Table 7.3 Atterberg limits for various clay minerals

MINERAL	SURFACE AREA ($m^2\ kg^{-1}$)	PLASTIC LIMIT (%)	LIQUID LIMIT (%)	SHRINKAGE LIMIT (%)	VOLUME CHANGE
Smectite	800 000	50–100	100–900	8.5–15	High
Illite	80 000	35–60	60–120	15–17	Medium
Kaolinite	15 000	25–40	30–110	3–15	Low

Source: Modified from M. J. Selby (1982), *Hillslope Materials and Processes*. Oxford University Press, Oxford, Table 4.8, p. 79; based on data in R. E. Grim, 1968, *Clay Mineralogy*. McGraw-Hill, New York.

water content on soil behaviour. They are expressed in terms of the weight of contained water as a percentage of the weight of dry soil.

When subject to the same stress different soils with an identical moisture content may fail by brittle fracture, deform plastically or behave as a viscous fluid. This is because of the varying abilities of different clay minerals to absorb water (Table 7.3). Smectite generally has the highest plastic and liquid limits because its crystal structure enables it to provide an enormous surface area for water absorption. Consequently, smectite-rich soils swell and shrink significantly when they are wetted and dried. Kaolinite, by contrast, has a much more limited water absorption capacity.

An important parameter derived from Atterberg limits is the **plasticity index**. This is defined as the liquid limit minus the plastic limit and indicates the range of moisture content over which a soil exhibits plastic behaviour. It is an important indicator of the potential instability of the soil since the higher the plasticity index the less stable slope materials will be.

Two further aspects of soil properties need to be mentioned briefly. Certain soils have an open 'honeycomb' structure which allows them to retain water at proportions in excess of the liquid limit. The structure of these soils, termed **sensitive soils**, is potentially unstable. If they are subject to high shear stresses (such as those induced by an earthquake), or high compressive stresses (such as those arising from loading by burial), they can collapse catastrophically as the water is squeezed out and the soil becomes a fluid. Such soils are sometimes called **quick clays** and are often associated with major and rapid flows of slope materials.

Sands can also act in a fashion similar to sensitive soils under certain conditions. In a saturated mass of sand most of the strength arises from point to point contacts between the solid sand grains. If the sand is shaken violently, by a seismic shock for instance, all the effective stresses can be transferred from grain-to-grain contacts to the pore water, an effect known as **liquefaction**. All the strength from interparticle friction is thereby lost, the sand mass consequently has no resistance to shear stress and liquid deformation occurs.

7.2 Mass movement

Mass movement is the downslope movement of slope material under the influence of the gravitational force of the material itself and without the assistance of moving water, ice or air. The distinction between mass movement and the transport of material by other denudational processes is, however, not always clear-cut in practice since mass movements involving material with a high water content grade into fluvial transport where streams carry very large loads of fine sediment. In a very real sense glacier flow itself is a form of mass movement, involving as it does the downslope movement of coherent masses of ice; nevertheless, glaciers have particular characteristics which merit special consideration and they are examined separately in the context of glacial landscapes (see Chapter 11). Very large-scale movements of rock which are transitional to tectonic processes can also occur under gravity; we discuss these briefly in Section 7.3. The term **mass wasting** is often regarded as synonymous with mass movement, but it is also used in a broader sense to encompass all processes involved in the lowering of the landscape. Before we consider the various mechanisms of mass movement we will look briefly at the conditions which give rise to them.

7.2.1 Slope stability

The stability of a slope can be expressed in terms of the relationship between those stresses tending to disturb the slope material and cause it to move and those forces tending to resist these driving stresses. Clearly, movement will occur where driving forces exceed resisting forces and this relationship is represented as the **safety factor** for a slope. This is expressed as the ratio between shear strength and shear stress (Box 7.2).

Slopes can exist in one of three states. Where shear strength is significantly larger than shear stress the slope is described as **stable** (safety factor > 1.3). Where shear stress exceeds shear strength (safety factor < 1) there will be continuous or intermittent movement and the slope is described as **actively unstable**. Since shear strength can vary over time, especially in response to changes in the water content of slope materials, the third stability category is the

Box 7.2 Safety factor for a slope

The safety factor (F) is defined as

$$F = \frac{s}{\tau}$$

where s is the total shear strength along a specific shear plane, and τ the total amount of shear stress developed along this plane. For shallow, translational slides F is defined as

$$F = c + \frac{(\gamma z \cos^2 \beta - u) \tan \phi}{\gamma z \sin \beta \cos \beta}$$

where c is cohesion, γ the unit weight of regolith, z the vertical depth to the shear plane, β the angle of the shear plane, u the pore-water pressure at the shear plane and ϕ the angle of internal friction.

conditionally stable slope which has a safety factor of 1–1.3 and fails on occasion in response to transient changes in shear strength. Numerous factors contribute to the occurrence of mass movements, and these are listed in Table 7.4. They can be categorized as either preparatory factors or triggering factors. Preparatory factors make the slope susceptible to movement without actually initiating failure by transforming it into a conditionally stable state. Triggering factors transform the slope from a conditionally stable to an actively unstable state.

Although the slope stability approach to analyzing mass movements provides a good theoretical understanding of the factors which promote movement, it has limited applicability to specific situations. This is because both cohesion and pore-water pressure are highly variable on most natural slopes, even over short distances and brief periods of time. For instance, fissures may traverse slope materials leading to drastic variations in pore-water pressure from place to place.

Table 7.4 Factors contributing to the occurrence of mass movement

FACTOR	EXAMPLES
Factors contributing to increased shear stress	
Removal of lateral support through undercutting or slope steepening	Erosion by rivers and glaciers, wave action, faulting, previous rock falls or slides
Removal of underlying support	Undercutting by rivers and waves, subsurface solution, loss of strength by extrusion of underlying sediments
Loading of slope	Weight of water, vegetation, accumulation of debris
Lateral pressure	Water in cracks, freezing in cracks, swelling (especially through hydration of clays). pressure release
Transient stresses	Earthquakes, movement of trees in wind
Factors contributing to reduced shear strength	
Weathering effects	Disintegration of granular rocks, hydration of clay minerals, dissolution of cementing minerals in rock or soil
Changes in pore-water pressure	Saturation, softening of material
Changes of structure	Creation of fissures in shales and clays, remoulding of sand and sensitive clays
Organic effects	Burrowing of animals, decay of tree roots

7.2.2 Mass movement processes

There have been numerous attempts to classify the diverse modes of mass movement, none of them universally satisfactory. Here we identify six fundamental types of movement – creep, flow, slide, heave, fall and subsidence. Each of these can be subdivided into more specific forms of mass movement (Table 7.5). Classifications of the various processes of mass movement are valuable in indicating the range of mechanisms and forms of motion, but it must be appreciated that most movements in reality involve a combination of processes. **Debris avalanches**, for example, may begin as slides consisting of large masses of rock but then rapidly break up to form flows as the material is pulverized in transit. The compound nature of many forms of mass movement is illustrated in Figure 7.4, which also indicates how the different types of movement vary in their moisture content and velocity. Flows tend to be wet and slides dry, while heave can occur over a fairly broad range of moisture conditions. Heave processes are invariably slow, whereas both flows and slides tend to be rapid.

7.2.2.1 Creep

Creep is the slow, plastic deformation of rock or soil in

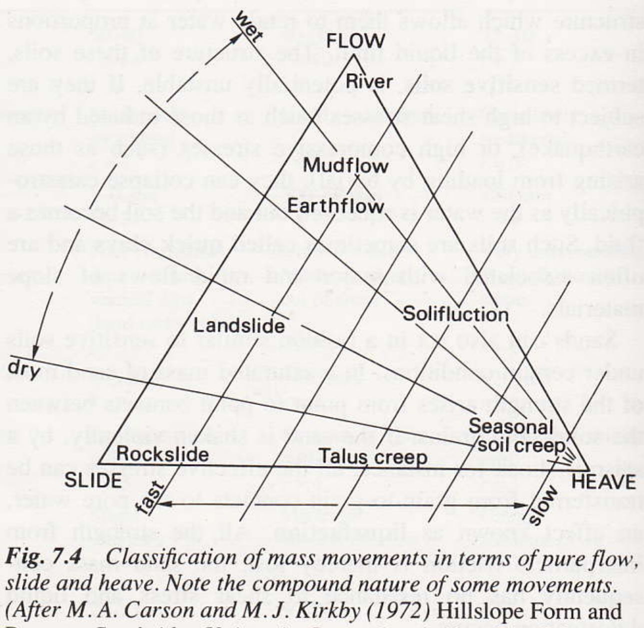

Fig. 7.4 Classification of mass movements in terms of pure flow, slide and heave. Note the compound nature of some movements. (After M. A. Carson and M. J. Kirkby (1972) Hillslope Form and Process. *Cambridge University Press, Cambridge, Fig. 5.2, p. 100.)*

Table 7.5 Classification and characteristics of the major types of mass movement

PRIMARY MECHANISM		MASS MOVEMENT TYPE	MATERIALS IN MOTION	MOISTURE CONTENT	TYPE OF STRAIN AND NATURE OF MOVEMENT	RATE OF MOVEMENT
LATERAL COMPONENT PREDOMINANT	Creep	Rock creep	Rock (especially readily deformable types such as shales and clays)	Low	Slow plastic deformation of rock, or soil producing a variety of forms including cambering, valley bulging and outcrop bedding curvature	Very slow to extremely slow
		Continuous creep	Soil	Low		
	Flow	Dry flow	Sand or silt	Very low	Funnelled flow down steep slopes of non-cohesive sediments	Rapid to extremely rapid
		Solifluction	Soil	High	Widespread flow of saturated soil over low to moderate angle slopes	Very slow to extremely slow
		Gelifluction	Soil	High	Widespread flow of seasonally saturated soil over permanently frozen subsoil	Very slow to extremely slow
		Mud flow	>80% clay-sized	Extremely high	Confined elongated flow	Slow
		Slow earthflow	>80% sand-sized	Low	Confined elongated flow	Slow
		Rapid earthflow	Soil containing sensitive clays	Very high	Rapid collapse and lateral spreading of soil following disturbance, often by an initial slide	Very rapid
		Debris flow	Mixture of fine and coarse debris (20–80% of particles coarser than sand-sized)	High	Flow usually focused into pre-existing drainage lines	Very rapid
		Debris (rock) avalanche (sturzstrom)	Rock debris, in some cases with ice and snow	Low	Catastrophic low friction movement of up to several kilometres, usually precipitated by a major rock fall and capable of overriding significant topographic features	Extremely rapid
		Snow avalanche	Snow and ice, in some cases with rock debris	Low	Catastrophic low friction movement precipitated by fall or slide	Extremely rapid
		Slush avalanche	Water-saturated snow	Extremely high	Flow along existing drainage lines	Very rapid
	Slide – *Translational*	Rock slide	Unfractured rock mass	Low	Shallow slide approximately parallel to ground surface of coherent rock mass along single fracture	Very slow to extremely rapid
		Rock block slide	Fractured rock	Low	Slide approximately parallel to ground surface of fractured rock	Moderate
		Debris/earth slide	Rock debris or soil	Low to moderate	Shallow slide of deformed masses of soil	Very slow to rapid
		Debris/earth block slide	Rock debris or soil	Low to moderate	Shallow slide of largely undeformed masses of soil	Slow
	Slide – *Rotational*	Rock slump	Rock	Low	Rotational movement along concave failure plane	Extremely slow to moderate
		Debris/earth slump	Rock debris or soil	Moderate	Rotational movement along concave failure plane	Slow
	Heave	Soil creep	Soil	Low	Widespread incremental downslope movement of soil or rock particles	Extremely slow
		Talus creep	Rock debris	Low		
VERTICAL COMPONENT PREDOMINANT	Fall	Rock fall	Detached rock joint blocks	Low	Fall of individual blocks from vertical faces	Extremely rapid
		Debris/earth fall (topple)	Detached cohesive units of soil	Low	Toppling of cohesive units of soil from near-vertical faces such as river banks	Very rapid
	Subsidence	Cavity collapse	Rock or soil	Low	Collapse of rock or soil into underground cavities such as limestone caves or lava tubes	Very rapid
		Settlement	Soil	Low	Lowering of surface due to ground compaction usually resulting from withdrawal of ground water	Slow

Source: Based largely on D. J. Varnes (1978) in: R. L. Schuster and R. J. Krizek (eds) *Landslide Analysis and Control*, Transportation Research Board Special Report 176. National Academy of Sciences, Washington, DC, 11–33.

response to stress generated by the weight of overburden. It begins once the yield stress of the slope material is exceeded. In rock it can extend to hundreds of metres below the surface. It occurs at very slow rates, typically 1 mm to 10 m a^{-1} and is likely to be especially active where weakly competent materials, such as clays, are overlain by more competent beds. Creep is often a precursor of slide-type movements, but it can also cause specific observable effects. The bending of the lower parts of tree trunks is often cited as evidence of creep, but this phenomenon can also be caused by other mechanisms. More substantial evidence of creep is provided by the downslope curvature of strata near the surface. Another consequence of creep is **cambering** which involves the extrusion of weak rocks (usually clays), either lying below, or interbedded with, more rigid strata which causes valley sides to bulge.

It is important to distinguish the type of creep described here from soil creep and talus creep. The former acts solely under gravity, whereas the latter involve heave and are consequently considered in Section 7.2.2.4.

7.2.2.2 Flow

In a pure **flow**, shear occurs throughout the moving mass of material and there is no well-defined shear plane (Fig. 7.5(A)). Flow is distinguished from creep by having discrete boundaries or narrow peripheral zones experiencing shear. Shear is at a maximum at the base of the flow, but here the rate of flow is relatively slow and nearly all the movement occurs as turbulent motion within the body of the flowing mass. **Dry flows** can occur, but abundant water is usually present. They are often initiated by falls or slides, becoming flows when the moving soil or rock mass breaks up. Flows are categorized as **avalanches**, **debris flows**, **earthflows** or **mudflows** depending on whether they consist of predominantly snow and ice, rock fragments, sand-sized material or clay (Fig. 7.6).

Where the flow has a high water content it may extend as a long, narrow tongue well beyond the base of the slope from which it originated. Such flows are usually more or less confined to existing drainage lines (Fig. 7.7) and there is in fact a transition between mudflows and streams laden with abundant fine sediment. Earthflows involve the extrusion of lobes downslope and are usually slow moving. Where the slope material is composed of sensitive soils, however, an initial disturbance can cause an instantaneous loss of shear strength and promote a rapid earthflow. The slowest type of flow is **solifluction** which involves the downslope movement of saturated soil. Solifluction can occur at slope angles as low as 1° and is particularly active in periglacial environments. Here abundant moisture is made available by seasonal thawing of soil above a frozen subsurface, and this form of solifluction is termed **gelifluction** (see Section 12.2.3). Although solifluction can be regarded as a distinct mass movement process it frequently occurs in close association with soil creep. Many hillslopes show the combined effects of both processes (Fig. 7.8).

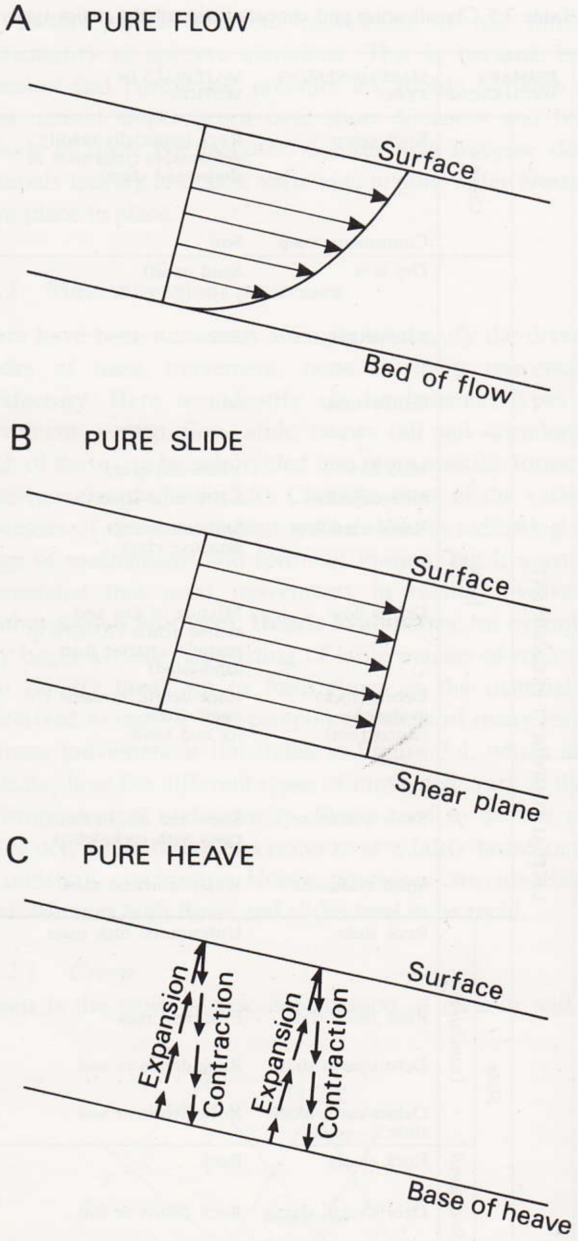

***Fig. 7.5** Velocity profiles for ideal types of mass movement: (A) pure flow, (B) pure slide and (C) pure heave. (Modified from M. A. Carson and M. J. Kirkby (1972)* Hillslope Form and Process. *Cambridge University Press, Cambridge, Fig. 5.1, p. 100).*

In addition to the transport of material from higher to lower elevations, flows can be effective erosional agents, especially the more energetic varieties. This is particularly true for debris flows and for debris and **snow avalanches** which travel over the ground, rather than predominantly

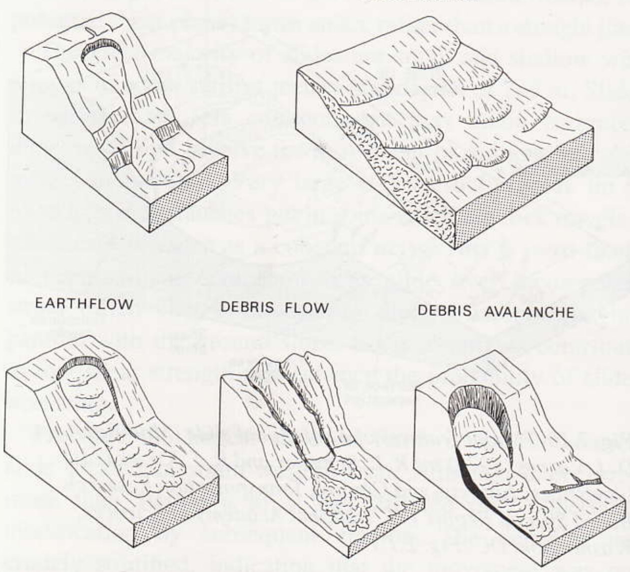

Fig. 7.6 *Varieties of flow-type mass movement. (Based on D. J. Varnes (1978) in R. L. Schuster and R. J. Krizek (eds)* Landslides: Analysis and Control. *Transportation Research Board Special Report 176. National Academy of Sciences, Washington, DC, Fig. 2.1.)*

through the air. The major geomorphic effects of avalanches are the removal of debris from gullies and slope faces, the excavation of rock to form **avalanche chutes**, the erosion and redistribution of unconsolidated slope deposits, and the deposition of snow and/or rock debris.

Major avalanches can be one of the most violent and destructive forms of geomorphic activity. Two particularly catastrophic avalanches, both triggered by earthquakes, crashed from the the mountain peak of Huascaran in the Peruvian Andes in 1962 and 1970. In the 1962 event 3 Mt of ice and 9 Mt of rock were transported at speeds well in excess of 100 km h^{-1} over a horizontal distance of 20 km. An estimated 3500 people were killed. In 1970 a second avalanche occurred which initially moved along the same route as the 1962 event, but after travelling some 16 km at an average speed of around 300 km h^{-1} part of the turbulent flow of rock debris and ice jumped across a 300 m high ridge and buried the town of Yungay beyond. On this occasion the death toll was possibly as high as 40 000.

The extremely high velocities achieved by some avalanches clearly require explanation. Some may ride on a layer of compressed air trapped between the avalanche debris and the ground surface. This has the effect of greatly reducing the frictional drag on the moving mass. Other possible explanations of high rates of movement include **fluidization** where fine particles are kept in suspension by a flow of air, and cohesionless grain flow in which particle motion is sustained by continuous collisions as in a fluid.

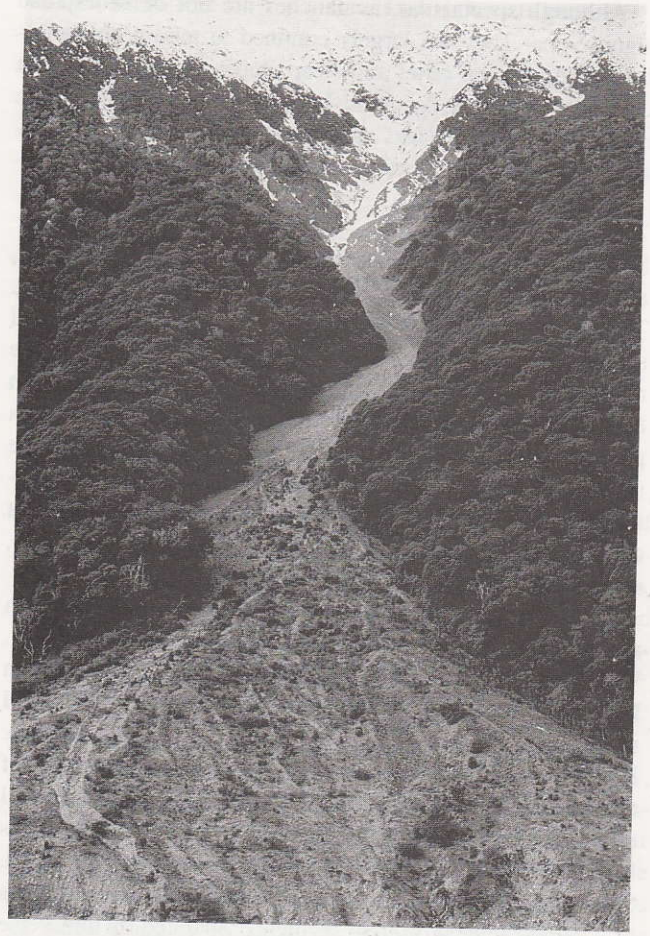

Fig. 7.7 *Debris flow on western flank of the Southern Alps, South Island, New Zealand.*

Fig. 7.8 *Valley cut into a chalk escarpment in Kent, UK. Such valleys on the chalk are known as coombes, and solifluction deposits, known as coombe rock, are often present on valley floors (evident in photograph from the flat bottom of the valley). These solifluction deposits probably accumulated at the end of the last glacial 10 000–15 000 a* BP *under periglacial conditions (and are therefore more accurately described as gelifluction deposits). Terracettes can be seen on the valley-side slopes and are probably related to soil creep.*

Although spectacular, avalanches are not of widespread significance. They are largely confined to terrain characterized by high local relief and steep slopes and are thus most common in active orogenic belts. On a global basis the more ubiquitous but less spectacular slower forms of flow are more significant denudational agents.

7.2.2.3 Slide

Slide is an extremely widespread form of mass movement, and the term landslide is part of our everyday vocabulary. This presents problems when using it in a specific technical sense since landslide in general usage simply means the rapid downslope movement of slope material. Applied in this sense many landslides also involve fall and flow. In a pure slide failure occurs along a well-defined shear plane (Fig. 7.5(B)). Resistance to movement falls sharply immediately the initial failure takes place, and downslope movement continues until there is a sufficient increase in resistance, often related to a decrease in slope angle, to halt it.

Slides are nearly always long in relation to their width and depth, their length–width ratio typically being 10 : 1. They can be subdivided into **translational slides**, which have predominantly planar shear surfaces, and **rotational slides** in which the shear plane is concave-up (Fig. 7.9). Rotational slides are most common where slopes consist of thick, homogeneous materials, such as clays. The rotational movement can result in the upper part of the slumped mass being back-tilted towards the failure surface (Fig. 7.10). The material can move as a single block, but usually it is broken into several discrete segments separated by transverse fissures. Movement at the base of rotational slides in clay or similar cohesive material is often transformed into that of an earthflow and this gives rise to a chaotic, hummocky

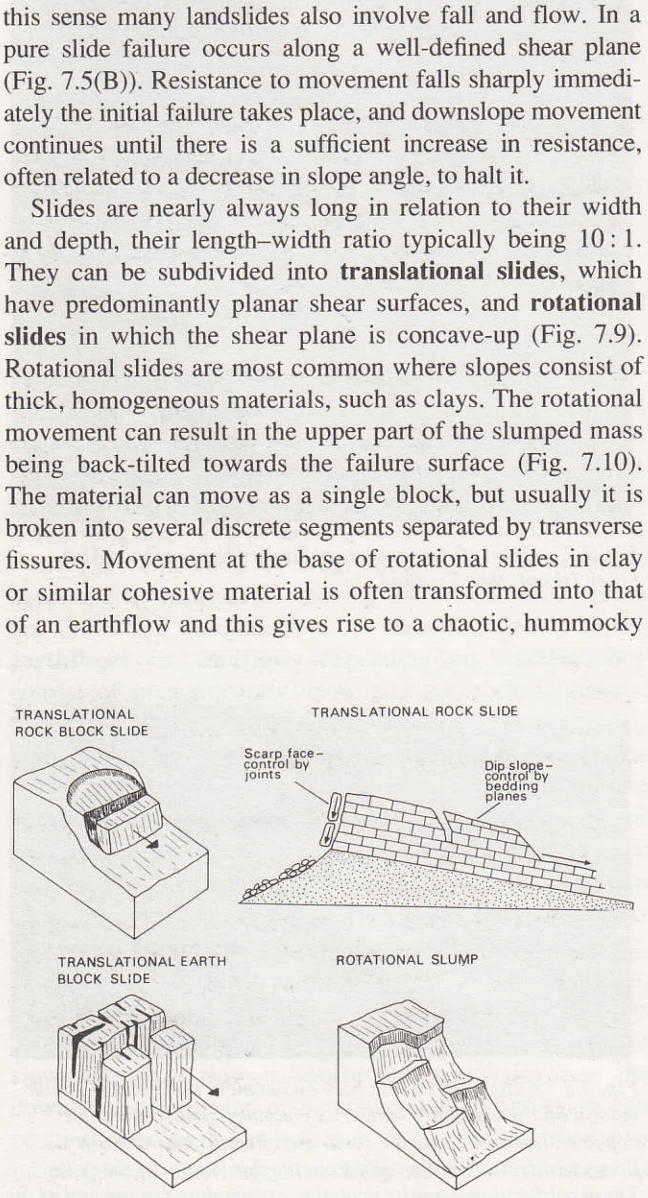

Fig. 7.9 Varieties of slide-type mass movements. (Based on D.J. Varnes, 1978, in: R.L. Schuster and R.J. Krizek (eds) Landslides: Analysis and Control. *Transportation Research Board Special Report **176**, National Academy of Sciences, Washington, DC, Fig. 2.1.)*

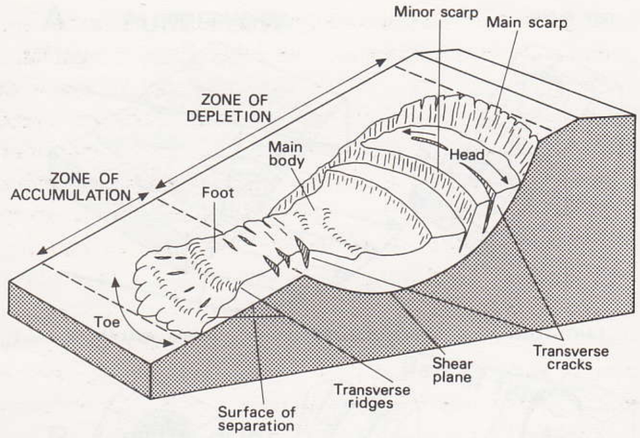

Fig. 7.10 Major features of a rotational slide (Modified from D.J. Varnes (1978) in: R.L. Schuster and R.J. Krizek (eds) Landslides: Analysis and Control. *Transportation Research Board Special Report **176**. National Academy of Sciences, Washington, DC, Fig. 2.1.)*

surface. Both rotational and translational slides are precipitated by a temporary excess of shear stress over shear strength within the slope (Box 7.3). The difference between the two types of movement is that in thick, relatively homogeneous material the depth at which the ratio between

Box 7.3 Analysis of rotational slides

The shear plane of a rotational slide is curved and therefore the stability analysis outlined in Box 7.2 must be modified. One way the stability of a rotational slide can be evaluated is to divide the slide into a number of 'slices' of length L and aggregate the forces acting of each of these slices (Fig. B7.3). The weight (W) is taken as operating through the centre of each slice. The angle of the shear plane (α) is calculated for each slice from the centre of rotation (O). The effective normal stress (σ') at the base of each slice is $W \cos \alpha$ and the shear strength (s) is $W \sin \alpha$. The safety factor (F) can then be defined as

$$F = \frac{\sum_{B}^{A} [cL + (W \cos \alpha - uL) \tan \phi]}{\sum_{B}^{A} W \sin \alpha}$$

where c is cohesion, u the pore-water pressure at the base of the slice and $\tan \phi$ the angle of internal friction.

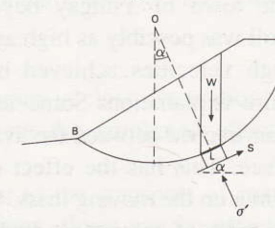

Fig. B7.3 Stability analysis of a deep-seated slide using the method of slices. (After M.A. Carson and M.J. Kirkby (1972) Hillslope Form and Process. *Cambridge University Press, Cambridge, Fig. 7.11, p. 167.)*

shear strength and shear stress is at a minimum (that is, the potential shear plane) forms an arc rather than a straight line.

The great majority of slides are small and shallow with lengths of a few tens of metres and depths of 2–3 m. Slides in bedrock are less common, but may attain enormous dimensions and involve the movement of millions of cubic metres of material. Very large slides usually break up to form debris avalanches but in some cases the rock travels a significant distance as a coherent mass. This is most likely to occur where competent beds slide over incompetent strata (often clay or mudstone) dipping steeply roughly parallel with the ground slope. Such conditions contribute to low shear strength and enhance the probability of slides occurring.

Probably the largest slide on Earth is the Saidmarreh slide located in south-western Iran. Although it occurred more than 10 000 a BP it has suffered only superficial modification by subsequent erosion. The deposits are, crudely stratified, indicating that the movement was not predominantly one of a turbulent debris avalanche. A mass of limestone some 15 km long, 5 km wide and at least 300 m thick slid off the underlying interbedded marl and limestone which dips at an angle of around 20° out of the slope. The initial vertical component of movement was only about 1000 m, but the slide travelled a total distance of 18 km, crossing an 800 m high ridge en route.

7.2.2.4 Heave

In pure **heave** the slope material experiences cycles of expansion and contraction (Fig. 7.5(C)). Downslope movement arises from the fact that while expansion occurs normal to the sloping ground surface contraction under gravity tends to be more nearly vertical. Cohesion between particles usually prevents a purely vertical return movement under gravity. Two types of heave can be distinguished on the basis of the size of the constituent particles – **soil creep** and **talus creep**; the latter involves coarser material than the former. Expansion and contraction can be caused by wetting and drying, freezing and thawing (in which case the process is described as **frost creep** – see Section 12.2.3), temperature changes and the burrowing activity of worms and other organisms.

The rate of soil or talus creep on a slope depends on a number of factors. It will become greater with increasing slope angle since this increases the downslope component of movement. It will also be high in soils containing abundant quantities of clays, such as smectite, which expand significantly on wetting, or in silt-sized material which is capable of substantial ice accumulation. Soil and talus creep will, however, decrease with depth below the slope surface, both because of the moderation of changes associated with wetting and drying and freeze–thaw, and the increase in the weight of the overburden. There is some support from experimental and field observations for these expected relationships, although there is an upper limit to the operation of soil creep because above an angle of around 25° the soil cover is thin or absent. On steep, grass-covered slopes flights of narrow steps, called **terracettes**, are commonly present and it is likely that these are related to soil creep, although shallow landslides may also be instrumental in their development (Fig. 7.8).

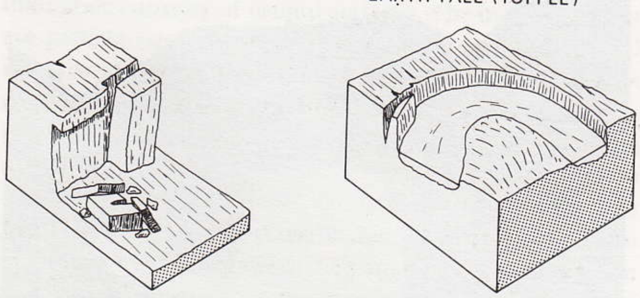

Fig. 7.11 *Varieties of fall-type mass movements. (Based on D. J. Varnes (1978) in R. L. Schuster and R. J. Krizek (eds)* Landslides: Analysis and Control. *Transportation Research Board Special Report **176**. National Academy of Sciences, Washington, DC, Fig. 2.1.)*

7.2.2.5 Fall

Fall involves the downward motion of rock or, more rarely, soil through the air (Fig. 7.11). Soil is not frequently involved for the simple reason that free fall can only occur from very steep slopes or cliff faces which, of course, have very little soil cover. An exception is the toppling of slabs of earth along river banks, a process often referred to as **bank calving**. This arises from the undercutting of banks by streams and is a very common phenomenon which contributes large quantities of sediment to river channels. **Topples** are distinguished from other types of fall by the rotation of the block of material as it falls away. Topple can occur in rock especially where joints are vertically extensive in relation to their width and where they dip out of a slope.

Rock can become detached as a result of various physical weathering processes, including pressure release and joint widening by frost action, and the fragments produced are rapidly removed under gravity. **Rock falls** are common phenomena in terrain characterized by high, steep rock slopes and cliffs (Fig. 7.12). Where the dislodged fragments are large they accumulate a significant amount of kinetic energy by the time they impact on the slope below and they can therefore be an active erosive agent by detaching other fragments. Large rock falls originating from a considerable height above the ground spread their debris over an extensive area unless the dispersal of material is confined by topography. As already mentioned, large rock falls are often transformed into debris avalanches once they have made their initial impact. In situations where deep valleys are cut into hard rocks, such as granites and some sandstones, by glaciers or rapidly incising river channels, the release of

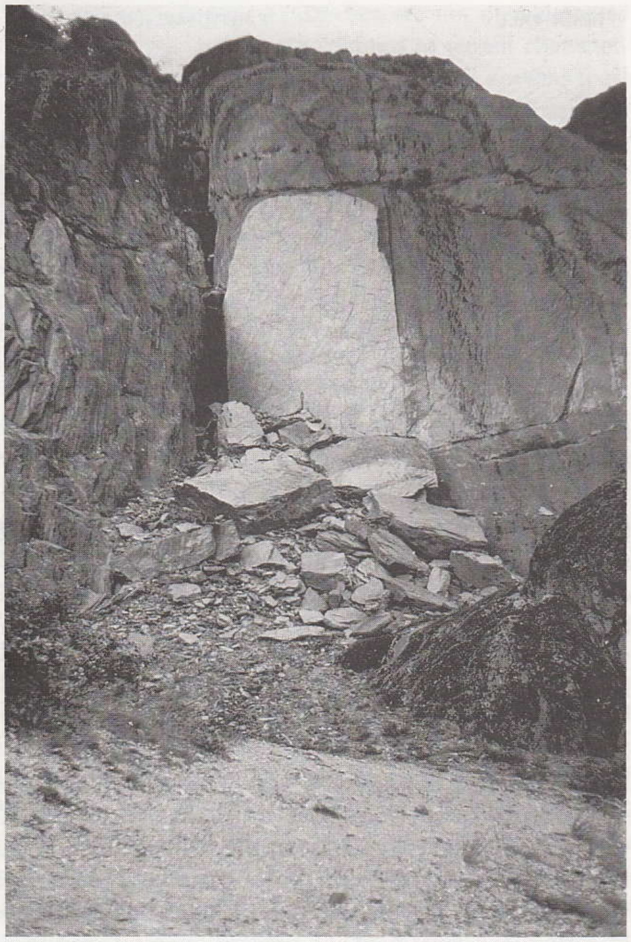

Fig. 7.12 Rock fall in a recently glaciated valley in the Southern Alps, South Island, New Zealand. The area of fresh rock face from which the large blocks of rock have fallen is more than 20 m high.

lateral confining pressure along the valley walls can give rise to pressure release and generate tension joints running roughly parallel with the ground slope. These can promote slab failure when the progressive widening of these joints eventually leads to the detachment of thick slices of rock (Fig. 6.21).

7.2.2.6 Subsidence

Subsidence can occur either as the more or less instantaneous collapse of material into a cave or other cavity (**cavity collapse**) or as a progressive lowering of the ground surface (**settlement**). Cavity collapse is largely confined to limestone terrains where the roofs of underground cavities occasionally collapse. More rarely lava tubes within lava flows may experience a similar fate. Cavity collapse can also occur as a result of human activites such as mining. Settlement usually arises from the lowering of water tables and is most dramatically illustrated in areas where there has been oil drilling or large-scale abstraction of ground water for irrigation. Settlement can also occur naturally where the volume of poorly compacted materials is decreased by the addition of water (**hydrocompaction**) or by vibrations such as those generated by earthquakes.

7.3 Gravity tectonics

Gravity tectonics is a useful term which covers a range of processes extending from the very large-scale movements of rock masses involved in the development of thrusts and nappes to smaller scale downdip translocations of material which are transitional to landslides. Many of the massive nappes occurring in intercontinental collision orogens such as the Alps are now considered to be vast **gravity slides** moving away from their high, axial zones (see Section 3.4.1).

Gravity tectonics can involve both spreading and sliding, the two processes being closely associated, but not identical. Rocks located high up in mountain masses and bounded by steep slopes gradually yield and move downslope under gravity. This kind of motion can be accommodated by internal movements within the rock (**gravity spreading**) or it may occur primarily through **gravity sliding** of the rock mass over a few well-defined planes composed of incompetent strata. Although the movement is essentially downslope, internal deformation and the rotation of blocks along small-scale faults can create chaotic patterns at the local scale (Fig. 7.13).

Such structures clearly have a combined endogenic and exogenic origin. The initial energy input is endogenic, involving as it does orogenic uplift. But the subsequent sliding, which may take place over gradients as low as 0.5°,

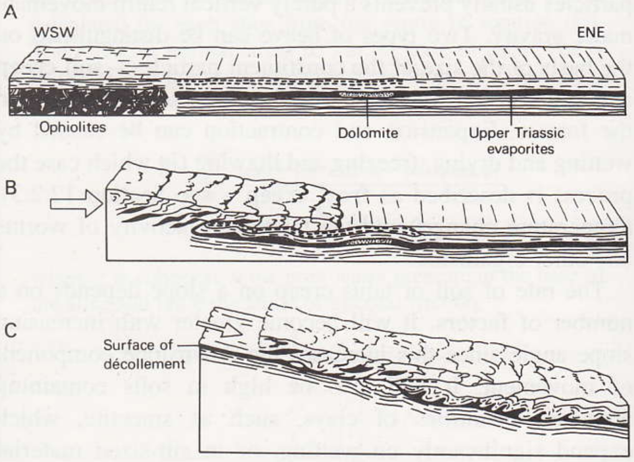

Fig. 7.13 Schematic representation of gravity tectonics in the northern Apennines, near Florence, Italy: (A) the original depositional basin; (B) thrusting from the west; (C) gravity sliding over Upper Triassic evaporites (solid shading) acting as a décollement surface. (After P. Elter and L. Trevisan (1973) in: K. A. De Jong and R. Scholten (eds) Gravity and Tectonics. *Wiley, New York, Fig. 15, p. 187.)*