

Chapter 2

Evolution of Cliffs

Abstract Cliffs are related to geological structure and rock types, and have evolved in response to tectonic movements of the land and changes in sea level. Their profiles are influenced by rock resistance, hinterland topography, exposure to wave action and the effects of coastal processes. Steep vegetated coastal slopes, termed bluffs, are generally former cliffs degraded by weathering; most are stable, but some are subject to occasional landslides. Slope-over-wall coasts occur where a weak formation (such as clay) rests upon more resistant rock, or where a coastal slope has been undercut by marine erosion; in high latitudes the slope may be inherited from prior weathering during periods of cold climate.

2.1 Origin of Cliffs

Cliffs border coastal uplands, produced by uplift of the land and lowering of sea level through geological time; for example there are extensive cliffs cut in Chalk, a rock formation of marine origin that originated in the Cretaceous Sea, 65 to about 100 million years ago, but is now above sea level. Most cliffs are on coasts that have been stable during the past few thousand years, but some have been modified by tectonic uplift or sea level fluctuations within this period. The simplest cliffs are found where marine erosion has attacked the margins of a stable land mass, removing a wedge of material to form a steep slope that may be vertical or even overhanging, fronted by a seaward-sloping shore platform that extends from the cliff base out to below low tide level (Fig. 2.1).

A few coastal cliffs originated as the result of uplift of the land along a fault or monocline and accompanying subsidence on the down-thrown side (Fig. 2.2). Slopes formed by dislocation along a fault line (so that they coincide with the fault plane) are known as fault scarps, and cliffs that originated in this way may be termed fault cliffs. They are found on parts of the Mediterranean coastline, as on the steep and cliffed coasts of Malta (Fig. 2.3), which have formed at least partly



Fig. 2.1 A vertical Chalk cliff and seaward-sloping intertidal shore platform at Birling gap on the Sussex coast. © Geostudies



Fig. 2.2 Cliff of Miocene sandstone in Beaumaris Bay, Melbourne Australia, following the axis of the Beaumaris monocline. © Geostudies



Fig. 2.3 The steep coast at Dingli in Malta, probably initiated by faulting, now consists of a rubble-strewn slope descending to a vertical cliff cut in Miocene limestone. A structural bench is seen at the base of the cliff. © Geostudies

as the result of land uplift along fault lines, which produced steep slopes that have been only slightly modified by marine erosion and weathering (defined as the disintegration or decomposition of a rock surface exposed to the atmosphere as the result of physical, chemical and biological processes). Cliffs formed as the result of uplift along a fault usually took shape as the result of repeated tectonic uplifts (earthquakes) on a small scale, each producing a metre or so of exposed fault plane. Recurrent earthquakes can form a high cliff, with several stages of exposure of the fault plane (their age diminishing downward), but weathering and erosion have modified the earlier stages of such a composite cliff, so that only the latest stage shows a freshly-exposed fault plane.

Some cliffs that follow fault lines are the outcome of differential erosion, where faulting had previously placed soft rock formations alongside more resistant rocks and removal of the softer rock has exposed the fault plane as a cliff. In fact very few coastal cliffs follow the lines of active or inactive faults, although some have been cut across transverse fault lines (Fig. 2.4).

Examples of a cliff produced by land uplift can also be seen where a fringing coral reef has been raised out of the sea (Fig. 2.5). Many of these have been modified by erosion and solution, forming ‘notch-and-visor’ profiles (Fig. 2.6). In the Loyalty Islands, New Caledonia, coral atolls have been raised and tilted by earth movements near the margins of a tectonic plate, forming cliffs with several notched terraces, each cut by the sea during an interval of stability between phases of intermittent uplift (Fig. 2.7).

A few cliffs have originated as the result of volcanic eruptions. Examples include the steep cliffs facing into the crater of Krakatau in Sunda Strait, Indonesia, formed by the explosive eruption of that volcano in 1883 (Fig. 2.8). Similar cliffs are seen on the Greek volcanic island of Santorini in the Mediterranean Sea, and on Deception Island in the South Shetland Islands, Antarctica.



Fig. 2.4 The sloping cliff (*left*) in Rinsey Cove, Cornwall, is a fault-line cliff exposed along the exhumed contact between the Mylor Slates and the overthrust Tregonning Granite, both of Devonian age. © Geostudies

Fig. 2.5 Notched coastal slope on emerged coral limestone at Baron, on the south coast of Java, Indonesia. © Geostudies



Fig. 2.6 Notch-and-visor on a cliff of emerged coral, Isle of Pines, New Caledonia. © Geostudies



Fig. 2.7 Multiple terraces formed during stages in intermittent uplift on the tilted coral island of Uvéa, Loyalty Islands, New Caledonia. © Geostudies

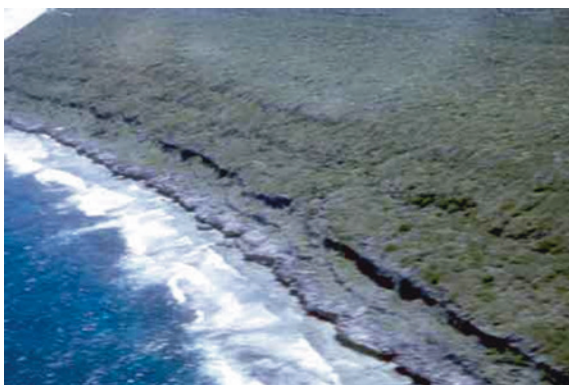


Fig. 2.8 The steep cliff on the island of Rakata is the wall of a volcanic crater formed by the 1883 explosion of Krakatau in Sunda Strait Indonesia. © Geostudies



2.2 Cliffs Formed by Marine Erosion

Most cliffs have been formed mainly by marine erosion of the margins of a pre-existing upland during the Holocene: generally the few thousand years since the Late Quaternary marine transgression brought the sea to its present level.

Waves breaking on the shore are powerful agents of abrasion (the wearing of a rock surface by friction, also known as corrasion) as the result of the hydraulic pressure of wave impact, which forces air into crevices and so generates pressure alternations that widen them. Abrasion is intensified where the waves mobilise rock fragments (sand, gravel or boulders), which are hurled at the cliff base during storms. This causes wearing, grinding and scraping, and can result in quarrying of rock fragments or excavation of sediment. Such erosion leads to the cutting of a sharp-angled junction or an undercut abrasion notch at the cliff-base (Fig. 2.9). Formation of a cliff-base notch is followed by the collapse of rock from the cliff face and the accumulation of rocky debris as talus at the base of the cliff. This is gradually consumed or removed by wave action until waves can again attack the base of the cliff.

Fig. 2.9 Cliff-base notch at Birling Gap, Sussex, formed largely by abrasion, which has cut across flint horizons in the Chalk. © Geostudies



2.2.1 *Cliff Profiles and Lithology*

The effects of marine erosion depend on the nature and resistance of the rock formations encountered. Their lithology varies from very hard quartzites, igneous formations such as granites and indurated metamorphic rocks such as greenstones, through moderately hard slates to sandstones and soft limestones such as chalk and weak mudrocks such as shales and clays. Categories of rock hardness suggested by Clayton and Shamooin (1998) were:

- Very hard quartzites and sandstones, massive granite and indurated metamorphic rocks.
- Moderately hard slates, shales, grits and basalts.
- Weak limestones (including Chalk) and sandstones.
- Very weak mudrocks (defined as rocks containing at least 90 % silt and clay, and formerly known as siltstones, shales and clays) and unconsolidated sands.

The resistance of an exposed rock formation depends not only on its hardness, but also on its structure, notably planes of division such as joints and bedding planes and lines or zones of relative weakness that are exploited by erosion and weathering processes.

Cliff profiles on resistant rock outcrops are generally bold and those on weak formations gentler: many of the bold headlands on the coast of Cornwall are on outcrops of dolerite (greenstone), in contrast with gentler coastal slopes on slates or phyllites (Bird 1998). In general, cliffs on rock outcrops on older geological formations (such as Pre-Cambrian and Palaeozoic outcrops on the Atlantic coasts of Britain) recede slowly because these rocks are more resistant to weathering than younger formations, but there are many exceptions to this: in northern Scandinavia and northern Canada there are cliffs cut into horizontally-bedded, relatively soft unconsolidated strata of Cambrian age, while cliff outcrops on Cretaceous and Tertiary rocks bordering the Mediterranean Sea have locally been hardened by intense tectonic compression during the Alpine earth movements. The Chalk cliffs at The Needles, at the western end of the Isle of Wight, persist in rock that has been made more resistant by intense folding.

Marine erosion has had little effect on massive resistant formations such as granite, which sometimes forms a steep coastal slope descending into the sea instead of cliffs and shore platforms (Fig. 2.10). This is the outcome of a long period of slow subaerial weathering. Typically, however, granite cliffs show dissection along joints (Fig. 2.11), and the cliffs at Lands End in Cornwall have a castellated appearance related to the excavation of clefts along vertical, inclined and horizontal joints (Fig. 2.12). Cliff profiles on hard sandstone (quartzite) may be similar. The Old Red Sandstone is a resistant formation that forms high cliffs up to 60 m high on the north coast of Scotland between Duncansby and Skirza Head and on the coast of the Orkney Islands; it is stratified and jointed, and cliff profiles are influenced by erosion along these planes of division (Fig. 2.13). Consolidated volcanic rocks such as basalt also show dissection along planes

Fig. 2.10 Granite coast south of Cape Tourville, Tasmania where the granite slopes down into the sea.
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Fig. 2.11 The influence of jointing on the profile of a granite cliff in the fiord of Qeqertarsuatsiat, SW Greenland. © Geostudies



Fig. 2.12 Pendower Cove, cliffs and caves in castellated granite near Land's End, Cornwall. © Geostudies



Fig. 2.13 The cliffs at Yesnaby on Orkney, dissected along joint planes in the Old Red Sandstone. © Geostudies



Fig. 2.14 Columnar basalt cliff at Fingal Head, New South Wales. © Geostudies



between successive lava flows or along joints, which may separate columnar structures as in the Giant's Causeway in Northern Ireland, Fingal Head in New South Wales (Fig. 2.14) and the vertical cliffs and stepped rocky shores on columnar dolerites at Pillar Point in south-east Tasmania. Such volcanic columns are usually vertical, but may have been modified by tectonic movements (Fig. 2.15).

On rocks of moderate resistance, such as Chalk, wave action undercuts the cliff, leading to the collapse of rock from the cliff face, which remains vertical or steep. There is often a basal abrasion ramp that declines to a gently-sloping or horizontal shore platform, often influenced by the outcrops of rock strata (Fig. 2.16). Cliffs in moderately resistant sandstone cliffs show variations related to sedimentary texture and structure, notably folding and faulting, and joints and bedding-planes (Figs. 2.17).

On soft rock formations vertical cliffs have been cut into coherent, homogeneous formations such as the Pleistocene brickearth (loess) of Pegwell Bay in Kent and the pindan deposits of the Dampier Peninsula in the Broome district of NW



Fig. 2.15 Cliff in basaltic columns that have been tilted and deformed by earth movements.
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Fig. 2.16 Chalk cliff and shore platform at Vaucottes, northern France, cut into horizontally bedded strata. © Geostudies

Australia (Fig. 2.18). Pindan is a soft, coherent red silty sand of aeolian origin, winnowed from a desert hinterland during dry phases in the Pleistocene. It sustains a vertical outcrop in coastal cliffs, which retreat as the result of recurrent slumping, remaining vertical as the slumped talus is dispersed by wave action. Pindan is much like the European loess, which is a silty aeolian deposit that formed during glacial periods (blown from a cold, dry morainic landscape), and is seen in vertical cliffs on the NW coast of the Black Sea.

On other soft formations, such as clay or sand, marine erosion is accompanied by subaerial weathering and erosion that results in slumping, and the formation of a wide irregular coastal slope (Fig. 2.19). Gulleying and slumping are seen on cliffs cut in glacial drift, as on the coasts of Block Island, Martha's Vineyard and Nantucket Island in Massachusetts, where the cliffs are receding at up to a metre per year, and on the Holderness cliffs in Yorkshire (Fig. 2.20), where cliffs cut in glacial

Fig. 2.17 Vertical cliff in stratified Jurassic sandstone with almost horizontal bedding-planes, West Bay, Dorset, England.
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Fig. 2.18 Vertical cliffs in pindan deposits on the coast near Broome, Western Australia, showing disintegration along joints.
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drift have been retreating for several centuries: many villages and farms have been lost. Similar slumping slopes, partly grassed, occur on the London Clay outcrop at Warden Point, on the Isle of Sheppey in Kent (Swale Borough Council 2011).

Recurrent slumping has also occurred, particularly after wet weather or the thawing of a snow cover, on the soft Tertiary sands and clays of the Bournemouth coast and the northern shores of the Isle of Wight, on Jurassic clays and shales on the Dorset and Yorkshire coasts, and on glacial drift deposits, as in eastern England, the Danish archipelago, New England or the islands of Puget Sound. Profiles of receding cliffs cut in glacial drift on the North Norfolk coast between West Runton and Sheringham, are bold on clay outcrops and sloping and slumping where the glacial drift is sandy.

On recently-formed volcanic islands (such as Surtsey, which started to form in 1963 off the south coast of Iceland) the softer sediment (volcanic ash, also known



Fig. 2.19 Successive landslides have led to rapid recession of a cliff at Blackgang Chine, Isle of Wight, behind a slumping undercliff on soft Lower Cretaceous clays and sands. © Geostudies

Fig. 2.20 Retreating cliffs cut in Pleistocene boulder clay on the Holderness coast in Yorkshire. © Geostudies



as tuff) is soon removed by erosion, but where hard lava outcrops at or above sea level, cliffs predominate.

2.2.2 Cliff Profiles and Geological Structure

Cliff morphology is also influenced by geological structure: massive rock outcrops form steep coasts, but cliff profiles on stratified or fractured rock formations are related to the dip, joint patterns, bedding planes, cleavage planes, faults and folds and the disposition of harder and softer components. Solid and massive formations are generally eroded more slowly than formations that disintegrate readily along joints, bedding planes, cleavage planes and fractured zones that facilitate



Fig. 2.21 Chalk forms vertical cliffs cut into strata that dip gently seaward at the Seven Sisters, Sussex. © Geostudies

cliff dissection. Most rock formations have planes of division that are weakened by weathering processes and penetrated by marine erosion, influencing the outline of a cliff and forming crevices, clefts, inlets and caves along the coast.

Where the dip is seaward the cliff profile remains steep because dislodged rock slides away. On the coasts of Kent and Sussex Chalk forms vertical cliffs cut into strata that dip gently seaward (Fig. 2.21), and landslides have occurred where the dipping Chalk rests upon Gault clay, as at Folkestone Warren (§3.5). On some coasts evenly-sloping cliffs may follow an exposed seaward-dipping bedding plane in stratified rock. Vertical cliffs may be formed where joint planes are exposed, as on the Lower Cretaceous sandstone cliffs at Hastings in Sussex (Fig. 2.22). Figure 2.23 shows structural ledges as steps on horizontal sandstones separated by weak clays.



Fig. 2.22 Angular pattern in cliffs in sandrock near Hastings in Sussex, related to exposure of vertical joint planes. © Geostudies

Fig. 2.23 Structural benches of Devonian sandstone separated by shale on Bay cliff at Wonboyn, south coast New South Wales.
© Geostudies



Where the Chalk outcrop dips steeply and is often strongly folded, as in the Isle of Wight and on the Dorset coast, there are more irregular features related to minor variations in lithology, such as ledges and reefs on the more resistant layers (e.g. the Melbourn Rock) and gentler slopes on softer marly horizons within the Chalk.

Where the dip is landward, as at Ballard Down in Dorset (Fig. 2.24) the cliffs undercut the steep slopes of the Chalk escarpment, and may be described as escarpment cliffs (Bird 1995).

On the north coast of Devon the cliffs near Hartland Point are generally vertical, cut back by stormy seas across Carboniferous sandstones and shales compressed into tight zigzag folds along vertical axes running at right angles to the coastline. In detail the harder sandstones protrude as ribs or small salients and the weaker shales have been cut out as coves, while on a larger scale there are ridges on anticlinal zones (upfolds) that have proved slightly more resistant, and inlets along the transverse synclines (downfolds).

Cliff profiles are thus related to variations in rock resistance, picked out by erosion as the cliff is cut back. The more resistant parts of coastal rock formations protrude as ledges, or persist as caprock on rocky stacks and islands offshore,

Fig. 2.24 Escarpment cliff at Ballard Down, Dorset.
© Geostudies



Fig. 2.25 Cliffs in Carboniferous Limestone, Flimston Bay, Pembrokeshire. © Geostudies



whereas the weaker elements are cut back as cliffs and caves. Weathering and erosion penetrate zones of weakness such as faults, joints or outcrops of less resistant rock, cutting clefts and crevices that may develop into caves and blowholes or deep, narrow inlets, and isolating stacks. Clifed coasts showing an array of such features are found on Carboniferous Limestone in south Pembrokeshire (Fig. 2.25), while on the Normandy coast of France the Porte d'Aval is a slender natural arch on the cliffs of hard (silicified) Chalk at Etretat (Fig. 2.26).

Sloping cliffs, sometimes vegetated, occur where a resistant formation (e.g. hard limestone) overlies a weaker horizon (e.g. soft sandstone) outcropping down to sea level, as at Quobba on the west coast of Australia. On the south-west coast of the Isle of Wight sandstone horizons in the clay-dominated Wealden Beds produce relatively steep cliffs where they outcrop at the cliff crest, as at Barnes High, and cliff-face ledges where they outcrop in the cliff profile, as at Sudmoor Point (Bird 1997). Steep, receding cliffs in Lias Clay are seen on the Dorset coast at Seatown (Fig. 2.27).

Contrasts in lithology have influenced the profiles of cliffs cut in Jurassic formations along the Lyme Bay coast in Dorset (Bird 1995). On Golden Cap

Fig. 2.26 Cliffs and stacks in thinly-bedded silicified Chalk at Etretat, on the Normandy coast in France. © Geostudies



Fig. 2.27 Sloping cliff in Lias clay at Seatown, Dorset.
© Geostudies



Fig. 2.28 Golden Cap, Dorset, the highest cliff on the south coast of England rising 191 m above sea level, with a capping of Upper Greensand over Lower Jurassic (Lias) clays and limestone layers.
© Geostudies



(Fig. 2.28) the harder sandstone outcrops form steep slopes and ledges and the softer clays gentler (partly vegetated) slopes and areas of subsidence. The high cliffs on the south coast of Malta are vertical on the Lower Coralline Limestone but sloping on the overlying Globigerina Limestone (Fig. 2.3).

Some cliffs show vertical grooves and buttresses cut out along joint planes. Examples are seen on soft Triassic sandstone at High Peak on the south coast of Devon (Fig. 2.29) and on the Chalk cliffs near the mouth of the Cuckmere River in Sussex (Fig. 2.30). Vertical grooves and buttresses have been excavated in the cliffs of Alum Bay, on the Isle of Wight, cut in alternations of Eocene sandstone and clay strata that stand vertically on the northern side of a monoclinal fold.



Fig. 2.29 Buttresses and grooves in sandstone on the cliff at High Peak, near Sidmouth on the south coast of Devon. © Geostudies



Fig. 2.30 Buttresses on the Chalk cliffs near Cuckmere Haven, Sussex. © Geostudies

2.2.3 Cliff Profiles and Exposure to Wave Action

Cliffs on coasts exposed to strong wave action from the open sea are typically bold, and often rapidly receding, whereas those on relatively sheltered coasts are often more subdued.

On the high wave energy coast near Port Campbell in Australia vertical cliffs have been cut by marine erosion in horizontally stratified Miocene calcareous silt-stones. The huge waves that break against these during storms have cut out ledges along the bedding-planes at various levels up to 60 m above high tide (Baker 1958). These structural ledges are rarely more than 5 m wide, and are the product of present-day storm wave erosion; they are not emerged shore platforms. The power of storm waves is illustrated where large boulders have been thrown up and over cliffs, as at Quobba in Western Australia.

In NW Australia storm waves produced by tropical cyclones have cut cliff-top features, as at Cape Leveque and Gantheaume Point, near Broome, where a cliff in red Cretaceous sandstone (Broome Formation) rises to a broad bench backed by an upper bluff, which is occasionally trimmed back by storm surge wave overwash in cyclones (Figs. 2.31 and 2.32).

Fig. 2.31 Cape Leveque
on the Dampier Peninsula,
Western Australia.
© Geostudies



Fig. 2.32 Gantheaume Point,
Broome, Western Australia.
© Geostudies



Cliffs on sheltered sections of the coast, where strong wave action is intercepted by headlands, islands, or offshore reefs, or attenuated by a gently sloping nearshore sea floor, may show profiles partly formed by subaerial weathering and erosion. Cliffs in these situations may have slope-over-wall profiles (§2.4).

Variations in cliff profiles with exposure are well illustrated around Sydney Harbour in New South Wales. The bold cliffs cut in Triassic Hawkesbury Sandstone at the entrance (Fig. 2.33) pass into lower and gentler cliffs and bluffs on the harbour shores, with variations related to the local fetch, which limits the strength of attack by wind-generated waves. The cliffs of Middle Head, facing the entrance from the Tasman Sea and receiving ocean swell and storm waves, are bordered by scrub-covered bluffs on the more sheltered sectors (Fig. 2.34).

Fig. 2.33 Vertical cliffs cut in Hawkesbury Sandstone on North Head, at the entrance to Sydney Harbour.
© Geostudies



Fig. 2.34 The cliff at Middle Head interrupts the scrubby bluffs on the coast of Sydney Harbour. © Geostudies



2.3 Bluffs and Steep Coastal Slopes

Bluffs are relatively stable vegetated slopes, usually abandoned cliffs that have been subaerially degraded after marine erosion was halted by the accumulation of a wide protective beach, by emergence due to land uplift or a fall in sea level, by the building of a sea wall or nearshore breakwater, or by land reclamation. Bluffs have slope gradients determined by the physical properties of the rock outcrop: they are usually between 8° and 10° on soft clays and steeper on more resistant formations such as Chalk. Early stages in cliff degradation can be seen on the Chalk coast at Samphire Hoe, near Dover in Kent (Fig. 2.35), where rubble from the Channel Tunnel was deposited on the shore as a fronting terrace between 1987 and 1992.

At Matata on the North Island of New Zealand cliffs became vegetated bluffs after the deposition of a wide protective beach (Fig. 2.36), and emergence due to



Fig. 2.35 The terrace fronting degraded Chalk cliffs at Samphire Hoe, near Dover in Kent.
© Geostudies



Fig. 2.36 Bluffs at Matata on the north coast of North Island, New Zealand. © Geostudies

land uplift in the Wellington district in New Zealand during the 1855 earthquake was followed by degradation of cliffs to bluffs. Former cliffs have been subaerially degraded in Denmark because the lowering of the Early Holocene ‘Litorina Sea’ has withdrawn wave action, the land having risen as the result of postglacial isostatic land uplift to form the marine foreland (Fig. 2.37). Coastal bluffs may also form where cliffs become degraded following artificial protection by sea wall construction, as at Byobugaura on the coast of Japan (Fig. 2.38) or land reclamation. Accretion within Newhaven Harbour in Sussex after the completion of the breakwater in 1891 has led to degradation of the backing Chalk cliff (Fig. 2.39).



Fig. 2.37 The coastal bluff at Mullbjerger in Denmark, fronted by a lowland (the marine foreland) that emerged during the fall of the 'Litorina Sea', about 4000 years ago. © Geostudies



Fig. 2.38 Cliff recession halted by a shore wall at Byobugura on the east coast of Japan. © Geostudies



Fig. 2.39 The Chalk cliff behind Newhaven harbour in Sussex has been modified following harbour construction. A slope has formed on the capping of Eocene clays, above an apron of down-washed sediment. The formerly vertical cliff is thus developing a convex-over-concave profile. © Geostudies

Fig. 2.40 Steep bluffs near Lynmouth on the North Devon coast. © Geostudies



Fig. 2.41 Hogsback cliff, Trentishoe Down, North Devon. © Geostudies



Bluffs that descend steeply to the shore are seen on the North Devon coast bordering Exmoor (Fig. 2.40). They carry grassland or woodland, and the lower slopes may be actively cliffed. Hogsback profiles occur where the geological strike is parallel to the coast, forming coastal escarpments where the dip is landward (Fig. 2.41).

Steep coastal slopes with a forest cover are extensive in humid tropical regions, where they may show little if any basal cliffing. These profiles result from the intensive subaerial weathering characteristic of the humid tropics, so that many coastal rock formations have been weakened as the result of rapid and deep decomposition by chemical weathering. They form steep coastal slopes with a soil and vegetation mantle, as on the Macalister Range in north Queensland (Fig. 2.42). Wave energy is generally low on humid tropical coasts, many of which are protected from erosion by fringing or nearshore coral reefs. However, these steep forested coastal slopes on deeply-weathered rock formations are subject to occasional landslides, and so to gradual and intermittent coastline recession.

Cliffed coasts are comparatively rare on humid tropical coasts in SE Asia and India, on the east and west coasts of tropical Africa, in Brazil and on the Pacific

Fig. 2.42 Humid tropical forested bluff, Macalister Range, Queensland, on a coast that is protected from strong wave action by the Great Barrier Reef.
© Geostudies



coast of Central America, as well as in NE Australia, because of generally low wave energy. On these coasts cliffs occur on exposed promontories, where wave action is relatively strong, and are more extensive on coasts receiving ocean swell, especially where the coastal rock formations are weak or deeply weathered, as in Paraiba, NE Brazil, where 21 % of the coastline consists of retreating cliffs cut in sandy clays (Guilcher 1985). Cliffs shaped by ocean swell are seen along the southern coasts of Indonesian islands, including Bali and Lombok, which receive swell from the Indian Ocean. Yampi Sound in northern Australia is bordered by low crumbling cliffs of deeply-weathered metamorphic rock, from which protrude bolder promontories of quartzite, a type of resistant rock that has been little modified by chemical weathering. Within the humid tropics marine erosion is more effective on coastal rock formations weakened by prior weathering than on their original lithology. On the Liberian coast at Mamba Point a dolerite cliff persists on a headland between vegetated bluffs on outcrops of more thoroughly weathered granite and gneiss.

On arid and semi-arid coasts bluffs may be sparsely-vegetated, as at Blanche Point, south of Port Noarlunga on the coast of South Australia (Fig. 2.43).

On the NE coast of Port Phillip Bay, Australia, bluffs of Tertiary sandstone became unstable when vegetation was cleared from the cliff-top area. This is because the cliff-top vegetation canopy had intercepted some rainfall, and its root systems drew upon water percolating down through the soil, as well as binding surface sediment. When the cliff-top vegetation was cleared runoff and seepage increased, causing erosion of the bluff (Fig. 2.44). Coastal bluffs can be rejuvenated as cliffs when marine erosion is intensified by coastal submergence, or the loss of a protective beach.

Coastal bluffs can be rejuvenated as cliffs when marine erosion is intensified by coastal submergence, or the loss of a protective beach. Bluffs bearing scrub and woodland on the NE coast of Port Phillip Bay have been undercut by wave action following the erosion of beaches that previously protected them (Fig. 2.45). At Sandringham this has been countered by beach renourishment, restoring the protective beach and halting erosion of the backing bluff, which has become revegetated (Fig. 2.46).

Fig. 2.43 A sparsely-vegetated bluff at Blanche Point, South Australia.
© Geostudies



Fig. 2.44 Seepage has contributed to slumping on the cliff at Black Rock, Victoria, Australia.
© Geostudies



Fig. 2.45 Erosion at the base of the bluff at Sandringham, Victoria, Australia, has followed depletion of the bordering beach.
© Geostudies



Some vegetated bluffs show intermittent and local slumping, and could be termed wasting bluffs. Examples are seen on the Pacific coasts of Oregon and Washington, where steep bluffs carrying scrub and forest appear fairly stable, but are in fact receding as the result of intermittent localised slumping (Fig. 2.47).

Fig. 2.46 Beach renourishment has halted bluff-base erosion at the southern end of Sandringham Beach, Victoria, Australia.
© Geostudies



Fig. 2.47 Cliffs are formed by occasional slumping on the forested bluffs near Moclips on the coast of Washington State.
© Geostudies



Landslides generally occur here in the wetter winter months, during or after occasional storm surges, as the result of earthquakes or in response to a long-term (e.g. 300 year) tsunami cycle (Komar and Shih 1993). The slump scars are quickly revegetated in this cool and moist environment and the debris fans of downwashed or slumped sediment are soon consumed by the sea. Similar processes are effective on vegetated bluffs on humid tropical coasts, such as the Ivory Coast in West Africa.

2.4 Slope-Over-Wall Coasts

Some steep coasts have a composite profile, with an upper slope descending to a basal cliff. Such slope-over-wall coasts can form in several ways. The simplest are on soft homogeneous rock formations where a coastal slope formed by subaerial processes (runoff, slumping, soil creep) descends to a basal cliff kept fresh by wave attack during occasional storms. Such coasts may show alternations in profile, the upper slope being extended by subaerial weathering and runoff during occasional downpours and undercut and steepened to revive the basal cliff after dispersal of downwashed or slumped fans by wave action.

Slope-over-wall profiles are also seen where the upper part of a cliff is a slope cut in weak or weathered rock while the lower part is a vertical cliff in more coherent rock. On the Dorset coast at Portland Bill a coastal slope in the soft Purbeck Beds descends to a cliff cut in harder Portland Limestone (Fig. 2.48), while on the limestone cliffs of south Pembrokeshire thinly-bedded horizontal strata have weathered into a convex upper slope above a vertical cliff of underlying more massive limestone. On Flamborough Head in Yorkshire a grassy upper slope (gradient 20° – 30°) cut in soft glacial drift deposits declines to a vertical cliff cut in firmer Chalk, with a basal talus apron (Fig. 2.49).

Fig. 2.48 Slope-over-wall coast at Portland Bill, Dorset.
© Geostudies



Fig. 2.49 Slope-over-wall coast at North Landing, Flamborough Head, Yorkshire. © Geostudies



Where a coastal slope follows a bedding-plane in seaward-dipping strata, or seaward-sloping cleavage, joint or fault planes, undercutting by a cliff produces a slope-over-wall profile.

Slope-over-wall profiles have also formed on coasts in high latitudes where cliffs cut in relatively resistant rock are degraded by periglacial freeze-and-thaw resulting in solifluction, forming coastal slopes that are then undercut by marine erosion. This process is still active on Arctic coasts, Baffin Island and Svalbard. It was more extensive during Pleistocene times, when coasts that are now temperate were subject to the down-slope movement of frost-shattered rubble during cold phases when sea level was lower. The Pleistocene cliffs then became slopes mantled by an earthy solifluction deposit with angular gravel (known as a Head deposit) that extended out on to what is now the sea floor in a broad, diminishing apron. Late in Pleistocene times the climate became milder, and these coastal slopes became vegetated. Sea level rose, and marine erosion undercut the Head-mantled slopes. Coastal landforms of this type are found on the west and SW coasts of Britain, where vegetated slopes (typically 20° – 30° but locally up to 45°) descend to steeper, rugged, rocky cliffs (Fig. 2.50).

The coastal slope may be a bevel of almost uniform gradient (especially where it follows seaward-dipping bedding, cleavage, joint or fault planes), but more often it is convex in form, like a hog's back, and occasionally it is concave, where the lower slopes of the Head deposit are preserved. Cliffs cut entirely in Head deposits are seen on the coast of Cornwall near St Ives, fronted by platforms in the underlying metamorphic rocks (Fig. 2.51).

The proportion of relict periglacial slope to actively-receding cliff depends on the degree of exposure of the coast to wave attack. On sheltered sectors of the south coast of Cornwall (as on the eastern side of the Lizard Peninsula near Coverack) the relict slope is well preserved down almost to high tide level. On the more exposed north coast of Cornwall, open to Atlantic storm waves, the relict slope has been undercut by a receding cliff, as on Beeny Cliff, near Boscastle (Fig. 2.52). With

Fig. 2.50 Brown seaward-dipping periglacial Head deposits above a cave in the cliff at Nelly's Cove, Porthallow, Cornwall.
© Geostudies



Fig. 2.51 Cliffs cut in Pleistocene Head deposits on the coast at Godrevy, near St Ives in north Cornwall.
© Geostudies



Fig. 2.52 Slope-over-wall coast at Beeny Cliff near Boscastle, Cornwall.
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even greater exposure to storm wave attack the relict slope has been largely, and in places completely destroyed by Holocene marine erosion, so that little if any of the coastal slope remains on the coast of Watergate Bay in north Cornwall, which has high, almost vertical receding cliffs (Fig. 2.53). The periglaciated coastal slope

Fig. 2.53 An air view of Watergate Bay, Cornwall, where the receding cliffs retain no remnants of the periglaciated slope seen on less exposed parts of the Cornish coast. © Geostudies



is better preserved on the sheltered eastern sides of major headlands, as on Start Point in Devon and Dodman Point in Cornwall, than on their more exposed western shores. Recession of the basal cliff has resulted in increased instability on the upper slope, with rock debris spilling down to the shore.

2.5 Hinterland Effects

Cliffs and bluffs are also influenced by the geomorphology of the immediate hinterland, in particular the topography intersected as they recede. Flat-topped cliffs have been cut into a coastal plateau on the Atlantic coast of Cornwall, particularly south of Portreath, where the even-crested cliffs of Reskajeage Downs rise about 100 m above sea level. Where the hinterland is undulating cliff recession leads to interfluvial ridges becoming promontories between valley-mouth embayments as on the Dorset coast east of Weymouth. This is illustrated on the Yorkshire coast north of Flamborough Head, where cliffs have been cut into a landscape of plateaux and incised valleys on Jurassic formations, forming headlands such as Filey Brigg and embayments such as Robin Hood's Bay. Where the hinterland slopes away from the coast cliffs diminish in altitude as they recede, as at Beachy Head in Sussex and in the vicinity of Childers Cove near Warrnambool in Australia.

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