of rain a year and has July mean daily maxima above 40 °C; **Niamey**, Niger (13.5° N), is semi-arid, with about 550 mm, nearly all of it from June to September.



The causes of aridity

Rain needs **moist air** that **rises**, **cools** to its dew point and **condenses** into clouds large enough to rain. Each cause of aridity removes one of these.

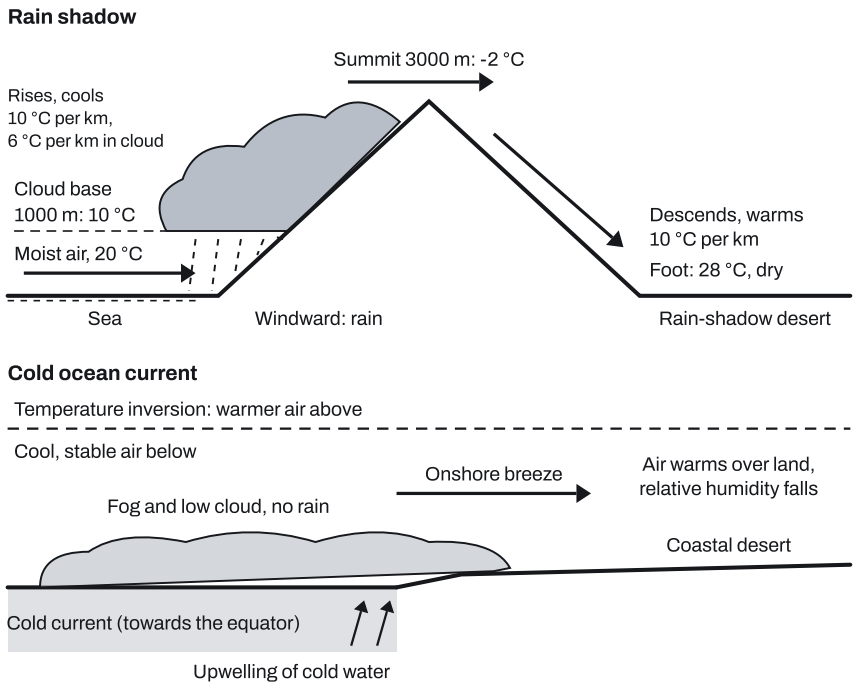
1. Pressure and wind systems: the subtropical anticyclones. In the **Hadley cell**, air that rose at the ITCZ flows poleward at high level and **sinks** at about **20–30° N and S**, forming belts of **high pressure** (the subtropical anticyclones). As it sinks it is compressed and **warms adiabatically**, so its relative humidity falls; the sinking air also forms a **temperature inversion** a kilometre or two up, which stops rising air from going higher. The atmosphere is **stable**: clouds rarely form, skies are clear, and rain is rare. This is the **main cause** of the great tropical deserts, which is why they lie in belts near the tropics. The surface winds flowing out of these highs are the **trade winds**. Over the Sahara the **north-east trades** blow **from the land** (the hot, dusty **Harmattan** in winter), so they carry little moisture; on west coasts they blow **offshore**. The **ITCZ**, which brings the rain to the tropics, reaches the semi-arid margins only briefly in summer, and the arid cores almost never.

2. Continentality. Air picks up moisture over oceans and loses it as rain as it moves inland, so places **far from the sea** get little rain. The central Sahara is more than 1000 km from the Atlantic, the Mediterranean and the Red Sea; the deserts of central Australia are similar. Continental interiors also heat strongly in summer, but the air drawn into them has already crossed hundreds of kilometres of land and is dry.

3. The rain shadow effect. Where moist air is forced over a mountain range it **cools as it rises**, condenses and rains on the **windward** side. On the **leeward** side it **descends**, and because it has lost its moisture it warms at the faster **dry adiabatic rate**, so it arrives **warmer and drier** than it started (the foehn effect). Examples: **Death Valley** and the **Mojave**, behind the Sierra Nevada, in the lee of moist Pacific air; the **Atacama**, where the **Andes** block moist air from the Amazon to the east; the **Simpson Desert** of Australia, partly in the lee of the Great Dividing Range. (The **Patagonian** desert, in the lee of the Andes, is a cold desert.)

4. Cold ocean currents. Cold currents flow towards the equator along the **west coasts** of continents: the **Benguela** current (Namib), the **Humboldt (Peru)** current (Atacama), the **Canary** current (western Sahara), the **California** current (Baja California) and the **West Australian** current. The mechanism, which examiners say is often confused:

1. The **cold water chills the air above it from below**, so the lowest air is cooler than the air above: a **temperature inversion**, which is very **stable** and stops convection.
2. Cold water **evaporates little**, and cold air **holds little water vapour**.
3. The small amount of moisture condenses as **fog** and low stratus cloud, not rain: the Namib's coastal fog and the Atacama's **camanchaca**. Walvis Bay, on the Namib coast, gets under 20 mm of rain a year but many foggy days.
4. When sea air moves **inland** it **warms** over the hot land, so its relative humidity falls and it cannot rain.
5. The currents are made colder by **upwelling** of deep water, driven by the trade winds blowing **offshore** or along the coast, which are themselves set up by the subtropical high: so this cause is **linked** to the first.



Most deserts have more than one cause, which is where the marks for evaluation lie:

Desert	Causes
Sahara	Subtropical high (main cause); continentality; dry north-east trades from the land; the cold Canary current on its Atlantic coast
Namib and **Kalahari**	Subtropical high near the Tropic of Capricorn; offshore south-east trades; the cold Benguela current (Namib); continentality (Kalahari)
Atacama (the driest)	Subtropical high; the cold Humboldt current; offshore south-east trades; the rain shadow of the Andes: all four together
Australian deserts	Subtropical high; continentality and rain shadow in the east (Simpson Desert); offshore winds and the West Australian current in the west (Great Sandy Desert)
Sonoran and Mojave	Subtropical high; rain shadow of the Sierra Nevada and other ranges; the California current near the coast
Gobi (cold desert, for contrast)	Almost entirely continentality and rain shadow

Human activity can make an area drier but cannot create a desert climate: removing vegetation makes the ground brighter, so it reflects more sunlight (higher **albedo**), heats the air less and may encourage sinking air and less rain (the Charney hypothesis for the Sahel). This is a sophisticated argument; don't confuse it with the causes of desertification.

High wind energy environments

Deserts are windy, and their bare, dry, loose sediment lets the wind do work. The reasons:

- **Strong heating**: intense sunshine through clear skies heats the ground, the air above it rises and creates local **low pressure**; steep **pressure gradients** between hot and cooler areas drive strong winds. By day the heating also mixes faster-moving air from higher up down to the ground, so winds are **strongest in the afternoon**.
- **Little friction**: wide, flat plains with **little or no vegetation** barely slow the wind.
- **Channelling** between mountains and through passes speeds it up.
- **Clear skies** make slopes heat by day and cool by night, giving **anabatic** (upslope) and **katabatic** (downslope) winds; coastal deserts have strong **sea and land breezes**.
- **Thunderstorm downdrafts** in semi-arid areas spread out at the ground as walls of dust called **haboobs** (Sudan, Arizona); regional winds such as the **Harmattan**, **sirocco** and **khamsin** carry dust over long distances.

Because winds vary so much with heating and passing storms, wind speed traces from deserts show **high variability** from hour to hour and day to day.

Diurnal and seasonal variations

Temperature, diurnal. With **clear skies**, **dry air** (water vapour absorbs heat) and **bare ground**, the sun heats the surface fiercely by day (the ground itself can pass 60–70 °C), and at night long-wave radiation escapes straight to space. So the **diurnal range is very large**: at Station D, a July day might run from 24 °C at dawn to 44 °C in mid-afternoon (a range of 20 °C), and a January day from 4 °C to 22 °C (18 °C), with occasional frost on winter nights. **Coastal deserts on cold currents** are the exception: fog and the cool sea keep both their diurnal and annual ranges small.

Temperature, seasonal. Away from the equator the noon sun and day length change through the year, and there is no cloud to damp the change, so hot deserts have **hot summers and mild winters**: Station D's monthly means range 23 °C. Semi-arid places near the tropics are hot all year, but their **hottest month comes just before the rains** (Station S in April), because the sun is high and the skies are still clear; cloud and evaporation in the wet season then cool the days.

Precipitation. Rain in hot deserts is **episodic**: years may pass with none, then a single convective storm may drop more than the annual mean in a few hours. Much rain **evaporates before reaching the ground** (virga). Semi-arid areas have a **seasonal** rhythm: on the equator side, rain comes in summer when the **ITCZ** moves furthest poleward (the Sahel, June–September); on the poleward side, in winter, from mid-latitude depressions (the Mediterranean margins). Rain often comes as **afternoon thunderstorms**. **Dew** and **fog** add moisture in some places.

Why rainfall variability is so high. Semi-arid areas lie at the **edge** of the rain-bearing systems. Their rain depends on **how far the ITCZ moves poleward and how long it stays** in any year: when the subtropical anticyclones stay strong and hold their ground, the rain belt stops short of the area and the rainy season fails. Small shifts make large differences to a small total. The **El Niño–Southern Oscillation** changes rainfall from year to year (El Niño years tend to be drier in southern Africa and Australia); changes in sea-surface temperatures in the Atlantic and Indian Oceans shift the Sahel's rains; and much rain comes from a few **convective storms**, which are hit-and-miss. The lower the mean rainfall, the **higher** its variability: the

coefficient of variation (Key facts) is usually over 40% in deserts. The **Sahel** shows variability over decades as well: rainfall in the 1970s and 1980s was about 20–40% below that of the 1950s and 1960s, with severe droughts in 1968–1974 and 1983–1985, and has partly recovered since the 1990s.

Hot arid against semi-arid. Both are dry, hot and variable, so they differ in **degree**: semi-arid areas have more rain, a reliable rainy season, lower variability, more cloud and humidity in the wet season and so a smaller diurnal range then; arid areas have rain at no fixed time. The difference is greatest in rainfall, least in temperature.

Weathering

Weathering is slow where there is little water, but deserts have plenty of bare rock exposed to sun, salt and occasional moisture. The products feed the wind and water: sand and dust from weathered rock are what the wind moves.

- **Thermal fracture (insolation weathering)**: rock heats by day and cools at night. Rock conducts heat poorly, so the **outer layer** expands and contracts more than the inside, and stresses build up; in coarse rocks such as granite, **dark and light minerals** expand by different amounts, loosening the grains (**granular disintegration**). Laboratory experiments that heated dry rock over and over produced little damage, so most geographers now think **moisture** (dew, rain) is needed for it to work well; it may be most effective with **rapid** temperature changes, such as a cold storm on hot rock.
- **Exfoliation**: the **peeling of curved sheets** of rock from the surface, giving rounded boulders and **exfoliation domes**. Causes: thermal stress in the outer layer, **pressure release** as overlying rock is removed (see rocks and weathering), and chemical changes in the outer skin when it is wetted by dew.
- **Salt weathering**, probably the most effective process in many deserts:
  1. **Salt crystallisation**: water carrying dissolved salts gets **into pores and joints**; as it evaporates, crystals grow and **press on the rock**, prying grains apart. The water must get **inside** the rock for it to work.
  2. **Hydration of salts**: some salts take up water and **swell** (sodium sulfate can grow by several times its volume as it changes form).
  3. **Thermal expansion of salts**: salt crystals expand more than the rock around them when heated. The salt comes from **saline groundwater** drawn up by capillary rise, **dew**, **fog and sea spray** near coasts, **playas**, and wind-blown dust. Effects: crumbling rock (granular disintegration), honeycomb hollows (**tafoni**), and undercutting at the foot of cliffs and boulders, where moisture and salt are greatest. Salt weathering is **fastest where water and salt are most common**: near the ground, on coasts and round playas.
- **Chemical weathering**: limited by the lack of water, but not absent. **Dew** and rare rain allow **hydration**, **oxidation** (reddening rocks and sand), **solution** and **hydrolysis** (more in semi-arid areas); **desert varnish**, a dark coating of iron and manganese oxides and clay, forms slowly on exposed rock. In the **semi-arid** margins, and during past **pluvials**, chemical weathering was more important.
- **Freeze–thaw** happens where night temperatures fall below 0 °C after rain or dew: in winter and in high deserts.

Which matters most? Salt weathering and thermal fracture are the typical **desert** processes and dominate in hyper-arid areas; chemical weathering grows in importance with moisture, so it matters more in semi-arid areas, near coasts and in the past. Weathering rarely **forms** a landform on its own: it **prepares** the material that wind and water remove and **modifies** landforms (rounding inselbergs, undercutting pedestal rocks).

Wind: erosion, transport and deposition

Erosion:

- **Deflation**: the wind **lifts and removes loose, fine particles** (silt, clay and fine sand). It lowers the surface into **deflation hollows**, can scour down to the water table (where oases form), and leaves behind a surface of stones too heavy to move: **desert pavement** (reg in the Sahara, gibber plains in Australia). The **Bodélé Depression** in Chad, the bed of a former lake, is the world's largest single dust source.
- **Corrasion (abrasion)**: sand grains carried by the wind **sand-blast** rock. Because most moving sand stays **within about 1–2 m of the ground**, abrasion is concentrated low down: it undercuts rocks, polishes and faces stones (**ventifacts**) and streamlines ridges (**yardangs**).

Transport (the faster the wind, the more is moved: roughly with the **cube** of wind speed, see Key facts):

- **Suspension**: **dust** (silt and clay, under about 0.06 mm) is lifted high and carried far. About 180 million tonnes of dust a year blow out of the Sahara, and about 28 million tonnes of it fall on the Amazon basin, where it adds nutrients.
- **Saltation**: **sand grains** (about 0.06–2 mm, most often 0.1–0.5 mm) bounce along: a grain is lifted, carried a short way and falls back, knocking other grains into the air. Most saltating sand moves within a metre of the ground. Saltation does most of the work of moving sand.
- **Traction (surface creep)**: larger grains are **rolled and pushed** along by the impacts of saltating ones.

Deposition happens when the wind **slows**: behind an **obstacle** (a rock, a bush), where the ground becomes rougher, where winds diverge, or where rain wets the sand.

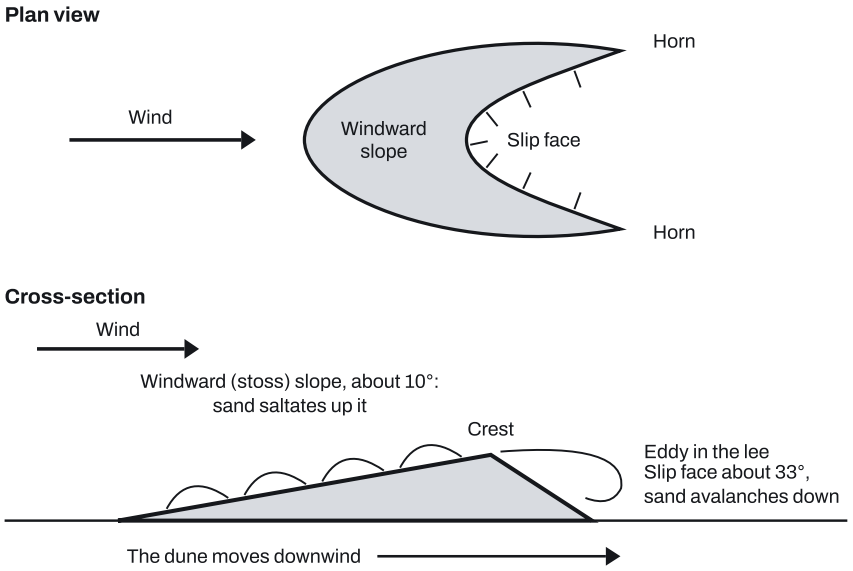
Sand dunes

Sand dunes form where there is a **supply of sand**, a **strong wind** to move it and something to start deposition (an obstacle or a patch of rough ground). Large areas covered by dunes are **ergs** (sand seas), such as Erg Chigaga in Morocco or the Namib Sand Sea; but only about a fifth of the world's deserts are sand-covered: most are rock and stone.

How a dune forms and moves:

1. Wind slows behind an obstacle and drops some sand, forming a small mound.
2. The mound itself becomes an obstacle: sand **saltates up the gentle windward (stoss) slope**, about 5–15°, and is dropped just beyond the crest, where the wind slows in the sheltered lee and an **eddy** forms.
3. Sand piles up on the lee side until the slope reaches the **angle of repose** (about 32–34°), then **avalanches** down: this steep side is the **slip face**.

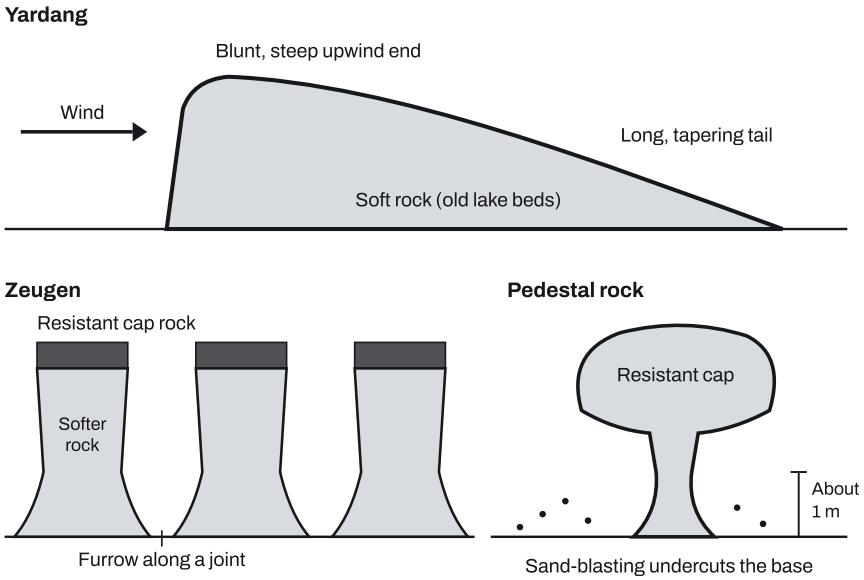
4. Sand is constantly eroded from the windward slope and added to the slip face, so the **whole dune moves downwind**; small dunes move fastest, by tens of metres a year.



Dune types depend on **sand supply**, **wind direction** and **vegetation**:

Type	Shape	Conditions	Example
Barchan	Crescent, **horns pointing downwind**; slip face inside the curve	**Limited sand** on a hard surface; **one steady wind direction**. The horns move faster than the centre, where there is more sand to move, and **wind shear** round the sides draws them out	Kharga Depression, Egypt
Transverse	Long ridges **at right angles** to the wind	**Plentiful sand**, one wind direction: barchans join into ridges	Parts of the Namib and Sahara
Seif (linear)	Long, sharp-crested ridges **parallel** to the wind	Limited sand and **two wind directions** at an angle, giving a long ridge between them	Simpson Desert, Australia, where parallel dunes run for tens to hundreds of kilometres
Star	Pyramid with several arms	**Winds from several directions**; plentiful sand; stay in place and grow tall	Namib Sand Sea, where some exceed 300 m
Parabolic	U-shaped, **arms pointing upwind** (the opposite of a barchan)	**Vegetation** anchors the arms while the bare centre blows forward; semi-arid margins and coasts	
Nebkha	Small mound behind a bush	A plant traps sand	Semi-arid scrub

Wind-sculptured rocks



- **Yardangs**: **streamlined ridges** parallel to the prevailing wind, with a **blunt, steep upwind end** and a long **tapering tail**, like an upturned boat hull. They form in **soft, fine rock** (often old lake beds): **abrasion** attacks lines of weakness parallel to the wind, and **deflation** removes the loosened material from the troughs between. They range from a few metres to tens of metres high; the Kaluts of the **Lut Desert, Iran**, are famous.
- **Zeugen**: **tabular ridges** of soft rock with a **horizontal cap of resistant rock**, separated by furrows. Weathering opens **joints** in the cap rock; wind abrasion then cuts down through the softer rock below, widening the furrows and undercutting the ridges. They are typically 3–30 m high.
- **Pedestal (mushroom) rocks**: a block of rock on a narrower neck. Sand-blasting is strongest **near the ground**, where most sand saltates; **salt weathering** is also strongest there, where moisture lingers. Both undercut the base. Examples in the White Desert of Egypt.
- **Ventifacts**: stones with flat, polished faces cut by sand-blasting from the prevailing wind.

Water: the hydrological regime, episodic rain and floods

Water is rare in deserts, but when it comes it is **very effective**, because the ground is bare.

The hydrological regime of dryland streams:

- **Ephemeral** streams flow **only during and just after rain**, for hours or days; **intermittent** streams flow for part of the year (the rainy season); **perennial** streams flow all year, usually because they are fed by **springs and groundwater** or come from wetter **mountains** outside the desert (**exotic rivers** such as the Nile and the Colorado).
- **Flashy hydrographs**: a near-vertical rising limb, a high peak and a fast fall back to **zero flow**, because rain is **intense** (convective storms), the ground has a **low infiltration capacity** (bare, sealed by crusts, sometimes baked hard) so water runs off as **overland flow** almost at once, there is **no vegetation** to intercept it, and **no baseflow** from groundwater to keep the stream going afterwards.

- **Transmission losses**: water soaks into the dry, sandy **channel bed** as it flows, and evaporates, so the flood **shrinks downstream** and many streams never reach the sea (**endoreic** drainage, ending in basins).
- **Why some streams stay perennial and others don't**: perennial reaches are fed by **groundwater** where impermeable rock forces it to the surface, by **springs**, or by mountain catchments with more rain or snowmelt; reaches become ephemeral where the water table falls, from **groundwater pumping** for towns and irrigation (the San Pedro River in Arizona has lost perennial reaches this way) and from a drier climate.

Sheet floods are thin, wide sheets of water spreading **across gently sloping surfaces** (pediments and fans) when rain is too heavy to soak in. They carry fine sediment and smooth the surface.

Flash floods are sudden, fast-rising floods in **channels**, carrying huge loads of sediment, from sand to boulders (sometimes as thick **debris flows** or mudflows). Their power to **erode** (by **abrasion** with their load and **hydraulic action**) and **transport** is far greater than their rarity suggests. They also endanger people, who camp in dry wadis.

Water-formed landforms

Wadis and arroyos. A **wadi** (an Arabic word) is a **steep-sided, flat-floored valley** cut by flash floods, dry most of the time, with a floor of sand and gravel. Their sides stay steep because there is little weathering and vegetation to wear them back, and floods undercut them; their floors are flat because floods spread across them and deposit as they lose water. Many are **too large for today's rare floods**, which suggests they were cut in wetter **pluvial** periods and are partly **relict**. An **arroyo** is the American equivalent: a steep-walled, flat-floored channel cut into **valley-floor alluvium** in the south-western USA. Many were cut quickly between about 1865 and 1915, when **overgrazing** stripped the vegetation and a run of intense storms made streams cut down.

Alluvial fans. A **fan-shaped** (cone-shaped in 3D) spread of sediment where a stream leaves a **narrow mountain canyon** onto a **flat plain**:

1. In the mountains, a flash flood is **confined** in a steep channel, so it is fast and carries a large load.
2. At the **mountain front** the channel suddenly **widens** and the **gradient falls**, so the water **spreads out**, slows and **loses energy**; water also **soaks into** the coarse sediment.
3. It **deposits** its load: the **coarsest** material (boulders, gravel) first, near the **apex** at the canyon mouth, and **finer** sand and silt further out at the **toe**. So the fan is steepest near the apex and has a **concave** long profile.
4. Channels on the fan fill with sediment and the next flood takes a new route (**distributary** channels switch), so deposits spread across the whole fan.

Fans are both **erosional and depositional**: the material comes from erosion in the canyon. Many grew mostly in wetter past periods.

Bajadas (bahadas): where neighbouring fans along a mountain front **join**, they form a continuous, gently sloping apron of sediment.

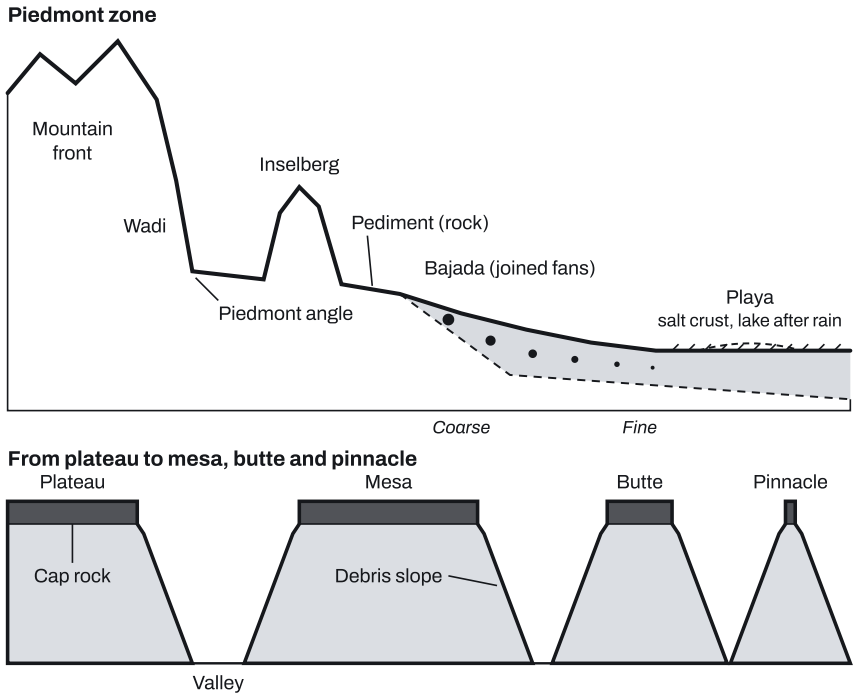
Pediments: **gently sloping rock surfaces** (about 0.5–7°) at the foot of a mountain front, often with a thin cover of debris, meeting the mountain at a **sharp break of slope** (the **piedmont angle**). Theories of their formation:

- **Parallel retreat** of the mountain front: weathering and sheet wash wear the steep front back, keeping its angle, and leave a gently sloping surface in front;
- **Lateral planation**: ephemeral streams shifting **sideways** across the mountain foot, cutting it back;
- **Sheet floods** smoothing the surface and carrying debris away;
- **Weathering below the surface** (when it was wetter) and later **stripping** of the weathered layer.

Inselbergs: steep-sided hills rising from the pediment, the **remains of a mountain front** that has retreated around them, often of more resistant rock (see tropical environments for the granite forms).

Mesas and buttes: in **horizontally bedded** rocks with a **resistant cap rock** (Monument Valley, Arizona and Utah). Rivers (during rare floods, or in wetter past periods) cut **valleys** into the plateau; the valley sides **retreat** by weathering, **rockfalls** from the cap and sheet wash, keeping a **steep cliff** in the cap rock above a **gentler debris slope**; the valleys widen until blocks are cut off. A **mesa** (Spanish "table") is wider than it is high; as it shrinks it becomes a **butte**, higher than it is wide, then a pinnacle, then disappears. The cap rock **protects** the softer rock below and keeps the top flat.

Playas and salt lakes: flat, low basins of **inland drainage** at the end of the piedmont, where floodwater collects in a **shallow, temporary lake** after rain. As it **evaporates**, the fine clay and silt settle and **dissolved salts are left behind** as a white crust: a **salt lake** or salt flat (salina). Examples: **Badwater Basin**, Death Valley (86 m below sea level); **Kati Thanda–Lake Eyre**, Australia, which fills only a few times a century; the **Chott el Djerid**, Tunisia.



Wind against water: their relative roles

Formed mainly by **wind**	Formed mainly by **water**	Formed by **both**, or by weathering too
Sand dunes, yardangs, zeugen, ventifacts, deflation hollows, desert pavement	Wadis, arroyos, gullies, alluvial fans, bajadas, sheet-flood surfaces	Pediments (water, weathering), inselbergs, mesas and buttes (water, weathering, rockfall), pedestal rocks (wind, salt weathering), playas (water fills them, wind deflates them)

- **Wind is most important** in **hyper-arid** areas today: almost no vegetation, constant winds, and plenty of loose sand. But wind mostly **moves and reshapes** sand: it **erodes** solid rock slowly, and many "wind" landforms start along **joints** opened by weathering.
- **Water is more important** in **semi-arid** areas, where rain is more frequent; but even in deserts **flash floods** do more erosion in hours than wind does in years, and most of the **large-scale** relief (mountain fronts, pediments, inselbergs, mesas, wadis) is water-shaped.
- **Weathering** prepares the material for both and modifies their landforms.
- **Time**: many water-formed landforms are **relict**, made in wetter past periods, and are being **modified** by wind today; but water is still active now, in every flash flood. Examiners criticise answers claiming that all water action happened in the past.

Past climate change: the evidence for pluvials

Pluvials were long periods **wetter** than today. During the Pleistocene (the last 2.6 million years), the climate of today's deserts swung between wetter and drier phases; the Sahara was dry during the last glacial maximum (about 20 000 years ago), when its dunes spread south beyond today's limit, then much wetter in the **African Humid Period** (about 14 500 to 5000 years ago), the "**Green Sahara**", with grassland, lakes and rivers.

Evidence:

- **Old lake shorelines**: **Lake Mega-Chad** covered more than 300 000 km² about 6000–7000 years ago; today's Lake Chad covers under 2000 km² in dry years. Lake Bonneville, in the western USA, was the larger ancestor of the Great Salt Lake.
- **Lake sediments and pollen**: layers of lake mud with pollen of grasses and trees, and fossils of fish, crocodiles and hippopotamuses, in places now too dry for them.
- **Rock art and settlement**: paintings and engravings of giraffes, cattle and even swimmers, at **Tassili n'Ajjer** (Algeria) and the **Gilf Kebir** (Egypt), and burial sites with fishing tools, such as **Gobero** in Niger.
- **Relict river systems**: radar from a Space Shuttle in 1981 revealed **buried river channels** under the sand of the eastern Sahara; large wadis and fans are **too big** for today's floods.
- **Fossil water**: groundwater in the **Nubian Sandstone Aquifer** under Egypt, Libya, Sudan and Chad is many thousands of years old, so it entered the rock when the climate was wetter.
- **Fossil soils (palaeosols)**, **tufa** and **spring deposits** (calcium carbonate deposited by springs when the water table was higher), and **fixed dunes** now covered by vegetation (which show drier periods in today's semi-arid margins).

Evaluating the evidence: the strongest evidence is **dated** and **physical** (lake shorelines, sediments, fossil water); rock art shows that animals and people lived there but its dating is less precise; landforms such as wadis may have been formed by many floods over long periods, wet or dry, so their size is suggestive but not proof. When several kinds of evidence **agree** (as for the Green Sahara), the case is strong.

Biomass productivity, biodiversity and fragility

- **Low productivity**: net primary productivity in hot deserts and semi-desert scrub averages about **90 g of dry matter per m² per year**, a tenth of the savanna's (about 900) and about a twenty-fourth of the rainforest's (about 2200). The main limit is **water**: plants close their stomata to save water, and so take in less carbon dioxide and grow less. Other limits: **high temperatures** (which raise water loss and respiration), **poor, thin soils** low in organic matter and nitrogen, **salinity**, and short growing periods after rain. **Semi-arid** areas are far more productive than hot arid ones.
- **Biodiversity** is **low** in the driest areas (large bare patches; some areas with no plants at all) but **higher** than often thought in semi-arid areas such as the Sonoran Desert, and **many species are endemic** (found nowhere else).
- **Limited nutrient cycling**: all the stores are **small**, the **soil store is the largest** of the three (little biomass, and litter is scarce), and the **flows are small** and come in **pulses** after rain: decomposition is slow when the ground is dry despite the heat, then rapid when it is wet. **Termites** do much of the decomposition. Nutrients are concentrated under shrubs ("islands of fertility").
- **Fragility**: because growth is slow, **damaged vegetation recovers slowly**: vehicle tracks from Second World War training camps are still visible in the Mojave. Thin soils with little organic matter erode easily once the cover is broken; **biological soil crusts** (cyanobacteria, lichens and mosses that bind the surface) take decades to recover after trampling. Rainfall variability means a drought can strike before vegetation has recovered from the last disturbance. So fragility results from low productivity **and** poor soils, variable rain and human pressure together.

Plant adaptations

Xerophytes are plants adapted to drought; **halophytes** are adapted to salty soil. The adaptations fall into three strategies:

1. Escaping drought: ephemerals. Annual plants survive the dry years as **seeds**, which can lie **dormant** for years. Some have chemical inhibitors that only enough rain can wash out, so they germinate only after a good soaking. They then grow, flower and set seed in a few weeks (the "flowering desert" of the Atacama after rare rains).

2. Resisting drought by storing or finding water:

- **Succulents** such as cacti (the **saguaro** of the Sonoran Desert) store water in **swollen, pleated stems** that expand after rain; they have a **thick, waxy cuticle**, few stomata, and **spines** instead of leaves (less surface to lose water, shade for the stem, a layer of still air, and protection from animals).

- **CAM photosynthesis** (in cacti and many succulents): stomata open at **night**, when it is cool and humid, to take in carbon dioxide, which is stored as an acid (malic acid); in the day the stomata **stay closed** and the stored carbon dioxide is used for photosynthesis.
- **Roots**: **deep tap roots** reach groundwater (**phreatophytes** such as **mesquite**, whose roots have been found more than 50 m down, and acacias); **shallow, wide lateral roots** catch rain before it evaporates (cacti).
- **Reducing water loss**: **small leaves** (creosote bush), **sunken stomata** on the underside of leaves, hairs that trap still, moist air, waxy surfaces, **leaf rolling**, and closing stomata in the heat of the day.
- **Drought-deciduous** shrubs drop their leaves in dry spells and grow new ones within days of rain (**ocotillo**).

3. Tolerating heat:

- **Pale, hairy or reflective** leaves and stems reflect sunlight (brittlebush); leaves held **vertically** or edge-on avoid the midday sun; **small leaves** lose heat quickly to the air; some plants are **dormant** in the hottest season.

Physical and physiological drought. Physical drought is a real **lack of water**. **Physiological drought** is when water is present but plants **cannot take it up**, because the soil water is too **salty**: roots take in water by osmosis, and salty soil water draws water **out** of the root instead. Halophytes such as **saltbush** cope by storing salt in their cells or **excreting it** through glands on the leaves.

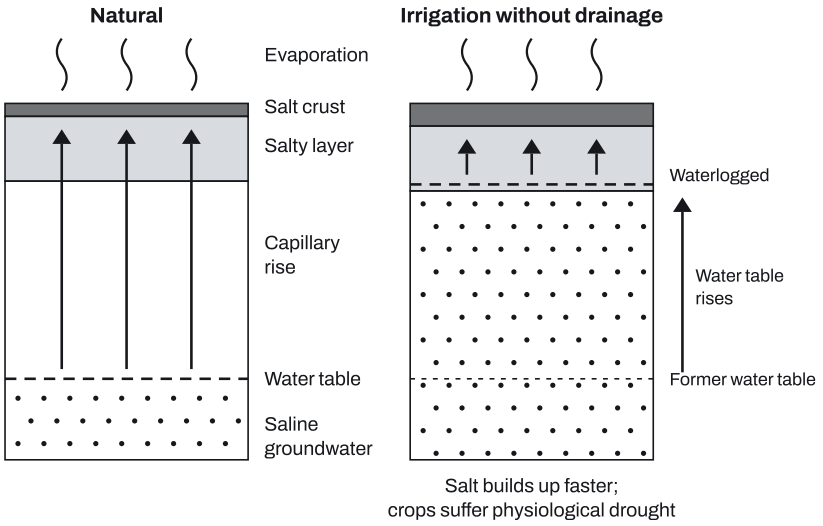
Temperature or water? Many "heat" adaptations are really about **water**: a plant could cool itself by transpiring, but can't afford the water, so it reduces the heat load instead. The **acacia's** flat, **umbrella-shaped crown** shades the ground round its roots, keeping the soil cooler and moister. The clearest test is the **oasis**: at an oasis, under exactly the same heat as the surrounding desert, dense vegetation thrives because water is available, while the dry land around it is almost bare. So **water shortage** is the main influence on plant adaptation, and heat acts mainly by **increasing** that shortage.

Soils and salinisation

Desert soils (**aridisols**) are **thin**, **stony or sandy**, **low in organic matter** (often under 1%), with **weak horizons** and **alkaline**, often with layers of salt, gypsum or calcium carbonate. **Leaching** is weak, because rain rarely soaks far.

Salinisation by upward capillary movement:

1. **Evaporation is far greater than precipitation**, so water moves **upward** through the soil more than downward.
2. Water rises through the **fine pores** between soil grains by **capillary action** (like water rising in a narrow tube), from groundwater or from moist layers below, carrying **dissolved salts** and minerals.
3. At or near the surface the water **evaporates**, and the **salts are left behind**.
4. Over time salts build up into **saline layers** and a white **salt crust** at the surface.



- **Solonchaks** are soils with **high concentrations of soluble salts** at or near the surface (white crusts), common round playas and in low-lying areas with shallow water tables.
- **Solonetz** are soils rich in **sodium**: the sodium disperses the clay, so the soil becomes **hard, sticky and poorly drained**, with a dense, columnar subsoil.
- **Calcification**: in **semi-arid** areas, rain is enough to leach the most soluble salts (sodium, potassium) but not calcium carbonate, which builds up at the depth the water reaches as a **calcic layer**; it can harden into a **calcrete** (caliche) crust. Gypsum and silica can form **gypcrete** and **silcrete**. These hard layers (**duricrusts**) also form from capillary rise.
- **Salinisation caused by people** (secondary salinisation): **irrigation** without good **drainage** raises the **water table**; once it is within about 2 m of the surface, capillary rise brings salt up fast. Irrigation water also contains small amounts of salt, which build up as it evaporates. Large areas of the irrigated **Indus plains** of Pakistan and the **Murray–Darling Basin** of Australia are affected. Salty soils cause **physiological drought** for crops, and solonchaks lose their structure and **erode** easily by wind.

Other soil processes to weigh against salinisation: **weathering** (supplying the mineral grains), **humification** (very limited: little organic matter), **limited leaching**, **calcification**, **wind and water erosion** (removing the topsoil), and **human** effects (compaction by livestock, irrigation, ploughing). Salinisation is the **typical natural** soil process of arid areas, and economically the most damaging in irrigated land, but in the **Sahel**, **erosion of human-degraded soil** does more harm to more people.

Desertification

Desertification is the **degradation of land** in **dry areas** (arid, semi-arid and dry sub-humid) caused by **climatic variations and human activities**: the soil, vegetation and water become less productive, so the land supports fewer plants, animals and people. It is **not** the natural spread of a desert, and not the cause of deserts themselves. Semi-arid areas such as the **Sahel** are the most affected, because they have enough rain to farm and graze but not enough to recover quickly from damage.

The process: the plant cover is reduced or removed → bare soil is exposed → **raindrops** seal the surface, so **infiltration** falls and **runoff** rises, cutting **sheet erosion and gullies** → **wind** deflates the loose, dry topsoil (the fine, fertile, organic-rich part), leaving **infertile, hard subsoil** → the soil holds less water and fewer

nutrients, so plants struggle to return → productivity falls, people need more land, and the cycle repeats. **Wind and water** are the **agents** that remove the soil; what makes them effective is the **loss of vegetation**. With an intact plant cover, wind does little.

Human factors:

- **Overgrazing**: herds grow in good years (cattle are **wealth and status**), and too many animals strip the vegetation and **trample** and compact the soil; **boreholes** sunk for cattle concentrate them, leaving rings of bare ground round each well.
- **Overcultivation**: shorter **fallow** periods, **monocropping**, and **cash crops for export** (cotton, groundnuts) taking the better land, which pushes food crops onto **marginal**, drier land.
- **Deforestation**: trees and shrubs cut for **fuelwood** and charcoal (the main fuel for cooking in much of the Sahel) and to clear land.
- **Poor water management**: over-irrigation causes **salinisation**; over-pumping lowers water tables.
- **Population growth**: Niger's population rose from about 3.4 million in 1960 to about 25 million in 2021, more than seven times; demand for food and fuel rises with it.
- **Government policy and conflict**: **settling nomads** in permanent villages (they can no longer move their herds to let pasture recover); **refugee migrations** from wars and droughts concentrating people; poor land management and insecure land rights.

Natural factors:

- **Short-term drought** and **highly variable rainfall**: in a drought, vegetation dies back and soil dries out, so it is exposed to the wind; the Sahel droughts of 1968–1974 and the early 1980s brought the crisis to world attention.
- **Long-term climate change**: more frequent, longer or more severe droughts, and **higher temperatures** with **higher evaporation**.
- **Intense rainfall events** after drought, which erode the bare soil and cut gullies.
- **Natural salinisation** and **wildfire**.

How they interact. A drought on its own causes **temporary** damage: the vegetation recovers when the rains return. Satellite images show the southern edge of the Sahara moving **back and forth** from year to year with the rain, and much of the Sahel has **re-greened** since rainfall partly recovered in the 1990s. Damage becomes **lasting** when **human pressure** stops the land recovering: herds and fields are kept going through the drought, so the soil is stripped just when it is most vulnerable. So drought is usually the **trigger**, human pressure the **underlying cause**, and wind and water the **agents**; the balance varies from place to place.

Case study: sustainable management in the Sahel (Burkina Faso and Niger)

The area. The **Sahel** is the semi-arid belt along the southern edge of the Sahara, several hundred kilometres wide, from Senegal to Sudan, with roughly 200–600 mm of rain in a single summer season from the ITCZ. **Burkina Faso** and **Niger** are among the poorest countries in the world; most people are farmers growing millet and sorghum, or herders.

Problems of sustainable management:

- **Physical**: low, **highly variable** rainfall and recurring **drought**; intense storms that erode the soil; poor, sandy or crusted soils; climate change raising temperatures and evaporation.
- **Human**: **rapid population growth** (fertility around six or seven children per woman in Niger); **poverty**, so people cannot afford fertiliser, wells or other fuels; dependence on **fuelwood**; **overgrazing** and shortened fallows; **insecure land rights** (until the 1990s trees on farms in Niger legally belonged to the state, so farmers had no reason to protect them); **conflict and insecurity**, since 2012, which have driven millions from their homes and halted projects.
- **The result**: **desertification**: lost tree cover, eroded soils and falling yields, which bring food shortages and migration.

Attempted solutions and their evaluation:

1. **Water harvesting: stone lines, zaï pits and half-moons (Burkina Faso, from the late 1970s). Stone lines** are rows of stones laid along the **contours**: they slow runoff, so water soaks in and eroded soil is trapped behind them. **Zaï** are small pits dug in crusted, bare ground in the dry season and filled with **manure**; they catch rainwater and concentrate nutrients round the seeds. A farmer in the **Yatenga** region, **Yacouba Sawadogo**, revived and improved the method in the 1980s and taught it widely. **Half-moons** are larger crescent-shaped banks that hold water on slopes. Across the Central Plateau, a few hundred thousand hectares of degraded land have been brought back into use, yields have often doubled, and groundwater has risen in places. They are **cheap, simple and local**, using farmers' own labour (**bottom-up**), but they are **hard work**, need stones carried and manure that not every farmer has, and cannot make up for a very dry year.
2. **Farmer-managed natural regeneration (FMNR) (Niger, from the 1980s).** Instead of planting seedlings, which mostly died, farmers **protect and prune the shoots** that regrow from **living tree stumps and roots** in their fields. Trees such as **Faidherbia albida**, which fixes **nitrogen** and drops its leaves in the wet season (so it does not shade the crops), improve the soil; trees also act as **windbreaks**, give **fuelwood, fodder and fruit**, and shade livestock. Once **forest law changes** let farmers own and sell the trees they protect, it spread from farmer to farmer: about **5 million hectares** of Niger have re-greened, with an estimated 200 million more trees. It is **cheap**, **spreads by itself** and pays farmers back quickly, but depends on **secure tree rights**, on enough rain for regrowth, and on neighbours not cutting the trees.
3. **The Great Green Wall (from 2007).** An African Union plan for a belt of restored land **8000 km** long across the Sahel, from Senegal to Djibouti, with a target of **100 million hectares** by 2030. It has raised attention and money (donors pledged about **14.3 billion US dollars** in January 2021), and has changed from planting a line of trees to a **mosaic** of land restoration, including FMNR and water harvesting. But by **2020** only about **4 million hectares** had been restored inside its zone, **4%** of the target; many planted seedlings died, and insecurity has stopped work in large areas. It is **top-down** and slow.
4. **Managing grazing and herding. Nomadic pastoralism** moves herds with the rains and lets pasture recover, which is well suited to variable rainfall; policies that settle herders, and boreholes that concentrate them, have often done harm. **Paddocking** (rotating herds between fenced areas), reducing herd sizes and restocking after drought help. These **work with** the variability of the climate, but conflict between farmers and herders over land and water is growing.

5. **Crops, fuel and water**: **drought-resistant** varieties of millet and sorghum; **crop rotation** and agroforestry; **improved cookstoves**, which burn less wood; small dams and wells, though **irrigation** without drainage risks **salinisation**.

Criteria for judging success: **environmental** (tree cover, soil, water), **economic** (yields, incomes, cost), **social** (food security, who benefits: women, herders, the poorest), **timescale** (short-term relief against long-term change), **scale** (one village or a whole region) and **how far** each problem has been **solved**.

Judgement. The **bottom-up**, low-cost methods (stone lines, zaï, FMNR) have done most, because they give farmers a **direct, quick return** and spread from farmer to farmer; the **Great Green Wall** has shown how hard top-down planting is, and has succeeded best where it has adopted those methods. No solution removes the **underlying** problems of **drought, rapid population growth, poverty and insecurity**, so the Sahel is managed **more sustainably than in the 1980s** but remains **vulnerable**. A contrast in a **hot arid** area: **Libya's Great Man-Made River** pumps **fossil water** from aquifers under the Sahara, including the Nubian Sandstone Aquifer, to coastal towns and farms; it supplies water now, but the water is **not being replaced**, so it is **not sustainable**.

Key facts and formulas

There is no formula list in Paper 3, so learn all of these.

Formula	Status
Hot arid (desert): under about 250 mm of rain a year; semi-arid: about 250–500 mm	Learn it
Aridity index $= \dfrac{P}{PET}$ (annual precipitation ÷ potential evapotranspiration): hyper-arid under 0.05; arid 0.05–0.20; semi-arid 0.20–0.50; dry sub-humid 0.50–0.65	Learn it
Mean annual rainfall $\bar{x} = \dfrac{\sum x}{n}$; standard deviation $\sigma = \sqrt{\dfrac{\sum (x - \bar{x})^2}{n}}$	Learn it
Coefficient of variation (rainfall variability) $= \dfrac{\sigma}{\bar{x}} \times 100$; over about 40% in hot deserts	Learn it
Rainfall anomaly = a year's rainfall − the long-term mean (as a percentage: anomaly ÷ mean × 100)	Learn it
Annual temperature range = highest mean monthly temperature − lowest; diurnal range = highest − lowest temperature in the same 24 hours	Learn it
Percentage of the year's rain in a period = rain in the period ÷ annual total × 100	Learn it
Sand moved by the wind rises roughly with the cube of wind speed: twice the speed moves about $2^3 = 8$ times as much sand	Learn it
Angle of repose of dry sand (a dune's slip face): about 32–34°	Learn it

Formula	Status
Air cools or warms at the dry adiabatic rate, 10 °C per km, outside cloud, and at about 6 °C per km (the saturated rate) inside cloud	Learn it
Net primary productivity (g per m² per year): hot desert and semi-desert about 90; savanna about 900; rainforest about 2200	Learn it

Term and meaning	Status
Aridity: a lasting climatic shortage of water, where potential evapotranspiration far exceeds precipitation	Learn it
Subtropical anticyclone: a belt of high pressure at about 20–30° N and S, where air sinks, warms and dries, so skies are clear	Learn it
Continentality: the effect of distance from the sea; inland air has lost its moisture	Learn it
Rain shadow: the dry area on the leeward side of mountains, where descending air warms and dries	Learn it
Temperature inversion: a layer where temperature rises with height, which stops air rising	Learn it
Thermal fracture: rock breaking from repeated heating and cooling; **exfoliation**: the peeling of curved sheets from a rock surface	Learn it
Salt weathering: the breaking of rock by salt crystal growth, hydration and expansion of salts in pores and joints	Learn it
Deflation: the removal of loose, fine particles by the wind; **abrasion (corrasion)**: wearing of rock by wind-blown sand	Learn it
Saltation: sand grains bouncing along in short hops; **suspension**: dust carried high in the air; **traction**: large grains rolled or pushed	Learn it
Ephemeral stream: a stream that flows only during and just after rain	Learn it
Flash flood: a sudden, fast-rising flood in a channel after intense rain; **sheet flood**: a thin sheet of water spreading across a gentle slope	Learn it
Wadi (arroyo in the Americas): a steep-sided, flat-floored desert valley or channel cut by flash floods, usually dry	Learn it
Alluvial fan: a fan of sediment deposited where a stream leaves a mountain canyon; **bajada**: joined alluvial fans along a mountain front	Learn it
Pediment: a gently sloping rock surface at the foot of a mountain front	Learn it
Playa: a flat basin of inland drainage, flooded briefly after rain, with a salt crust when dry	Learn it

Term and meaning	Status
Inselberg: a steep-sided isolated hill rising from a plain; **mesa**: a flat-topped hill wider than it is high; **butte**: a flat-topped hill higher than it is wide	Learn it
Barchan: a crescent dune with horns pointing downwind; **seif**: a linear dune parallel to the wind	Learn it
Yardang: a streamlined ridge cut by wind in soft rock; **zeugen**: ridges of soft rock under a resistant cap, cut along joints	Learn it
Pluvial: a past period much wetter than today	Learn it
Xerophyte: a plant adapted to drought; **halophyte**: a plant adapted to salty soil	Learn it
Physical drought: a real lack of water; **physiological drought**: water present but too salty for plants to take up	Learn it
CAM photosynthesis: stomata open at night to store carbon dioxide, and stay closed in the day	Learn it
Salinisation: the build-up of salts in soil as water drawn up by capillary action evaporates	Learn it
Desertification: the degradation of land in dry areas by climatic variations and human activities	Learn it
Sustainable management: using an environment to meet people's needs today without destroying it for the future, balancing economic, social and environmental aims	Learn it

How to do it

We have tagged 87 questions for this topic (2021–2025, all Paper 3), 60 different (the variants 31, 32 and 33 often share questions). Every Question 10 (29 of them) has a describe part (a) and an explain part (b), so it counts under two types and the counts add up to 116.

Question type	Questions
Describe a figure, photograph, graph or map	29
Explain how a landform formed or how water or wind shaped a landscape	14
Essay: wind against water in forming landforms	11
Essay: the causes of aridity	11
Desertification and land degradation	9
Explain the climate: aridity, rainfall variability or wind energy	8
Essay: sustainable management case study	8

Question type	Questions
Essay: soils, productivity and fragility	7
Plant adaptations to drought and heat	6
Explain stream flow in dry areas	4
Essay: comparing hot arid and semi-arid environments	3
Weathering processes	3
Essay: past against present processes	3

Marking: Question 10(a) gives **1 mark for each accurate point** (3 or 4 marks), usually with a mark kept for **data**; naming a landform scores nothing, describing it does. Question 10(b) (6 or 7 marks) is marked in **three levels** (Level 3, 5–6 marks: clear explanation, applied to the figure; where it asks for "two" reasons or ways, both must be clearly explained). The 20-mark essays are marked in **four levels** (Level 4, 16–20 marks: sustained evaluation and a sound conclusion, with examples integrated), with a **maximum of 8 without examples** and of Level 2 without **explicit evaluation**.

1. Describe a figure, photograph, graph or map (29 questions)

Figures: **climate graphs and tables** (Lajamanu in Australia, Monterrey in Mexico), **world maps** (hot semi-arid areas), **rainfall graphs** (Sahel anomalies, southern African variability), a **wind-speed trace**, a **stream hydrograph**, a map of **perennial streams**, **laboratory results** (rock weight loss from salt weathering), a **dune diagram**, a **model of desert landforms**, a **cross-section** of a mountain front and fan, and **photographs** (wadis, a flash flood, dunes, yardangs, an inselberg, desert vegetation).

1. **Overall pattern first**, then detail, then **anomalies**.
2. **Quote data**: values with units, months, years, places, latitudes, compass directions. One point per mark, and one mark is kept for data.
3. **Describe only**: no reasons. For photographs, **physical features only**, and only what is **shown** (examiners report answers describing landforms that were not in the photograph).
4. If the figure has **two series** (temperature and rainfall; daily and 10-year averages), describe **both**: answers on one are capped at 3.

Variants:

- **World maps**: relation to the **tropics and the equator** (bands either side, little on the equator or poleward of the tropics), **continents** in order of area (Africa, then Australia), **inland against coastal**, east–west bands, two zones in Africa (a narrow belt north of the equator, a broader zone near the Tropic of Capricorn), small areas (North African coast to the Middle East and India, south-western North America and Mexico, isolated patches in South America).
- **Climate graphs and tables**: annual total (is it arid or semi-arid?), the wet and dry seasons and their months, the wettest and driest months with values, the annual temperature range, the hottest and coolest months, whether rain falls in the hot or the cool season. **Select** data: don't turn the whole table into words.

- **Rainfall anomaly or variability graphs**: overall fluctuation, **periods** of mostly positive or negative anomalies (with years), the largest positive and negative values with units, any trend; describe **variability**, not just amount.
- **Wind or flow traces**: degree of variability, peaks and calm spells with dates and values, the range.
- **Landform photographs or diagrams**: shape, height and steepness (relative to the surroundings), slopes and breaks of slope, bare rock and **bedding**, debris size and shape (**angular** high up, **rounded** low down), colour, sand or gravel floors, vegetation (or its absence). For a fan: where it starts (a canyon), its spread, its gentle slope, its shape. For a dune: its shape, the gentle and steep sides, the crest, ripples on the surface.
- **Vegetation photographs**: plant spacing and bare ground, height, layers, shapes (columns, rosettes, shrubs), leaves or spines, colours.
- **"Compare"**: link every point ("Experiment A lost weight steadily, **whereas** B lost little until cycle 20").
- **"With the aid of a labelled diagram"**: a simple sketch with labelled features; without it, the mark is capped.

2. Explain how a landform formed or how water or wind shaped a landscape (14 questions)

Landforms asked: **mesas, buttes and inselbergs**, **alluvial fans** (three times), **wadis**, **sand dunes** (barchans), **yardangs**, and "how water shaped the landscape" in photographs (Egypt, Kazakhstan, Anza-Borrego in California) or the role of **flash floods**.

1. **Identify** the landform and the **process** that dominates (water, wind, weathering).
2. **Explain the sequence**, step by step, linking each process to the shape it produces (as in "Understand it": flash flood → loss of gradient and confinement → deposition, coarse first → fan).
3. **Apply it to the figure**: point to the features you described in (a) (the rounded debris at the slope foot shows water transport; the cap rock keeps the mesa flat).
4. **Add the supporting processes**: weathering (salt, thermal fracture, **freeze–thaw on cold nights**), rockfall, and **past pluvial** activity.
5. "**Two landforms**" or "**two ways**": develop both.

Variants:

- **How water shaped a landscape** (a wadi in a photograph): flash floods **eroding** the wadi (abrasion with their load, hydraulic action); **transport and deposition** of the sandy, flat floor; **weathering** of the slopes by salt crystallisation and hydration after rain, and freeze–thaw at night, providing the **blocky debris**; **rounded** rocks at the foot showing **water** action; **pluvial** periods doing much of the cutting. Don't write about wind landforms here (examiners report this).
- **Alluvial fans**: explain both the **erosion** in the canyon and the **deposition** on the fan (examiners note answers that miss the link).
- **Barchans**: a reliable sand supply, an obstacle, a steady wind from one direction, turbulence over the crest, the slip face at the angle of repose, and **wind shear round the sides** stretching the horns.
- **Pediments**: parallel retreat, **lateral planation** by shifting streams, and sheet floods.

3. Essay: wind against water in forming landforms (11 questions)

"Wind action (or water action, wind transportation, water erosion) is the most important", "assess the influence of water", "landforms formed by water rather than wind", "the role of water in **piedmont zone** landforms".

1. **Define** the processes: wind (deflation, abrasion, saltation, suspension, deposition), water (flash floods, sheet floods, abrasion, hydraulic action, deposition), and weathering.
2. **Group the landforms** (the table in "Understand it"), and explain each one's formation briefly with its process.
3. **Weigh, landform by landform**: which process forms it, which modifies it, and whether **more than one** works together (pedestal rocks, inselbergs, playas).
4. **"It depends"**: on **aridity** (wind dominates in hyper-arid areas, water in semi-arid ones), on **time** (relict **pluvial** landforms against present flash floods), on **scale** (water shapes the large relief; wind reshapes sand and soft rock), and on **rock type** (yardangs need soft rock).
5. **Use located examples**: Erg Chigaga, the Namib Sand Sea, the Kaluts of Iran, Death Valley's fans and Badwater playa, Monument Valley.
6. **Conclude**: for example, "Water forms more of the large landforms, much of it in the past, while wind is the dominant process today in the driest areas."

For **piedmont** essays: mountain front, pediment, bajada, playa and inselbergs, with **sheet floods**, **flash floods** and **lateral planation**, against weathering and wind (examiners saw answers on landforms that are not in the piedmont).

4. Essay: the causes of aridity (11 questions)

"Assess the relative importance of the causes", or one cause singled out: **pressure and wind systems**, the **rain shadow effect**, **ocean currents**, "**always a combination**".

1. **Define aridity** (and don't write about desertification: examiners report this).
2. **Explain each cause with its mechanism**: the subtropical high and the Hadley cell (sinking, adiabatic warming, stability, inversion); trade winds from the land and offshore winds; continentality; the rain shadow (with the wind direction right: the desert is on the side the wind blows **towards**); cold currents (chilling, inversion, fog, warming inland).
3. **Match causes to named deserts** (the table in "Understand it"): the best answers show that **most deserts have several causes** and that some have **one dominant** cause.
4. **Show the links**: the subtropical high drives the trade winds, which drive upwelling and strengthen the cold currents.
5. **Conclude**: the **subtropical high** is usually the most important, because it explains the belts of deserts near the tropics; the others explain **where** within or beyond those belts the driest areas are (west coasts, interiors, lee sides).

5. Desertification and land degradation (9 questions)

Essays on **human against natural** factors, or one factor singled out (**wind action**, **salinisation**, **population pressure**), and one 6-mark part: how a **lack of precipitation** leads to desertification.

1. **Define** desertification: degradation of land in **semi-arid** areas, not the existence of deserts.
2. **Explain the process** (the chain in "Understand it"): vegetation loss → bare soil → crusting, runoff, gullies → wind deflation → infertile subsoil → less regrowth. Link **every factor to this process** (examiners report lists of causes that never explain how they degrade land).
3. **Human factors and natural factors**, each with **located evidence**: the Sahel (Niger, Burkina Faso, Mali), the Indus plains (salinisation).
4. **Weigh them**: drought as **trigger**, human pressure as **cause**, wind and water as **agents**; the evidence of re-greening when rain returns; differences from place to place.
5. **Conclude**: for example, "Drought starts the damage, but people's use of the land decides whether it recovers."

For the **6-mark part on lack of precipitation**: plants die back or fail → soil dries and loses cohesion → **wind** removes topsoil → infertile, hard subsoil cannot support regrowth; drought also leads people to pump **groundwater** for irrigation, risking **salinisation**; worse where people have already weakened the land (overgrazing, marginal cultivation).

6. Explain the climate: aridity, rainfall variability or wind energy (8 questions)

"Suggest why area X is semi-arid", "suggest two reasons for the climate of Lajamanu", "explain the influence of latitude on Monterrey's seasonal rain", "why rainfall variability is very high", "why these environments have high wind energy".

1. **Use the figure's information**: the **latitude** (and so the sun angle, the pressure belt and the ITCZ's reach), **distance from the sea**, **altitude**, the **months** of rain and heat.
2. **For a semi-arid station**: high sun angle all year, so it is hot; the **ITCZ** arrives briefly in summer, bringing convectional rain in the hottest months; for the rest of the year the **subtropical high** (the sinking limb of the Hadley cell) and dry winds from the land (**continentality**) keep it dry; a mountain range may add a rain shadow.
3. **For variability**, explain why the **amount varies from year to year**: the ITCZ's reach, blocking highs, **ENSO**, ocean temperatures, hit-and-miss convective storms. Answers about the amount of rain, not its **variability**, stay in Level 1.
4. **For wind energy**: heating and pressure gradients, little friction from bare flat ground, channelling, anabatic and katabatic winds, sea breezes, thunderstorm downdrafts.
5. "**Two reasons**": develop **both**.

7. Essay: sustainable management case study (8 questions)

Usually "evaluate **solutions** to the problems"; once "evaluate the **problems**", once "**variations in precipitation** are the main problem".

1. **Name and locate** one **hot arid or semi-arid** area (the Sahel of Burkina Faso and Niger), with facts.
2. **Problems**: physical (drought, variable rain, soils) and human (population, poverty, fuelwood, grazing, land rights, conflict), and **rank** them (does one cause the others?).
3. **Solutions, each linked to the problem it targets**: stone lines and zaï (runoff and soil loss), FMNR (tree loss, fuel, fodder, soil fertility), the Great Green Wall, grazing management, drought-resistant crops, stoves, wells and dams.
4. **Criteria**: environmental, economic and social; **stakeholders**; **timescale**; **scale**; **how far** each problem is solved.
5. **Conclude**: which worked best and why, and whether management is truly **sustainable**.

For "**precipitation variations are the main problem**": they are the **natural** base of the problem (drought, unreliable harvests, erosion by intense storms), but **human** factors (population, poverty, land use, policy, conflict) decide whether a dry year becomes a disaster; solutions that **work with** variability (mobile herding, water harvesting) show this.

8. Essay: soils, productivity and fragility (7 questions)

"Salinisation is the **most important soil process**", "the role of **upward movement of water** in soil formation", "the causes of **low biomass productivity**", "the **fragility** of vegetation is the result of low productivity".

1. **Describe** desert soils (aridisols) and vegetation briefly.
2. **Explain the named process or cause** fully: capillary rise, evaporation and salt build-up; solonchaks, solonetz and duricrusts; or the water limit on productivity.
3. **Weigh it against the others**: calcification and limited leaching, humification, weathering, wind and water erosion, irrigation-made salinity; or for productivity, heat, soils, salinity and grazing; for fragility, poor soils, variable rain and human pressure.
4. **Distinguish** arid from semi-arid (true soils are scarce in the driest areas; calcification and erosion matter more in semi-arid areas) and **natural** from **human** (slow natural processes, fast human ones).
5. **Conclude**: for example, "Salinisation is the characteristic natural process, but in the semi-arid Sahel, soil erosion after human degradation is the more important."

9. Plant adaptations to drought and heat (6 questions)

Essays asking whether plants are adapted more to **extreme temperatures** or to **physical and physiological drought** (5 essays, 3 different, once with "the main influence"), and one 6-mark part on **drought** adaptations.

1. **Define** physical and physiological drought, and the extreme temperatures (over 40 °C by day, near or below 0 °C on winter nights).
2. **Explain specific adaptations, each linked to its function**, and name the plants: CAM, stomata, cuticles, spines, water storage, tap roots and lateral roots, ephemerals, deciduousness; pale, hairy and vertical leaves; halophytes.
3. **Sort them**: which are for water, which for heat, and which **both** (most heat adaptations reduce water loss; the acacia's umbrella crown).

4. **Conclude** with the **oasis** argument: water is the main influence.

10. Explain stream flow in dry areas (4 questions)

"Suggest reasons for the hydrological regime" of a small stream in Arizona; "explain why some streams in arid environments are **perennial** whereas others are not".

1. **Regime**: long periods of **zero flow**; sudden, short **peaks** after **intense convective storms**; low **infiltration** (bare, crusted ground) giving fast overland flow; no vegetation to intercept; high **evaporation** and **transmission losses** into the bed, so flow shrinks downstream; no baseflow.
2. **Perennial or not**: perennial where **groundwater** or **springs** feed the stream (geology forcing water to the surface), or where it rises in **wetter mountains** (relief, rain and snowmelt); not perennial where the water table has dropped from **pumping** or a drier climate. Use the figure's places and compass directions.

11. Essay: comparing hot arid and semi-arid environments (3 questions)

"To what extent do their **global distributions** differ?", "assess the **variability of temperature and precipitation** between them".

1. **Distributions**: answer about **where** they are, not their causes (examiners report this); semi-arid areas mostly **surround** arid cores, but also stretch into areas without deserts (north-east Brazil, East Africa); name and locate them.
2. **Variability**: both **seasonal and diurnal**, for both **temperature and precipitation**, in **both** environments, with figures (the comparison table and the model stations); link it to controls (pressure and wind systems, cloud cover).
3. **Conclude** on the **degree** of difference.

12. Weathering processes (3 questions)

"Explain how rocks are weathered by **salt**" (with a figure of laboratory experiments), "**salt crystal growth** is the most important", "**chemical weathering** is the most important in forming landforms".

1. **Salt weathering**: crystallisation, hydration and thermal expansion of salts, the **sources** of salt, and the need for water to get **inside** pores and joints.
2. **Weigh the processes**: salt, thermal fracture and exfoliation, chemical (from dew, fog and rare rain), freeze–thaw (high deserts, winter nights), and biological (roots in semi-arid areas).
3. **Where and when** each is strongest: coasts against inland deserts, arid against semi-arid, high against low deserts, present against pluvial periods.
4. **Link to landforms**: weathering supplies the sand and dust for **wind**, rounds and undercuts landforms, and helps form pedestal rocks and tafoni (examiners note few answers made this link).

13. Essay: past against present processes (3 questions)

"Assess the evidence for past climate change", "to what extent are landforms influenced by **past** processes rather than present ones".

1. **Explain pluvials** and when they happened (Pleistocene, the African Humid Period).
2. **Evidence**, each piece assessed for how strong it is (dated and physical, or circumstantial).
3. **For landforms**: relict water landforms (wadis too big for today's floods, inactive fans, pediments, buried rivers), against present **aeolian** activity (dunes, yardangs) and **present flash floods**, which still work.
4. **Conclude**: much of the large-scale landscape is inherited from wetter times, but it is being actively modified today.

Worked examples

Example 1

The climate graph of Station S (14° N) is in "Understand it".

(a) Describe the climate of Station S. **[4]**

(b) Explain the seasonal pattern of rainfall at Station S. **[6]**

(a) One mark for each point; one mark kept for data.

- It is semi-arid: the annual total is 437 mm **(1)**.
- Rain is strongly seasonal: 410 mm (93.8% of the total) falls from June to September, with a peak of 165 mm in August, and there is none from November to March **(1)**.
- It is hot all year: the coolest month, January, averages 24 °C and the annual range is only 10 °C **(1)**.
- The hottest month is April (34 °C), before the rains; temperatures dip to 27.5 °C in August, during the rains, and rise again to 30.5 °C in October **(1)**.

(b)

Station S lies at 14° N, near the poleward edge of the area the ITCZ reaches, so its rain depends on the seasonal movement of the ITCZ and the subtropical anticyclone.

In June the overhead sun reaches the Tropic of Cancer, and the ITCZ follows it north, reaching about 14° N in July and August. Moist south-westerly air from the ocean is drawn in, the hot ground heats it, and it rises by convection, cools, condenses and forms cumulonimbus clouds, giving heavy afternoon storms. The ITCZ stays over Station S only briefly, at its most northerly position, which is why the wet season is short and peaks in August (165 mm).

From October the ITCZ retreats south towards the equator, and Station S comes under the subtropical anticyclone. Air in the sinking limb of the Hadley cell warms adiabatically and is stable, so clouds cannot form; the north-east trade winds blow from the Sahara, so they are hot, dry and dusty. So there is no rain from

November to March.

Because the station is at the edge of the ITCZ's reach, a small change in how far north it moves in a given year makes a large difference to the rain, so the total is also very variable.

Level 3 (5–6 marks): the wet and dry seasons are clearly explained by the movement of the ITCZ and the subtropical high, with the processes and timing linked to the figure's months and values.

Example 2

Explain how alluvial fans and bajadas form in hot arid environments. **[6]**

An alluvial fan is a fan-shaped spread of sediment at the foot of a mountain front, such as those along the edge of Death Valley, California; a bajada is a line of fans that have joined.

In the mountains, rare but intense convective storms fall on bare, steep slopes where little water can soak in, so runoff collects quickly in narrow canyons as **flash floods**. Confined and on a steep gradient, the floods are fast and powerful: they **erode** the canyon by **abrasion** with their load and by hydraulic action, and pick up large amounts of sediment, from boulders to silt, much of it supplied by weathering of the slopes.

At the mountain front, the channel suddenly loses its **confinement** and its **gradient** falls. The water spreads out across the plain, becomes shallow, slows and loses energy, and much of it **soaks into** the coarse sediment or evaporates. It can no longer carry its load, so it **deposits** it: the **coarsest** boulders and gravel first, near the apex at the canyon mouth, and the **finer** sand and silt further out. So the fan is steepest at the apex and has a concave long profile.

Each flood fills its channel with sediment, so the next flood breaks out on a new course: the channels **switch** across the fan, which spreads deposits evenly into a fan shape. Where several canyons emerge along the same mountain front, their fans grow sideways until they **join**, forming a continuous apron, the **bajada**. Many fans grew mostly in wetter **pluvial** periods and are only slowly added to today.

Level 3 (5–6 marks): both the erosion in the canyon and the deposition on the fan are clearly explained, with the reasons for sorting and shape, and the formation of the bajada.

Example 3

'Desertification in semi-arid environments is caused mainly by drought.' How far do you agree with this statement? **[20]**

Introduction. Desertification is the degradation of land in dry areas, where soils and vegetation lose their productivity, through climatic variations and human activities. A drought is a period of rainfall well below normal. The question is whether drought is the main cause, or whether human pressure matters more.

The case for drought. Semi-arid areas such as the Sahel have highly variable rainfall. In the Sahel, rainfall in the 1970s and 1980s was about 20–40% below that of the 1950s and 1960s, and the severe droughts of 1968–1974 and the early 1980s coincided with the worst degradation. In a drought, grasses and shrubs die back and crops fail, so the soil is left bare and dry; it loses its cohesion, and the wind deflates the fine, fertile

topsoil, leaving infertile subsoil. When the rains return, they often come as intense storms that strip more soil and cut gullies. Longer-term climate change may make droughts more frequent and raise temperatures and evaporation. So drought is clearly a major factor.

The case for human factors. But droughts have always happened in the Sahel, and the land recovered. Damage became lasting when human pressure grew. Niger's population rose more than seven times between 1960 and 2021, so more land was farmed, with shorter fallows and more marginal land cultivated; cash crops for export took the better land. Herds grew in wet years and were kept through the droughts; boreholes concentrated cattle, leaving bare rings of land round them. Trees were cut for fuelwood. Policies that settled nomads, and refugees concentrated by conflict, added to the pressure. In irrigated areas, poor drainage led to salinisation, which has nothing to do with drought.

The evidence on the balance. Satellite images show the edge of the Sahara moving back and forth with the rainfall from year to year, and much of the Sahel has re-greened since the rains partly recovered, which shows how strongly rainfall controls vegetation. But re-greening has been greatest where people changed how they used the land: in southern Niger, farmers protecting regrowing trees (FMNR) restored about 5 million hectares, while similar areas without it did not recover as much. This shows that human management decides whether the land recovers after drought.

Conclusion. Drought is the trigger and wind and water the agents of desertification, but its main cause is human pressure on the land: without overgrazing, overcultivation and deforestation, the vegetation would recover after each drought, as it always has. I agree only partly: drought is a necessary part of the process, but human activity turns temporary drought damage into lasting desertification, and the balance between them varies from place to place.

Level 4 (16–20 marks): both sides explained through the process of degradation, with located evidence; the interaction weighed; and a judgement that answers "how far".

Common mistakes

- **Confusing aridity with desertification**, or with drought. Aridity is a lasting climatic condition; desertification is land degradation; drought is a temporary shortage.
- **Describing the cold-current mechanism wrongly**: the cold water chills the air from below, making it stable, with fog rather than rain, and the air warms and dries as it moves inland. It is not about cold currents "blowing" dry winds.
- **Getting the rain shadow upside down**: the desert is on the **leeward** side, where the air descends; check the wind direction for your example.
- **Treating each desert as having one cause**, or listing causes without placing them in real deserts.
- **Naming instead of describing** in Question 10(a) ("an inselberg" scores nothing; "an isolated, steep-sided, rounded hill rising abruptly from a flat plain" does), and describing landforms that are **not in the photograph**.
- **Transferring a climate table into sentences** instead of selecting and manipulating the data.
- **Answering about rainfall amount** when the question asks about **variability**.

- **Writing about wind landforms when the question is about water** (yardangs in a flash-flood answer), or describing every possible process without applying them to the figure.
- **Explaining alluvial fans by deposition only**, without the erosion and flood flow in the canyon; and struggling with pediments (learn lateral planation and parallel retreat).
- **Speculative accounts of mesas and buttes**: they depend on a resistant cap rock, valley cutting and slope retreat.
- **Claiming that all water action happened in past pluvials**: flash floods shape landforms today.
- **Forgetting that salt weathering needs water inside the rock**, and that weathering supplies the material for wind.
- **Not linking plant adaptations** to heat or to drought, and not distinguishing **physical** from **physiological** drought.
- **Generic desertification answers** that could apply anywhere (Amazon deforestation is not desertification), or that list causes without explaining how each degrades soil and vegetation.
- **Distribution questions answered with causes**: describe and compare where the environments are, naming regions.

How to get the marks

- **Command words. Describe** = what the figure shows, with data, no reasons. **Compare** = linked similarities and differences ("whereas", "both"). **Explain** = reasons and processes, cause and effect. **Suggest** = apply what you know to the figure or place. **Assess**, **evaluate**, **how far**, **to what extent** = weigh both sides and reach a judgement.
- **Question 10(a)**: one point per mark; overall pattern first; quote values, units, places and dates; describe both series where there are two; physical features only in photographs.
- **Question 10(b)**: Level 3 needs clear, **developed** explanation **linked to the figure**; "two reasons" or "two ways" needs both developed; a labelled diagram (a dune profile, a fan, a piedmont cross-section, a rain shadow) earns credit.
- **Essays**: an introduction that defines the terms; both sides, each point explained and backed by a **located example** (place, date, number); "it depends" on aridity, time, scale and place; a conclusion that answers the question directly. Without examples, the maximum is 8 of 20; without explicit evaluation, Level 2.
- **Landform essays**: cover a **range** of landforms (wind, water and weathering), not just the one process named.
- **Aridity essays**: mechanisms precisely, then **match causes to named deserts** and note combinations.
- **Case studies**: one named area, with facts; problems ranked; each solution linked to a problem; criteria for evaluation (economic, social, environmental, stakeholders, timescale); a final judgement.
- **Time**: Question 10 is 10 marks and the essay 20, so spend about twice as long on the essay, and leave time for its conclusion.

Quick check

1. A semi-arid station's annual rainfall (mm) over eight years was: 250, 520, 190, 360, 410, 160, 305, 205. Calculate the mean, the standard deviation (dividing by n), the coefficient of variation, and the percentage anomaly of the driest year.
2. During a dust storm the wind speed rises from 8 m/s to 12 m/s. Roughly how many times as much sand will it move?
3. Place A has 350 mm of rain a year and a potential evapotranspiration of 1400 mm; place B has 40 mm and 2800 mm. Calculate their aridity indices and classify them.
4. Explain the difference between physical and physiological drought, and give one plant adaptation to each.
5. Explain why the diurnal temperature range in a hot inland desert is much larger than on a desert coast beside a cold ocean current.

Answers

1. Mean $= \dfrac{250+520+190+360+410+160+305+205}{8} = \dfrac{2400}{8} = 300$ mm, within the semi-arid band. Deviations from the mean: $-50, 220, -110, 60, 110, -140, 5, -95$; their squares sum to $107\,350$. So $\sigma = \sqrt{\dfrac{107\,350}{8}} = \sqrt{13\,418.75} = 115.8$ mm, and the coefficient of variation is $\dfrac{115.8}{300} \times 100 = 38.6\%$: high, at the top of the usual semi-arid range. The driest year (160 mm) has an anomaly of $160 - 300 = -140$ mm, which is -46.7%.
2. Sand moved rises roughly with the cube of the speed: $\left(\dfrac{12}{8}\right)^3 = 1.5^3 = 3.375$, so about 3.4 times as much, though the speed rose by only half.
3. A: $\dfrac{350}{1400} = 0.25$, which is between 0.20 and 0.50, so **semi-arid**. B: $\dfrac{40}{2800} = 0.014$, under 0.05, so **hyper-arid**.
4. **Physical drought** is a real lack of water in the soil; for example, cacti store water in swollen stems, and mesquite sends tap roots tens of metres down to groundwater. **Physiological drought** is when water is present but is too salty for roots to take up by osmosis; for example, saltbush excretes salt through glands on its leaves.
5. Inland, the air is dry and the skies clear, so by day strong sunshine heats the bare ground and the air above it, and at night long-wave radiation escapes freely to space, so temperatures fall fast. On a cold-current coast the cool sea keeps the air cool by day, and fog and low cloud, with the moister sea air, reduce heating by day and trap heat at night, so the range stays small.

Past questions to try

- **9696/33/O/N/24 Q10**: a model of desert landforms, then how a butte and an alluvial fan formed.
- **9696/33/M/J/25 Q12**: case study essay evaluating solutions to the problems of sustainable management.
- **9696/32/O/N/25 Q11**: essay on whether extreme temperatures are the main influence on plant adaptation.
- **9696/33/O/N/25 Q11**: essay assessing the evidence for past climate change.