3.6 Landforms and landscapes of coastal erosion

In this section you will learn about landforms and landscapes of coastal erosion and factors and processes in their development

Coastal landforms and landscapes

Figure **1** was taken from Beachy Head, to the west of Eastbourne, on the Sussex Heritage Coast, one of the UK's most iconic stretches of coastline. Towards the bottom right is Birling Gap, a collection of buildings that has for some time been threatened by coastal erosion.

It is important to appreciate the difference between *landscape* and *landform*. The landscape in Figure **1** is the big picture – the entirety of the sea, coast and rolling countryside. Landforms are individual components of the landscape – cliffs, beach and the emerging wave-cut platform. You need to be able to distinguish between the two; always consider individual landforms in the context of the broader landscape.

Landforms of coastal erosion

Cliffs and wave-cut platforms

When waves break against the foot of a *cliff*, erosion (hydraulic action and corrosion in particular) tends to be concentrated close to the high-tide line. This creates a *wave-cut notch* (Figure **2**). As the notch gets bigger, the cliff is undercut and the rock above it becomes unstable, eventually collapsing.

As these erosional processes are repeated, the notch migrates inland and the cliff retreats (Figure **3**), leaving behind a gently sloping *wave-cut platform* (Figure **4**), which is usually only completely exposed at low tide. Wave-cut platforms rarely extend for more than a few hundred metres, because a wave will break earlier and its energy will be dissipated before it reaches the cliff, thus reducing the rate of erosion, limiting the further growth of the platform. This is another excellent example of a negative feedback.

Figure 1 *The landscape of the Sussex Heritage Coast*

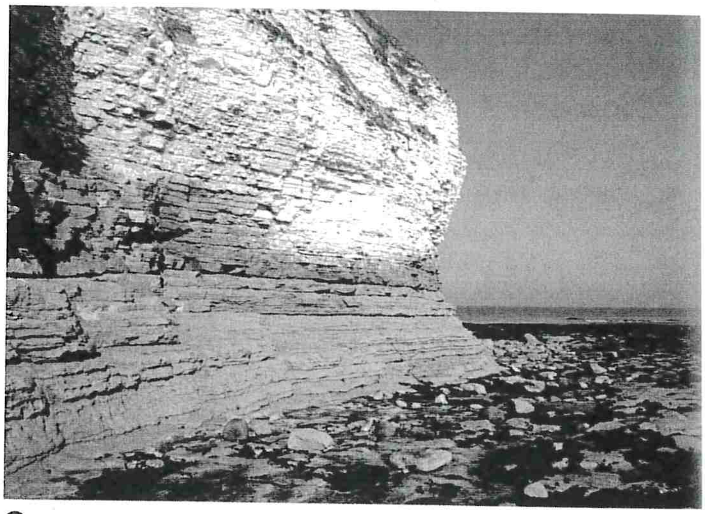

Figure 2 *A wave-cut notch at Flamborough Head in Yorkshire*

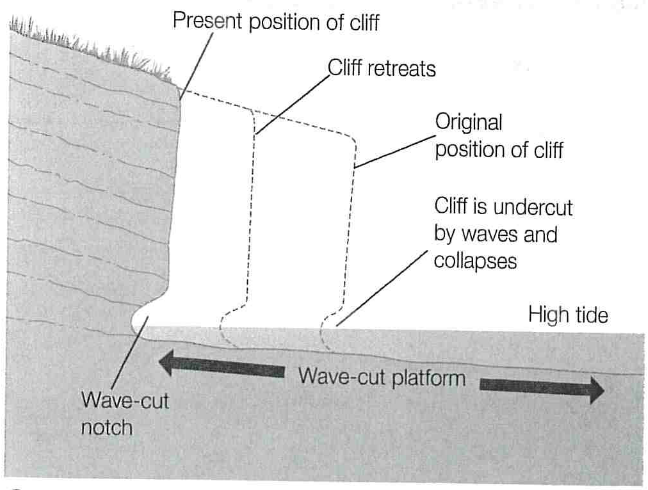

Figure 3 *Cliff retreat*

3.4 Coastal landscape development

If coastal processes are the 'how and why' of what is taking place in a coastal system, coastal features are the components upon which they operate and alter. They can be classified as features of erosion or features of deposition.

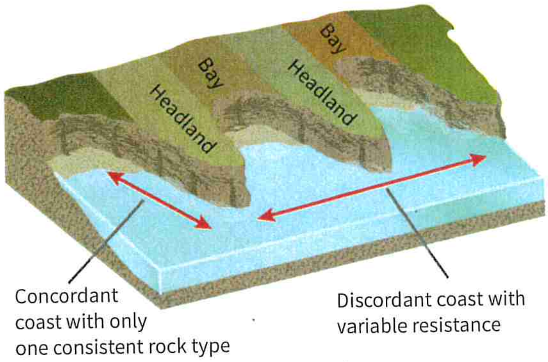

Figure 3.16 Discordant and concordant coasts.

Features of coastal erosion

Headlands and bays

Headlands are most likely to develop where varying geology is aligned at right angles to the coast – termed a discordant coast. If the alternation lies parallel to the coast (concordant coast), then a series of cliffs and coves may develop depending on whether the more resistant rock forms the cliff line (Figure 3.16).

Watch a video on **Cambridge Elevate** about coastal erosion on the Jurassic coast in England.

Cliff line and wave-cut platform

As cliffs of solid rock recede over time from their original shore position they may leave a basal shelf, uncovered at low tide and submerged at high tide. This wave-cut platform represents the base of the cliff that lies below the dominant intertidal zone erosion processes (Figure 3.17). As the cliff line retreats, the wave-cut platform becomes wider and has an increasing frictional effect on advancing waves.

A negative feedback loop develops in the erosional system, as wave energy dissipates the wider the wave-cut platform. Erosive power at the base of the cliff declines and the rate of cliff retreat slows. A change in inputs, such as sea-level rise, can induce a system response and result in more rapid cliff erosion once again.

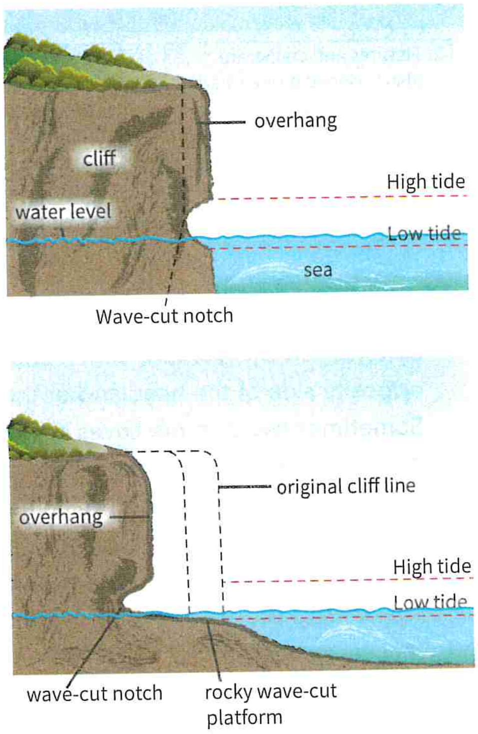

Figure 3.17 Cliff retreat.

Maths for geographers

You wish to calculate the height of a cliff. Study Figure 3.18. You are standing 22.6 m from the foot of the cliff and measure an angle of 36° to the cliff top using a clinometer. Your eye-height is 1.7 m above the beach. What is the height of the cliff?

Use the formula: $X = D \times \tan(\text{angle}) + H$

$X = 22.6 \times \tan 36 + 1.7$

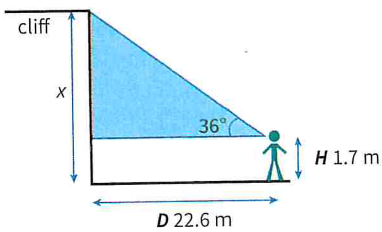

Figure 3.18 Calculating the height of a cliff.

Caves, blow holes, arches, stacks and stumps

A succession of features can develop on a headland where the geology is hard enough to provide some resistance and support (Figure 3.19). Where the rock is more jointed, fractured or weakened by earth movements, the agents of erosion and weathering can wear it away more rapidly. Joints enlarge into small caves, which become larger caves over time.

- Cave to blow hole: where caves face directly towards oncoming waves, the full hydraulic force of the wave is experienced towards the rear of the cave. Over time, this can enlarge joints in the cave roof and weaken the overlying rock to the extent that localised roof collapse occurs and a blow hole represents the exposed cave roof.

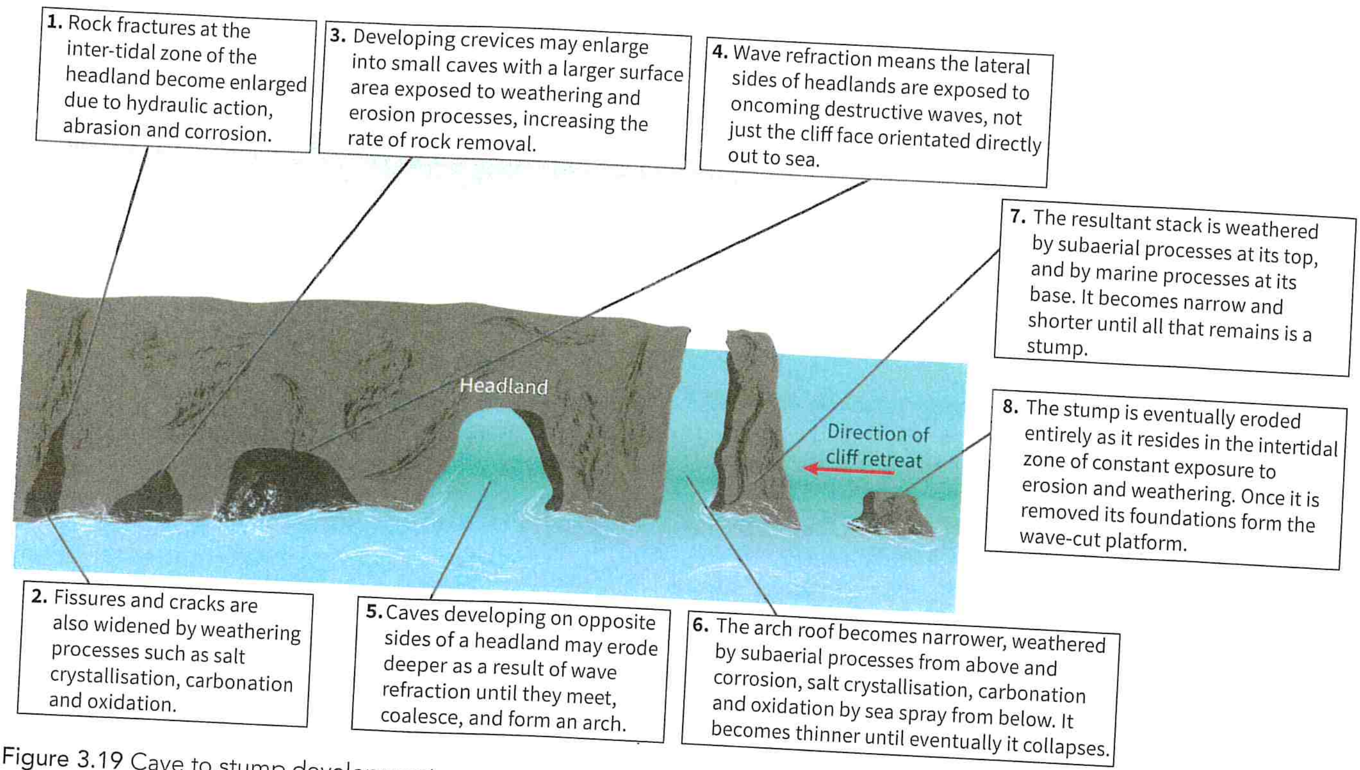

Figure 3.19 Cave to stump development.

- Cave to arch: where caves develop along the sides of a headland, they can be enlarged by hydraulic action and other processes to erode through to the opposite side of the headland or through a curtain of more resistant rock. Sometimes two or more caves coalesce.
- Arch to stack: while the arch walls may be further eroded by marine erosion, the roof – extending increasingly above wave height – is more likely to be subject to subaerial weathering from above and chemical action due to wave splash from below. If the roof becomes too weak for the sides to provide sufficient support, it may collapse, leaving the seaward wall unattached to the headland and standing as an isolated pillar of rock – or a stack (Figure 3.20).
- Stack to stump: a stack in the intertidal zone will be eroded at its base (and slightly above) by marine erosion and at its summit be subject to subaerial weathering. It is reduced in both height and width, collapsing in successive stages until it becomes a much smaller remnant of the original stack. This is a stump, which is eventually worn away completely to the level of the wave-cut platform.

Figure 3.20 A stack and wave cut-notch.

Investigate

Look up images of arches and stacks on the internet. Try to establish the type of rock that forms the coastline in these locations. Why are some types of rock more likely to result in the development of arches and stacks than others?

Run-off

Run-off is another important process that operates on coastlines. It may take the form of a stream emerging in a bay, taking with it large quantities of load during times of flood, or it may be a stream cascading over a cliff excavating a V-shaped groove as it does so. It can also simply be water that flows over the surface to reach the coastline, the presence of which will also assist many of the mass movement processes above.

3.3 Coastal landscape development

Characteristic coastal landscapes

As the coastline is simply the zone where the land meets the sea, there is not one single *typical* landscape type that typifies all coasts. Around the world individual coastal locations will have a coastal landscape with features that reflect the interaction of a range of factors, including, among other things:

- coastal geology and lithology
- climate
- nature of tides and waves.

However, it is possible to place coastlines in the following simple classification. They can be either:

- concordant or discordant
- a cliffed coast, flat coast or graded shoreline
- an emergent or submergent coastline.

The characteristics of a particular coastal landscape will depend on whether it is:

- a high or low energy coast
- dominated by processes of erosion or deposition
- more or less intensely managed by people.

One thing is certain, and that is that coastal landscapes are not static and have many characteristic features that change over a range of timescales. Waves and tides continually shape and rework coastlines on a daily basis, yet as noted above the nature of these waves and tides is not static. Over longer periods of time processes of erosion, transportation and deposition create landscapes that we become familiar with, which over human timescales we classify as characteristic of a particular location. For example, the cliffs of parts of the Yorkshire coast in Eastern England are seen as *characteristic* of that place, and the long sandy beaches and barrier reefs of Queensland, Australia are *characteristic* of that place. However, over even longer geological timescales coastal landscapes respond to more significant changes. For example, the Yorkshire cliffs above are composed of material deposited during recent glacial periods, before which that material would not have been there. Equally, the timescales followed by glacials and interglacials of ice ages create coastlines that have emerged from formerly high sea levels, like the raised beaches of the Atlantic coast of Ireland, or others that have become submerged as sea levels have risen, like the flooded glacial valleys forming the fjords of Norway and New Zealand.

This section explores a range of landforms that are part of characteristic coastal landscapes from around the world, including some from the British Isles. It is important that students understand the diversity of coastal landscapes that exist globally and, accordingly, study examples from a wide range of places.

Skills focus

For each landform explored here use the internet to search for another example in a contrasting part of the world.

For each landform in this chapter, practise drawing an annotated sketch to describe its characteristics and explain its sequence of formation.

Origin and development of landforms of coastal erosion

The section above illustrated how the nature of the geology of the coastline can influence the landforms found at a coastline, and where this leads to differential rates of erosion one of the most recognisable combinations of landforms is created: headlands and bays.

Headlands and bays

Figure 3.21 (page 104) shows the impact of geology on a coastline. Areas with alternating more and less resistant rocks are a common feature of many coastlines. Initially erosional processes predominate in areas with less-resistant rock, forming bays, leaving the more resistant rock protruding out to sea as headlands. Because of refraction, the headlands then receive the highest-energy waves and are more vulnerable to the forces of erosion than are the bays. The bays experience low-energy waves that allow sediment to accumulate and form beaches. These then act to protect that part of the coastline.

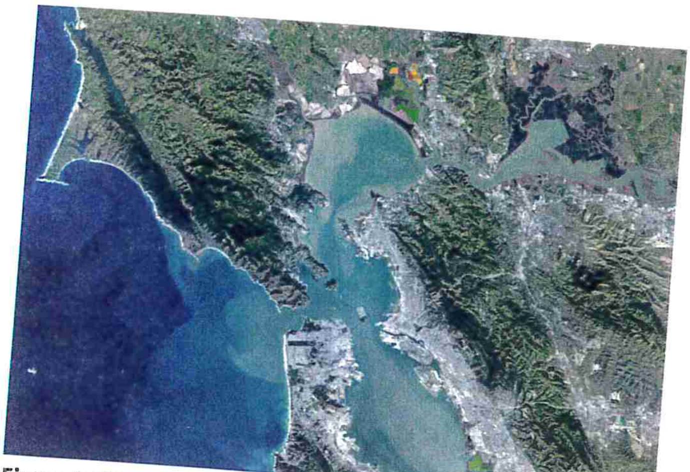

Figure 3.20 Concordant coast of San Francisco Bay

When geology runs parallel to the coast, as in Purbeck, Dorset, or the San Francisco Bay area of the Californian coast, it is possible for marine processes to create headlands and bays. In San Francisco Bay (Figure 3.20), sea level rise over the last 10,000 years has slowly inundated a series of valleys running parallel to the coastline that correspond to the alignment of the complex geology of the Californian coast. Figure 3.21 illustrates how the differential erosion of alternating geology has also led to the formation of headlands and bays on the Purbeck coast.

Remember that it is important to think of landforms at places like Lulworth as being the result of systems operating at the coast, where the main inputs include:

- the geology and lithology of the coast, the angle of the dip of the coastline in front of the headland, the nature of the waves approaching the coast and the direction and strength of the prevailing wind.

The components (or processes) include:

- the differential rates of erosion of the different rocks
- wave refraction
- erosion of the headland
- deposition in the bay.

The outputs include:

- the characteristic features of the resulting landscape including:
  - the headland and bay
  - the erosional features of the headland
  - the depositional features in the bay.

Cliffs and wave-cut platforms

When high and steep waves break at the foot of a cliff their energy and erosive action is concentrated into a small area of the rock face. With erosion concentrated at its base the cliff begins to be undercut, forming a feature known as a **wave-cut notch**. Further erosion increases the stress on the cliff above and over time it will collapse; how long this takes will depend on the characteristics of the cliffs and waves.

The cliff line will begin to retreat and after successive collapses a gently sloping (less than 5°), relatively smooth, **wave-cut platform** is formed at the base of the cliff (Figure 3.22). If the platform is still in the tidal zone and continually exposed to cycles of marine erosion and sub-aerial processes, weaknesses in the rock surface may be exploited, and on closer inspection

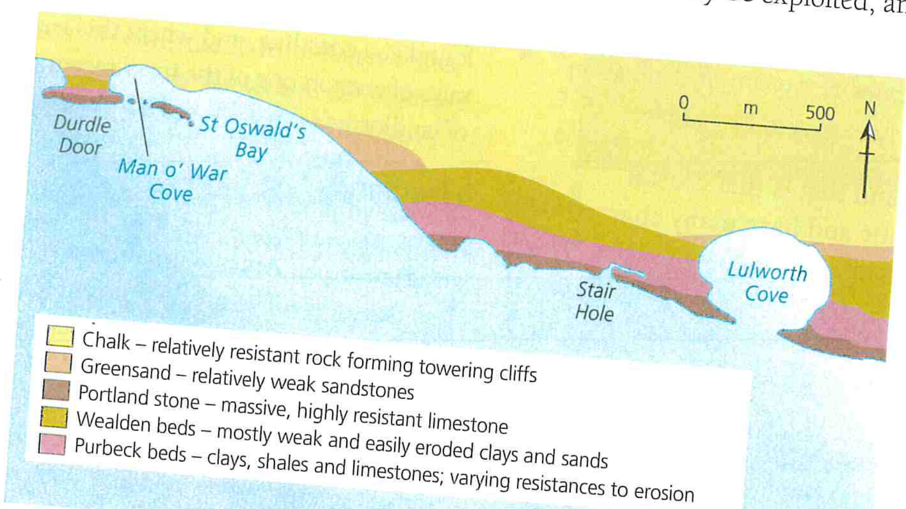

Figure 3.21 The geology of south Purbeck

Cliff profile and rate of retreat

There are several factors that affect the cliff profile and its rate of retreat.

- Steep cliffs tend to occur where the rock is strong and resistant to erosion, such as most igneous and metamorphic rocks. Sedimentary rocks that are dipping steeply or even vertically tend to produce steep and dramatic cliffs (Figure **5**), as will the absence of a beach and an exposed orientation with a long fetch and high-energy waves that encourage erosion and undercutting by the sea.
- Gentle cliffs usually reflect weak or unconsolidated rocks that are prone to slumping. Rocks that are dipping towards the sea also tend to have low-angle cliffs. A sheltered location with low-energy waves and a short fetch will result in subaerial debris building up at the foot of the cliff, reducing its overall angle. A wide beach will absorb wave energy, preventing significant undercutting and steepening.
- The rate of retreat of a cliff very much depends on the balance between marine factors – such as wave energy, fetch, presence of a beach – and terrestrial factors – such as subaerial processes, rock geology and lithology (Figure **6**). The most rapidly retreating cliffs tend to be composed of very weak rock, such as the glacial till cliffs of the Holderness coast.

Figure 4 *Cliffs and a wave-cut platform near Eastbourne, West Sussex*

Figure 5 *Vertical rock structure in cliffs near Tenby, South Wales*

Other factors leading to rapid rates of cliff retreat include rising sea levels, and human activities such as coastal defences elsewhere leading to increased erosion.

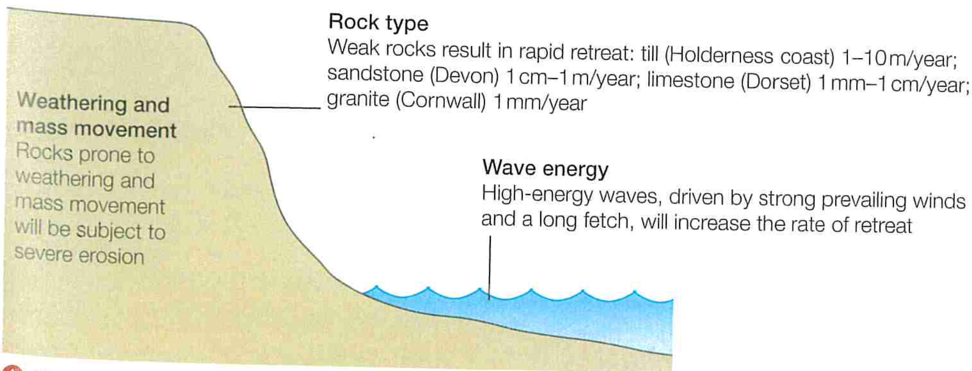

Figure 6 *Factors affecting the rate of retreat*

Coastal morphology is related not only to the underlying geology, or rock type, but also to its *lithology* – its geological structure. Lithology means any of the following characteristics:

- Strata – layers of rock
- Bedding planes – horizontal, natural breaks in the strata, caused by gaps in time during periods of rock formation
- Joints – vertical fractures caused either by contraction as sediments dry out, or by earth movements during uplift
- Folds – formed by pressure during tectonic activity, which makes rocks buckle and crumple (e.g. the Lulworth Crumple)
- Faults – formed when the stress or pressure to which a rock is subjected, exceeds its internal strength (causing it to fracture). The faults then slip or move along fault planes
- Dip – refers to the angle at which rock strata lie (horizontally, vertically, dipping towards the sea, or dipping inland).

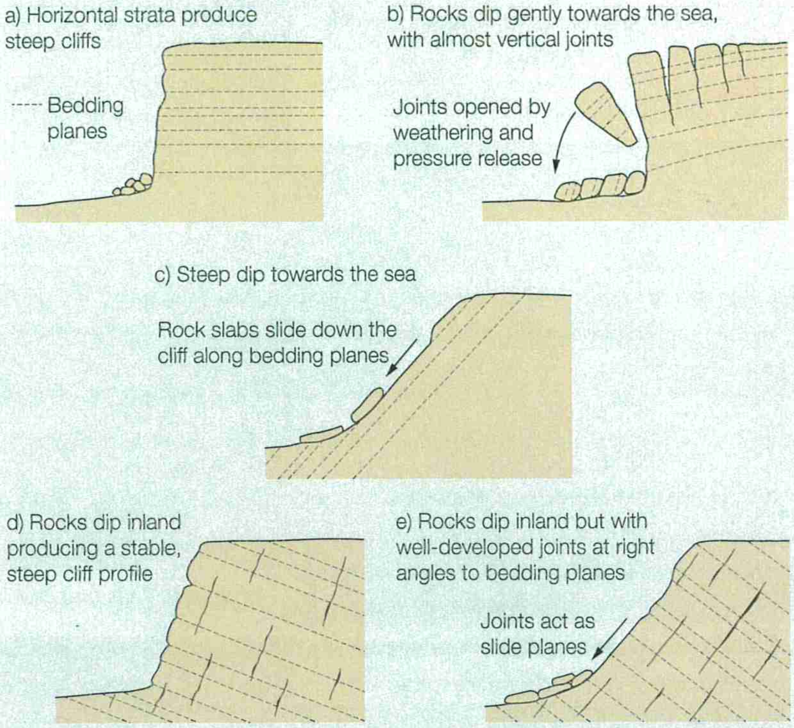

Figure 7 *Cliff profiles and geological structure*

The relief – or height and slope of land – is also affected by geology and geological structure. There is a direct relationship between rock type, lithology and cliff profiles. The five diagrams that make up Figure **7** help to illustrate this.

Cliffs profile features – caves, arches and stacks

One of the world's most iconic road trips is the Great Ocean Road coastal route in Southern Australia between Melbourne and Adelaide. With its towering sandstone cliffs, isolated stacks and spectacular arches, this stretch of coastline is one of the most dramatic landscapes in Australia (Figure **8**). It demonstrates clearly how erosion on a high-energy coast will create several landforms as the cliffs – notice their steep profile – are steadily eroded.

Figure 8 *Coastal landforms on the Great Ocean Road in southern Australia. The stacks in the foreground are called the Twelve Apostles and are a big tourist attraction.*