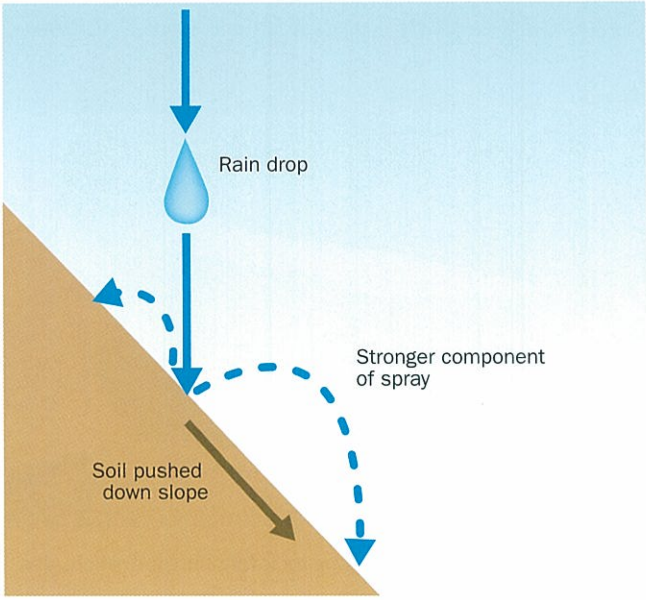

Fig. 3.33 Rainsplash erosion

The human impact

How human activity can result in mass movement on slopes

Excavations

Perhaps the most common way that human activity can result in mass movement is where the ground is removed, e.g. in road and railway cuttings, to make level ground for a building, or in quarries. In areas prone to mass movements (e.g. where there are soft or unconsolidated rocks, where the rock strata dip down the slope, or where there are alternating permeable and impermeable layers) this can create a slope which is too steep to be stable and therefore liable to failure.

Where an excavation removes the toe of an old landslip (see Fig. 3.27) this can re-activate the feature and lead to further movement. Other, smaller excavations are those for road and railway cuttings, and for the foundations of buildings. New slopes are being created and this must be done in a way that ensures that the new slopes are stable and not liable to catastrophic mass movements.

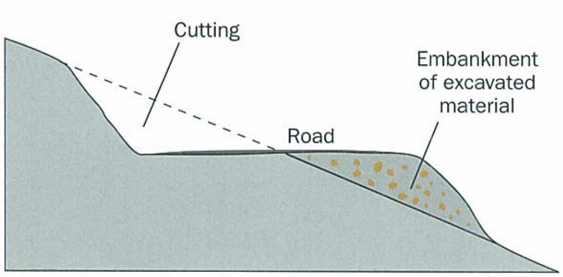

Fig. 3.34 A cross-section through a road constructed across a slope. This method raises various questions. Is the cutting sufficiently gentle to ensure that mass movement will not occur? If not the measures described in Fig. 3.37 should be employed. Is the embankment of excavated material stable? Is water drainage from the road adequate and will it cause mass movement or erosion? Will the material in the embankment settle over time and cause the road surface to be uneven?

Waste heaps

Often waste heaps from quarrying and mining have steep slopes and are made of material which is unconsolidated or highly porous.

Fig. 3.35 The spoil heaps of the quarry

The newly created steep slopes may be unstable and liable to slope failures. One example of this was the catastrophic slope failure of a coal mine spoil tip in the village of Aberfan, near Merthyr Tydfil, Wales, on 21 October 1966, which killed 116 children and 28 adults. It was caused by a build-up of water in the accumulated rock waste, which started to move downhill as a mudflow.

Loading by building

Building on the top of a slope liable to landslip can add sufficient mass to the ground that it will trigger the process described in Fig. 3.27.

Loading by water

When rock cuttings or building projects are carried out, drainage may be disturbed, diverting water into these areas. Water has a lubricating effect on unconsolidated material and saturated clays are unstable, all of which can lead to landslips. However the extra weight of water in the rock is also a factor. If the saturated sands or clays are shaken by an earthquake then liquefaction may occur. Before the earthquake, the water pressure in the sand is relatively low, but shaking causes the water pressure to increase, allowing the sand particles to move relative to each other, acting like a liquid.

Removal of vegetation

Deforestation, construction projects or even leaving land bare after cultivation can increase surface runoff leading to mudflows in susceptible areas.

Case study: The Merriespruit tailings dam disaster, Virginia, Free State, South Africa

Gold is extracted from the ground at very low purities and the processing produces large quantities of fine-grained waste mixed with water known as tailings or locally as 'slime'. This waste is deposited in 'slime dams' which are prominent features of the landscape, appearing as rectangular, steep-sided, flat-topped hills.

Fig. 3.36 Tailings from gold mining, Johannesburg, South Africa. The Central Business District (CBD) can be seen in the background

Like many others in South Africa, the Merriespruit tailings dam was made by constructing a 'daywall' perimeter which was allowed to settle and dry out. This activity was often done during the day under supervision. After this and often at night, the slurry was pumped into the 'nightpan' between the perimeter walls. A drainage system was installed in the dam to drain away the water plus any rain water.

There were 250 houses in Merriespruit, a suburb of the goldfields town of Virginia, when the dam was constructed in 1978.

Late in the afternoon on 22 February 1994 there was a thunderstorm and about 50 millimetres of rain fell in 30 minutes. That night the tailings dam failed and flooded Merriespruit when 600 000 m^3 of liquid slurry flowed 4 kilometres away from the dam. The nearest houses were located 300 metres downslope of the dam and when the wave of water and slime reached them it was 2.5 metres high. There was widespread devastation and environmental damage, 17 people were killed and 80 houses were destroyed. Inadequate systems for draining water from the dam were blamed for the disaster.

Traffic vibrations

Movement of heavy vehicles is not a sole cause of mass movement but it can be a trigger for movements.

How human activity can result in erosion on slopes

Removal of vegetation

This could be through:

- overgrazing,
- soil exposure during cultivation
- cultivating in areas of low rainfall
- construction projects.

All these activities can lead to bare surfaces liable to rainsplash erosion, sheet erosion, rill erosion and gullying. In extreme cases, after heavy rainfall, it may also lead to mudflows.

Ploughing up and down slopes

Ploughing up and down steep slopes creates pathways for surface runoff which can lead to the development of rills.

Destroying soil structure

Poor agricultural practices such as growing too many crops in an area (overcropping) or allowing the organic content of the soil to deteriorate can lead to the destruction of the crumb structure which helps to bind the soil together. This leaves the soil loose and prone to erosion both by wind and running water.

Case study: Railway landslide in Cumbria, UK, 1995

Landslides are surprisingly common on railway cuttings. The line from Settle to Carlisle, UK, runs through an area of Carboniferous shales and sandstones and the alternating impermeable and permeable rocks are prone to slippage. At 18:55 on 31 January 1995, a train was derailed by a landslide on this line at Aisgill. It was dark and raining heavily. The train was hit by a train travelling in the opposite direction. The conductor of the first train was fatally injured in the collision.

Strategies to reduce mass movement and its impact on slopes

The methods described below are generally used to prevent slides and falls, often on artificially-created slopes.

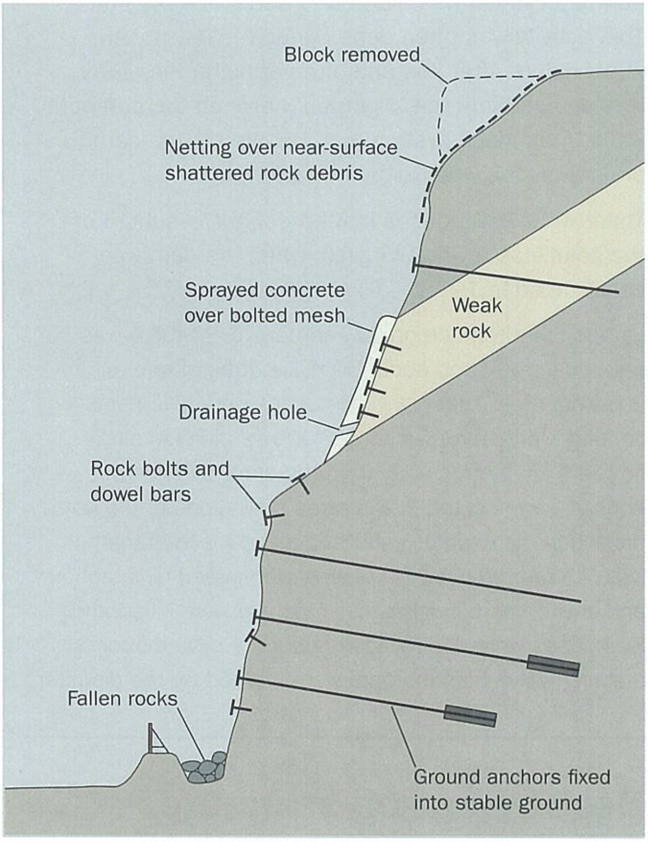

Fig. 3.37 Rock slope stabilisation

Pinning (including rock bolts, dowel bars and ground anchors)

Fig. 3.38 Rock bolts

These methods involve drilling a long hole through loose blocks into the stable rock beyond. A metal rod is inserted and fixed in place with a resin or an expansion bolt. A metal plate is then bolted onto the outside of the rod. Rock bolts and dowel bars are relatively short but ground anchors may be long cables used to stabilise whole landslide areas.

Netting

Fig. 3.39 Netting

Metal netting is fastened to road cuttings to prevent loose blocks falling on the road below.

Gabions

Fig. 3.40 Gabions

Gabions are boxes made of metal mesh. They fold flat for transport and are assembled on-site and filled with rocks. They do have other purposes but they may be used to stabilise the toe of a landslip.

Drainage

Fig. 3.41 Beneath the crash barrier on this road, a gravel-filled trench provides drainage

Excess water on slopes adds mass, provides lubrication and is often a key factor in the formation of flows and slides. Moving water away from vulnerable slopes is one of the most important ways of preventing these mass movements. The simplest and cheapest way of doing this is often to dig a trench, as shown in Fig. 3.41, and fill it with a highly permeable aggregate (gravel).

Grading

Fig. 3.42 A gently graded cutting. The slope here consists of strata dipping towards the road. Alternating layers of permeable limestone and impermeable shale make it unstable after heavy rain and liable to slip along the bedding planes. For this reason the cutting has been made with a gentle slope

Slope angle is a key feature in mass movements. The steeper the slope, the more potentially unstable it is. Where slopes are artificially created, they need to be made more gentle if there is a risk of movement. However, this requires more excavation and produces more waste rock to be transported away and disposed of, increasing costs. Similarly, the slope angle of natural slopes can be decreased to reduce risk. The process of making slopes more gentle is referred to as grading.

Fig. 3.43 The rocks in this cutting are stable as they dip at right angles to the slope (the same would be true if the rocks dipped away from the road and into the slope). It has been possible to make a steep cutting and save costs

Afforestation

Planting trees and other vegetation is often used to reduce soil erosion but it can also reduce the risk of mass movements. The trees have various effects. Trees increase interception and therefore evaporation losses are greater. Roots absorb water and therefore increase transpiration losses. This means that there is less surface runoff (which might otherwise result in mudflows) and less infiltration to add mass to the rocks. The roots themselves may have the effect of binding soil and loose rock.

Grouting

This involves injecting permeable rocks with cement to reduce pore water and increase strength.

Shotcrete

Loose rock surfaces can be sprayed with concrete which can help to prevent loose blocks falling from the slope.

Mapping hazards

Many landslides occur when old landslides, which have moved many times in the past, are re-activated as a result of heavy rainfall, excavations or earthquakes. The case study of California in this chapter illustrates this (see page 92). Detailed mapping of these features can help planners to decide which areas should be avoided by future house or road building or to decide what precautionary measures need to be taken. This mapping can make use of historical accounts but often looks for topographic features like those described in Fig. 3.27.

Strategies to reduce erosion on slopes

Method	Erosion prevented	
	Wind	Water
Terracing		✓
Contour ploughing		✓
Crop rotation	✓	✓
Fallow periods	✓	✓
Strip cultivation and inter-cropping	✓	✓
Cover cropping	✓	✓
Reducing stock density	✓	✓
Check dams		✓
Filling gullies		✓
Afforestation	✓	✓
Shelter belts (wind breaks)	✓	
Dry farming	✓	
Irrigation	✓	✓

Table 3.6 Strategies for reducing erosion on slopes

16. Explain how each of the strategies in Table 3.6 can reduce erosion on slopes.

Case Study: California and Los Angeles

Slides and flows are common in California, damaging roads, railways, pipelines, electricity cables, and other infrastructure. The suburbs of Los Angeles are particularly affected.

The causes are as follows.

Intense rainfall

Downtown Los Angeles has an annual precipitation of only 385 mm, which mainly occurs during the winter and spring, with heavy rainfall during winter storms. The coast gets slightly less but the hilly suburbs get slightly more. However, there is great variation from year to year. Heavy rainfall on dry ground can lead to mudflows and loading of the ground resulting in landslides.

Soft, poorly-consolidated rocks

The geology of the area consists of relatively young Neogene and Pleistocene marine sediments deposited between 15 million and 1 million years ago.

Steep relief

Los Angeles rises from sea level to 1547 m (Mount Lukens) in the form of a basin. The central parts of the city are flat but the outer suburbs are hilly, for example areas such as the San Fernando Valley, the Santa Monica Mountains, Mount Washington, Boyle Heights and San Pedro.

Road and housing construction

Los Angeles (population 3.88 million in 2013) has grown rapidly outwards into hilly districts prone to mass movements. Construction in these hilly districts can add load to unstable slopes and road cuttings in these areas may also be unstable.

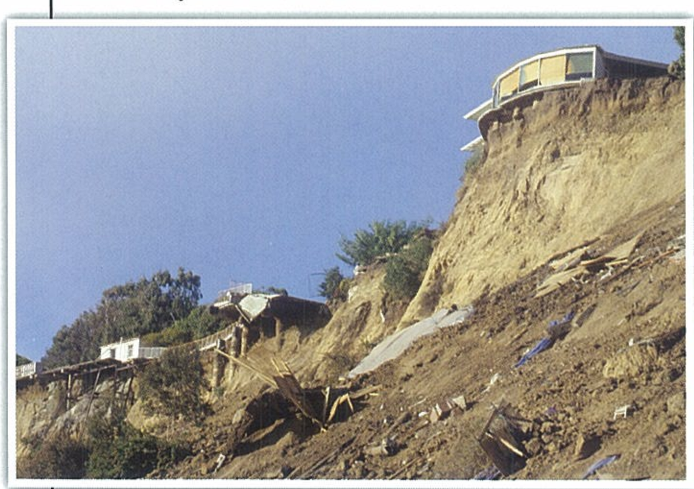

Fig. 3.44 Landslide damage in the Pacific Palisades area of Los Angeles

Oil and water extraction

Groundwater extraction for water supply and petroleum extraction have both caused ground subsidence. In 1963 in the Baldwin Hills a dam collapsed as a result of this.

Earthquakes

The San Andreas fault system and other active faults in the area can trigger landslides on slopes affected by the factors listed above. As mentioned earlier in the chapter (pages 85–86), earthquakes can also cause liquefaction of the ground.

Examples

Although slope failures are common in California, some of the most significant include:

- April 18, 1906. A major earthquake in San Francisco triggered numerous landslides, including the Devil's Slide in San Mateo County. The latter is still active today.
- January 3–5, 1982. Landslides in the San Francisco Bay area killed 25 people and caused at least 66 million USD in damage.
- January 10, 2005. A mudslide in La Conchita killed 10 people and destroyed 18 homes.

Mudflows in southern California, December 2010

In one week in December 2010 the area received half of its annual average rainfall and some streets flooded. California Governor, Arnold Schwarzenegger, declared a state of emergency for half a dozen communities and residents were evacuated and authorities put on alert for landslides and mudflows. Hundreds of people were evacuated in the suburbs of Los Angeles, with particular concerns for homes in steep-sided valleys previously affected by wildfires. 'The ground is so saturated it could move at any time', said Bob Spencer, spokesman for the Los Angeles County Department of Public Works.

Then heavy rains of up to 25 mm per hour caused a landslide on a heavily used section of Interstate 10 early on Wednesday, covering three lanes near the city of Pomona. In Highland District, 104 km east of Los Angeles, two rivers overflowed, swamping as many as 20 homes in mud. In Silverado Canyon, Orange County 25 to 30 people were evacuated from their mountain homes. 'This mudflow moved cars, picked them up, stood them up on their nose at 45-degree angles, buried them', said Bill Peters, a spokesman for the California Department of Forestry and Fire Protection.

Homes in the mountains were blocked by boulders and mud as rescue workers helped residents seek shelter. Officials ordered the evacuation of 232 homes at the bottom of large hillsides in La Canada Flintridge and La Crescenta, in the suburbs of Los Angeles.

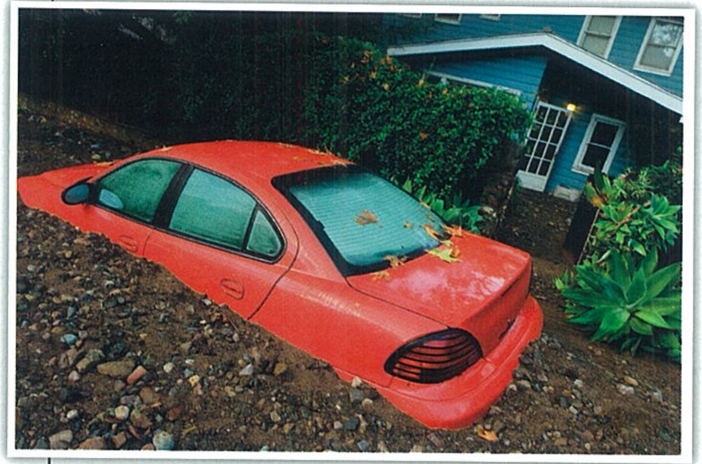

Fig. 3.45 A mudflow in Silverado Canyon, CA, December 2010

Attempts to reduce mass movement

The main method of reducing risk has been to produce maps that show past landslide features which are likely to be re-activated. This is done by the California Geological Survey. The maps indicate areas where the probability of liquefaction and earthquake-triggered landslides are significant enough to require a more detailed site evaluation prior to developments such as buildings or road construction. Before 1995 these site evaluations were voluntary but they are now a legal requirement.

A landslide inventory and related hazard zone maps are available on the California Geological Survey website. The new landslide inventory maps cover 62 square mile areas known as 'quadrangles', including parts of Burbank, Universal City, Beverly Hills, West Hollywood, Culver City and Glendale, as well as communities of Baldwin Hills and nearby View Park.

Systems such as rock bolts, netting and shotcrete are not appropriate for stabilising slopes in the soft, poorly-consolidated rocks which form many of the slopes.

Slope failures still happen frequently outside the built-up area but the system is focused on reducing the risk to property and human life where slope failures are the result of human activity.

It is difficult to produce hard statistics to evaluate the success of the system but there is little doubt that it will have had a significant effect.

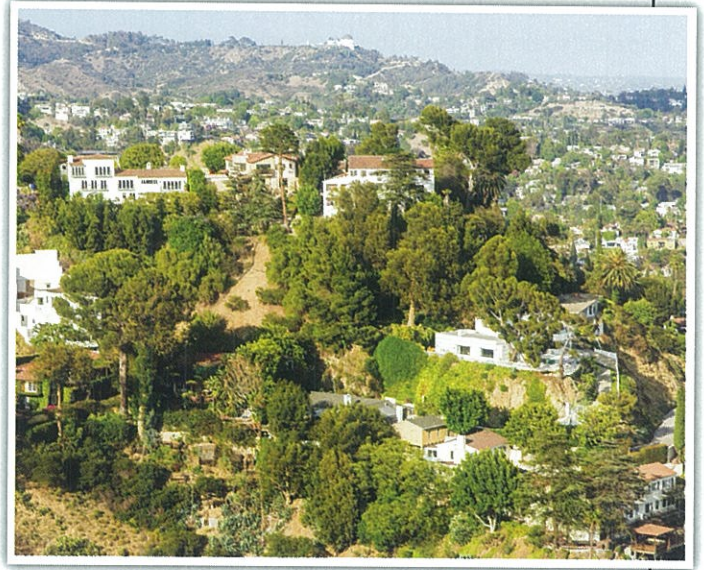

Fig. 3.46 Landslide damage in the Griffith Observatory area of Los Angeles

RESEARCH Examine mass movements in California through historical accounts such as those found at: http://articles.latimes.com/keyword/landslides-los-angeles.

Key concepts

The key concepts listed in the syllabus are set out below. For each one a summary of how it applies to this chapter is included.

Space: this chapter shows the concept of space in the way that weathering processes act differently in different global spaces as a result of different climatic factors. The global spatial patterns of phenomena associated with global plate tectonics are discussed. Plate tectonics provide a good illustration of the concept of changing spaces, as continents move their positions and oceans open, grow, shrink and disappear. Different global spaces have different landforms depending on the plate tectonic situation and the operating weathering processes.

Scale: this chapter shows the importance of the time scale in interpreting change from the geological past to future scenarios. Plate tectonics show how small changes over a long time scale result in the global landforms we see today. The California Geological Survey maps past slope failures which may be re-activated at some point in the future. This chapter also illustrates the importance of spatial scale. Slope processes can operate on very long time scales, e.g. creep, or very short time scales, e.g. flows, slides and falls. The chemical weathering processes operate at a molecular spatial scale yet result in large scale landform development.

Place: distinctive landforms resulting from the processes of weathering, or plate tectonics or on slopes occur in similar places in different continents. Island arcs form where oceanic plates converge wherever that place is on the globe. Granite weathers in a particular climate in the same way wherever that place happens to be on the globe. This chapter shows how widely separated places can have great similarities.

Environment: interactions between people and their environment create the need for environmental management, particularly of slope processes. Human activity is one of the key factors that can trigger slope failures which, in turn, can lead to loss of life. Building projects can lead to slope instability but measures can be taken to stabilise slopes. The last section of this chapter and the California case study demonstrate this.

Interdependence: understanding the interactions between humans and slope processes is important in knowing how particular building projects can be managed. The systems operating on slopes show how the complex nature of interacting physical processes and human activities can lead to slope failures but, once these interactions are understood, measures can be taken to prevent slope failures and to ensure human safety.

Diversity: the range of landscapes produced by plate tectonics is diverse: from fold mountains, to ocean basins, ocean trenches, island arcs and oceanic ridges. Weathering processes differ greatly in different climates and with different rock types. Slope processes differ on different slope angles and in different geological situations.

Change: the key point of plate tectonic theory is that the Earth's surface is in a state of constant change. Plates are generally moving at rates between 1 and 10 cm per year but these small movements produce the major features of the Earth's surface. Weathering and slope processes are similar in that they show how slow changes over long time periods can have major effects on the landscape. Weathering has a low magnitude and high frequency but a slope failure has high magnitude and lower frequency.

Exam-style questions

1 Study Fig. 3.47 which shows a cross-section through a road cutting.

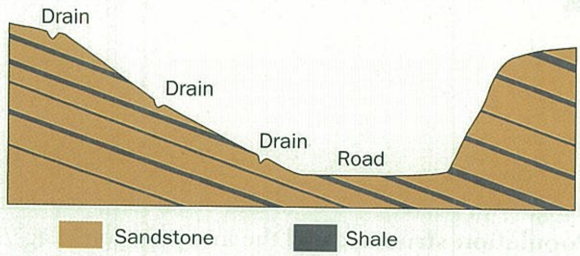

Fig. 3.47 A cross-section through a road cutting

(a) Explain why the left side of the cutting is more liable to slope failure than the right side. [3]

(b) Explain how the cutting has been designed to reduce the risk of slope failure. [3]

(c) Describe the process of soil creep and explain how it takes place on slopes. [4]

2 (a) Describe the process of sea floor spreading. [7]

(b) With the help of a diagram, explain the formation of landforms at the convergent plate margin formed by the meeting of an oceanic plate and a continental plate. [8]

(c) Why are some of the world's oceans shrinking but others are expanding? [15]