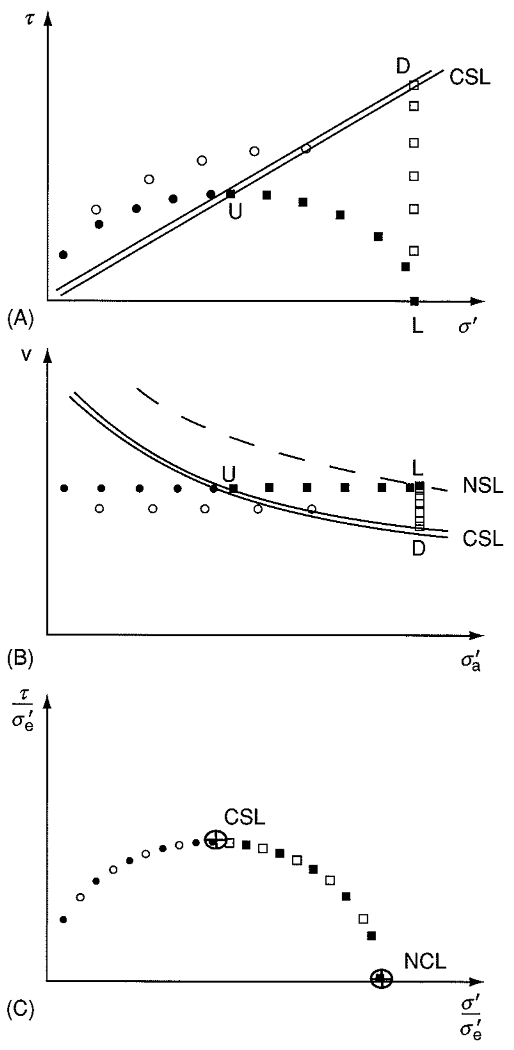

Figure 14 A state boundary surface.

Applications

The simple theories presented above for granular materials form the basis for analysis and design of engineering works which interact with the ground such as foundations, slopes, tunnels and retaining walls.

The basic theories for the mechanical behaviour granular materials are applicable equally to coarse-grained soils (sands and gravels) and fine-grained soils (clays). The principle factor to consider is the relative rate of loading and drainage. For routine analysis a particular case must be taken to be either fully drained or fully undrained.

If the soil is assumed to be fully drained, pore pressures can be determined and effective stresses calculated. Analyses are then carried out using *effective stresses* with effective stress strength and stiffness parameters. If the soil is assumed to be undrained, there are no changes in volume but there are changes in pore pressure which cannot be easily determined. In this case analyses have to be carried out using *total stresses* with undrained strength and stiffness parameters.

The critical state strength should be used to investigate ultimate failures. The peak strengths, with appropriate factors, should be used to investigate designs which are required to limit movements.

Simple analyses of foundation settlement are often carried out assuming one-dimensional conditions using the one-dimensional modulus, M, or using simple elastic theories using a shear modulus, G, and a bulk modulus, K. In all cases, it is necessary to take account of non-linear stress-strain behaviour and the appropriate drainage conditions. Simple analyses of rate of settlement due to consolidation can only be carried out assuming one-dimensional conditions.

The advanced soil mechanics theories, such as Cam Clay, are not used in simple analysis and design except for extremely simplified cases. Instead they form the basis for analyses using finite element or other comparable numerical methods.

See Also

Engineering Geology: Liquefaction; Made Ground; Problematic Soils; Subsidence. **Soils:** Modern; Palaeosols.

Further Reading

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SOILS

Contents

Modern

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Introduction

There are many soil-forming processes, which in varying combinations create the large array of soils forming at the surface of the Earth. The study of soils is aided by the observation that soil-forming processes are slow and seldom go to completion. The parent materials of soils are modified over thousands of years by physical, chemical, and biological influences. However, few of these processes can be observed directly. Podzolization is one of the few soil-forming processes that is rapid enough to be recreated in the laboratory. Soil-forming processes that operate over thousands of years are studied using a space-for-time strategy (that is, studying soils of differing ages that are subject to the same soil-forming regime). A set of soils of different ages with comparable climates, vegetation, topographical positions, and parent materials is called a chronosequence (**Figure 1**). Mathematical relationships between the development of particular soil features and time are called chronofunctions, and include the increased clayeyness produced by the soil-forming process of lessivage (**Figure 2**). While specifying the rate and progress of soil formation, chronofunctions can also be used to infer the ages of landscapes from undated soils by comparison with dated soils. Such estimates of soil age can be important in the study of the neotectonic deformation of landscapes and their suitability for long-term installations such as dams and nuclear power plants. Soil fertility also varies with soil age, and chronofunctions can guide agricultural use and rehabilitation of soils.

Soil-forming processes vary not only with time but also with parent materials, topographical relief, vegetation, and climate. For example, the fragments of volcanic glass in certain kinds of air-fall tuff are distinct from the minerals of most soils, and they bestow high fertility and low bulk density on some volcanic soils (the process of andisolization). Waterlogging in low-lying parts of the landscape prevents the rusting of iron minerals and imparts a grey-green colour to the soil (the process of gleization). Leachates from highly acidic vegetation, such as pine forest, create soils in which clays are destroyed but quartz and haematite accumulate (the process of podzolization). Finally, climate is also an important factor in

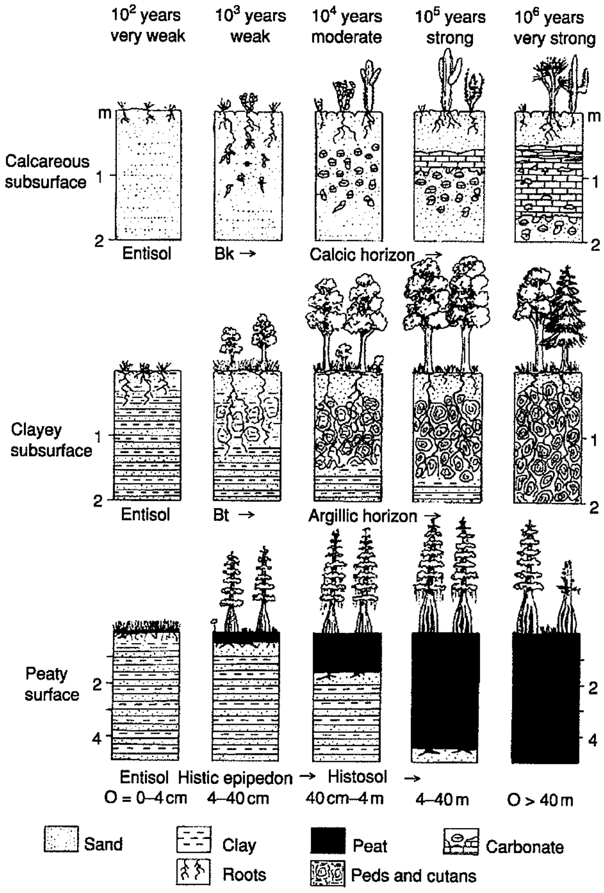

Figure 1 Soil development stages involving progressive calcification (top), lessivage (middle), and paludization (bottom). Reproduced with permission from Retallack GJ (2001) *Soils of the Past*. Oxford: Blackwell.

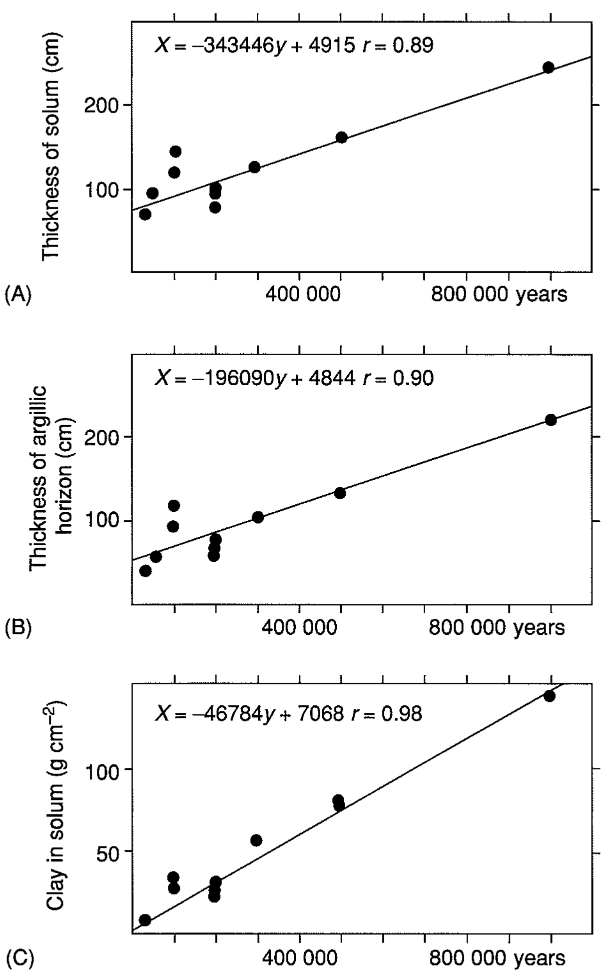

Figure 2 Chronofunctions for the progress of lessivage in soils of the Coastal Plain and Piedmont of south-eastern USA over time: (A) solum thickness; (B) thickness of the argillic horizon; and (C) the amount of clay in the solum. The solum is the A and B horizons; the argillic horizon is the Bt horizon; and the total profile is the A, B, and C horizons as defined in **Table 2**. Reproduced with permission from Retallack GJ (2001) *Soils of the Past*. Oxford: Blackwell, using data from Markewich HW, Pavich MJ, and Buell GR (1990) Contrasting soils and landscapes of the Piedmont and Coastal Plain, eastern United States. *Geomorphology* 3: 417–447.

soil-forming processes, encouraging deeper and more thorough weathering in wetter and warmer climates (**Figure** 3).

The study of soil-forming processes has informed both soil taxonomy (**Table** 1) and soil-profile terminology (**Table** 2). The following outlines of soil-forming processes are presented in the order in which they would be encountered from warm wetlands to cold arid lands.

Gleization

Gleying or gleization is a process that produces and maintains unoxidized minerals in soils and is a term derived from a Russian term for the grey clay of swamps and bogs. Waterlogged peat-covered stagnant groundwaters allow the preservation of ferrous iron in clay minerals, such as grey smectite, carbonates, such as the siderite of freshwater bogs, and sulphides, such as the pyrite of mangrove swamps and salt marshes. In normally drained soils these minerals rust to produce red and brown clays, hydroxides such as goethite, and oxides such as haematite (**Table** 3). Goethite and haematite also form within gleyed soils when a short-term depression of the water table allows the atmospheric penetration of oxygen. Despite these red nodules and concretions, the dominant colour of gleyed soils is bluish or greenish grey (**Figure** 4).

Paludization

Paludization is literally ponding, but a pond would not be commonly understood as a soil. Paludization is soil flooding that is tolerated by swamp trees but not by most soil decomposers. Paludization is thus an accumulation of undecayed plant debris as peat in the waterlogged surface layer (O horizon of **Table** 2) of Histosols (**Table** 1). This process requires a balance between plant production and decomposition. If ponding is intermittent and the soil is moderately oxidized, usually because of a low subsidence rate, then fungal and other decay prevents the accumulation of plant debris. If, on the other hand, ponding is too deep or prolonged, because of high subsidence rates, then soil stagnation kills the roots of woody plants, thus cutting off the supply of vegetation for further peat accumulation. As swamp forests die from anoxia at the roots, peaty soils become overwhelmed by lakes, bayous, or lagoons. The rate of subsidence and accumulation of woody peats is generally between 0.5 mm and 1 mm per year, because of constraints on the growth rate of woody plants in low-fertility peaty substrates and the depth of penetration of air and decomposers within woody peats. Herbaceous plants and mosses are less constrained in their growth rates and form domed peats that rise well above the water table. Peat accumulation in both cases involves addition from the top, in the same way as sediment accumulation, and thus differs from soil-forming processes that modify pre-existing materials. The progress of paludization leads to progressively thicker peat (**Figure** 1).

Podzolization

Podzol in its original Russian means ‘under ash’ and refers to the light-coloured quartz-rich (E) horizon immediately beneath the humus. Many podzolic

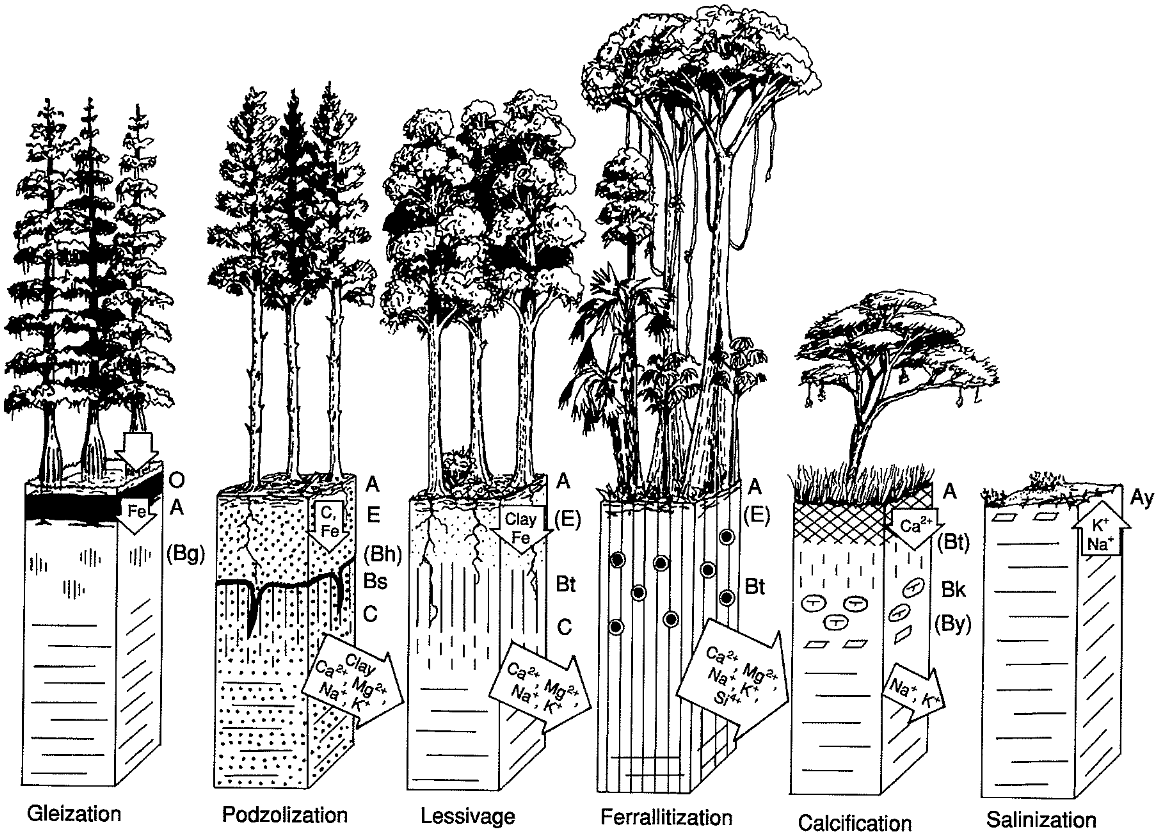

Figure 3 Selected common soil-forming processes arranged along a climatic gradient. The ecosystems depicted are (from left to right): bald cypress swamp, spruce forest, oak forest, tropical rain forest, *Acacia* savannah, and saltbush scrub. Horizon nomenclature is described in **Table 1**, and the large arrows indicate the movement of key soil components. Reproduced with permission from Retallack GJ (2001) *Soils of the Past*. Oxford: Blackwell.

Table 1 Outline of soil taxonomy

Order	*Description*
Entisol	Very weakly developed soil with surface rooting and litter (A horizon) over weathered (C horizon) sediment with relict bedding or weathered igneous or metamorphic rock with relict crystals
Inceptisol	Weakly developed soil with surface rooting and litter (A horizon) over somewhat weathered (Bw horizon) clayey (Bt horizon) or calcareous (Bk horizon) subsurface
Andisol	Soil composed of volcanic ash with low bulk density and high fertility
Histosol	Peat (O horizon) over rooted grey clay (A horizon)
Spodosol	Quartz-rich clay-poor soil with bleached subsurface (E horizon) above a red-black iron–aluminia–organic cemented zone (Bs horizon)
Vertisol	Very clayey profile with common swelling clay (smectite), laterally variable thickness of surface (A horizon), and strongly slickensided subsurface (Bt horizon)
Mollisol	Grassland soil with thick crumb-textured carbon-rich surface (A horizon)
Gelisol	Permafrost soil with frost heave and other periglacial features
Aridisol	Desert soil with a shallow subsurface accumulation of pedogenic carbonate (Bk horizon) and soluble salts (By horizon)
Alfisol	Fertile forest soil with clay-enriched subsurface (Bt horizon) and high amounts of Mg, Ca, Na, and K
Ultisol	Infertile forest soil with clay-enriched subsurface (Bt horizon) and low amounts of Mg, Ca, Na, and K
Oxisol	Deeply weathered tropical soil, often highly ferruginous and aluminous, but with very low amounts of Mg, Ca, Na, and K

For technical limits of soil orders see Soil Survey Staff (2000) *Keys to Soil Taxonomy*. Blacksburg: Pocahontas Press.

soils are now included in the USDA (United States Department of Agriculture) soil order Spodosol (Table 1), which refers to the red, brown, or black (Bs) horizon below the light coloured near-surface layer. This striking differentiation between white near-surface and dark subsurface horizons is created by podzolization, which effectively leaches iron and organic matter from the upper horizons and reprecipitates them in a lower horizon. The resulting effect is as striking as the chromatographic separation of organic compounds, and podzolization is one of the few soil-forming processes that is rapid enough to have been recreated under controlled laboratory conditions. The process is particularly helped by highly acidic soil solutions (with a pH of less than 4) in well-drained soils of humid climates under acid-generating litter such as that of conifer forest (**Figure** 3). Under highly acidic conditions clay minerals are destroyed, so Podzols and Spodosols usually have a sandy texture.

Ferrallitization

The term ferrallitization is derived from iron (Fe) and aluminium (Al), which become enriched in minerals such as haematite, kaolinite, and gibbsite during intense weathering of well-drained tropical soils such as Oxisols (**Figure** 3). Much of the loss of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) by hydrolysis requires carbonic acid derived from the carbon dioxide of soil respiration, yet the soil pH remains above 4, so that clays are not destroyed. Mitigation of acidity and deep oxidation of these soils may in part be due to the activity of termites and tropical trees, as ferrallitization is primarily found in soils under tropical rainforest. The broad-leaved trees of tropical rainforests produce less acidic litter than conifers and other plants, and litter decomposition rates are high on humid and warm forest floors. Furthermore, ferrallitic soils commonly contain abundant microscopic (125–750 μm) spherical to ovoid pellets of oxidized clay, like the faecal and oral pellets of termites. Some ferrallitic soils appear to have passed through the guts of termites many times. Termites are unique in having extremely alkaline midguts (with a pH of 11–12.5).

Table 2 Standard acronyms for soil-horizon description

Acronym	*Description*
O	Surface accumulation of peaty organic matter
A	Surface horizon of mixed organic and mineral material
E	Subsurface horizon rich in weather-resistant minerals, e.g. quartz
Bt	Subsurface horizon enriched in washed-in clay
Bs	Subsurface horizon enriched in organic matter, or iron or aluminium oxides
Bk	Subsurface horizon enriched in pedogenic carbonate
Bn	Subsurface horizon with domed columnar structure and sodium-clays
By	Subsurface horizon enriched in salts such as gypsum and halite
Bo	Subsurface horizon deeply depleted of Ca, Mg, Na, and K
Bw	Subsurface horizon mildly oxidized and little weathered
C	Mildly weathered transitional horizon between soil and substrate
R	Unweathered bedrock

For technical limits of soil orders see Soil Survey Staff (2000) *Keys to Soil Taxonomy*. Blacksburg: Pocahontas Press.

Biocycling

Biocycling includes a variety of processes in which nutrient elements are exchanged by soil biota without reincorporation into soil minerals. In tropical soils such as Oxisols (**Table** 1) this is a very efficient process in which the decay of leaves and wood is orchestrated by waves of bacteria, fungi, ants, and termites, which excrete and die to feed a copious network of epiphytes and tree roots. Effective biocycling explains the spectacular luxuriance of tropical-rainforest ecosystems despite their extremely nutrient-depleted and humus-poor mineral soils (Oxisols). Comparable mechanisms operate in swamp forests growing in peat (Histosols), which also experience severe mineral-nutrient limitations. These mineral nutrients include the major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), but these are seldom as limiting as nitrogen, which is derived largely from the microbial recombination of atmospheric nitrogen, or phosphorous, which is derived largely from the weathering of apatite. Biocycling of

Table 3 Common kinds of chemical reactions during weathering

Reaction	*Example*
Hydrolysis	$2NaAlSi_3O_8 + 2CO_2 + 11H_2O \rightarrow Al_2Si_2O_5(OH_4) + 2Na^{+} + 2HCO_3^{-} + 4H_4SiO_4$ albite + carbon dioxide + water → kaolinite + sodium ions + bicarbonate ions + silicic acid
Oxidation	$2Fe^{3+} + 4HCO_3^{-} + 1/2O_2 + 4H_2O \rightarrow Fe_2O_3 + 4CO_2 + 6H_2O$ ferrous ions + bicarbonate ions + oxygen + water → haematite + carbon dioxide + water
Dehydration	$2FeOOH \rightarrow Fe_2O_3 + H_2O$ goethite → haematite + water
Dissolution	$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^{-}$ calcite + carbon dioxide + water → calcium ions + bicarbonate ions

Figure 4 Red and brown mottles of goethite in the upper part of the profile and dark stains of pyrite formed by gleization in the lower part of the profile of a gleyed Inceptisol, excavated as a soil column from a salt marsh on Sapelo Island, Georgia, USA. Hammer handle is 25 cm long.

nitrogen is especially important during the early development of soils such as Entisols and Inceptisols, which are developed over decades or centuries. Biocycling of phosphorous becomes increasingly important in very old soils such as oxisols and ultisols, which are depleted in apatite over thousands or millions of years.

Lessivage

Lessivage or argilluviation is the process of clay accumulation within a subsurface (Bt or argillic) soil horizon (**Figures 1, 2** and 3). This is a common and widespread soil-forming process in the forested soils of humid climates, particularly Alfisols and Ultisols (**Figure** 5). The clay is primarily derived from a hydrolytic weathering reaction in which clays remain as a residuum and dissolved cations are removed in groundwater during the incongruent dissolution of feldspars and other minerals by carbonic acid

Figure 5 Light-brown near-surface (E) and dark-brown subsurface (Bt) horizons of an Alfisol produced by lessivage near Killini, Greece. Hammer handle upper right is 25 cm long.

(**Table** 3). Driving the reaction are abundant rainfall and high soil respiration rates fuelled by high primary productivity. Clay forms rinds around mineral grains of the sedimentary, igneous, or metamorphic parent material, but is also washed down cracks in the soil created by desiccation, roots, and burrows. This washed in or illuvial clay has a very distinctive banded appearance, which is obvious in petrographic thin sections. The clay is not washed any lower than the water table, where percolating rainwater ponds. Clay is less common near the surface of the soil, where unweathered grains are added by wind and water, and grains are leached of clay by plant acids. The net effect is a subsurface clayey horizon that becomes more clayey over time (**Figures 1, 2** and 3).

Lixiviation

Lixiviation is a process of leaching of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) from soil minerals and their loss from the soil in groundwater. Lixiviation is a component of ferrallitization, podzolization, and lessivage, and represents the progress of the hydrolysis chemical reaction, in which hydronium ions (H^{+}) of a weak acid (usually carbonic acid) displace cations into solution and thus convert primary minerals such a feldspars into soil minerals such as clays (**Table** 3). The term lixiviation is primarily used to describe the beginnings of this process in soils such as Entisols and Inceptisols that have developed over only decades or centuries. Such young soils have not yet acquired the distinctive deeply weathered and oxidized horizons produced by ferrallitization in Oxisols, the distinctive leached (E) and enriched (Bs) horizons produced by podzolization in Spodosols, or the distinctive clay-enriched subsurface (Bt) horizons produced by lessivage in Alfisols and Ultisols.

Melanization

Melanization is a process of soil darkening due to the addition of soil organic matter. The process is best known in Mollisols, the fertile dark crumb-textured soils of grasslands (**Figure 6**). In these soils melanization is largely a product of the activities of grasses and earthworms. Earthworms produce faecal pellets rich in organic matter and nutrients such as carbonate. Earthworms also produce slime, which facilitates their passage through the soil. Root exudates from grasses are also added to soil crumbs. Many soils have dark humic near-surface horizons, but a peculiarity of grassland soils is that dark organic fertile crumb-textured soil extends to the base of the rooting zone, which can be more than a metre deep in soils under tall-grass prairie. Melanization also occurs in swamp and marsh soils (gleyed Inceptisols and Entisols), where the decay of humus is suppressed by poor oxidation and waterlogging. Unlike the alkaline crumb-textured melanized surface of grassland soils, the melanized surface of wetland soils is nutrient-poor, acidic, and has a massive to laminated fabric. Melanization is not usually applied to the precipitation of amorphous Fe–Mn oxides (birnessite) in gleyed soils, which can also produce dark soil. The creation of these Fe–Mn-stained (placic) horizons is a process of gleization rather than melanization.

Figure 6 Dark organic-rich surface (mollic epipedon) of a Mollisol formed by melanization near Joliet, IL, USA. The shovel handle is 15 cm wide at the top.

Andisolization

Andisolization is the formation of fertile mineralogically amorphous low-density horizons within soils of volcanic ash (Andisols). Many volcanic ashes are composed largely of small angular fragments (shards) of volcanic glass. Unlike soil minerals such as feldspar, volcanic glass weathers, not to crystalline minerals such as clay, but to non-crystalline compounds such as imogolite. The loosely packed angular shards and colloidal weathering products create a soil of unusually low bulk density (1.0–$1.5\,\mathrm{g\,cm^{-3}}$, compared with 2.5–$3.0\,\mathrm{g\,cm^{-3}}$ for most common minerals and rocks). Furthermore, these colloidal compounds contain plant-nutrient cations, and particularly phosphorous, in a form that is more readily available to plants than those of other kinds of soils dominated by crystalline minerals such as apatite. Andisolization is not sustainable for more than a few thousand years unless there are renewed inputs of volcanic glass, because glass and other colloids (such as imogolite) weather eventually to oxides and clay minerals.

Vertization

Vertization is the physical soil overturning and mixing by means of the shrink–swell behaviour of clays. It occurs mostly in Vertisols but also in Entisols, Inceptisols, Mollisols, and Alfisols. It is especially characteristic of soils rich in swelling clays (smectites), which swell when wet and shrink when dry. Also characteristic is a climate with a pronounced seasonal contrast in precipitation. During the wet season the clays swell and buckle under the pressure of their inflation. During the dry season they open up in a system of cracks, which are then partly filled by wall collapse. This fill exacerbates the buckling in the next wet season so that the soil develops ridges or mounds with intervening furrows or pits, called gilgai microtopography. In a soil pit, the cracks of mounded areas divide areas of festooned slickensides under the furrows and pits in a distinctive arrangement called mukkara structure (**Figure 7**). Vertization is mainly a phenomenon of semiarid to subhumid regions. Soils of arid regions are generally not sufficiently clayey, whereas soils of humid regions are generally too deeply weathered to contain abundant smectite and are also stabilized by massive plant and animal communities.

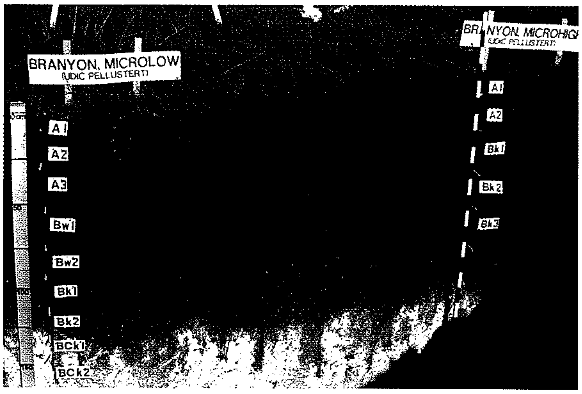

Figure 7 Gilgai microrelief (low to left, high to right) and its subsurface mukkara structure (festooned intersecting slickensided cracks) produced by vertization in the Branyon clay soil, a Vertisol, near New Braunfels, TX, USA. Scale to left shows 50 cm and 100 cm; red and white bands on pole to right are 10 cm wide.

Anthrosolization

Anthrosolization is the alteration of soil by human use, such as buildings, roads, cesspits, garbage dumps, terracing, and ploughing. Archaeological ruins and artefacts are important clues to prior occupation of a site, but many sites also contain impressive amounts of mollusc shells and mammal and fish bones. A distinctive soil structure of subsoil pockets of laminated clay between large soil clods is produced by moldboard ploughs. The primitive or ard plough also tends to disrupt the natural crumb structure to a fixed depth (plough line). Phosphorous content is an indicator of human use. Many soils have trace amounts of phosphorus (10–20 ppm by weight), but occupation floors and long-used garden soils and middens have large amounts of phosphorous (1000–2000 ppm). Anthrosolization is locally common worldwide in cities and fields, both ancient and new, but is scattered and local in deserts, polar regions, and high mountains.

Calcification

Calcification is the accumulation of calcium and magnesium carbonates in the subsurface (Bk) horizons of soils (**Figures 1** and **3**). The carbonate is usually obvious, appearing as soft white filaments, hard white nodules, and thick white benches within the soil. Calcification is largely a soil-forming process of dry climatic regions, where evaporation exceeds precipitation. It is characteristic of Aridisols but is also found in some Mollisols, Andisols, Vertisols, Inceptisols, and Alfisols. The source of the carbonate is the soil respiration of roots, soil animals, and microorganisms. Calcification requires soil respiration at levels greater than those in hyperarid soils, where halite and gypsum formed by salinization prevail, and less than those in humid soils, where lessivage prevails. The source of the cations of calcium and magnesium, which create the soil minerals calcite and dolomite, respectively, is the weathering of soil minerals by hydrolysis (**Table 3**). Some of these cations originate from feldspars and other minerals of the parent material, but dry regions of calcification have open vegetation and are often dusty, so that carbonate and feldspar dust is an important source of cations. Dissolved cations from hydrolytic weathering are commonly lost downstream in the groundwater in humid regions, but in arid lands the water table is commonly much deeper than the soil profiles, which are seldom wet much beyond the depth of rooting. The subsurface zone of groundwater evaporation and absorption is where the wisps of soil carbonate form, then coalesce into nodules and, eventually, thick layers.

Solonization

Solonization is a process by which clays rich in soda are formed within the soils of dry climates (Aridisols), where the hydrolytic mobilization of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) is weak. Hydrolysis removes cations from soils by lixiation in humid climates, but in dry climates the acidity created by soil respiration after rain storms is sufficient to remove cations from minerals such as feldspar without leaching them from the profile. Solonized soils commonly contain carbonate nodules of dolomite or low-magnesium calcite, formed by calcification, as well as salts of halite and gypsum, formed by salinization. Solonized soils have illitic clays rich in potassium and smectite clays rich in sodium, and the progress of solonization can be assessed by measuring the pH (which is usually around 9–10), by chemical analysis, or by X-ray diffraction to determine the mineral composition. A field indicator of solonization is the presence of domed columnar peds that run through most of the subsurface (natric or Bn) horizon of the soil (**Figure 8**). The sodium-smectite clays of solonized soils have some shrink–swell capacity, meaning that they form prismatic cracks as the soil dries out and swelling or domed tops to the prisms when the soil is wet. Solonization is common around desert playa lakes and salinas and in coastal soils affected by saltwater spray.

Solodization

Solodization is intermediate between solonization and lessivage, and creates profiles with acidic-to-neutral near-surface horizons but alkaline subsurface

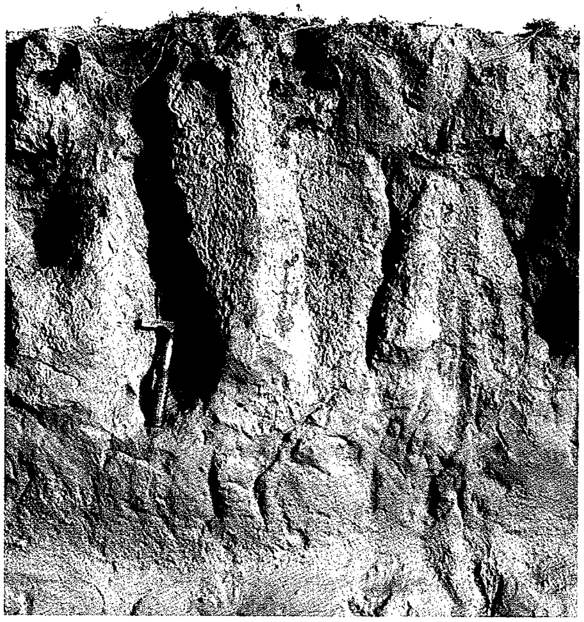

Figure 8 Domed columnar peds produced by solonization in an inceptisol near Narok, Kenya. Hammer handle is 25 cm.

horizons dominated by sodium-smectite. Solodized soils have domed columnar clayey peds in a subsurface (Bn) horizon, but these are sharply truncated by a granular leached (E) horizon. Solodization occurs in desert soils (Aridisols) with better vegetative cover and a more humid climate than solonized soils.

Salinization

Salinization is the precipitation of salts in soils (**Figure** 3) and is found mostly in desert soils (Aridisols). The most common salts are halite and gypsum, which can form either as clear crystals within soil cracks or as sand crystals that engulf the pre-existing soil matrix. Salts are easily dissolved by rain and so accumulate in regions where there is a marked excess of evaporation over precipitation, which is generally less than 300 mm per year. There is a strong relationship between mean annual precipitation and the depth of leaching of salts in soils. Salinized soils are sparsely vegetated or lack vegetation, and occur in playa lakes, sabkhas, and salinas. Although these are commonly regarded as depositional environments, they are significant soil environments as well.

Cryoturbation

Cryoturbation is the mixing of soils by the freezing and thawing of ground ice. The ice can form disseminated crystals, hair-like threads, thin bands, thick benches, or vertical cracks depending on the local climatic conditions. Soil mixing results from the expansion of water to ice during winter freezing and the relaxation of the deformation on summer melting. Ice-wedge polygons, for example, are wide polygonal cracks that are filled with ice in winter but can be filled with layered sediments in water during the summer in climates where the mean annual temperature is less than −4°C. Sand-wedge polygons form in colder climates where the mean annual temperature is less than −12°C; here, summer melting of ice is limited and sediment fills cracks between the ice and soil in a series of near vertical layers.

Conclusion

Soil-forming processes are varied and complex, and our understanding of them guides the classification, description, and management of soils. The processes are also of interest in simplifying the vast array of chemical reactions, biological processes, and physical effects that create soil. Some processes are more common and widespread than others. Lixiviation and its underlying hydrolysis chemical reaction is perhaps the most important weathering process on Earth, affecting geomorphology, sedimentation, ocean chemistry, and climate. Other processes are restricted to more specific climatic, biotic, geomorphological, geological, and temporal environments, but are no less important in their local environments.

Glossary

Alfisol	A fertile forested soil with subsurface enrichment of clay.
Andisol	A volcanic-ash soil.
Andisolization	A soil-forming process that creates low-density non-crystalline fertile soil from volcanic ash.
Anthropic epipedon	A soil surface modified by human use.
Anthrosolization	A soil-forming process involving modification by human activities.
Argillic horizon	A subsurface horizon of soil enriched in clay.
Argilluviation	A soil-forming process that involves creating clay and washing it into a subsurface clayey horizon.
Aridisol	A soil of arid regions, usually containing carbonate nodules.
Biocycling	The recycling of nutrient elements by biota.
Birnessite	A non-crystalline mixture of iron and manganese oxides.
Entisol	A very weakly developed soil.

Ferrallitization A soil-forming process involving intense weathering that removes most elements other than iron and aluminium.

Gelisol A soil of permafrost regions, usually containing ground ice.

Gibbsite An aluminium hydroxide mineral ($Al(OH)_3$).

Gilgai A soil microrelief consisting of ridges or mounds alternating with furrows or pits.

Gleization A soil-forming process involving chemical reduction of the soil due to waterlogging.

Halite A salt mineral (NaCl).

Haematite An iron oxide mineral (Fe_2O_3).

Imogolite A colloidal weathering product of volcanic-ash soils.

Inceptisol A weakly developed soil.

Lessivage A soil-forming process that creates clay and washes it into a subsurface clayey horizon.

Lixiviation A soil-forming process that involves leaching nutrient cations from the soil.

Melanization A soil-forming process that involves darkening the soil with organic matter.

Mollic epipedon A humic fertile crumb-textured soil surface typical of grassland soils.

Mollisol A grassland soil with a humic fertile crumb-textured surface.

Mukkara A soil structure consisting of festooned and slickensided cracks between uplifted parts of the soil; the subsurface structures below gilgai microrelief.

Natric horizon A subsurface horizon of soil enriched in sodium-clay.

Oxisol A deeply weathered soil of tropical humid regions.

Paludization A soil-forming process involving peat accumulation in waterlogged soils.

Ped A clod, a unit of soil structure.

Placic horizon Iron- and manganese-stained bands and nodules in soils.

Plaggen epipedon A ploughed surface horizon of soils.

Podzol A sandy soil with a bleached near-surface horizon.

Podzolization A soil-forming process in which acid leaching creates a bleached sandy upper horizon and an iron- or organic-rich subsurface horizon.

Siderite An iron carbonate mineral ($FeCO_3$).

Solonization A soil-forming process that creates soda-rich clays and domed columnar peds in arid regions.

Spodosol A sandy clay-poor soil with an iron- or organic-rich subsurface horizon.

Ultisol A deeply weathered forest soil with subsurface enrichment in clay.

Umbric epipedon A humic acidic clayey massive-to-laminar soil surface found in wetland soils.

Vertisol Swelling clay soil.

Vertization A soil-forming process involving deformation and mixing due to the shrink–swell behaviour of clay during drying and wetting cycles.

See Also

Carbon Cycle. **Clay Minerals**. **Engineering Geology:** Ground Water Monitoring at Solid Waste Landfills. **Sedimentary Environments:** Deltas; Deserts. **Sedimentary Processes:** Glaciers. **Soils:** Palaeosols. **Weathering**.

Further Reading

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