Cambridge AS & A Level · Geography 9696 · Notes

Coastal environments A2

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Read first: **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. **Explain how waves are generated and what they are like**: **fetch**, wave **energy**, **refraction**, how waves **break**, **high- and low-energy** waves, **swash** and **backwash**.
2. **Explain the processes of marine erosion**: **hydraulic action**, **cavitation**, **corrasion (abrasion)**, **solution** and **attrition**.
3. **Explain the sub-aerial processes** that work on coasts: **weathering** and **mass movement**.
4. **Explain marine transport and deposition**: where coastal **sediment comes from** and what it is like, **sediment cells**, and **longshore drift**.
5. **Describe and explain erosional landforms**: **cliffs** and **wave-cut platforms**, **caves**, **arches** and **stacks**.
6. **Describe and explain depositional landforms**: **beaches** in cross-section (profile) and in plan, **swash-aligned** and **drift-aligned** beaches, **simple** and **compound spits**, **tombolos**, **offshore bars**, **barrier beaches**, **coastal dunes**, **tidal sedimentation in estuaries**, **coastal saltmarshes** and **mangroves**.
7. **Explain the role of sea-level change** in forming coastal landforms.
8. **Describe the characteristics and distribution of coral reefs and explain how they form**: **fringing reefs**, **barrier reefs** and **atolls**, and the **conditions corals need** to grow.
9. **Explain the threats to coral reefs** (global warming, sea-level rise, pollution, physical damage) and **evaluate ways of managing them**.
10. **Know a case study of a stretch or stretches of coastline**: the problems of managing it sustainably, and an **evaluation of the attempted solutions**, including **hard** and **soft engineering**.

It is one of the options in Paper 3 (Advanced physical geography options), where you answer two options. For this option you answer Question 4 (10 marks: a describe part and an explain part, built on a figure) and one essay, Question 5 or Question 6 (20 marks). Read the notes on rocks and weathering (weathering and mass movement) and on hydrology and fluvial geomorphology (how sediment is carried) first.

Understand it

The coastal system

A coast is an **open system**: energy arrives from **waves**, **tides**, **wind** and **currents**, and sediment from rivers, cliffs and the sea floor. **High-energy coasts** (exposed, long fetch, often rocky, such as the Atlantic coast of Cornwall) are dominated by erosion; **low-energy coasts** (sheltered bays, estuaries, the lee of spits and islands) are dominated by deposition.

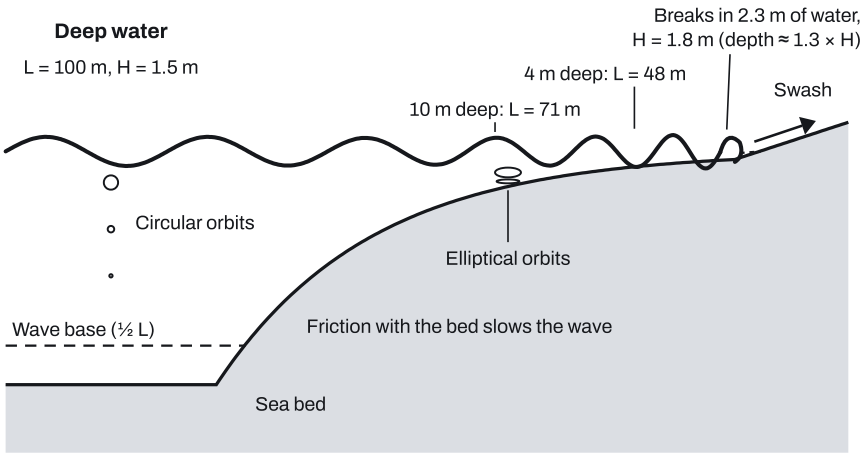
How waves are generated

Waves are made by **wind blowing over the sea**: friction drags the surface into ripples, and the wind pushes on their back slopes so they grow. Their size depends on **wind speed**, **how long the wind blows** and **fetch**, the distance of open water the wind blows over (Cornwall faces thousands of kilometres of Atlantic; the North Sea coast of England has a long fetch only from the north-east). The **depth of water** and the **shape of the coast** then change them as they arrive.

Parts of a wave: **wave height** H (trough to crest); **wavelength** L (crest to crest); **wave period** T (seconds between crests); **frequency** (waves per minute $= 60/T$); **steepness** $= H/L$. **Wave energy rises with the square of the height**, so a 3 m storm wave carries about nine times the energy of a 1 m wave. **Storm waves** are still driven by the wind (short, steep, chaotic); **swell waves** have left their source area (long, regular, lower) and carry energy across whole oceans.

In deep water a wave is energy moving through the water: each water particle moves in a **circular orbit**, and the orbits die out at the **wave base**, about **half a wavelength** below the surface. **In shallow water** (shallower than about half the wavelength):

1. **Friction** with the bed slows the base of each wave, so waves bunch up: the **wavelength shortens**.
2. The faster water near the surface piles up, so **height increases** and the **wave steepens**; the orbits flatten into **ellipses**.
3. The crest overtakes the base and the wave **breaks** when the water depth is about **1.3 times the wave height**. The water rushes up the beach as **swash** and drains back as **backwash**.



The model wave in the diagram has a period of 8 s, so 7.5 waves arrive a minute. Its steepness rises from $1.5/100 = 0.015$ in deep water to about $1.8/37 = 0.049$ just before it breaks, when its wavelength has shortened to about 37 m.

Waves break by **spilling** on gentle beaches (energy lost gradually), **plunging** on moderate slopes (the crest crashes down in one erosive blow) or **surging** up steep beaches.

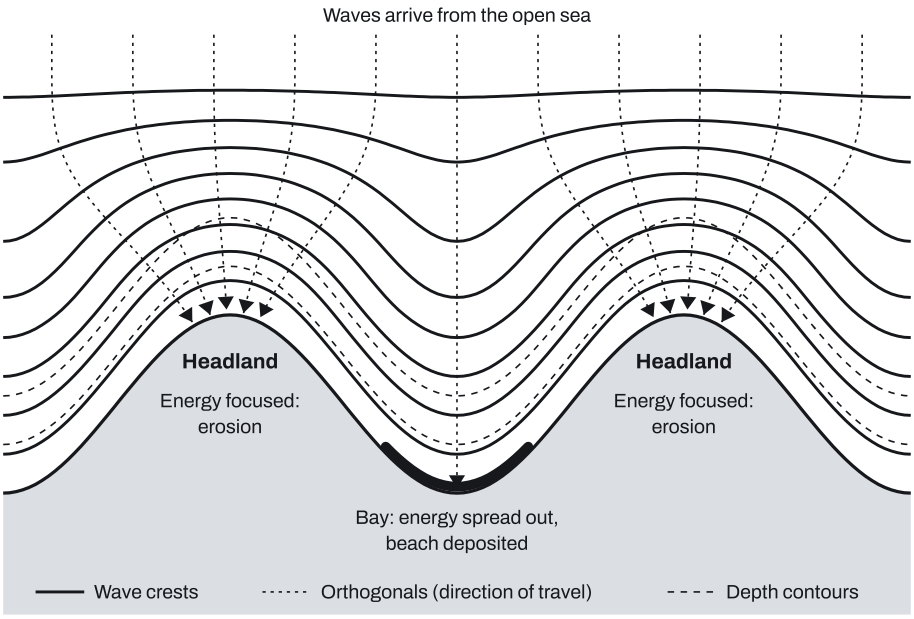
High-energy and low-energy waves: swash and backwash

	Constructive (low-energy) waves	**Destructive (high-energy) waves**
Height and shape	Low (often under 1 m), long wavelength, flat	High, short wavelength, steep
Frequency	Low, roughly 6–8 a minute	High, roughly 11–15 a minute
Breaker	Spilling or surging	Plunging
Swash and backwash	**Swash stronger than backwash**: water soaks into the beach, so the backwash is weak	**Backwash stronger than swash**: the wave crashes down, and each backwash slows the next swash
Effect	Carry sediment **up** the beach: build **berms**	Drag sediment **down** the beach: build **offshore bars**, leave a flatter beach
When	Calm weather, summer, swell	Storms, winter

Wave refraction

Wave refraction is the bending of wave crests in shallow water until they run **roughly parallel to the coast**. Off a **headland** the water is shallow further out, so that part of each wave slows first while the parts over the deeper water of the bays keep going; the crests wrap round the headland.

- The direction lines (**orthogonals**) **converge** on the headland: energy is **concentrated** there, so headlands are **eroded**, and caves on both sides lead to arches and stacks.
- They **diverge** in the bay: energy is **spread out**, so **deposition** builds a bay-head beach. Over time the coast is straightened.
- Round an **island**, refraction brings waves into its lee from both sides, where they drop sediment (a **tombolo**).
- Where refraction turns waves parallel to the shore, the beach is **swash-aligned**; where it can't, it is **drift-aligned**.



Marine erosion

Process	How it works
Hydraulic action	The force of water hitting rock; water and air are forced into cracks, **compressing the air**, which expands again as the wave retreats, widening the crack
Cavitation	Air bubbles collapse under pressure, sending out tiny **shock waves** that weaken the rock
Corrasion (abrasion)	Sand and pebbles are **hurled at** and **scraped along** the rock, wearing it away; strongest at the cliff foot
Solution (corrosion)	Minerals **dissolve** in sea water, especially limestone and chalk
Attrition	Sediment particles **knock into each other**, becoming **smaller and rounder**

Erosion is fastest with high **wave energy** (fetch, storms, plunging breakers), weak or well-jointed **rock**, no protecting **beach**, and rising **sea level**. Examiners warn against "hard" and "soft" rock: say a rock is **more or less resistant to a named process**. Limestone dissolves easily, yet resists abrasion well enough to form headlands such as Durlston Head, Dorset.

Sub-aerial processes

Sub-aerial processes act on the cliff above the reach of the waves: they weaken the cliff and deliver debris to its foot, where the waves remove it.

- **Weathering** (see the rocks and weathering note): **salt crystallisation** (spray evaporates in cracks and growing crystals press on the rock); **freeze–thaw** (water expands by about 9% as it freezes); **wetting and drying** of clays; **carbonation** of limestone; **biological** (roots, boring molluscs, algae).

- **Mass movement**: **rockfalls** from undercut cliffs; **slides** along bedding planes dipping seaward; **slumps** (rotational slides), where saturated clay or till slips on a curved surface, as on the Holderness coast; **mudflows** and **creep**.

Marine processes **undercut** and **remove**; sub-aerial processes **weaken** and **supply**. Where waves dominate, cliffs are **steep**; where sub-aerial processes dominate (sheltered coasts, weak rock, cliffs behind defences), they are **lower-angled**, slumped and vegetated. Sub-aerial processes also **modify** landforms after they form (collapsing arches, lowering stacks), but matter little to depositional landforms except by **supplying sediment**.

Sediment: sources, characteristics and transport

Sources: **rivers** (the largest source worldwide, mostly fine; dams cut the supply, so the Nile delta has eroded since the Aswan High Dam); **cliff erosion** and mass movement (locally dominant on weak-rock coasts; coarse and angular at first); **offshore** sediment pushed onshore as sea level rose after the last glacial period (Chesil Beach, Dorset); **longshore drift** from further along the coast; **shells and coral**; **wind**; **people** (beach nourishment).

Characteristics: **size** (clay, silt, sand, gravel or shingle, cobbles, boulders; see Key facts), **shape** (angular when fresh, rounded by attrition), **sorting**, **volume** and **mineral make-up**, which reflects the source: quartz sand from granite, black sand from basalt (Hawaii), white sand from coral.

Transport: traction, saltation, suspension and solution, as in rivers.

Longshore drift moves sediment **along** the coast:

1. The prevailing wind drives waves onto the beach **at an angle**.
2. The **swash** carries sediment **up the beach at that angle**.
3. The **backwash** drains **straight down the slope** under gravity.
4. Particles zigzag along the beach in the direction of the prevailing waves. On the Holderness coast of eastern England, waves from the north-east drive drift **north to south**, towards Spurn Head.

Sediment cells are stretches of coast, usually bounded by large headlands, within which sediment moves **almost as a closed system**, from **sources** (cliffs, rivers) by **transfers** (drift, currents) to **sinks** (beaches, spits, dunes, offshore banks). England and Wales have **11 major cells**. A groyne or sea wall that holds sediment in one place starves the coast **downdrift** in the same cell, so the cell is the unit to plan for.

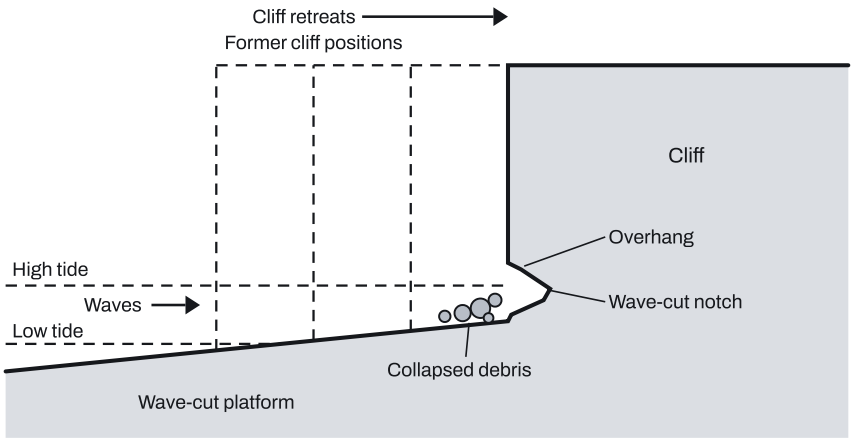
Erosional landforms

Cliffs and wave-cut platforms

1. Waves attack the cliff foot between high and low tide by hydraulic action, abrasion and solution, cutting a **wave-cut notch**.
2. The notch deepens under an **overhang**, which sub-aerial weathering weakens until it **collapses**.
3. The waves remove the debris, using some of it to abrade the next notch, and the cliff **retreats**.

4. A gently sloping rock surface is left in front, the **wave-cut platform**, usually sloping seaward at less than 4° and exposed at low tide.
5. As it widens, waves lose energy crossing it, so erosion of the cliff **slows**; platforms are rarely more than a few hundred metres wide.

Cliff profile depends on **rock structure** (beds dipping inland or horizontal give steep cliffs; beds dipping seaward give sloping cliffs and slides), **resistance** (weak till forms low, slumping cliffs), whether **marine or sub-aerial** processes dominate, and **past sea levels** (relict cliffs).

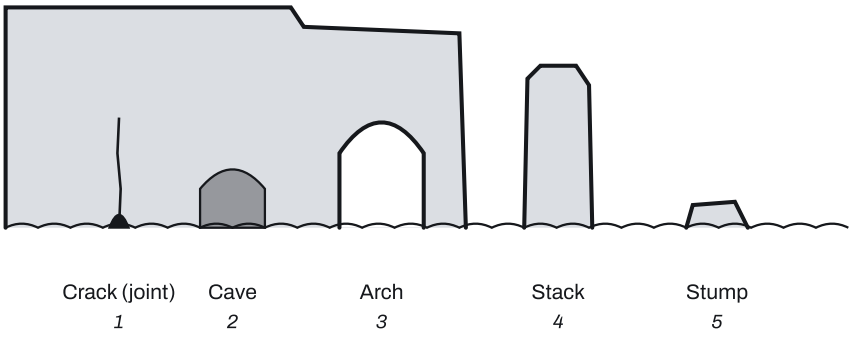


Caves, arches, stacks and stumps form on headlands, where refraction concentrates energy:

1. Hydraulic action and abrasion widen a **line of weakness** (a joint, fault or weak bed) at the foot of the headland into a **cave** (a cave eroded up a joint to the top makes a **blowhole**).
2. Refraction brings waves round to both sides, so caves meet or one cuts through: an **arch**.
3. Waves undercut the arch while sub-aerial weathering (salt, frost, rain) weakens its roof, until it **collapses**, leaving a **stack**.
4. The stack is undercut and collapses to a **stump**, covered at high tide.

Examples: Old Harry Rocks (chalk stacks, Dorset); Durdle Door (an arch in Portland limestone, Dorset); the Twelve Apostles, Victoria, Australia (limestone stacks, one of which collapsed in 2005).

Sequence of erosion on a headland, 1 to 5



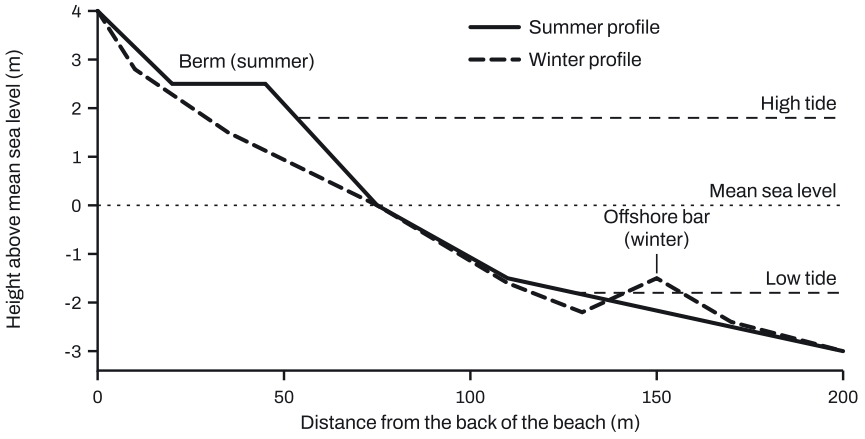
Headlands and bays: where rock bands of different resistance meet the coast **at right angles** (a **discordant** coast), weaker rock is cut back into **bays** and resistant rock stands out as **headlands** (Swanage Bay, between the chalk of Ballard Down and the limestone of Durlston Head). Where bands run **parallel** to the coast (**concordant**), a resistant outer band protects the weak rock behind until breached, which is then hollowed into a **cove** (Lulworth Cove, Dorset).

Beaches

A **beach** is sand or shingle between the lowest tides and the reach of storm waves. In **profile**, from land to sea: a **storm ridge** of coarse material; **berms** at the normal high-tide level, built by constructive waves; **cusps** (crescent hollows); **ridges and runnels** on wide sandy beaches; and **offshore bars**, built where destructive backwash drops its load.

Gradient: **shingle beaches are steep** (often 10–20°), because water **percolates** into the large pores, so the backwash is weak; **sand beaches are gentle** (often under 5°), because little water soaks in and the backwash is strong.

Summer and winter profiles. In summer, constructive swell pushes sand up the beach into a **berm**, so the beach is **higher and steeper**. In winter, destructive storm waves cut the berm back and drag the sand **offshore into bars**, so the upper beach is **lower and flatter**. In spring the swell moves the sand back: it mostly moves up and down the beach, not away.



In the model, the summer foreshore drops from the berm (2.5 m) to mean sea level in 30 m, a gradient of about 1 in 12; the winter upper beach drops from 1.5 m to mean sea level in 40 m, about 1 in 27.

In plan:

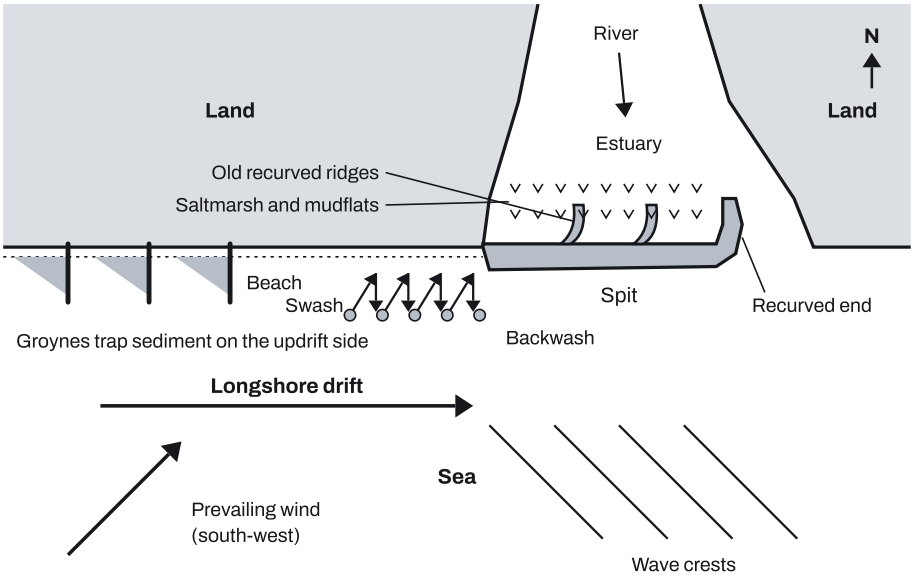
- **Swash-aligned beaches** form where waves arrive **parallel** to the shore, often after refraction: sediment moves up and down the beach, not along it, and the beach curves to match the wave crests, often between headlands (Chesil Beach faces the dominant south-westerly swell).
- **Drift-aligned beaches** form where waves arrive **at an angle**: longshore drift moves sediment along them, they are long and straight, and **spits** grow where the coast changes direction.

Spits, tombolos, bars and barrier beaches

Spits are ridges of sand or shingle joined to the land at one end, ending in open water.

1. **Longshore drift** carries sediment along a drift-aligned beach.
2. Where the coast **changes direction** (an estuary mouth or bay), drift carries on into deeper, calmer water, where sediment is **deposited** and the ridge grows out.
3. The end is **recurved** by **wave refraction** round its tip and by waves from a **secondary wind direction**.
4. Behind the spit, in sheltered water, mud settles and **saltmarsh** develops; wind builds **dunes** on the spit.
5. The river's flow and tidal currents stop it crossing the estuary.

A **simple spit** is a single ridge; a **compound spit** has **several recurved ridges** on its landward side, each a former end. Spurn Head, about 5.5 km long across the Humber estuary, is fed by sediment from the Holderness cliffs; a storm surge in December 2013 breached its neck, so its tip is now a tidal island at high tide. Hurst Castle Spit, Hampshire, is a compound shingle spit with saltmarsh behind.



Tombolos join an island to the mainland, built by **longshore drift** or by **wave refraction** round the island (a short **cuspate tombolo**). Chesil Beach, about 29 km long, joins the Isle of Portland to the mainland; it was mostly **pushed onshore by rising sea level** after the last glacial period, and its pebbles are largest at the Portland end.

Offshore bars are ridges of sand near low tide, built where **destructive waves** break offshore.

Barrier beaches and islands are ridges of sand or shingle across a bay or parallel to the coast, with a **lagoon** behind: Slapton Sands, Devon, encloses Slapton Ley; barrier islands line the Outer Banks of North Carolina, USA. Many were driven landwards by **rising sea level** after the last glacial period, and storms still wash sand over them, so they roll slowly inland.

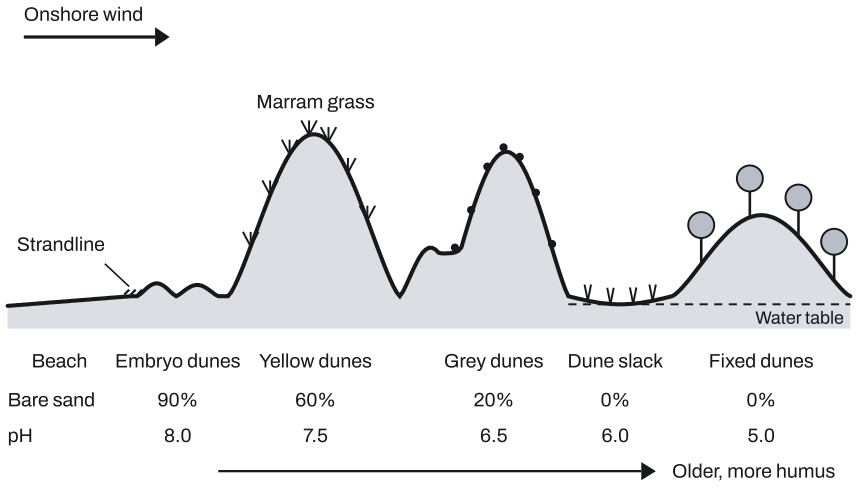
Coastal sand dunes

Conditions: a **large supply of sand**; a wide, flat beach and a **large tidal range**, so a big area of sand dries out at low tide; **strong, frequent onshore winds**; an **obstacle** at the back of the beach, above high tide (the strandline of seaweed and driftwood, a rock, a plant), where the wind drops its sand; **vegetation** to trap and hold it; a **sheltered** or low-lying coast.

Succession (a psammosere): plants colonise the sand and change the conditions, so the dunes change inland.

Zone (from the beach)	Typical height	What it is like	Plants
Embryo dunes	under 1 m	Low mounds round the strandline; salty, dry, alkaline	Salt- and drought-tolerant pioneers: sea rocket, sand couch grass
Foredunes and yellow (mobile) dunes	up to about 10 m	Steep, mostly bare yellow sand; still moving	**Marram grass**, which grows up through fresh sand and rolls its leaves to save water
Grey (semi-fixed) dunes	lower	More humus darkens the sand; less salty, more acidic	Lichens, mosses, grasses, herbs
Dune slacks	hollows	Damp hollows where the water table reaches the surface	Rushes, sedges, creeping willow
Fixed dunes, heath and woodland	stable	Soil develops; acidic	Heather, gorse, then scrub, pine and birch (the climax)

Inland the dunes are **older**, with **more humus**, **less bare sand** and lower pH: pH falls from about 8 near the beach to about 5 on the fixed dunes, as shell lime is leached. Where trampling or storms break the plant cover, the wind scoops out a hollow called a **blowout**. Examples: Braunton Burrows, Devon; Studland, Dorset.



Wind carries the sand, but the **supply**, **tidal range**, an **obstacle** and above all **vegetation** decide whether dunes form and last; **succession** gives their characteristics; **people** trample them or stabilise them by planting marram and fencing.

Estuaries, saltmarshes and mangroves

Tidal sedimentation in estuaries. At **slack water** around high tide the current almost stops, so fine sediment settles. In fresh water, charges keep clay particles apart; in salt water they **clump together (flocculate)** and sink. Layer by layer, **mudflats** build up between the tides, drained by **creeks**. A **large tidal range** brings in sediment twice a day.

Coastal saltmarshes (a **halosere**) form on mudflats in **sheltered, low-energy** places: estuaries, behind spits and barrier islands.

1. **Algae** and eelgrass colonise the mud and trap sediment.
2. **Pioneer halophytes** (glasswort, *Salicornia*; cordgrass, *Spartina*) slow the water, trap more sediment and raise the surface.
3. Higher up, flooded **less often**, less salt-tolerant plants (sea aster, sea lavender) form a **low marsh**, then a **high marsh** flooded only by spring tides; **creeks** drain it and **salt pans** form in hollows.
4. At the top the marsh grades into rushes, then land plants.

Examples: behind Hurst Castle Spit, Hampshire; Morecambe Bay, England.

Mangroves are the tropical equivalent: forests of **salt-tolerant trees** on tidal mudflats, mostly between about 30° N and 30° S. **Stilt roots** anchor them in soft mud and **breathing roots (pneumatophores)** reach up for oxygen; the dense roots slow the water and trap mud, building the land out and up, in zones from the most salt-tolerant species at the sea edge. Once established, they help protect the coast from **storm surges**. The Sundarbans, in the Ganges–Brahmaputra delta of Bangladesh and India, is the world's largest mangrove forest (about 10 000 km^2).

Both need **sheltered, low-energy tidal flats**, a supply of **fine sediment**, and **halophytic plants** that trap it; the main difference is **climate**: saltmarshes on temperate coasts, mangroves on warm tropical ones.

Sea-level change

- **Eustatic change** is a **global** change in the **volume of water** in the oceans. At the last glacial maximum, about 20 000 years ago, sea level was about **120 m lower**; as the ice melted it rose rapidly (the **Flandrian transgression**), reaching about its present level some 6000 years ago. Today it is rising by about 3–4 mm a year, from **thermal expansion** and melting ice.
- **Isostatic change** is a **local** rise or fall of the **land**: crust pressed down by ice sheets rises slowly after they melt (**isostatic rebound**), so Scotland is still rising while south-east England sinks slightly.

Change	Landforms	Examples
Sea level rises relative to the land (submergence)	**Rias** (drowned river valleys); **fjords** (drowned glacial troughs); **Dalmatian coasts** (drowned valleys parallel to the coast, leaving long islands)	Kingsbridge Estuary, Devon; Sognefjord, Norway; Croatia
	Barrier beaches and some tombolos pushed onshore; estuaries, mudflats and marshes; barrier reefs and atolls grow up	Chesil Beach; Slapton Sands
Sea level falls relative to the land (emergence)	**Raised beaches** and **relict cliffs** behind them, now shaped only by sub-aerial processes	Isle of Arran, Scotland

Present sea-level rise brings more **cliff erosion**, flooding, beaches and barrier islands moving inland, and **coastal squeeze**: marshes and dunes trying to move inland are trapped against sea walls and shrink.

How important is it? Sea-level change set the **outline** of most coasts (nearly every coast was drowned by the Flandrian transgression) and **is the cause** of rias, fjords, raised beaches and many barrier beaches. But most smaller landforms (caves, stacks, spits, dunes, marshes) are made by **waves, wind, sediment and plants** at today's level; sea level only decides **where** they work. Depositional landforms respond **faster** to a change in level than rocky ones.

Coral reefs

Reef-building corals are colonies of **polyps** that build skeletons of **calcium carbonate**. Algae called **zooxanthellae** live in their tissues in a **symbiotic** relationship: the algae photosynthesise and give the coral most of its food; the coral gives them shelter and nutrients.

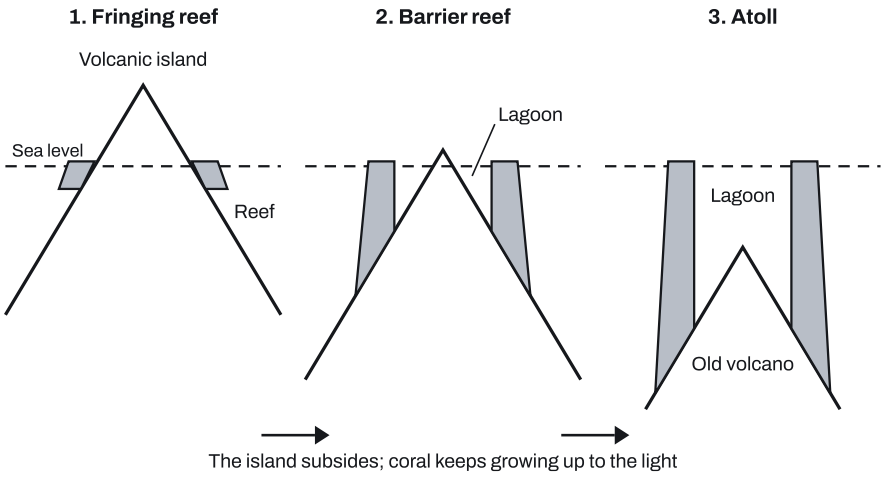
Conditions corals need:

- **warm water**: above about 18 °C all year, best at about 23–29 °C; stressed above about 30 °C;
- **light**: **clear, shallow water**, mostly less than about 25 m deep;
- **normal salinity**: roughly 32–42 parts per thousand (no fresh water from big rivers);
- **clean water**, free of **sediment** and pollution;
- **moderate wave action**, bringing oxygen and food without breaking the reef;
- only brief **exposure to air** at the lowest tides.

Distribution: mainly **between about 30° N and 30° S**: the Caribbean, the Red Sea, the Indian Ocean, south-east Asia (the "Coral Triangle", richest in species) and the tropical Pacific. They are mostly in the **western parts of oceans**, where **warm currents** flow, and **absent from the western coasts** of the Americas and Africa, where **cold currents** and upwelling keep water too cool, and near the mouths of **large rivers** (fresh water and sediment). Bermuda, at about 32° N, has reefs because the warm **Gulf Stream** passes it.

	Fringing reef	Barrier reef	Atoll
Position	Attached to or very close to the shore	Further offshore, roughly parallel to the coast	A ring of reef in the open ocean with no central island

	Fringing reef	Barrier reef	Atoll
Lagoon	None, or a narrow, shallow channel	A **wide, deep lagoon** between reef and land	A central lagoon
Examples	Red Sea coast at Eilat, Israel	The Great Barrier Reef, Australia (about 2300 km long, about 2900 separate reefs)	The Maldives (26 atolls); Tuvalu



How they form:

- **Darwin's subsidence theory** (1842): a **fringing reef** grows round a volcanic island; as the island slowly **sinks**, the coral keeps growing **upwards** to the light, so the reef is left offshore with a lagoon behind (a **barrier reef**); when the island disappears, the ring remains (an **atoll**). Drilling on Enewetak atoll in the Marshall Islands in 1952 found volcanic rock beneath more than 1200 m of reef limestone.
- **Daly's glacial control theory**: waves cut platforms across islands when sea level was low in glacial periods; as the sea **rose**, corals grew up on the platform edges.
- **Murray's theory**: reefs grow **outward** on their own debris, and the inner part dies and dissolves into a lagoon.
- Most geographers now see **subsidence and sea-level change working together**.

Similar or different? All three are built by the **same organisms** under the **same conditions**, and in Darwin's model they are **stages of one sequence**; they differ in **distance from shore**, **lagoon size**, **relation to an island** and **age**.

Threats to coral reefs

Threat	Effect on the reef	Scale
Warming sea temperatures (global warming)	When water stays about 1 °C or more above the usual summer maximum for weeks, corals expel their zooxanthellae, turn white (**bleaching**) and starve, and may die. The Great Barrier Reef had mass bleaching in 2016, 2017, 2020, 2022 and 2024; in 2016 about 30% of its shallow-water corals died	**Global**; the most serious

Threat	Effect on the reef	Scale
Ocean acidification	Oceans absorb carbon dioxide; surface pH has fallen by about 0.1 since the 1800s (about 26% more hydrogen ions), so skeletons grow more slowly	Global
Sea-level rise	Deeper water means less light; but most healthy reefs grow upward several millimetres a year, faster than the sea rises (about 3–4 mm a year), so it is a **minor** threat unless the coral is already stressed	Global but slow
Pollution	**Sediment** from farming, logging and building smothers polyps and blocks light; **nutrients** (fertiliser, sewage) let algae overgrow coral and feed outbreaks of the coral-eating **crown-of-thorns starfish**; oil, industrial waste, pesticides, plastics and sunscreen chemicals poison them	**Local** to regional; manageable
Physical damage	**Storms** and cyclones break reefs (Cyclone Yasi, Great Barrier Reef, 2011); tsunamis; **blast fishing** and cyanide fishing, anchors, trampling and diving, coastal development	Local
Overfishing	Removing grazing fish lets algae smother coral	Local
Invasive species and disease	Lionfish, introduced to the Caribbean, eat the small grazing fish; diseases spread faster in warm, polluted water	Regional

Weighing the threats: by **scale** (global threats hit every reef, local ones only some), by **how hard they are to manage** (local threats yield to local action; warming and acidification need global emission cuts), by **how they combine** (a reef stressed by pollution recovers more slowly from bleaching), and by **level of development** (poorer countries may have more blast fishing and untreated sewage, and less money to manage them). Reefs in warm, shallow, enclosed seas near people, farms and resorts are most at risk. The Intergovernmental Panel on Climate Change (2018) estimated that 70–90% of tropical reefs would be lost with 1.5 °C of global warming and more than 99% with 2 °C, so warming is now the greatest threat almost everywhere.

Managing the threats to coral reefs

- **Global**: cutting greenhouse gas emissions (the Paris Agreement, 2015) is the only answer to warming and acidification, and is far from achieved.
- **Marine protected areas and zoning**: the Great Barrier Reef Marine Park (1975) is zoned for different uses; in 2004 the "no-take" green zones, where fishing is banned, grew to about a third of the park, and fish numbers rose inside them.
- **Community reserves**: on Apo Island, Philippines, villagers have run a small no-take sanctuary since 1982; fish numbers and incomes recovered. Cheap and well enforced, but small.
- **Fishing rules**: bans on blast and cyanide fishing, quotas; hard to police at sea.
- **Water quality**: Australia's **Reef 2050 Plan** (2015) pays farmers to cut fertiliser and sediment runoff; progress is slow.
- **Tourism controls and direct action**: mooring buoys, visitor limits, treated sewage; culling crown-of-thorns starfish; replanting coral grown in nurseries.

Evaluation: protected reefs have more fish and recover faster after bleaching or storms, so local management **builds resilience**; but it cannot stop **global** threats, as repeated bleaching of the well-managed Great Barrier Reef shows. It also depends on **enforcement**, **money** and **local support**, weakest in many poorer countries with the most reefs. So management can **reduce** the threats, but not **remove** them without global action on climate change.

Sustainable management of coasts

Sustainable management protects people, property and environments in ways that last, without moving the problem elsewhere, balancing **economic**, **social** and **environmental** needs.

Why it is hard: coasts are **dynamic**; defending one place starves another in the same **sediment cell**; **sea-level rise** and **stronger storms** with climate change raise the costs; users **conflict** (homeowners, farmers, tourism, ports, conservation); defences are **costly** and **cost–benefit analysis** may say a stretch isn't worth defending; short-term and long-term aims clash; some countries lack money, data or **effective governance**.

Hard engineering: structures that resist the sea.

Strategy	How it works	For	Against
Sea wall	Concrete wall reflecting wave energy	Strong; protects towns	Very expensive; reflected waves scour the beach and undermine it
Revetment	Sloping structure that absorbs energy	Cheaper than a wall	Needs maintenance
Rock armour (rip-rap)	Large boulders at the cliff foot	Absorbs energy, quick to place	Looks out of place
Gabions	Wire cages filled with rocks	Cheap	Short life; wire rusts
Groynes	Barriers across the beach	Trap longshore drift, widening the beach	**Starve the coast downdrift**
Offshore breakwaters and reefs	Make waves break out at sea	Reduce energy, let sediment build	Costly
Cliff drainage and regrading	Remove water; lower the cliff angle	Reduce slumps	Regrading loses land

Soft engineering: working with natural processes.

Strategy	How it works	For	Against
Beach nourishment (recharge)	Sand or shingle added to the beach	Natural look; a wide beach absorbs energy	Must be repeated

Strategy	How it works	For	Against
Beach reprofiling	Sediment moved back up the beach	Cheap	Short-term
Dune stabilisation	Planting marram, fencing, boardwalks	Cheap; habitat	Slow
Managed retreat (realignment)	Old defences breached; new ones inland; saltmarsh forms	Marsh absorbs energy; habitat; cheaper long term	Land is lost
Land-use zoning, rollback, do nothing	No building in risky areas; help people move	No construction cost	People lose homes

In England and Wales, **Shoreline Management Plans** set one of four policies for each stretch: **hold the line**, **advance the line**, **managed realignment** or **no active intervention**.

Case study: the Holderness coast, eastern England

The coast. Holderness runs about **61 km** from the chalk headland of **Flamborough Head** to the spit of **Spurn Head** at the mouth of the Humber. South of the resistant chalk, the cliffs are **boulder clay (glacial till)**, soft sediment left by ice sheets, retreating about **2 m a year on average**, among the fastest rates in Europe. More than 20 medieval villages have been lost to the sea.

Why it erodes so fast: the till is **weak** and **slumps** when saturated; most of it is fine clay carried away in suspension, so **beaches are narrow**; strong **north-easterly waves** cross the North Sea; **longshore drift** carries sediment south to Spurn, and defences updrift reduce the supply; **sea level is rising**.

Problems for sustainable management: homes, farmland, roads and caravan parks are lost every year (around Skipsea, for example) with little compensation; the **Easington gas terminal**, which brings North Sea gas ashore, is near the cliff edge; the eroded sediment feeds Spurn Head and the Humber mudflats, so defending everywhere would damage them; defending all 61 km would cost more than the land is worth; residents, farmers, councils and conservationists want different things; and sea level is rising.

Attempted solutions and how well they have worked:

1. **Hold the line at towns and key sites**: sea walls, groynes and rock armour at **Bridlington, Hornsea and Withernsea**, and rock armour at the **Easington gas terminal**. The towns and terminal are safe, but defences are costly to maintain and beaches in front of the walls have narrowed.
2. **Mappleton (1991)**: a **rock armour revetment** and **two rock groynes**, at a cost of about £2 million, saved the village and coast road; but the groynes trap sediment, so the cliffs **downdrift**, towards **Cowden**, eroded **faster**: the problem was moved, not solved.
3. **No active intervention and rollback**: the **Shoreline Management Plan** holds the line only at the towns, Mappleton and Easington; elsewhere the cliffs erode, and the council's **rollback** policy lets threatened homes and caravan parks be rebuilt inland. This keeps sediment flowing to Spurn and is cheap, but is hard on those who lose their land.
4. **Spurn Head** is now left to evolve naturally as a nature reserve, including since the 2013 breach.

Judgement. Economically, defending towns and the gas terminal passes cost–benefit analysis, and leaving farmland saves money; **environmentally**, letting most cliffs erode keeps the sediment cell working; **socially**, people on undefended stretches lose homes with little help. Mappleton shows hard engineering moving the problem downdrift. Holderness is managed **more sustainably than before**, as one sediment cell, but not fully sustainably while erosion destroys property.

Other examples to compare:

- **Medmerry, West Sussex (2013)**: managed realignment. 7 km of new embankments were built inland and the old shingle bank was then deliberately breached, for about £28 million, creating about 180 hectares of intertidal habitat while protecting the homes behind.
- **The Sand Motor (Zandmotor), Netherlands (2011)**: 21.5 million m^3 of sand were placed as a hook-shaped peninsula near The Hague, for waves and wind to spread along the coast, feeding beaches and dunes naturally instead of recharging each beach every few years.

Key facts and formulas

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

Formula	Status
Wave steepness = wave height ÷ wavelength (H/L)	Learn it
Waves per minute = 60 ÷ wave period in seconds	Learn it
Wave energy rises with the square of wave height: twice the height gives four times the energy	Learn it
Wave base ≈ half the wavelength; waves begin to change where the water is shallower than this	Learn it
A wave breaks where the water depth is about 1.3 × its height	Learn it
Mean rate of change = total change ÷ number of years	Learn it
Range = highest value – lowest value	Learn it
Percentage change = (new – old) ÷ old × 100 (negative for a fall)	Learn it
Carbonation (solution of limestone and chalk; also builds coral skeletons in reverse): $\mathrm{CaCO_3 + H_2O + CO_2 \rightleftharpoons Ca(HCO_3)_2}$	Learn it
Sediment sizes: clay under 0.004 mm; silt 0.004–0.063 mm; sand 0.063–2 mm; gravel (shingle) 2–64 mm; cobbles 64–256 mm; boulders over 256 mm	Learn it

Term and meaning	Status
Fetch: the distance of open water over which the wind blows to make waves	Learn it
Constructive wave: a low-energy wave whose swash is stronger than its backwash, building beaches; **destructive wave**: a high-energy wave whose backwash is stronger, removing material	Learn it
Wave refraction: the bending of wave crests in shallow water so they come to match the shape of the coast	Learn it
Sub-aerial processes: weathering and mass movement acting on the coast above the reach of the waves	Learn it
Longshore drift: the movement of sediment along the coast by swash at an angle and backwash straight down the beach	Learn it
Sediment cell: a stretch of coast within which sediment moves almost as a closed system, from sources to sinks	Learn it
Swash-aligned beach: built parallel to the wave crests; **drift-aligned beach**: built along the direction of longshore drift	Learn it
Eustatic change: a global change in sea level from a change in the volume of ocean water; **isostatic change**: a local rise or fall of the land	Learn it
Coral bleaching: corals expelling their zooxanthellae when stressed, especially by heat, turning white	Learn it
Hard engineering: structures that resist the sea; **soft engineering**: working with natural processes	Learn it
Coastal squeeze: the loss of intertidal habitat trapped between rising sea level and fixed defences	Learn it
Sustainable management: managing a coast to meet present needs without harming 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 4 (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
Evaluate how far one process or factor forms coastal landforms (20-mark essay)	27
Describe or compare a pattern in a graph or map, quoting data	18
Suggest or explain reasons why erosion, deposition or coastal change varies	12

Question type	Questions
Assess sustainable management of a stretch of coastline (case study essay)	12
Describe landscape features from a photograph or diagram	11
Explain how a named landform formed	10
Weigh the threats to coral reefs (essay)	8
Assess how far management reduces threats to coral reefs (essay)	6
Explain wave behaviour or beach profiles shown in a diagram	4
Explain why coral reefs lose cover or face different risk	3
Compare the formation and characteristics of reef types (essay)	3
Evaluate sediment sources and characteristics (essay)	2

Marking: Question 4(a) gives **1 mark for each accurate point** (usually 4), often with a mark kept for **data**; plain lists of places or names score at most 2. Question 4(b) (6 marks, once 7) is marked in **three levels** (Level 3, 5–6 marks: clear explanation, tied to the figure). The 20-mark essays are marked in **four levels** (Level 4, 16–20 marks: thorough discussion, sustained evaluation and a sound conclusion), with a **maximum of 8 without examples**.

1. Evaluate how far one process or factor forms coastal landforms (20-mark essay) (27 questions)

The question names one driver and asks how far it explains a set of landforms: **wave energy** (caves, arches and stacks; erosional landforms), **sub-aerial processes** (cliffs and platforms; erosional landforms; all landforms), **sea-level change**, **longshore drift** (depositional landforms), **wave refraction**, **wave characteristics**, **swash** (beach profile and plan), **marine processes** (cliff characteristics), **wind** (dunes); variants ask for the factors behind **waves** themselves, or behind **saltmarshes and mangroves**.

1. **Define** the factor and the landforms in the question (for example, sub-aerial = weathering and mass movement, not marine erosion).
2. **The case for the factor**: explain the processes it drives and **link each to named landforms**, step by step (for wave energy: hydraulic action, cavitation, abrasion → notch → cave → arch → stack).
3. **The other factors**, each linked to the same landforms:
   - **rock type** (resistance to each process) and **structure** (joints, faults, bedding, dip);
   - **wave refraction** (energy concentrated on headlands);
   - **sub-aerial weathering and mass movement**;
   - **sediment supply** (for depositional landforms);
   - **sea-level change** (the level waves work at; rias, raised beaches, barrier beaches);
   - **wind** (waves, longshore drift, dunes), **vegetation** (dunes, marshes, mangroves), **tides** (tidal range);
   - **storms** and climate change (more frequent, more energetic storms);
   - **human activity** (groynes, walls, nourishment, trampling).

4. **Show they interact**: wave energy depends on wind and fetch, refraction controls where it is spent, rock structure decides where it erodes, sub-aerial processes weaken the rock first and modify the landform after.
5. **Cover the full range** the question asks for: if it says "coastal landforms", include **depositional as well as erosional** (examiners report one-sided answers); if it names beaches, cover **profile and plan**.
6. **Use located examples** (Old Harry Rocks, Durdle Door, Holderness, Chesil Beach, Spurn Head, Lulworth Cove, Sognefjord).
7. **Conclude** with a weighed judgement, for example: "marine erosion forms these landforms, rock structure decides where, and sub-aerial processes modify them"; or "sea-level change sets the stage, but waves, wind and sediment make most landforms".

Variants:

- **Factors generating waves**: wind speed, duration and fetch generate them; depth, sea-bed shape, coastline shape and refraction change them as they arrive; tides, currents and the beach material affect how they break; earthquakes and submarine landslides make tsunamis. Wind is the main cause, but the other factors decide their characteristics at the coast.
- **Saltmarshes and mangroves**: shelter and low energy, fine sediment, flocculation, the tidal range, halophytic plants trapping sediment and succession; climate decides which forms (temperate saltmarsh, tropical mangrove).
- **Wind and dunes**: wind carries the sand, but supply, tidal range, an obstacle, vegetation, succession and people matter as much.
- **Swash and beaches**: swash builds berms and steep profiles, but backwash, sediment size, wave type and season shape the profile; the plan depends on refraction and longshore drift.

2. Describe or compare a pattern in a graph or map, quoting data (18 questions)

Figures: line graphs or bar charts of change **along a coast** (beach volume, erosion rates, erosion against deposition, land lost and gained), a map of a **spit's past positions**, **world maps** (dunes, saltmarshes, coral reef risk), a map of **coral cover loss** or erosion impacts, a graph of salt weathering rates over time.

1. **Overall pattern first**: the trend with distance or time ("retreat increases southwards", "most loss in the north").
2. **Highest and lowest**, with **values, units and locations** (site, distance, place name, year).
3. **Anomalies**: places that break the trend.
4. **Variability**: steady or fluctuating; where it changes.
5. **Manipulate the data**: range, difference, how many times larger. One mark is often kept for data.
6. **Describe only**: no reasons. **Don't go site by site** along a transect: examiners reward patterns, not lists.

Variants:

- **"Compare"** two things (dunes and saltmarshes; risk in different regions; erosion and deposition): link them in every sentence ("whereas", "both"), with at least one similarity and one difference. Covering only one item caps the mark.

- **World maps**: hemispheres, latitudes, continents and oceans, east and west coasts, where they are absent; not a list of countries.
- **Change over time** (a spit's position): the direction of movement, the distance (use the scale), the fastest and slowest periods, reversals.

3. Suggest or explain reasons why erosion, deposition or coastal change varies (12 questions)

Usually "**suggest two reasons**" for the pattern in (a), or "explain why rates of erosion (and deposition) vary along coastlines".

1. **Choose reasons that fit the figure**: a high-erosion site needs a reason that applies there and not elsewhere.
2. **Develop each reason as a chain**: factor → process → effect on erosion or deposition → where on the figure.
3. Reasons to draw on:
   - **wave energy and exposure**: fetch, wind direction and strength, storms, high- and low-energy waves;
   - **wave refraction** and the shape of the coast: headlands exposed, bays sheltered;
   - **rock type and structure**: resistance to the processes acting, joints, slumping till;
   - **beach width and sediment**: a wide beach absorbs energy; sand against shingle;
   - **longshore drift**: removes sediment from some places and delivers it to others;
   - **sediment supply**: rivers, cliffs, offshore bars, dunes;
   - **human activity**: groynes and sea walls trap or reflect, so downdrift beaches are starved; nourishment adds sediment; dredging removes it;
   - **sea-level change** and land subsidence or uplift.
4. "**Two reasons**" means two developed reasons; one developed reason reaches Level 2 at most.

Variants: changes to a **spit's position** (wind direction and strength through time, longshore drift, groynes, sea-level change, sediment supply); **land lost and gained** (the balance of erosion and deposition, defences, reclamation); **salt weathering rates** (evaporation is higher in warm, dry summers, so more salt crystals grow in confined spaces and press on the rock; years vary with the weather).

4. Assess sustainable management of a stretch of coastline (case study essay) (12 questions)

Asks how effective **hard engineering** is, **hard against soft**, the **advantages against disadvantages** of hard engineering, the **success of management**, the **problems** of managing sustainably (their relative importance, or whether they have been solved), or whether understanding **sediment cells** is essential.

1. **Name and locate** a specific stretch of coast (Holderness, from Flamborough Head to Spurn Head), with facts and figures. A whole country stays in Level 2.

2. **Set out the problems**: physical (erosion rate, weak rock, storms, sea-level rise, sediment cells) and human (land use, conflicts, cost, governance).
3. **Explain the strategies**, each linked to the problem it targets: name them precisely (rock armour revetment, rock groynes, managed realignment, rollback).
4. **Judge them with criteria**: **economic** (cost–benefit, jobs, tourism), **social** (homes, people's lives, who gains and loses), **environmental** (habitats, sediment supply downdrift), **timescale** (short against long term), and how far each problem is actually solved.
5. **Answer the exact question**: if it asks about **problems**, the answer is about problems, not mainly strategies; if it asks for **advantages against disadvantages of hard engineering**, weigh those, not hard against soft (examiners report both mistakes).
6. **Conclude**: which approach worked best, for whom, and whether management is truly **sustainable**.

For **sediment cells**: explain the cell (sources, transfers, sinks), show with Holderness (Mappleton's groynes starving Cowden; cliff sediment feeding Spurn) that defences in one place affect others, then weigh other needs (money, politics, people's priorities, climate change) and conclude.

5. Describe landscape features from a photograph or diagram (11 questions)

Photographs of dunes, headlands and stacks, a bay with a tombolo, a spit, a cliffed coast; diagrams of beach profiles, waves approaching the shore, wave approach to an irregular coast.

1. **Name the feature and describe it**: shape, size (relative to other things), steepness, colour, rock layers, vegetation cover, materials. Naming without description scores nothing.
2. **Work across the picture** systematically (foreground to background, sea to land), **physical features only**.
3. One developed descriptive point per mark.

Variants:

- **Two profiles to compare** (summer and winter): berm against no berm, steep against gentle, bars present or not, how much beach above high tide.
- **Waves nearing the shore**: height up, wavelength down, steepness up, orbits from circular to elliptical, crest overtakes base and breaks, waves closer together.
- **Wave approach to a headland and bay**: crests bend round the headland, converge on it, spread out in the bay, become parallel to the shore.
- **"With the aid of a labelled diagram"**: draw a simple sketch with labelled features (cliffs, stacks, bays, beach, strata); without it the mark is capped.

6. Explain how a named landform formed (10 questions)

Coastal **dunes** (twice, plus why dunes form on some coasts), a **stack**, a **tombolo**, a **saltmarsh**, a **spit**; variant: how **geology** shaped a landscape.

1. **Identify** the landform and say **what conditions it needs**.

2. **Explain the sequence** of stages, linking process to form at each step (crack → cave → arch → stack; supply → obstacle → embryo dune → vegetation → succession).
3. **Name the processes** precisely (hydraulic action, abrasion, refraction, flocculation, longshore drift, saltation).
4. **Tie it to the figure** where there is one: the direction of drift shown by the spit's recurves, the island causing refraction.
5. A **labelled diagram** of the stages earns credit.

Variants: **why dunes form on some coasts** (supply, wind, tidal range, beach width, obstacle, vegetation, shelter, low-lying coast); **geology and the landscape** (resistant and less resistant beds, joints and faults guiding caves and gullies, horizontal or dipping strata, sub-aerial weathering of weaker beds).

7. Weigh the threats to coral reefs (essay) (8 questions)

"Pollution (or sea-level rise) is the greatest threat", "some threats are more significant than others", "some reefs are under greater threat than others".

1. **Start with the conditions corals need** (temperature, light, salinity, clear water, wave action): every threat works by upsetting one of them. Examiners mark down answers that skip this.
2. **Explain each threat** and how it harms coral: warming and bleaching (don't leave this out: examiners note it is often missed), acidification, sea-level rise, pollution and sediment, physical damage (storms, tsunamis, anchors, blast fishing), overfishing, crown-of-thorns starfish, invasive species.
3. **For sea-level rise, compare rates**: sea level rises about 3–4 mm a year; healthy reefs grow faster, so it is a threat only to stressed reefs.
4. **Weigh them**: global against local, short against long term, manageable or not, and how they combine. Pollution can include **atmospheric** carbon dioxide (warming and acidification), which changes the answer.
5. **Use named reefs**: the Great Barrier Reef (bleaching since 2016, crown-of-thorns, farm runoff), the Caribbean, south-east Asia (blast fishing), the Maldives.
6. **Conclude**: warming is the greatest threat to almost every reef; local threats decide which reefs suffer most.

8. Assess how far management reduces threats to coral reefs (essay) (6 questions)

1. **Conditions and threats** briefly first, so you can judge what management has to tackle.
2. **Named schemes**: Great Barrier Reef Marine Park zoning, Apo Island, Reef 2050 Plan, fishing bans, mooring buoys, starfish culling, coral nurseries.
3. **Match strategies to threats**: local threats (fishing, pollution, tourism) can be managed locally; global threats (warming, acidification) need emissions cuts.
4. **Evaluate**: evidence of success (fish numbers, faster recovery), and of failure (continued bleaching, poor enforcement); scale, cost, time, level of development, local support.
5. **Conclude**: management reduces local threats and builds resilience, but cannot protect reefs from global warming on its own.

9. Explain wave behaviour or beach profiles shown in a diagram (4 questions)

1. **Summer and winter profiles**: summer constructive waves, swash greater than backwash, sand pushed up into a berm; winter destructive waves, backwash greater than swash, sand dragged offshore into bars.
2. **Waves approaching the shore**: depth less than half the wavelength, so friction slows the base of the wave; waves bunch up (wavelength shortens), water piles up (height and steepness increase), orbits flatten, the crest overtakes the base and the wave breaks. Friction at the base is the key.
3. **Wave approach to an irregular coast**: shallower water off the headland slows waves there first (check the depth contours: they are closer to the shore in the bay), so crests bend; orthogonals converge on headlands (more energy, erosion) and diverge in bays (less energy, deposition).

10. Explain why coral reefs lose cover or face different risk (3 questions)

"Explain two factors that account for loss of coral cover", "explain two reasons why risk varies".

1. Pick **two** factors and, for each, **link it to a growth condition**: warming → above the temperature limit → bleaching → starvation; farm runoff → sediment blocks light and nutrients feed algae and starfish.
2. For **varying risk**, use the difference between **global threats** (warming, acidification, which affect all reefs) and **local threats** (pollution, tourism, fishing, storms), which depend on where the reef is: near people, farms and resorts, in cyclone belts, or remote and protected.
3. Describing a threat without saying **how it harms the coral** stays in Level 1.

11. Compare the formation and characteristics of reef types (essay) (3 questions)

1. **Conditions for growth** shared by all.
2. **Characteristics** of each type (position, lagoon, size, relation to an island), with examples.
3. **Formation**: Darwin's subsidence sequence (fringing → barrier → atoll), Daly's glacial control, Murray's outward growth; evidence (Enewetak drilling).
4. **Weigh**: similar in builders, conditions and growth processes; different in setting, form and history; Darwin's model makes them stages of one process, so the differences may be ones of **time**.
5. **Explain the differences**, don't only describe them (examiners note most answers only describe).

12. Evaluate sediment sources and characteristics (essay) (2 questions)

Asked as "how far do sediment sources and characteristics vary?" and "is cliff erosion the main source of sediment?"

1. **Sources**: rivers (the largest worldwide; fine sediment), cliff erosion and mass movement (locally dominant on weak-rock coasts like Holderness; coarse and angular at first), offshore (glacial deposits moved onshore by rising sea level, as at Chesil Beach), longshore drift, biological (shells, coral), wind, people (nourishment).
2. **Characteristics**: size, shape, sorting, volume, mineral make-up, each linked to its source and to transport (attrition rounds and reduces).

3. **Weigh by scale and coast type**: cliffs dominate only on soft-rock coasts; rivers dominate near deltas and estuaries; coral sand in the tropics. Sources are few, but characteristics vary a lot.
4. **Use longshore drift only as a transfer** from a named source to a named landform; examiners note answers that drift off into it.

Worked examples

Example 1

The table shows the mean rate of cliff retreat, 2005–2020, at eight sites along a model 24 km coast of glacial till that ends at a chalk headland in the north. The prevailing waves drive longshore drift from north to south. Site C is a village protected by rock armour and two rock groynes.

Site	Distance from the headland (km)	Mean retreat (m per year)
A (chalk headland)	0	0.2
B	3	1.4
C (protected village)	6	0.1
D	8	3.6
E	12	2.5
F	16	2.1
G	20	1.9
H	24	1.8

(a) Describe the pattern of cliff retreat shown in the table. **[4]**

(b) Suggest two reasons for the pattern you described in (a). **[6]**

(a) One mark for each point; data are needed for full marks.

- Overall, retreat is much faster south of the headland: every site from D to H retreats at 1.8 m a year or more, against 0.2 m a year at A **(1)**.
- The fastest retreat, 3.6 m a year, is at D, just 2 km south of the protected village **(1)**.
- C is an anomaly: only 0.1 m a year, the lowest of all, although it is between two fast-retreating sites **(1)**.
- South of D, retreat slows steadily to 1.8 m a year at H, and the range is 3.5 m a year; the mean of the eight sites is 1.7 m a year **(1)**.

(b)

The first reason is **rock type**. Site A is on chalk, which is far more resistant to hydraulic action and abrasion than glacial till, so it retreats only 0.2 m a year. The till further south is unconsolidated clay with stones; waves remove it easily, and after heavy rain it becomes saturated and slumps onto the beach, where the next storm

carries the debris away. So every till site except C retreats far faster than the headland.

The second reason is **human activity interrupting longshore drift**. At C, rock armour absorbs the waves' energy at the cliff foot and the groynes trap sediment moving south, so the beach there is wide and retreat is almost zero. But that sediment no longer reaches D, just downdrift, so its beach is narrow; waves break against the cliff foot rather than on the beach, and retreat is the fastest on the coast, 3.6 m a year, which over the 15 years means $3.6 \times 15 = 54$ m of land lost. Further south the beach is fed again by sediment from the eroding cliffs at D and E, so retreat slows towards H.

Level 3 (5–6 marks): two reasons clearly explained, each linked to particular sites and values in the table.

Example 2

Explain the formation of a compound spit. **[6]**

A compound spit, such as Hurst Castle Spit in Hampshire, is a long ridge of sand or shingle attached to the land at one end, with several hooked ridges on its landward side.

It forms on a **drift-aligned** coast. The prevailing wind drives waves onto the beach at an angle, so the swash carries sediment up the beach obliquely while the backwash returns straight down the slope; particles zigzag along the shore by **longshore drift**. Where the coastline turns sharply inland, at an estuary mouth, the drift continues in its original direction into deeper, calmer water. The waves there lose energy, so sediment is deposited and a ridge builds out from the land.

The tip of the ridge is curved landward by **wave refraction** round its end and by waves from a **secondary wind direction**, forming a **recurved end**. As the spit grows further, a new recurve forms at each new position of the tip, and storms from other directions bend the end back, leaving a series of **old recurved ridges** along the inner side: this makes the spit compound. Its length is limited because the **river's flow and tidal currents** in the estuary carry away sediment that reaches the deep channel.

In the sheltered, low-energy water behind the spit, fine sediment settles and flocculates, building mudflats on which **saltmarsh** develops, while wind blows beach sand into dunes on the spit; vegetation then stabilises it.

Level 3 (5–6 marks): the conditions and the sequence of processes clearly explained (longshore drift, deposition at the change in coastline, refraction and recurves, the compound stages), with an example.

Example 3

'Rock type and structure are the most important influences on the formation of erosional landforms on coasts.' How far do you agree with this statement? **[20]**

Introduction. Erosional landforms include cliffs and wave-cut platforms, headlands and bays, and caves, arches, stacks and stumps. **Rock type** is the rock's composition and how resistant it is to the processes acting on it; **structure** is how it is arranged: joints, faults, bedding planes and the dip of the beds. Other influences are wave energy, wave refraction, sub-aerial processes, sea-level change and people.

The case for rock type and structure. Rock type decides **how fast** a coast erodes and so the scale and form of its landforms. On the Holderness coast, weak glacial till retreats about 2 m a year and forms low, slumping cliffs with no caves or stacks, while the resistant chalk of Flamborough Head, at the north end, stands in high vertical cliffs with caves, arches and stacks. Where bands of different resistance meet the coast at right angles, the less resistant ones are cut back into bays and the resistant ones stand out as headlands: in Dorset, Swanage Bay is cut into weak clays and sands between the chalk of Ballard Down and the limestone of Durlston Head. Resistance must be judged against each process: limestone dissolves by solution and carbonation, yet is strong enough against hydraulic action and abrasion to form headlands such as Durdle Door.

Structure decides **where** erosion concentrates. Hydraulic action and abrasion exploit joints and faults at the cliff foot, so caves form along them, and the sequence of cave, arch, stack and stump follows these lines of weakness: the chalk stacks of Old Harry Rocks stand where the headland was cut along its joints. Dip controls the cliff profile: beds dipping inland give vertical cliffs, while beds dipping seaward give sloping cliffs with slides along bedding planes. Where strata run parallel to the coast, a resistant outer band protects the weak rock behind until the sea breaks through, then a cove is hollowed out, as at Lulworth Cove.

The case for other factors. Rock can't erode itself: **wave energy** does the work. Plunging storm waves with a long fetch cause hydraulic action, cavitation and abrasion, so exposed Atlantic coasts have far more erosional landforms than sheltered estuaries cut in the same rocks. **Wave refraction** concentrates that energy on headlands and spreads it out in bays, which is why caves form on both sides of a headland and why arches form there. **Sub-aerial processes** weaken cliff faces by salt crystallisation, freeze–thaw and wetting and drying, and mass movement delivers debris for waves to remove; they also collapse arch roofs and lower stacks. **Sea-level change** decides the level at which waves attack: relict cliffs and raised platforms on the Isle of Arran were cut at a higher relative sea level and are now shaped only by sub-aerial processes. **People** change the balance: sea walls and rock armour stop the waves reaching the cliff foot, so cliffs become lower-angled and vegetated, while groynes updrift can speed erosion elsewhere, as at Cowden, south of Mappleton.

It depends. On **timescale**: over thousands of years rock type and structure decide the broad plan of headlands and bays; over a single winter, storm wave energy decides how much is eroded. On **landform**: headlands, bays and coves are mainly lithological, while caves and arches depend on structure **and** refraction together. On **place**: where the rock is uniform, as on the till of Holderness, wave energy and human activity explain the differences along the coast instead.

Conclusion. Rock type and structure are the most important influence on **what** erosional landforms form and **where**, because they decide which parts of the coast resist and which give way. But they are a passive control: without wave energy, focused by refraction and helped by sub-aerial processes, no landforms would form. I agree largely, but rock type and structure work only through the processes acting on them, so the landforms are the product of their interaction.

Level 4 (16–20 marks): the factor in the question explained with located examples, every major other factor weighed against it, variation with timescale, landform and place, and a judgement that answers "how far".

Common mistakes

- **Calling rocks "hard" or "soft".** Say **resistant** or **less resistant** to a named process; limestone is not a "soft" rock.
- **Not knowing what sub-aerial means**, or mixing it up with marine erosion. Sub-aerial = weathering and mass movement on the cliff above the waves.
- **Describing processes without linking them to landforms**: explain how each process forms or changes a named landform.
- **One-sided essays**: writing only on erosional landforms when the question says "coastal landforms", or only on landforms where sea level matters (or doesn't).
- **Confusing eustatic and isostatic change**, or whether the land rose or the sea fell.
- **Explaining longshore drift vaguely**, or drawing it wrongly: show the swash at the angle of the waves, the backwash straight down the beach, and the direction of drift from the prevailing wind.
- **Explaining spit formation when asked about a saltmarsh**: the spit is only the shelter; explain the marsh itself (flocculation, halophytes, succession).
- **Misreading wave refraction diagrams**: the water is **shallower off the headland**, not in the bay; explain why friction slows the waves.
- **Going site by site** along a graph or transect instead of describing the pattern.
- **Coral answers with no growth conditions**, ignoring rising sea temperature, or calling sea-level rise a major threat without comparing it with coral growth rates.
- **A case study that is a whole country**, or that lists strategies without the **problems**, or weighs hard against soft engineering when the question asks about hard engineering's advantages and disadvantages.
- **Using "sustainable" without meaning it**: judge the economic, social and environmental strands and the long term.
- **Abbreviations** such as "LSD": write **longshore drift** in full.

How to get the marks

- **Command words. Describe** = what the figure shows, with data, no reasons. **Compare** = linked similarities and differences. **Explain** = reasons and processes, cause and effect. **Suggest** = apply what you know to the figure. **Assess**, **evaluate**, **how far**, **to what extent** = weigh both sides and reach a judgement.
- **Question 4(a)**: one point per mark; overall pattern, then extremes, anomalies and variation; quote values with units and places; physical features only on photographs.
- **Question 4(b)**: Level 3 needs **clear explanation linked to the figure**; "two reasons" needs both developed; a labelled diagram helps.
- **Essays**: define the terms; explain each point **and link it to a named landform or place**; weigh the named factor against others; "it depends" on timescale, scale, place and rock type; finish with a conclusion that answers the question. Without examples, the maximum is 8 of 20.

- **Diagrams** (cliff retreat, longshore drift, refraction, Darwin's reef sequence) are credited when labelled and annotated and used in the answer.
- **Case studies**: one named stretch of coast, with facts and figures, problems explained and ranked, each strategy linked to a problem, judged against economic, social and environmental criteria and timescale.
- **Time**: Question 4 is 10 marks and the essay 20, so spend about twice as long on the essay.

Quick check

1. A swell wave has a period of 10 s, a height of 1.2 m and a deep-water wavelength of 156 m. How many waves reach the beach each minute, and what is its steepness? Is it more likely to be constructive or destructive?
2. A storm wave is 3.6 m high. How many times more energy does it carry than the swell wave in question 1?
3. A reef surface grows upward at 4 mm a year while sea level rises at 3.5 mm a year. Find the change in water depth over the reef in 40 years. Then find it again if marine heatwaves stop the reef growing for 15 of those 40 years.
4. A council places 300 000 m^3 of sand along a 1.5 km beach. Longshore drift removes 25 000 m^3 a year. How much sand is placed per metre of beach, and how many years until the beach is back to its original state?
5. Explain the difference between eustatic and isostatic change, giving a landform formed by each.

Answers

1. Waves per minute $= 60 \div 10 = 6$. Steepness $= 1.2 \div 156 = 0.0077$. Few, low, long, gently sloping waves: more likely **constructive**, with swash stronger than backwash.
2. Energy rises with the square of height: $(3.6 \div 1.2)^2 = 3^2 = 9$ times as much.
3. Without heatwaves the reef gains $4 - 3.5 = 0.5$ mm a year on the sea, so the water over it becomes $0.5 \times 40 = 20$ mm **shallower**: the reef keeps up. With 15 years of no growth, the reef grows $4 \times 25 = 100$ mm while the sea rises $3.5 \times 40 = 140$ mm, so the water becomes $140 - 100 = 40$ mm **deeper**: sea-level rise becomes a threat only when other stresses stop the reef growing.
4. Per metre: $300\,000 \div 1500 = 200$ m³ per metre of beach. Time: $300\,000 \div 25\,000 = 12$ years, after which it must be recharged again.
5. **Eustatic** change is a **global** change in sea level from a change in the **volume of water** in the oceans (ice sheets growing or melting, thermal expansion); the rise after the last glacial period drowned river valleys to form **rias**, such as the Kingsbridge Estuary. **Isostatic** change is a **local** rise or fall of the **land**, such as rebound after the weight of an ice sheet is removed; it has lifted old beaches above the sea as **raised beaches**, such as those on the Isle of Arran.

Past questions to try

- **9696/32/O/N/25 Q4**: a photograph of a cliffed coast, then how a stack forms.
- **9696/32/O/N/24 Q4**: summer and winter beach profiles to compare and explain.
- **9696/32/O/N/25 Q6**: essay on how far management can reduce the threats to coral reefs.
- **9696/31/M/J/25 Q5**: essay on how far coastal sediment sources and characteristics vary.