Slope processes

Mass movement

Mass movement (also known as mass wasting) is the term for the downslope movement of rock and weathered debris by gravity alone. It does not include the work of erosive agents such as running water or glaciers. Care is needed when reading accounts of mass movements because phrases such as 'landslide' may not be used in a technically correct way.

Mass movement	Creep and solifluction	
	Debris flows and lahars	
	Slope failures	Slides
		Falls

Table 3.5 Types of mass movement

Fig. 3.25 Terracettes caused by soil creep

Creep

This is the slow, downslope movement of unconsolidated material and soft rocks. This movement is rarely more than 1–2 centimetres a year. It is the result of several different processes:

- Clay-rich material is liable to **plastic flow**. This is more likely to happen on saturated, thick, surface deposits on steeper slopes. It can also be affected by pressure from overlying cap rocks or human constructions.
- Freezing and thawing of water in the surface layers of the clay or soil can produce **heave**. The expansion of water on freezing causes bulging of the surface parallel to the slope. On thawing, the material drops back vertically leading to a net downslope movement of the particles.
- Wetting and drying causes clays to expand and contract, causing heave to occur in the same way as freezing and thawing.

In areas of permafrost, the waterlogged summer conditions lead to accelerated creep known as **solifluction**, although this may involve some viscous flow.

Creep may be responsible for the convexo-concave rolling landscapes found in temperate areas such as western Europe. The process is also thought to be responsible for the small ridges across hillsides known as **terracettes**.

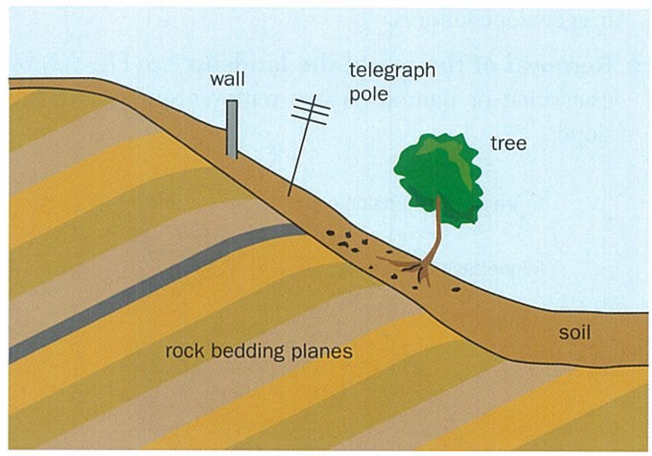

Fig. 3.26 Evidence for soil creep

13. Study Fig. 3.26. Describe the evidence for soil creep shown in the diagram.

Flows

Often referred to as mudflows (see Fig. 3.45), these involve the rapid movement of rock and weathered debris mixed with water down valleys. They do not involve shearing and are a turbulent, structureless mixture of sediment and water. Flows are linked to the following factors:

- steep slopes
- narrow valleys
- removal of vegetation and construction projects
- a thick regolith, therefore they are common in the tropics where deep chemical weathering occurs
- heavy rainfall to saturate the ground
- a slope failure or slide (see below) which may trigger the flow
- earthquakes or traffic vibration; earthquakes can also cause liquefaction of saturated material.

These conditions may be found on the slopes of active volcanoes where the mudflows are termed **lahars**. In this case loose, volcanic ash combines with run-off from convectional rainstorms produced by eruptions.

Mudflows have devastating effects in less-economically developed countries, especially when the narrow valleys are densely populated. However, they affect affluent areas too.

Slides

Landslides are single dramatic events when a section of a hillside becomes unstable, shears away and moves downhill. The shear stresses in the slope exceed the shear strength of the soil or rock. The slopes in question could be natural or the result of human activity such as road cuttings, embankments and spoil heaps.

Factors leading to slope failure include the following:

- **Slope angle** – the steeper the slope the greater the potential for instability.
- **Geological structure** – fractures such as bedding planes dipping out of the slope increase the possibility of slippage.
- **Rock type** – vertical cliffs may be quite stable in some rocks whereas some clay slopes are unstable on slope angles of less than 10 degrees. Layers of impermeable rock trap water above them, leading to highly lubricated layers.
- **Amount of water present** – water increases the weight of soil or rock. Pore water pressure decreases the shear strength of the material, with saturated clays being particularly unstable. Heavy rain or snow melt can trigger slope failures.
- **Removal of the toe of the landslip** (see Fig. 3.2) by excavation or natural erosion removes support for the slope.

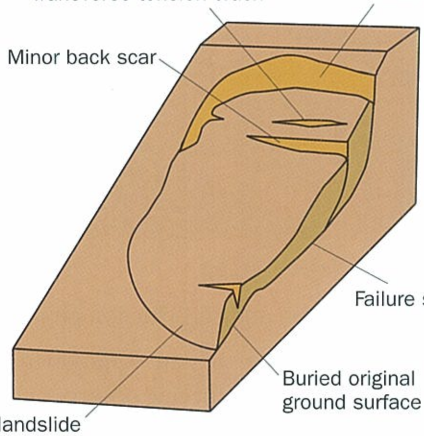

Fig. 3.27 The effect of a landslide on the surface. The failure surfaces can be planar as well as curvilinear. Notice the curved slip faces and the rotational movement which tilts the slope backwards. The toe of the slip is often an area of uneven, deformed ground

Fig. 3.28 An old landslide at Black Combe, Cumbria, UK. Notice the main back scar

- **Loading of the head of the slope** by construction projects can cause the slope to fail.
- **Vibrations** from explosions, earthquakes or heavy traffic temporarily increase stress.

These factors work by either increasing the shear stresses in the slope or reducing the shear strength of the soil or rock.

Case study: The Vaiont dam disaster, Italy, 1963

This landslide resulted in the loss of 2600 lives. A dam 266 metres high was constructed across the Vaiont River to produce hydro-electricity. The site was a deep, narrow valley chosen to store large volumes of water. Slippage started when the reservoir started to be filled, so the slope was reinforced. When the reservoir was filled completely, water seeped into the rock layer, increasing pore water pressure and reducing cohesion. On 9 October 1963 heavy rainfall resulted in 270 million cubic metres of rock sliding into the reservoir at a speed of 25 metres per second. This created a wave 100 metres high which flowed over the dam and into the valley below.

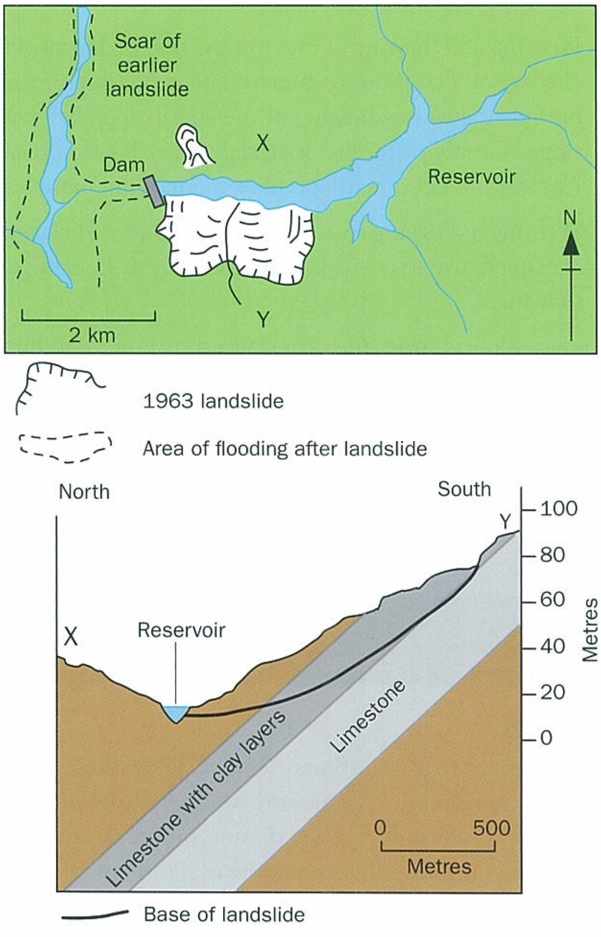

Fig. 3.29 The Vaiont dam landslide

Rock type	**Sandstone** The cement is generally attacked to produce granular disintegration. Resistance depends on the nature of the cement. For example, quartz cement is most resistant, while $CaCO_3$ cement is prone to carbonation. Joints and bedding planes may provide lines of weakness for physical or chemical attack. **Shale** The clay minerals in shale are weathered products of other rocks, therefore tend to be resistant to chemical weathering. Iron oxides and sulfides are commonly present and these tend to oxidise and hydrate, resulting in changes in volume and disintegration. Laminations (and porosity in clays) allow water penetration, increasing both physical and chemical attack. The softness of the rock also increases susceptibility to physical weathering. Shales and clays usually form lowlands as they are easily weathered (and eroded). **Slate** Chemical reactions occur similar to those in shale. Slate is chemically resistant to many reactions, but iron compounds, e.g. pyrite, are prone to oxidation, leaving brown stains; weathered cubes of pyrite often leave holes in slate. Cleavage may allow water penetration and allow freeze–thaw action to produce 'flat' scree fragments. **Basalt** Basalt is rich in minerals which are less resistant to decay by hydrolysis (see the list above). Basalt is often highly weathered, as seen in the rusty residues of iron oxides. The resulting soils are dark coloured and highly fertile due to the presence of a wide range of elements held in montmorillonite clay. Joints allow water penetration which encourages chemical decay and physical processes leading to block disintegration. **Dolerite** Chemical decay occurs in the same way as described for basalt. **Spheroidal weathering** (see Fig. 3.21) is controlled by the joint pattern and is often a sub-surface process. **Limestone** The carbonate minerals are weathered by carbonation and removed in solution. Insoluble clay minerals are left as a residue. Joints allow water penetration and deeper weathering. **Granite** The quartz and muscovite in granite resist chemical decay and are left as a residue of sand grains and mica flakes. Feldspar and other minerals break down by hydrolysis to produce clay minerals. Joints allow water penetration and deeper weathering.
Vegetation	In general, increased amounts of vegetation increase the rate of chemical action through the release of organic acids, important in processes such as chelation. The increased level of carbon dioxide from plant respiration forms carbonic acid when dissolved in water and increases rates of carbonation. Rates of physical weathering will decrease due to the thermal insulation of the vegetation which decreases frost action and thermal effects. Direct biological weathering, through the growth of plant roots into joints and along bedding planes and wedging rock apart, will increase.
Relief	The effect of relief is largely because of its indirect effect on climate. For example, in temperate areas where chemical weathering is usually dominant, freeze–thaw action may be important in mountainous areas. Rainfall totals tend to be higher in upland areas and temperatures colder, again increasing rates of physical weathering such as freeze–thaw action. Slope processes, such as landslides, can result in the exposure of previously unexposed, bare rock which then becomes susceptible to weathering. In lowland areas, unweathered rock may be protected by thick layers of soil and weathered material. The accumulation of water at the base of slopes may also provide more water for chemical processes to take place. Aspect of different slope faces may also affect rates of weathering. In the northern hemisphere, rates of physical weathering are greater on north-facing slopes, which experience more freeze–thaw cycles due to the lack of direct sunlight. The opposite is the case in the southern hemisphere.
Human activity	Humans have increased rates of weathering by increasing the concentrations of chemical pollutants in the atmosphere by industry, power stations and vehicle emissions. The increase in gases such as carbon dioxide, sulfur dioxide and nitrogen oxides has lead to increased acidity of rainfall. This acid rain increases rates of carbonation and hydrolysis. Removal of vegetation can result in a decrease in chemical and biological weathering, e.g. through a reduction in organic acids.

Table 3.4 Factors influencing weathering

Climate

Polar and sub-polar areas

These high latitude areas are affected mainly by freeze-thaw action. These conditions may also occur on mountains in temperate areas. The degree of activity depends on the number of freeze-thaw cycles rather than the degree of frost, therefore the rate of weathering in very cold areas is restricted.

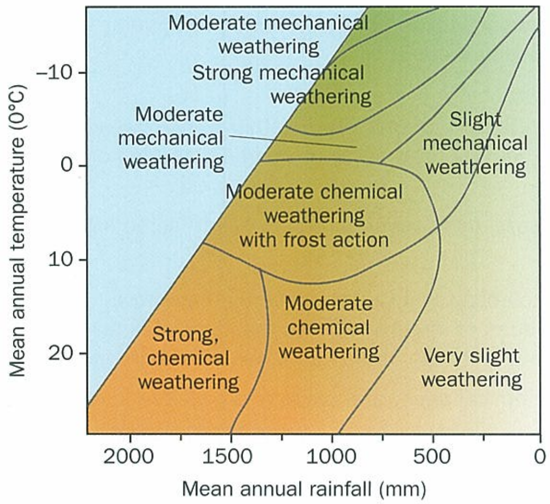

Fig. 3.23 The effect of climate on weathering, as described by Peltier in 1950

Chemical action is restricted by the cold temperatures which slow rates of chemical reactions. However, carbon dioxide is more soluble at low temperatures so carbonation can occur. Hydration may occur in waterlogged areas in summer.

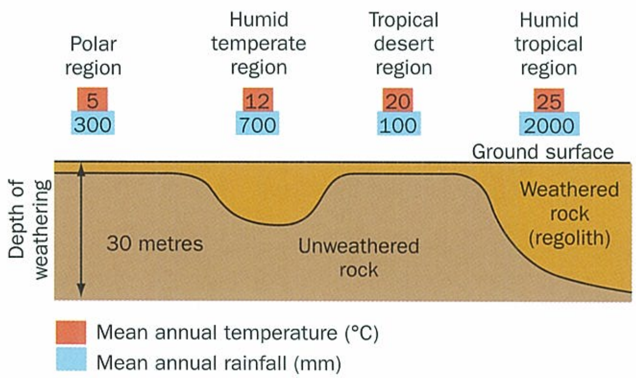

Fig. 3.24 Rates of weathering in different climates

Humid temperate areas

Physical weathering is minimal; the screes of upland areas may be relict features of periglacial conditions in the Quaternary period (the last 2 million years). Similarly, the tors of areas such as Dartmoor in south-west England may also have formed in past climates, although in this case possibly in warm conditions in the Tertiary period when rates of chemical weathering were greater.

All the chemical and biological weathering processes are significant due to the wet climate and the blanket of vegetation which causes the biological effects. Pollution effects are important, especially in urban areas.

Arid and semi-arid areas

Rates of weathering are the slowest on Earth in these areas. This is illustrated by well-preserved archaeological remains, e.g. Cleopatra's Needle weathered more in 10 years in the wet, polluted atmosphere of London than in 3500 years in the Egyptian desert.

Chemical action is probably very slow due to the lack of moisture. Salt crystal growth, and physical expansion and contraction, due to the large diurnal ranges of temperature, may lead to granular disintegration, block disintegration and exfoliation (see Chapter 10).

Humid tropical areas

These areas have the most rapid rates of weathering on Earth. The regolith is often up to 40 metres deep and rocks are observed to weather significantly in decades. Rates of chemical reaction are accelerated by the hot, wet conditions; in particular, the increased ionisation of water increases the rate of hydrolysis of silicates. The increase rate of weathering at higher temperatures is known as Van't Hoff's Law.

12. Study Fig. 3.23 and the information on weathering processes. Describe the rates of weathering and weathering processes that are likely to occur in each of the following conditions:

(a) mean annual temperature 25˚C and mean annual precipitation 2000 millimetres

(b) mean annual temperature 15˚C and mean annual precipitation 1000 millimetres

(c) mean annual temperature 20˚C and mean annual precipitation 250 millimetres

(d) mean annual temperature 5˚C and mean annual precipitation 1000 millimetres.

14. Study Fig. 3.29. Explain how the geology of the area led to the landslide.

Falls

Rock falls from vertical faces share many of the features of landslides and are caused by similar factors. In addition, undercutting of the base of the cliff by a river or the sea are common factors.

Rock falls reduce horizontal pressure on a cliff face, allowing the growth of vertical cracks which, in turn, lead to further rock falls. This mechanism is significant after glaciation has occurred. Glaciers excavate deep valleys and support steep valley sides. After the ice has melted the sides are less supported and liable to rock falls.

Rock falls produce scree (talus) which accumulates as cones or fans at the base. These may eventually join together to produce a continuous slope like those in Fig. 3.30 or huge boulders like those shown in Fig. 3.31. Some fragments may bounce significant distances. Scree slope angles rarely exceed 40°, despite their appearance.

The angle of the scree slope depends on:

- the size of the rock fragments
- the shape of the rock fragments
- the height of the cliff (or 'free face') through which the fragments have fallen.

15. Suggest the effect that each of the factors listed above is likely to have on the angle of a scree slope. Illustrate your answer with diagrams.

Fig. 3.30 Scree slopes on Arkle, a mountain in north-west Scotland

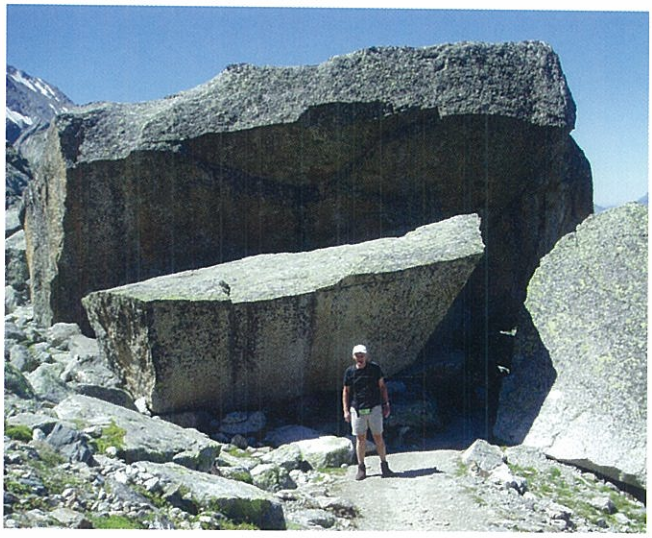

Fig. 3.31 Boulders produced by rock falls in the French Alps

Erosion processes on slopes

The slope processes described above are all types of mass movement in that they are all independent of running water. However, running water does play a part, particularly where **rainfall intensity** exceeds the **infiltration rate** and **overland flow** occurs. The effects are often increased by human activity such as deforestation, over-grazing, burning or cultivation which leaves the soil bare. On gentle slopes, water may run off the surface as a uniform sheet, causing **sheet erosion**. On steeper slopes the water becomes concentrated in channels leading to **gully erosion**. Ploughing down the slope rather than across it is also a factor. The intermediate stage between the two produces fine channel networks known as **rills**.

Fig. 3.32 Gullies on farmland in Kwazulu Natal, South Africa

Intense rainfall with large droplets can have a direct erosive effect on bare soil known as rainsplash erosion. The effect is greatest on steeper slopes because more of the energy of the impact is used in pushing soil down the slope.