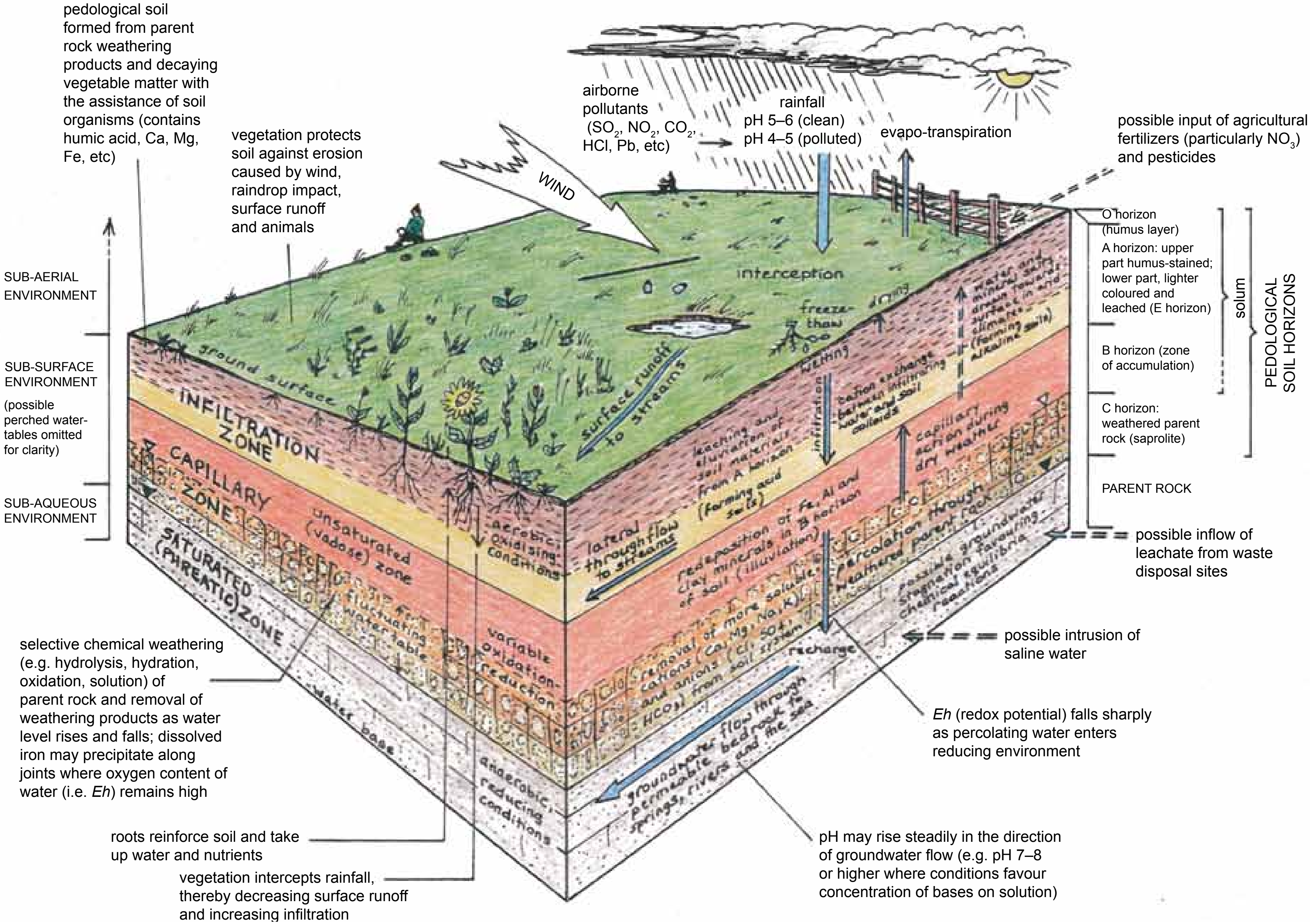


pedological soil formed from parent rock weathering products and decaying vegetable matter with the assistance of soil organisms (contains humic acid, Ca, Mg, Fe, etc)

vegetation protects soil against erosion caused by wind, raindrop impact, surface runoff and animals

airborne pollutants (SO_2, NO_2, CO_2, HCl, Pb, etc)

rainfall pH 5–6 (clean) pH 4–5 (polluted)

evapo-transpiration

possible input of agricultural fertilizers (particularly NO_3) and pesticides

possible inflow of leachate from waste disposal sites

possible intrusion of saline water

Eh (redox potential) falls sharply as percolating water enters reducing environment

pH may rise steadily in the direction of groundwater flow (e.g. pH 7–8 or higher where conditions favour concentration of bases on solution)

selective chemical weathering (e.g. hydrolysis, hydration, oxidation, solution) of parent rock and removal of weathering products as water level rises and falls; dissolved iron may precipitate along joints where oxygen content of water (i.e. *Eh*) remains high

roots reinforce soil and take up water and nutrients

vegetation intercepts rainfall, thereby decreasing surface runoff and increasing infiltration

Figure 2.1 Idealized soil block model: temperate zone.

Part 2. Near-surface ground changes

Basic soils and landscapes (Figure 2.1)

COMMON SURFACE CONDITIONS

Ground materials consist of unweathered rock (bedrock), which may be overlain by in situ weathered rock (*saprolite*) and/or soils. Engineers describe any non-lithified soils that overlie solid rock as *overburden,* although this is known to geologists and geomorphologists as *regolith*. Regolith may consist of saprolite, alluvium, glacial till, wind-blown loess or dune sand, volcanic dust and various other unconsolidated materials.

The nature of the bedrock underlying an area is the product of its geological history. This includes the mode of deposition of the sedimentary rocks forming part or all of the bedrock and any post-depositional (diagenetic) changes in the sediments. These changes include compaction, lithification, cementation and weathering changes related to the history of the area (see Figure 1.8). Tectonic activity (folding, faulting and the emplacement of igneous and metamorphic rocks) is not considered to be part of the diagenetic changes. Igneous and metamorphic rocks may also form part or all of the local bedrock.

The extent to which the bedrock geology of an area is reflected in the landscape depends on whether the rocks are covered by a significant thickness of regolith. The enormous range of combinations of rock types, rock structures, weathering and erosional history means that every terrain model constructed during the early part of the site investigation is unique. In practical terms the observed materials within a system or in the ground are not necessarily predictable, so further investigations by boreholes, pits and geophysical surveys are required (see Parts 4 and 5).

In the longer term (e.g. hundreds to tens of thousands of years), the rate and nature of local landscape changes are dependent on the mass characteristics of the rocks and soils, mainly their intact strength, discontinuities and susceptibility to the local weathering and erosion processes of past and present climates.

Earth surface systems can be used to describe how the transfer of sediments and energy (e.g. down-slope creep, erosion along stream channels) produces the relationships between the landforms in an area (Fookes *et al*., 2007). Local surface systems are primarily controlled by the geological setting, the geographical location (including the climate zone; see Figure 2.2) and the local ground materials. The geological character of the local bedrock and its structure determine the broad-scale form of the local geomorphological landscape and its systems, relief and slope gradients. It also determines the materials available for erosion and transport by surface processes.

Engineering soils are typically described in engineering terms according to their dominant particle size using, for example, the Unified Soil Classification System (Norbury, 2010; Bibliography, Group B books). Three main soil types are recognized.

- *Residual soils* are the product of the in situ weathering of bedrock where the soil thickness and type are broadly associated with the past and present climate and the intensity of weathering (Figures 2.2–2.5, 3.6 and 3.8). A weathered rock profile is created over fresh bedrock and distinctive zones (layers or horizons) can develop in response to variations in the intensity of weathering and the movement of moisture and minerals. The upper layers contain rock debris that has been completely weathered to a soil. Lower down the profile there are increasing amounts of unweathered and partly weathered rock (Figure 2.1). *Tropical residual soils* are a special case of residual soil found in wet tropical areas. They exhibit distinctive engineering properties and characteristics (Fookes, 1997b), ranging in grade VI weathering (see later) from fersiallitic to ferruginous to ferrallitic soils formed by the increasing length of time of weathering and the climate of the area.
- *Transported soils* (e.g. alluvium, loess) are the products of the erosion of residual soils or bedrock that have been transported and deposited elsewhere.
- *Organic soils* are formed in situ by the growth and decay of vegetation – for example, peat, which forms in anaerobic conditions when the ground is waterlogged. Peat formation is encouraged in areas of high rainfall and low temperatures, stimulating further water-logging. About 15% of Ireland is covered by blanket peat bog.

Three main weathering phases are recognized in engineering geology, starting from grade VI at ground level.

- Weathering grades IV to VI (solum or 'true' soil to saprolite or chemically weathered rock), which form a continuum of specific mineral soil development in increasing order of weathering (see Figures 2.4 and 2.5).
- Grades II and III are increasing degrees of weathering developed on the underlying fresh bedrock. Corestones are commonly present in grade III weathering, depending on the original joint spacing.
- Grade I is unweathered fresh bedrock.

It is important to note that some ancient over-consolidated bedrock clays – for example, the Tertiary London Clay and the Jurassic Oxford Clay in Britain, which are not lithified – are likely to be called 'engineering clays' by engineers.

GROUNDWATER

Typical near-surface groundwater conditions are illustrated in Figure 2.1, which is based on a temperate zone climate. Permeability characteristics are given in Table 2.1.1 and 2.1.2. The rates of evapotranspiration and infiltration generally vary seasonally and from year to year. They may also vary on shorter timescales, perhaps in response to local major storms. It should be noted that conditions during the construction phase may differ significantly from those found during the ground investigation.

Table 2.1.1 Typical permeability values.

Soil types				
	Homogeneous clays below the zone of weathering	Silts, fine sands, silty sands, glacial till, stratified clays	Clean sands, sand and gravel mixtures	Clean gravels
		Fissured and weathered clays and clays modified by the effects of vegetation		

Coefficient of permeability (log scale)												
m/sec	10^{-11}	10^{-10}	10^{-9}	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1
cm/sec	10^{-9}	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1	10	100
ft/sec	10^{-10}	10^{-9}	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1	

Practically Impermeable	Very low	Low	Medium	High

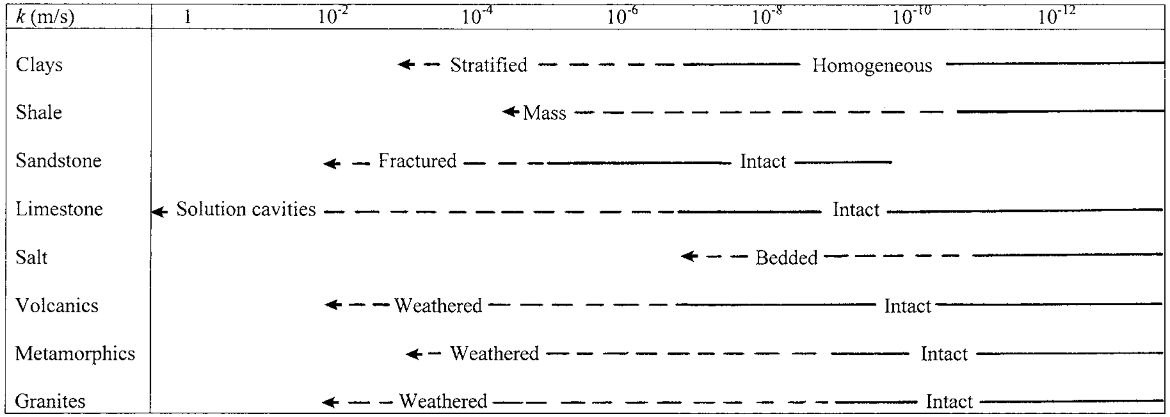
Drainage conditions			
	practically impermeable	Poor	Good

Estimation of coefficient of permeability: for granular soils, the coefficient of permeability can be estimated using Hazen's formula:

$$k = c_1 D^2_{10}$$

where k is the coefficient of permeability in m/s, D^{10} is the effective particle size in mm, and c_1 is a factor varying between 100 and 150.

Table 2.1.2 Typical ranges of coefficient of permeability (k) for different types and conditions of rock.



- Where the annual infiltration exceeds the evapotranspiration, groundwater flows downwards from the surface. It eventually reaches a zone of saturation within the capillary fringe, where it is held within the soil pores by surface tension. Fine-grained soils within this zone will be either partially or 'fully' saturated, even on slopes. Water may descend further to the water-table (where water can seep into the base of a borehole) and then flows as groundwater through an aquifer towards discharge points at lower elevations.

  Excavation and underground works generally suffer from water inflow and dewatering may lead to settlement as a result of the consolidation of fine soils or internal erosion and the loss of fine particles from coarse soils. Such works need careful monitoring and management of water flows.

  Seasonal variations will lead to heave and the settlement of superficial clays and shallow foundations depending on the conditions before construction. Vegetation is the source of transpiration and its presence causes an increase in soil suction and a decrease in water content. The development of tree-root systems (which need moisture) will lead to shrinkage in clays and ground settlement as the tree grows. The clearance of vegetation leads to swelling of clays and heave of foundations. Seasonal variations may also lead to complex groundwater conditions and there may be different water pressures in permeable strata separated by less permeable strata.
- Partially saturated soils, which locally occur to great depths, may be subject to desiccation over a long period of time. Plastic clays tend to heave on wetting when evaporation is prevented by sealing of the ground surface (e.g. by a new building or road). Soil suction can facilitate the construction of temporary steep slopes, excavation and shafts. However, the effects are short-lived and the long-term protection of slopes from erosion is generally required.
- When the annual evapotranspiration exceeds infiltration, water-tables are generally low and are controlled by local

stream levels and the presence of permeable strata. In hot, dry areas without tree cover, the upward movement of moisture and evaporation from the ground surface may produce a chemically active zone at ground level. This may lead to situations with aggressive evaporation conditions, as in coastal sabkha or where duricrusts form on dryland surfaces (see Figures 2.2, 2.5 and 3.6).

- Artesian groundwater pressure is driven by high water-tables in adjacent high ground. It is common below the floor of valleys in folded, bedded strata and in glaciofluvial deposits beneath glacial till on the lower slopes of some valleys. Lenticular aquifers may allow perched water-tables to form on valley sides.

Ground profile with a thin, brown, organic-rich soil developed over an alluvial soil of transported sediment, which lies on the rockhead surface beneath which there is little weathering of the dipping rocks.

[right] Fersiallitic, smectite-rich residual soil, with a pale kaolin-rich horizon, developed on young volcanic ash in a Mediterranean climate.

Soil developed in a temperate environment, by the complete breakdown of the underlying shale, aided by plant roots that open fractures.

Profile exposed in a road cutting through dipping beds of pale sandstones and darker shale; a valley in the hillside above has been formed along the outcrop of the weaker shale, but the shale outcrop is hidden, beyond the first bush, by blocks of sandstone fallen from the adjacent outcrops of the stronger rock.

Terra rosa, a red soil of insoluble residues left after solution of limestone in the wet tropics, filling solution-enlarged fissures in the bedrock.

[left] A ferruginous, smectite-rich, black earth developed on young pyroclastic rocks in a wet tropical environment.

[above] Deep contraction fissures formed by desiccation of a clay-rich mud, with blocks about half a metre across.

[left] Variation in peat soils in temperate environments:
above; a thin peat soil beneath a wet grassland;
[middle] thick hill peat eroded into deep gullies;
[below] lowland or fen peat being extracted today for fuel, with cut blocks of saturated peat thrown up onto the bank to drain before being taken to storage, where a whole summer is needed to dry them ready for the fire.

A sabkha of clay and silt sediments intergrown with gypsum along a desert coastline flooded at high tides.

A zeugen (or mushroom rock) eroded by wind-driven sand-blasting near ground level in a desert, with salt crystallisation and physical weathering in a lower bed.

Artesian groundwater rising through a borehole due to natural pressure in an underlying confined aquifer.