3.4 Weathering, mass movement and runoff

In this section you will learn about geomorphological processes in coastal environments

Weathering

Weathering is the breakdown or disintegration of rock in situ (its original place) at or close to the ground surface. Energy flows can be clearly demonstrated as most processes involve (directly or indirectly) energy transfer from the Sun, in the form of radiation, or rain. As a process, weathering leads to the transfer (flow) of material. There are also important links with other natural systems, such as the water cycle (e.g. freeze-thaw) and the carbon cycle (e.g. carbonation).

Weathering is active at the coast where rock faces are exposed to the elements and cliff faces kept fresh by the constant removal of debris by the sea.

- If the rate of debris removal exceeds the rate of weathering and *mass movement* then a positive feedback may operate, as the rate of weathering and mass movement could increase.
- If debris removal is slow and ineffective, this will lead to a build-up of an apron of debris (*scree*) that reduces the exposure of the cliff face as it extends up the cliff face. Weathering and mass movement rates will decrease – a negative feedback.

Weathering can be divided into three different types: mechanical, biological and chemical. By breaking rock down, weathering creates sediment that the sea can then use to help erode the coast.

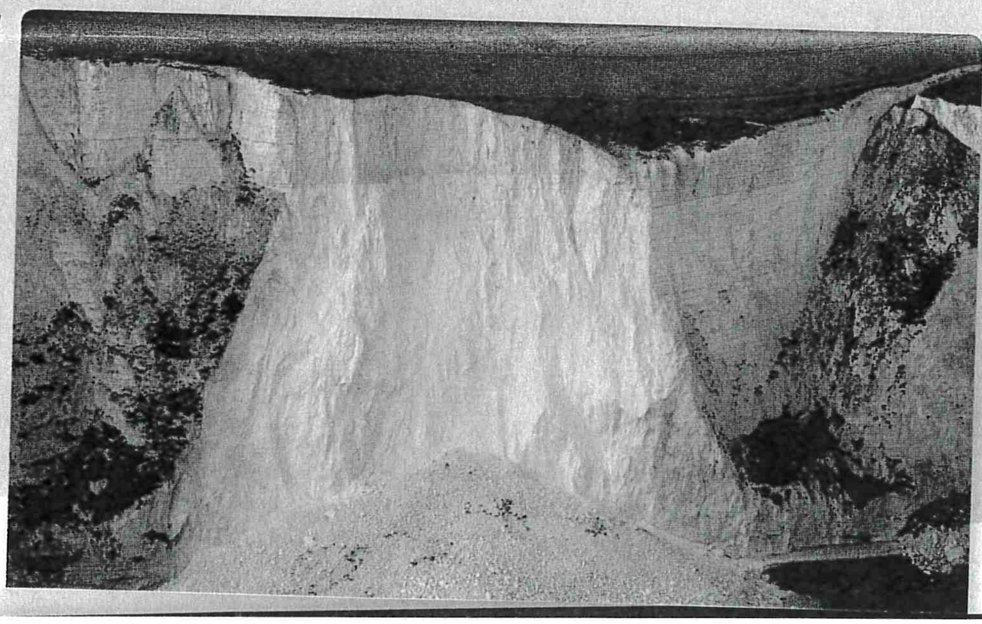
Mechanical (physical) weathering

Mechanical (or physical) weathering involves the break-up of rocks without any chemical changes taking place. There are several types of mechanical weathering processes that are active at the coast.

- *Frost shattering* (also known as *freeze-thaw*) occurs when water enters a crack or joint in the rock when it rains and then freezes in cold weather. When water freezes, it expands in volume by about 10 per cent. This expansion exerts pressure on the rock, which forces the crack to widen (see 2.6 and 4.6). With repeated freezing and thawing, fragments of rock break away and collect at the base of the cliff as scree. These angular rock fragments are then used by the sea as tools in marine erosion. Although the coast tends to be milder than inland, frost shattering is still important.

  For example, in 2001 (following a very wet autumn and a cold February) frost shattering triggered several major rockfalls along the south coast of England (see Figure **1**). Chalk (a permeable and porous rock) was the main rock affected.
- *Salt crystallisation.* When salt water evaporates, it leaves salt crystals behind. These can grow over time and exert stresses in the rock, just as ice does, causing it to break up (see 2.6). Salt can also corrode rock, particularly if it contains traces of iron.
- *Wetting and drying.* Frequent cycles of wetting and drying are common on the coast. Rocks rich in clay (such as shale) expand when they get wet and contract as they dry. This can cause them to crack and break up.

Figure 1 *A major rockfall at the White Cliffs of Dover in 2012, caused by frost shattering*



Biological weathering

The breakdown of rocks by organic activity is *biological weathering*. There are several ways in which this can operate at the coast.

- Thin plant roots grow into small cracks in a cliff face. These cracks widen as the roots grow, which breaks up the rock (Figure **2**).
- Water running through decaying vegetation becomes acidic, which leads to increased chemical weathering (see below).
- Birds (e.g. puffins and sand martins) and animals (e.g. rabbits) dig burrows into cliffs.
- Marine organisms are also capable of burrowing into rocks (e.g. piddocks, which are similar to clams), or of secreting acids (e.g. limpets).

Figure 2 *Biological weathering*

Chemical weathering

Chemical weathering involves a chemical reaction where salts may be dissolved or a clay-like deposit may result which is then easily eroded.

- *Carbonation* – rainwater absorbs carbon dioxide from the air to form a weak carbonic acid. This reacts with calcium carbonate in rocks, such as limestone and chalk, to form calcium bicarbonate, which is easily dissolved. The cooler the temperature of the rainwater, the more carbon dioxide is absorbed (so carbonation is more effective in winter). Carbonation is an important part of the carbon cycle (see 1.13).
- *Oxidation* – the reaction of rock minerals with oxygen, for example iron, to form a rusty red powder leaving rocks more vulnerable to weathering.
- *Solution* – the dissolving of rock minerals, such as halite (rock salt).

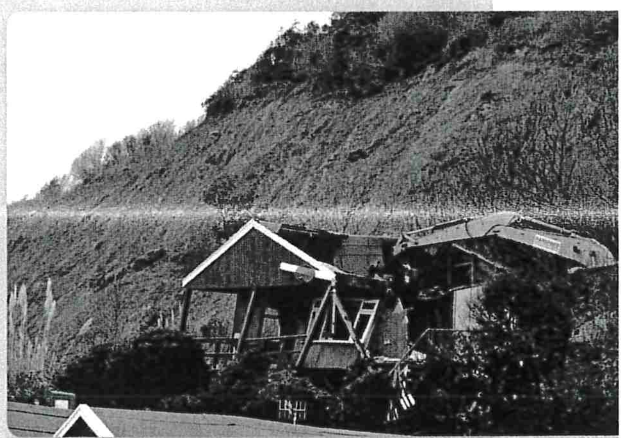


Figure 3 *One of seven holiday chalets that had to be demolished and removed from this location at Lyme Regis in 2014 following a series of landslips*

Mass movement

The downhill movement of material under the influence of gravity is known as **mass movement**. It can range from being extremely slow – less than 1 cm a year (e.g. soil creep) – to horrifyingly fast (e.g. rockfalls and landslides). Mass movement at the coast is common – the sheer weight of rainwater, combined with weak geology, is the major cause of cliff collapse.

In February 2014, following the wettest winter on record, the Jurassic Coast near Lyme Regis in Dorset was affected by a number of dramatic landslips, damaging holiday chalets (Figure **3**). This exposed stretch of coastline and is constantly being shaped and reshaped by processes of mass movement invigorated by undercutting by the sea.

Mass movement forms an important group of processes and flows within the coastal system, transferring both energy (in response to gravity) and sediment. The sediment forms an important input to shoreline processes, forming the 'tools' for erosion and providing material to be transported and deposited elsewhere along the coastline. Mass movement, along with cliff erosion, provides an important input to sediment cells (see 3.3).

set up by the warmer land and colder sea. When there is a large tidal range, large amounts of sand may be exposed at low tide thus providing a supply of sediment to be entrained (picked up) by the wind.

Sand-sized sediment is the most significant in terms of depositional features at the coast. Once entrained, sand is generally transported close to the ground and over relatively short distances. Sand is transported by wind in two ways, which are dependent on wind speed and how dry or moist the source of sand is.

- **Surface creep:** A process similar to traction, where wind rolls or slides sand grains along the surface.
- **Saltation:** Where the wind is strong enough to temporarily lift the grains into the airflow to heights of up to one metre for distances up to 20 to 30 m.

Wind action can shape and form a range of landforms at the coast, but the most obvious is a beach itself and perhaps the most distinctive are dunes, which are explored later in the chapter.

Sub-aerial processes

As mentioned above, as well as marine processes there are also **sub-aerial** (land-based) **processes** which shape the coastline. These come under the general headings of **weathering** and **mass movement**.

Sub-aerial weathering

Sub-aerial weathering includes processes that slowly (usually) **break down** the coastline, weaken the underlying rocks and allow sudden movements or erosion to happen more easily. Material is broken down *in situ*, remaining in or near its original position. Weathering processes are common at the coast due to the presence of air and water and cycles of wetting and drying, and can be categorised as:

- mechanical/physical weathering
- biological weathering
- chemical weathering.

Mechanical/physical weathering processes that occur at coasts depend on the nature of the climate. In latitudes where temperatures fluctuate above and below freezing, **freeze-thaw** action is common, especially as there is a ready supply of water. Water that enters cracks in the rocks freezes as temperatures remain below 0°C. As it freezes the water expands by almost 10 per cent, meaning the ice occupies more space and so exerts pressure on the surrounding rock. As the process repeats and continues, the crack widens, and eventually pieces of rock break off. Where processes of erosion, weathering and mass movement remove overlying material, the rock beneath is said to experience **pressure release**. As the overlying mass is unloaded mechanisms within the rock cause it to develop weaknesses, or cracks and joints as it is allowed to expand. This makes the rock susceptible to other processes of erosion and weathering.

Biological weathering includes processes that lead to the breakdown of rocks by the action of vegetation and coastal organisms. Biological weathering is quite active on coastlines. Some marine organisms, such as the piddock (a shellfish), have specially adapted shells that enable them to drill into solid rock. They are particularly active in areas with chalk geology where they can produce a sponge-like rock pitted with holes. Seaweed attaches itself to rocks and the action of the sea can be enough to cause swaying seaweed to prise away loose rocks from the sea floor. Some organisms, algae for example, secrete chemicals capable of promoting solution. Some animals can also weaken cliffs as they burrow or dig into them, such as rabbits or some cliff-nesting birds.

Chemical weathering is common on coasts as it occurs where rocks are exposed to air and moisture so chemical processes can breakdown the rocks. **Solution** is the main chemical process and was included above as it combines with erosion to produce many distinctive features. Other processes include:

- **Oxidation** causes rocks to disintegrate when the oxygen dissolved in water reacts with some rock minerals, forming oxides and hydroxides. It especially affects ferrous, iron-rich rocks, and is evident by a brownish or yellowish staining of the rock surface.
- **Hydration** is included here as it makes rocks more susceptible to further chemical weathering, although it involves the physical addition of water to minerals in the rock. This causes the rock to expand, creating stress, which can itself cause the rock to disintegrate. The process weakens the rock and can create cracks, or widen joints allowing further chemical weathering to occur.
- **Hydrolysis** is where mildly acidic water reacts or combines with minerals in the rock to create clays and dissolvable salts; this itself degrades the rock, but both are likely to be *weaker* than the parent rock, thus making it more susceptible to further degradation.
- **Carbonation** occurs where carbon dioxide (CO_2) dissolved in rainwater makes a weak carbonic acid

(H_2CO_3). This reacts with the calcium carbonate ($CaCO_3$) in rocks like limestone and chalk to create calcium bicarbonate ($Ca(HCO_3)_2$) which then dissolves easily in water. Carbonation is more effective in locations with cooler temperatures as this increases the amount of carbon dioxide that is dissolved in the water.

- As well as naturally occurring CO_2 there are increasing levels of other gases associated with industry and the burning of fossil fuels in the atmosphere that also react with rainwater making it mildly acidic. The presence of sulphur dioxide and nitric oxides can create rainwater with weak sulphuric and nitric acids. This **acid rain** then reacts with various minerals in different rocks weakening or even dissolving them.

Fieldwork opportunities

Visit a local beach and investigate which are the dominant weathering processes and why.

Mass movement

Mass movement is common on coastlines, especially those that are steep. The nature of the mass movement experienced on a particular coastline is dependent on a number of factors:

- the level of cohesion within the sediment
- the height of the slope and slope angle
- grain size within the sediment
- temperature and level of saturation.

Mass movements are generally either rapid sudden failures of the slope or the effects of processes that develop over some time. Types of mass movement:

- **Landslides:** Occur on cliffs made from softer rocks or deposited material, which slip as a result of *failure* within it when lubricated, usually following heavy rainfall.
- **Rock falls:** These occur from cliffs undercut by the sea, or on slopes affected by mechanical weathering like frost action.
- **Mudflows:** Heavy rain can cause large quantities of fine material to flow downhill. Here the soil becomes saturated and if excess water cannot percolate deeper into the ground surface layers become very fluid and flow downhill. The nature of the flow is dependent on the level of saturation, type of sediment and slope angle. On relatively gentle slopes the flows are often referred to as 'solifluction', creating lobe-like features towards the base of the slope.
- **Rotational slip, or slumping:** Where softer material overlies much more resistant materials, cliffs are subject to slumping. With excessive lubrication, whole sections of the cliff face may move downwards with a slide plane that is concave, producing a rotation movement. Slumps are a common feature of the British coast, particularly where glacial deposits form the coastal areas, for example, east Yorkshire and north Norfolk.

  Figure 3.19 shows a typical rotational slump in an area where glacial deposits form cliffs on top of an impermeable layer.
- **Soil creep:** This occurs where there is a very slow, almost imperceptible, but continuous movement of individual soil particles downslope. There is some uncertainty about the exact causes of creep, but most geographers agree that the presence of soil moisture is important, together with a range of weathering and other processes.

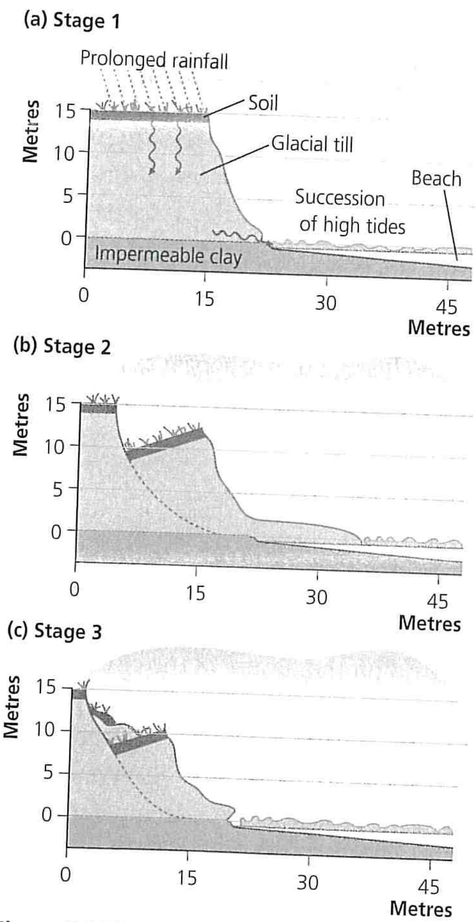


Figure 3.19 Rotational slumping
Source: AQA

Coastlines can vary seasonally between high- and low-energy conditions. Months of winter storms can make for a high-energy coastline. The same coast in summer may become a low-energy environment.

Physical material inputs

Inorganic matter

Besides energy, another key input into a coastal system is physical material. The forms this may take are as particles in suspension, sediment, sand and gravel, pebbles, boulders and cliff debris. The key sources of this input are:

- River discharge: sediment and fine material brought to an estuary and entering the sea.
- Ocean currents: these may transport material thousands of miles and upwelling currents may bring material to surface waters from significant depths.
- Seabed disturbance: severe storms can destabilise material on the sea floor and move it towards a coast.
- Cliff and shore disintegration: the transfer of material as cliffs erode and upper beach material is removed into the active zone of coasts provides an input of solid material that can be transported.

Organic matter

The coast is a living environment that provides a habitat for flora (plants) and fauna (animals). These can colonise an area of seabed from elsewhere if conditions become hospitable (such as kelp, or coral), or can decline if conditions deteriorate. Species can invade an area of coast and compete to the detriment of another species (e.g. crown-of-thorns starfish devastate some coral reefs). Many species of fish are migratory and make a regular passage through a region of coast while others inhabit localised feeding grounds all year round.

Biota is not only part of the natural coastal system in its own right but can contribute to biological weathering of the shore zone, as well as reducing erosion in the form of living shorelines.

3.3 Coastal geomorphology: Processes

Process is the 'how and why' of change; the mechanisms operating upon the inputs that result in particular outputs.

Weathering

Coastal weathering is the disintegration of rock as it loses its integrity or coherence. The rock mass stays largely the same, but its structure is increasingly fragmented. Because coastal weathering is not dependent on the sea, it often takes the form of **subaerial weathering**.

The coastal zone involves weathering due to subaerial and marine processes. The processes take place via physical changes in rock (mechanical weathering), changes in mineral structure (chemical weathering) and the action of plant and animal organisms (biological weathering).

Thinking like a geographer

Geographers need to consider potential changes within a system and consider 'scale' in terms of both area and time. Are mechanical weathering processes likely to operate equally all year round on coasts, or will there be a seasonal variation in each of them?

Research point

Consult tide tables for a selection of coastal regions. Identify spring and neap tide phases from the high- and low-tide heights. What is the tidal range at spring and neap tide conditions?

Physical and human

Large tidal ranges have considerable potential for energy generation. But what *problems* do changing daily tide times and variable monthly tidal ranges, as spring and neap tides alternate, cause for human activity?

For an activity on coastal inputs, processes and outputs, download Worksheet 3.1 from **Cambridge Elevate.**

Key terms

biota: the distinctive animal and plant life of a particular habitat or environmental zone

subaerial weathering: involves processes at the base of the atmosphere that cause solid rock to lose integrity, internal coherence and to fragment

Mechanical (physical) weathering

Internal pressures are exerted on rock as a result of changes in the physical structure within its mass. This occurs due to:

- Wetting and drying: rock in the intertidal zone (and some above, within wave and spray reach) may alternate between being wet and being dry. Some rocks, such as shale, expand when they are wet and contract when they are dry, and this can contribute to tiny fissures developing and the rock fragmenting.
- Exfoliation: dry rock in the sunshine may absorb considerable heat, then be cooled rapidly by contact with the much colder sea. Repeated expansion and contraction may lead to the outer layers of rock fracturing.
- Crystallisation: the high salt content of seawater can lead to the growth of salt crystals within rock under drier conditions. These can exert pressure within small joints and, over time, cause the rock to lose integrity.
- Freeze–thaw activity: rainwater penetrates joints in exposed rock and if night temperatures drop below freezing, the resulting conversion to ice expands and exerts pressure within the rock, enlarging the fissure (Figure 3.9).

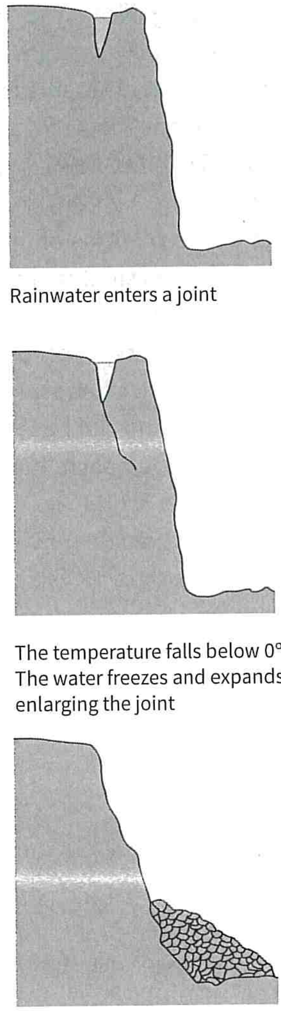


Figure 3.9 Freeze–thaw action: a form of mechanical weathering.

Chemical weathering

Both rain and seawater contain chemicals that can increase the reactivity of minerals within coastal rocks. As mineral compounds undergo chemical reaction, they can alter the rock structure.

- Carbonation: coastlines composed of chalk or limestone may be dissolved by acidic rainwater or seawater. The rain/sea absorbs carbon dioxide from the atmosphere, creating a weak carbonic acid. This can convert solid calcium carbonate to soluble calcium bicarbonate and the rock dissolves.
- Oxidation: rocks containing iron (ferrous) compounds experience oxidation of the iron into a ferric state (or 'rusting') when oxygen and water are readily available from air or sea. This can lead to disintegration.

Biological weathering

Living organisms can contribute to the **weathering** of coastal rocks through the activity of both plants and animals which can disrupt the existing structure of rocks.

- The roots of surface plants on cliff tops can create and expand tiny fissures. Subsurface seaweed such as bladderwrack attached to rocks can weaken and detach them as it sways in the currents of storm conditions.
- Surface animals such as sand martins and puffins may excavate nesting burrows in cliff faces. Subsurface marine creatures such as the piddock drill holes in rock and limpets create a home indentation on their base rock to which they return after grazing.

Mass movement

This is the movement of consolidated material (solid rock) or unconsolidated material (clay and soil) due to gravity (Figure 3.10). It is a common feature of coastlines with higher relief. Wave action in the intertidal zone at the base of a cliff undercuts the cliff face via a **wave-cut notch**, resulting in material above becoming unsupported and more likely to collapse. Forms of mass movement include (rapid to slower):

- Rockfall: arch roofs, stacks and cliff faces collapse as a weakness becomes unsupportable.

Key terms

weathering: the disintegration of rock in situ

wave-cut notch: a horizontal indentation at the base of cliffs where wave action is most focused and erosional processes are concentrated; it results in the undercutting of cliffs