6

WEATHERING AND RELATED LANDFORMS

The decomposition and disintegration of rock is a primary process in the tectonic cycle and landscape evolution. This chapter covers:

- weathering waste
- weathering landforms
- the global pattern of leaching and weathering
- weathering and buildings

Weathering in action: the decay of historic buildings

The Parthenon is a temple dedicated to the goddess Athena, built between 447 and 432 BC on the Acropolis of Athens, Greece. During its 2,500-year history, the Parthenon has suffered damage. The Elgin Marbles, for example, once formed an outside frieze. Firm evidence now suggests that continuous damage is being caused by air pollution and that substantial harm has already been inflicted in this way. For example, the inward-facing carbonate stone surfaces of the columns and the column capitals bear black crusts or coatings. These damaged areas are not significantly wetted by rain or rain runoff, although acid precipitation may do some harm. The coatings seem to be caused by sulphur dioxide uptake, in the presence of moisture, on the stone surface. Once on the moist surface, the sulphur dioxide is converted to sulphuric acid, which in turn results in the formation of a layer of gypsum. Researchers are undecided about the best way of retarding and remedying this type of air pollution damage.

Weathering is the breakdown of rocks by mechanical disintegration and chemical decomposition. Many rocks form under high temperatures and pressures deep in the Earth's crust. When exposed to the lower temperatures and pressures at the Earth's surface and brought into contact with air, water, and organisms, they start to decay. The process tends to be self-reinforcing: weathering weakens the rocks and makes them more permeable, so rendering them more vulnerable to removal by agents of erosion, and the removal of weathered products exposes more rock to weathering. Living things have an influential role in weathering, attacking rocks and minerals through various biophysical and biochemical processes, most of which are not well understood.

WEATHERING PRODUCTS AND LANDFORMS

Weathering waste

Regolith

The **weathered mantle** or **regolith** is all the weathered material lying above the unaltered or fresh bedrock (see Ehlen 2005). It may include lumps of fresh bedrock. Often the weathered mantle or crust is differentiated into visible horizons and is called a **weathering profile** (Figure 6.1). The **weathering front** is the boundary between fresh and weathered rock. The layer immediately above the weathering front is sometimes called

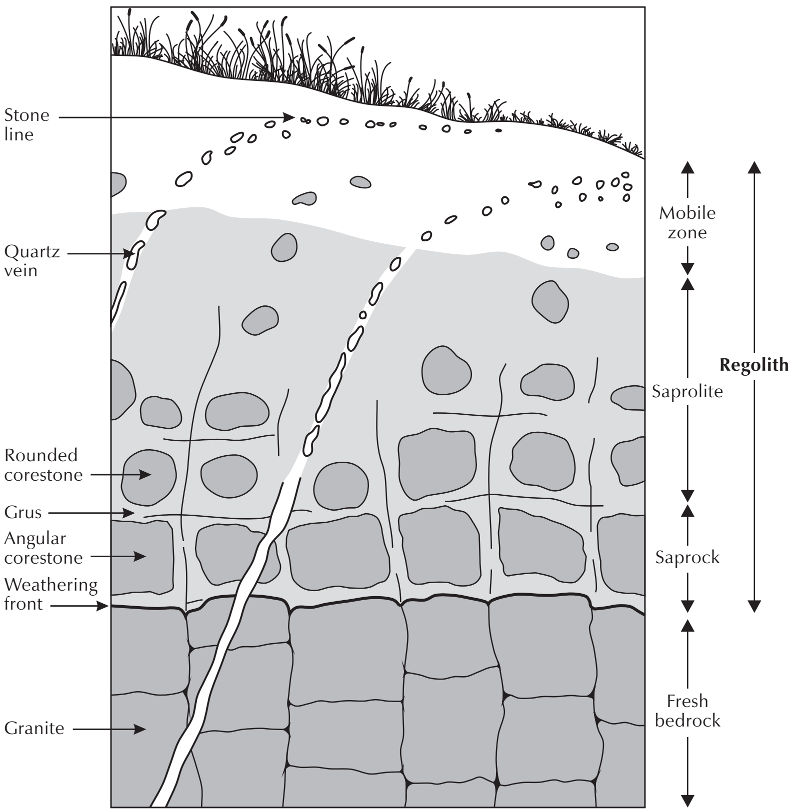

Figure 6.1 Typical weathering profile in granite. The weathering front separates fresh bedrock from the regolith. The regolith is divided into saprock, saprolite, and a mobile zone.

saprock, which represents the first stages of weathering. Above the saprock lies saprolite, which is more weathered than saprock but still retains most of the structures found in the parent bedrock. **Saprolite** lies where it was formed, undisturbed by mass movements or other erosive agents. Deep weathering profiles, saprock, and saprolite are common in the tropics. No satisfactory name exists for the material lying above the saprolite, where weathering is advanced and the parent rock fabric is not distinguishable, although the terms '**mobile zone**', '**zone of lost fabric**', '**residuum**', and '**pedolith**' are all used (see Taylor and Eggleton 2001, 160).

Weathering can produce distinct mantles. The intense frost weathering of exposed bedrock, for instance, produces **blockfields**, which are also called felsenmeer, block meer, and stone fields. Blockfields are large expanses of coarse and angular rock rubble occurring within polar deserts and semi-deserts. Steeper fields, up to 35°, are called blockstreams. An example is the 'stone runs' of the Falkland Islands. **Talus** (**scree**) **slopes** and **talus cones** are the result of weathering processes on steep rock faces aided by some mass wasting.

Duricrusts and hardpans

Under some circumstances, soluble materials precipitate within or on the weathered mantle to form duricrusts, hardpans, and plinthite. **Duricrusts** are important in landform development as they act like a band of resistant rock and may cap hills. They occur as hard nodules or crusts, or simply as hard layers. The chief types are ferricrete (rich in iron), calcrete (rich in calcium carbonate), silcrete (rich in silica), alcrete (rich in aluminium), gypcrete (rich in gypsum), magnecrete (rich in magnesite), and manganocrete (rich in manganese).

Ferricrete and **alcrete** are associated with deep weathering profiles. They occur in humid to subhumid tropical environments, with alcretes favouring drier parts of such regions. **Laterite** is a term used to describe weathering deposits rich in iron and aluminium. **Bauxite** refers to weathering deposits rich enough in aluminium to make economic extraction worthwhile. **Silcrete**, or siliceous duricrust, commonly consists of more than 95 per cent silica. It occurs in humid and arid tropical environments, and notably in central Australia and parts of northern and southern Africa and parts of Europe, sometimes in the same weathering profiles as ferricretes. In more arid regions, it is sometimes associated with calcrete. **Calcrete** is composed of around 80 per cent calcium carbonate. It is mostly confined to areas where the current mean annual rainfall lies in the range 200 to 600 mm and covers a large portion of the world's semi-arid environments, perhaps underlying 13 per cent of the global land-surface area. **Gypcrete** is a crust of gypsum (hydrated calcium sulphate). It occurs largely in very arid regions with a mean annual precipitation below 250 mm. It forms by gypsum crystals growing in clastic sediments, either by enclosing or displacing the clastic particles. **Magnecrete** is a rare duricrust made of magnesite (magnesium carbonate). **Manganocrete** is a duricrust with a cement of manganese-oxide minerals.

Hardpans and **plinthite** also occur. They are hard layers but, unlike duricrusts, are not enriched in a specific element.

Duricrusts are commonly harder than the materials in which they occur and more resistant to erosion. In consequence, they act as a shell of armour, protecting land surfaces from denudational agents. Duricrusts that develop in low-lying areas where surface and subsurface flows of water converge may retard valley down-cutting to such an extent that the surrounding higher regions wear down faster than the valley floor, eventually leading to **inverted relief** (Box 6.1). Where duricrusts have been broken up by prolonged erosion, fragments may persist on the surface, carrying on their protective role. The **gibber plains** of central Australia are an example of such long-lasting remnants of duricrusts and consist of silcrete boulders strewn about the land surface.

Weathering landforms

Bare rock is exposed in many landscapes. It results from the differential weathering of bedrock and the removal of weathered debris by slope processes. Two groups of weathering landforms are (1) large-scale cliffs and pillars and (2) smaller-scale rock-basins, tafoni, and honeycombs.

Box 6.1

INVERTED RELIEF

Geomorphic processes that create resistant material in the regolith may promote **relief inversion**. Duricrusts are commonly responsible for inverting relief. Old valley bottoms with ferricrete in them resist erosion and eventually come to occupy hilltops (Figure 6.2). Even humble alluvium may suffice to cause relief inversion (Mills 1990). Floors of valleys in the Appalachian Mountains, eastern USA, become filled with large quartzite boulders, more than 1 m in diameter. These boulders protect the valley floors from further erosion by running water. Erosion then switches to sideslopes of the depressions and, eventually, ridges capped with bouldery colluvium on deep saprolite form. Indeed, the saprolite is deeper than that under many uncapped ridges.

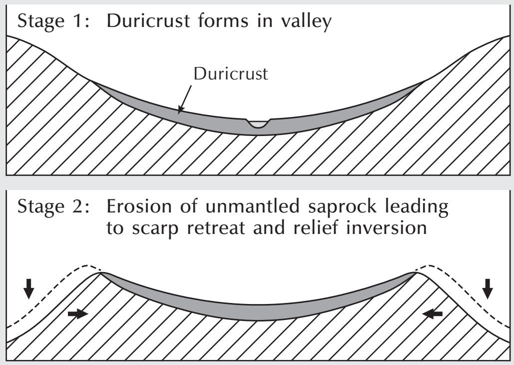

Figure 6.2 Development of inverted relief associated with duricrust formation.

Cliffs and pillars

Cliffs and crags are associated with several rock types, including limestones, sandstones, and gritstones. Take the case of sandstone cliffs (Robinson and Williams 1994). These form in strongly cemented sandstones, especially on the sides of deeply incised valleys and around the edges of plateaux. Isolated pillars of rock are also common at such sites. Throughout the world, sandstone cliffs and pillars are distinctive features of sandstone terrain. They are eye-catching in arid areas, but tend to be concealed by vegetation in more humid regions, such as England. The cliffs formed in the Ardingly Sandstone, south-east England, are hidden by dense woodland. Many cliffs are dissected by widened vertical joints that form open clefts or passageways. In Britain, such widened joints are called **gulls** or **wents**, which are terms used by quarrymen. On some outcrops, the passageways develop into a labyrinth through which it is possible to walk.

Many sandstone cliffs, pillars, and boulders are undercut towards their bases. In the case of boulders and pillars, the undercutting produces **mushroom, perched** or **pedestal rocks**. Processes invoked to account for the undercutting include (1) the presence of softer and more effortlessly weathered bands of rock; (2) abrasion by wind-blown sand (cf. p. 301); (3) salt weathering brought about by salts raised by capillary action from soil-covered talus at the cliff base; (4) the intensified rotting of the sandstone by moisture rising from the soil or talus; and (5) subsurface weathering that occurs prior to footslope lowering.

Rock-basins, tafoni, and honeycombs

Virtually all exposed rock outcrops bear irregular surfaces that seem to result from weathering. Flutes and runnels, pits and cavernous forms are common on all rock types in all climates. They are most apparent in arid and semi-arid environments, mainly because these environments have a greater area of bare rock surfaces. They usually find their fullest development on limestone (Chapter 8) but occur on, for example, granite.

Flutes, **rills**, **runnels**, **grooves**, and **gutters**, as they are variously styled, form on many rock types in many environments. They may develop a regularly spaced pattern. Individual rills can be 5–30 cm deep and 22–100 cm wide. Their development on limestone is striking (pp. 191–4).

Rock-basins, also called **weathering pits**, **weather-pits** or **gnammas**, are closed, circular, or oval depressions, a few centimetres to several metres wide, formed on flat or gently sloping surfaces of limestones, granites, basalts, gneisses, and other rock types (Plate 6.1). They are commonly flat-floored and steep-sided, and no more than a metre or so deep, though some are more saucer-shaped. The steep-sided varieties may bear overhanging rims and undercut sides. Rainwater collecting in the basins may overflow to produce spillways, and some basins may contain incised spillways that lead to their being permanently drained. Rock-basins start from small depressions in which water collects after rainfall or snowmelt. The surrounding surfaces dry out, but the depression stays moist or even holds a small pool for long periods, so providing a focus for more rapid weathering. In consequence, the rock-basin expands and deepens. As rock-basins expand, they may coalesce to form compound forms. **Solution pools** (pans, solution basins, flat-bottomed pools) occur on shore platforms cut in calcareous rocks.

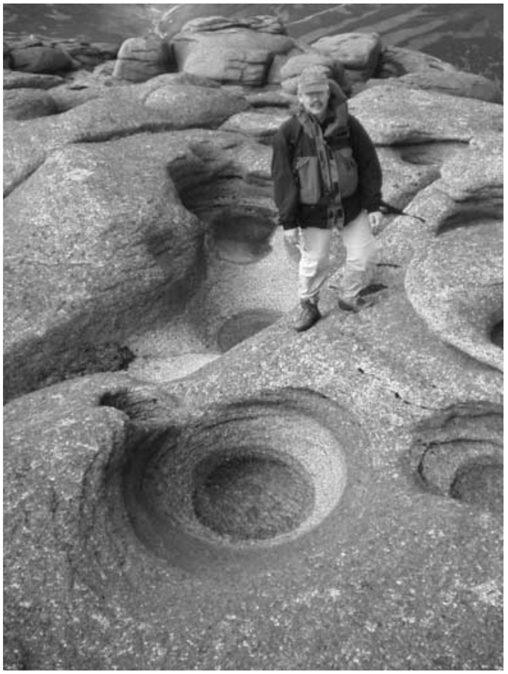

Plate 6.1 Weathering pit on Clach Bhàn, Ben Avon, in the eastern Cairngorms, Scotland.
(*Photograph by Adrian M. Hall*)

Tafoni (singular **tafone**) are large weathering features that take the form of hollows or cavities on a rock surface (Plate 6.2), the term being originally used to describe hollows excavated in granites on the island of Corsica. They tend to form in vertical or near-vertical faces of rock. They can be as little as 0.1 m to several metres in height, width, and depth, with arched-shaped entrances, concave walls, sometimes with overhanging hoods or visors, especially in case-hardened rocks (rocks with a surface made harder by the local mobilization and reprecipitation of minerals on its surface), and smooth and gently sloping, debris-strewn floors. Some tafoni cut right through boulders or slabs of rock to form rounded shafts or windows. The origins of tafoni are complex. Salt action is the process commonly invoked in tafoni formation, but researchers cannot agree whether the salts promote selective chemical attack or whether they promote physical weathering, the growing crystals prising apart grains of rock. Both processes may operate, but not all tafoni contain a significant quantity of salts. Once formed, tafoni are protected from rainwash and may become the foci for salt accumulations and further salt weathering. Parts of the rock that are less effectively case-hardened are more vulnerable to such chemical attack. Evidence also suggests that the core of boulders sometimes more readily weathers than the surface, which could aid the selective development of weathering cavities. Tafoni are common in coastal environments but are also found in arid environments. Some appear to be relict forms.

Honeycomb weathering is a term used to describe numerous small pits or **alveoli**, no more than a few centimetres wide and deep, separated by an intricate network of narrow walls and resembling a honeycomb (Plate 6.3). They are often thought of as a small-scale version of multiple tafoni. The terms **alveolar**

Plate 6.2 Tafoni, northern Atacama desert, Chile.
(*Photograph by Heather A. Viles*)

Plate 6.3 Alveoli (honeycomb) and tafoni, northern Atacama, Chile.
(*Photograph by Heather A. Viles*)

Table 6.1 Honeycomb weathering grades on sea walls at Weston-super-Mare, Avon, UK

Grade	*Description*
0	No visible weathering forms
1	Isolated circular pits
2	Pitting covers more than 50 per cent of the area
3	Honeycomb present
4	Honeycomb covers more than 50 per cent of the area
5	Honeycomb shows some wall breakdown
6	Honeycomb partially stripped
7	Honeycomb stripping covers more than 50 per cent of the area
8	Only reduced walls remain
9	Surface completely stripped

Source: Adapted from Mottershead (1994)

weathering, **stone lattice**, and **stone lace** are synonyms. Honeycomb weathering is particularly evident in semi-arid and coastal environments where salts are in ready supply and wetting and drying cycles are common. A study of honeycomb weathering on the coping stones of the sea walls at Weston-super-Mare, Avon, England, suggests stages of development (Mottershead 1994). The walls were finished in 1888. The main body of the walls is made of Carboniferous limestone, which is capped by Forest of Dean stone (Lower Carboniferous Pennant sandstone). Nine weathering grades can be recognized on the coping stones (Table 6.1). The maximum reduction of the original surface is at least 110 mm, suggesting a minimum weathering rate of 1 mm/yr.

WEATHERING AND CLIMATE

Weathering processes and weathering crusts differ from place to place. These spatial differences are determined by a set of interacting factors, chiefly rock type, climate, topography, organisms, and the age of the weathered surface. Climate is a leading factor in determining chemical, mechanical, and biological weathering rates. Temperature influences the rate of weathering, but seldom the type of weathering. As a rough guide, a 10°C rise in temperature speeds chemical reactions, especially sluggish ones, and some biological reactions by a factor of two to three, a fact discovered by Jacobus Hendricus van't Hoff in 1884. The storage and movement of water in the regolith is a highly influential factor in determining weathering rates, partly integrating the influence of all other factors. Louis Peltier (1950) argued that rates of chemical and mechanical weathering are guided by temperature and rainfall conditions (Figure 6.3). The intensity of chemical weathering depends on the availability of moisture and high air temperatures. It is minimal in dry regions, because water is scarce, and in cold regions, where temperatures are low and water is scarce (because it is frozen for much or all of the year). Mechanical weathering depends upon the presence of water but is very effective where repeated freezing and thawing occurs. It is therefore minimal where temperatures are high enough to rule out freezing and where it is so cold that water seldom thaws.

Leaching regimes

Climate and the other factors determining the water budget of the regolith (and so the internal microclimate of a weathered profile) are crucial to the formation of clays by weathering and by **neoformation**. The kind of secondary clay mineral formed in the regolith depends chiefly on two things: (1) the balance between the rate of dissolution of primary minerals from rocks and the rate of flushing of solutes by water; and (2) the balance between the rate of flushing of silica, which tends to build up tetrahedral layers, and the rate of flushing of cations, which fit into the voids between the crystalline layers formed from silica. Manifestly, the leaching regime of the regolith is crucial to these balances since it determines, in large measure, the opportunity that the weathering products have to interact. Three degrees of leaching are associated with the formation of different types of secondary clay minerals – weak, moderate, and intense (e.g. Pedro 1979):

1 **Weak leaching** favours an approximate balance between silica and cations. Under these conditions the process of bisiallitization or smectization creates 2 : 2 clays, such as smectite, and 2 : 1 clays.

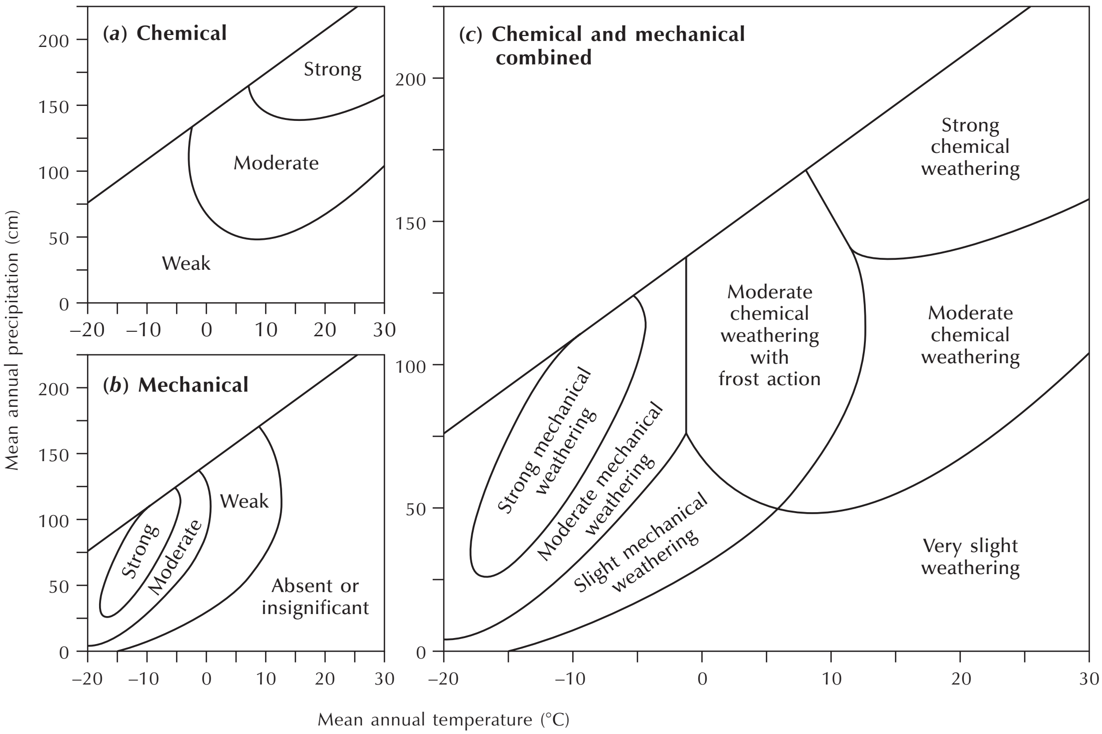

Figure 6.3 Louis Peltier's scheme relating chemical and mechanical weathering rates to temperature and rainfall.
Source: Adapted from Peltier (1950)

2 **Moderate leaching** tends to flush cations from the regolith, leaving a surplus of silica. Under these conditions, the processes of monosiallitization or kaolinization form 1 : 1 clays, such as kaolinite and goethite.
3 **Intense leaching** leaves very few bases unflushed from the regolith, and hydrolysis is total, whereas it is only partial in bisiallitization and monosiallitization. Under these conditions, the process of **allitization** (also termed soluviation, ferrallitization, laterization, and latosolization) produces aluminium hydroxides such as gibbsite.

Soil water charged with organic acids complicates the association of clay minerals with leaching regimes. Organic-acid-rich waters lead to cheluviation, a process associated with **podzolization** in soils, which leads to aluminium compounds, alkaline earths, and alkaline cations being flushed out in preference to silica.

Weathering patterns

Given that the neoformation of clay minerals is strongly influenced by the leaching regime of the regolith, it is not surprising that different climatic zones nurture distinct types of weathering and weathering crust. Several researchers have attempted to identify **zonal patterns in weathering** (e.g. Chernyakhovsky *et al.* 1976; Duchaufour 1982). One scheme, which extends Georges Pedro's work, recognizes six weathering zones (Figure 6.4) (Thomas 1994):

1 The **allitization zone** coincides with the intense leaching regimes of the humid tropics and is

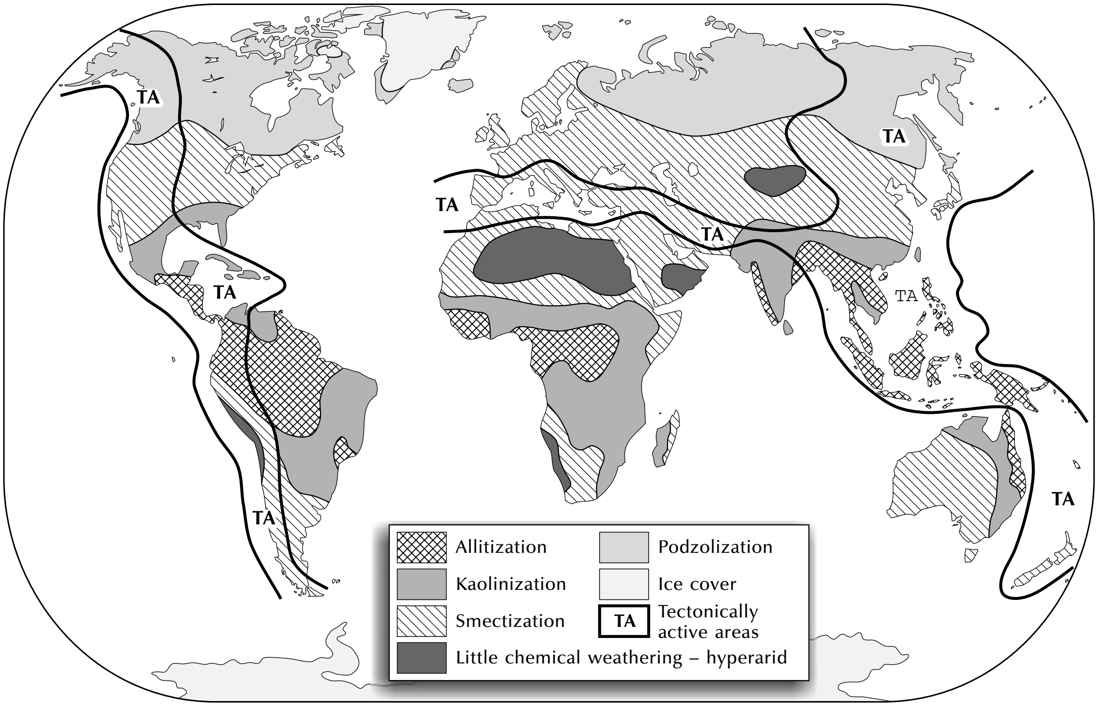

Figure 6.4 The main weathering zones of the Earth.
Source: Adapted from Thomas (1974, 5)

associated with the tropical rainforest of the Amazon basin, Congo basin, and South-East Asia.

2 The **kaolinization zone** accords with the seasonal leaching regime of the seasonal tropics and is associated with savannah vegetation.

3 The **smectization zone** corresponds to the subtropical and extratropical areas, where leaching is relatively weak, allowing smectite to form. It is found in many arid and semi-arid areas and in many temperate areas.

4 The **little-chemical-weathering zone** is confined to hyperarid areas in the hearts of large hot and cold deserts.

5 The **podzolization zone** conforms to the boreal climatic zone.

6 The **ice-cover zone**, where, owing to the presence of ice sheets, weathering is more or less suspended.

Within each of the first five zones, parochial variations arise owing to the effect of topography, parent rock, and other local factors. Podzolization, for example, occurs under humid tropical climates on sandy parent materials.

The effects of local factors

Within the broad weathering zones, **local factors** – parent rock, topography, vegetation – play an important part in weathering and may profoundly modify climatically controlled weathering processes. Particularly important are local factors that affect soil drainage. In temperate climates, for example, soluble organic acids and strong acidity speed up weathering rates but slow down the neoformation of clays or even cause pre-existing clays to degrade. On the other hand, high concentrations of alkaline-earth cations and strong biological activity slow down weathering, while promoting the neoformation or the conservation of clays that are richer in silica. In any climate, clay neoformation is more marked in basic volcanic rocks than in acid crystalline rocks.

Topography and drainage

The effects of local factors mean that a wider range of clay minerals occur in some climatic zones than would be the case if the climate were the sole determinant of clay formation. Take the case of tropical climates. Soils within small areas of this climatic zone may contain a range of clay minerals where two distinct leaching regimes sit side by side. On sites where high rainfall and good drainage promote fast flushing, both cations and silica are removed and gibbsite forms. On sites where there is less rapid flushing, but still enough to remove all cations and a little silica, then kaolinite forms. For instance, the type of clay formed in soils developed in basalts of Hawaii depends upon mean annual rainfall, with smectite, kaolinite, and bauxite forming a sequence along the gradient of low to high rainfall. The same is true of clays formed on igneous rocks in California, where the peak contents of different clay minerals occur in the following order along a moisture gradient: smectite, illite (only on acid igneous rocks), kaolinite and halloysite, vermiculite, and gibbsite (Singer 1980). Similarly, in soils on islands of Indonesia, the clay mineral formed depends on the degree of drainage: where drainage is good, kaolinite forms; where it is poor, smectite forms (Mohr and van Baren 1954; cf. Figure 6.5). This last example serves to show the role played by landscape position, acting through its influence on drainage, on clay mineral formation. Comparable effects of **topography** on clay formation in oxisols have been found in soils formed on basalt on the central plateau of Brazil (Curi and Franzmeier 1984).

Age

Time is a further factor that obscures the direct climatic impact on weathering. Ferrallitization, for example, results from prolonged leaching. Its association with the tropics is partly attributable to the antiquity of many tropical landscapes rather than to the unique properties

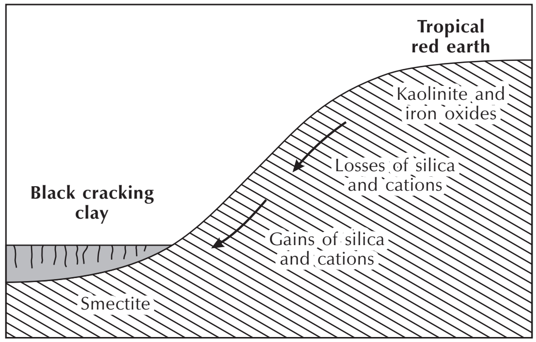

Figure 6.5 Clay types in a typical tropical toposequence.
Source: Adapted from Ollier and Pain (1986, 141)

of tropical climates. More generally, the extent of chemical weathering is correlated with the age of continental surfaces (Kronberg and Nesbitt 1981). In regions where chemical weathering has acted without interruption, even if at a variable rate, since the start of the Cenozoic era, advanced and extreme weathering products are commonly found. In some regions, glaciation, volcanism, and alluviation have reset the chemical weathering 'clock' by creating fresh rock debris. Soils less than 3 million years old, which display signs of incipient and intermediate weathering, are common in these areas. In view of these complicating factors, and the changes of climate that have occurred even during the Holocene epoch, claims that weathering crusts of recent origin (recent in the sense that they are still forming and have been subject to climatic conditions similar to present climatic conditions during their formation) are related to climate must be looked at guardedly.

WEATHERING AND HUMANS

Limestone weathers faster in urban environments than in surrounding rural areas. Archibald Geikie established this fact in his study of the weathering of gravestones in Edinburgh and its environs. Recent studies of weathering rates on marble gravestones in and around Durham, England, give rates of 2 microns per year in a rural site and

Plate 6.4 Weathered balustrade on the Ashmolean Museum, Oxford, England. The balustrade has now been cleaned. (*Photograph by Heather A. Viles*)

10 microns per year in an urban industrial site (Attewell and Taylor 1988).

In the last few decades, concern has been voiced over the economic and cultural costs of **historic buildings** being attacked by pollutants in cities (Plate 6.4). Geomorphologists can advise such bodies as the Cathedrals Fabric Commission in an informed way by studying urban weathering forms, measuring weathering rates, and establishing the connections between the two (e.g. Inkpen *et al.* 1994). The case of the Parthenon, Athens, was mentioned at the start of the chapter. St Paul's Cathedral in London, England, which is built of Portland limestone, is also being damaged by weathering (Plate 6.5). It has suffered considerable attack by weathering over the past few hundred years. Portland limestone is a bright white colour. Before recent cleaning, St Paul's was a sooty black. Acid rainwaters have etched out hollows where it runs across the building's surface. Along these channels, bulbous gypsum precipitates have formed beneath anvils and gargoyles, and acids, particularly sulphuric acid, in rainwater have reacted with the limestone. About 0.62 microns of the limestone surface is lost each year, which represents a cumulative loss of 1.5 cm since St Paul's was built (Sharp *et al.* 1982).

Salt weathering is playing havoc with buildings of ethnic, religious, and cultural value in some parts of the world. In the towns of Khiva, Bukhara, and Samarkand, which lie in the centre of Uzbekistan's irrigated cotton belt, prime examples of Islamic architecture – including mausolea, minarets, mosques, and madrasses – are being ruined by capillary rise, a rising water table resulting from over-irrigation, and an increase in the salinity of the groundwater (Cooke 1994). The solution to these problems is that the capillary fringe and the salts connected with it must be removed from the buildings, which might be achieved by more effective water management (e.g. the installation of effective pumping wells) and the construction of damp-proof courses in selected buildings to prevent capillary rise.

Weathering plays an important role in releasing trace elements from rocks and soil, some of which are beneficial to humans and some injurious, usually depending on the concentrations involved in both cases. It is therefore relevant to **geomedicine**, a subject that considers the effects of trace elements or compounds in very small amounts – usually in the range of 10 to 100 parts per million (ppm) or less – on human health. For example, iodine is essential to the proper functioning of the thyroid gland.

Plate 6.5 A bust of St. Andrew, removed from St. Paul's Cathedral because of accelerated decay.
(*Photograph by Heather A. Viles*)

Low iodine levels lead to the enlargement of the thyroid and to the deficiency disease known as goitre. This disease is common in the northern half of the USA, probably because the soils in this area are deficient in iodine owing to low levels in bedrock and the leaching of iodine (which has soluble salts) by large volumes of meltwater associated with deglaciation. Weathering may also influence the accumulation of toxic levels of such elements as arsenic and selenium in soils and water bodies.

SUMMARY

The weathered mantle or regolith is all the weathered debris lying above the unweathered bedrock. Saprock and saprolite is the portion of the regolith that remains in the place that it was weathered, unmoved by mass movements and erosive agents. Geomorphic processes of mass wasting and erosion have moved the mobile upper portion of regolith, sometimes called the mobile zone, residuum, or pedolith. Weathering processes are influenced by climate, rock type, topography and drainage, and time. Climatically controlled leaching regimes are crucial to understanding the building of new clays (neoformation) from weathering products. A distinction is made between weak leaching, which promotes the formation of 2 : 2 clays, moderate leaching, which encourages the formation of 1 : 1 clays, and intense leaching, which fosters the formation of aluminium hydroxides. The world distribution of weathering crusts mirrors the world distribution of leaching regimes. Weathering processes attack historic buildings and monuments, including the Parthenon and St Paul's Cathedral, and they can be a factor in understanding the occurrence of some human diseases.

ESSAY QUESTIONS

1. **Describe the chief weathering processes.**
2. **Evaluate the relative importance of factors that affect weathering.**
3. **Explore the impact of weathering on human-made structures.**

FURTHER READING

Goudie, A. (1995) *The Changing Earth: Rates of Geomorphological Process*. Oxford and Cambridge, Mass.: Blackwell.
A good section in here on rates of weathering.

Ollier, C. D. and Pain, C. F. (1996) *Regolith, Soils and Landforms*. Chichester: John Wiley & Sons.
An intriguing textbook on connections between geomorphology, soil, and regolith.

Taylor, G. and Eggleton, R. A. (2001) *Regolith Geology and Geomorphology*. Chichester: John Wiley & Sons.

An excellent book with a geological focus, but no worse for that.

Thomas, M. F. (1994) *Geomorphology in the Tropics: A Study of Weathering and Denudation in Low Latitudes*. Chichester: John Wiley & Sons.

A most agreeable antidote to all those geomorphological writings on middle and high latitudes.