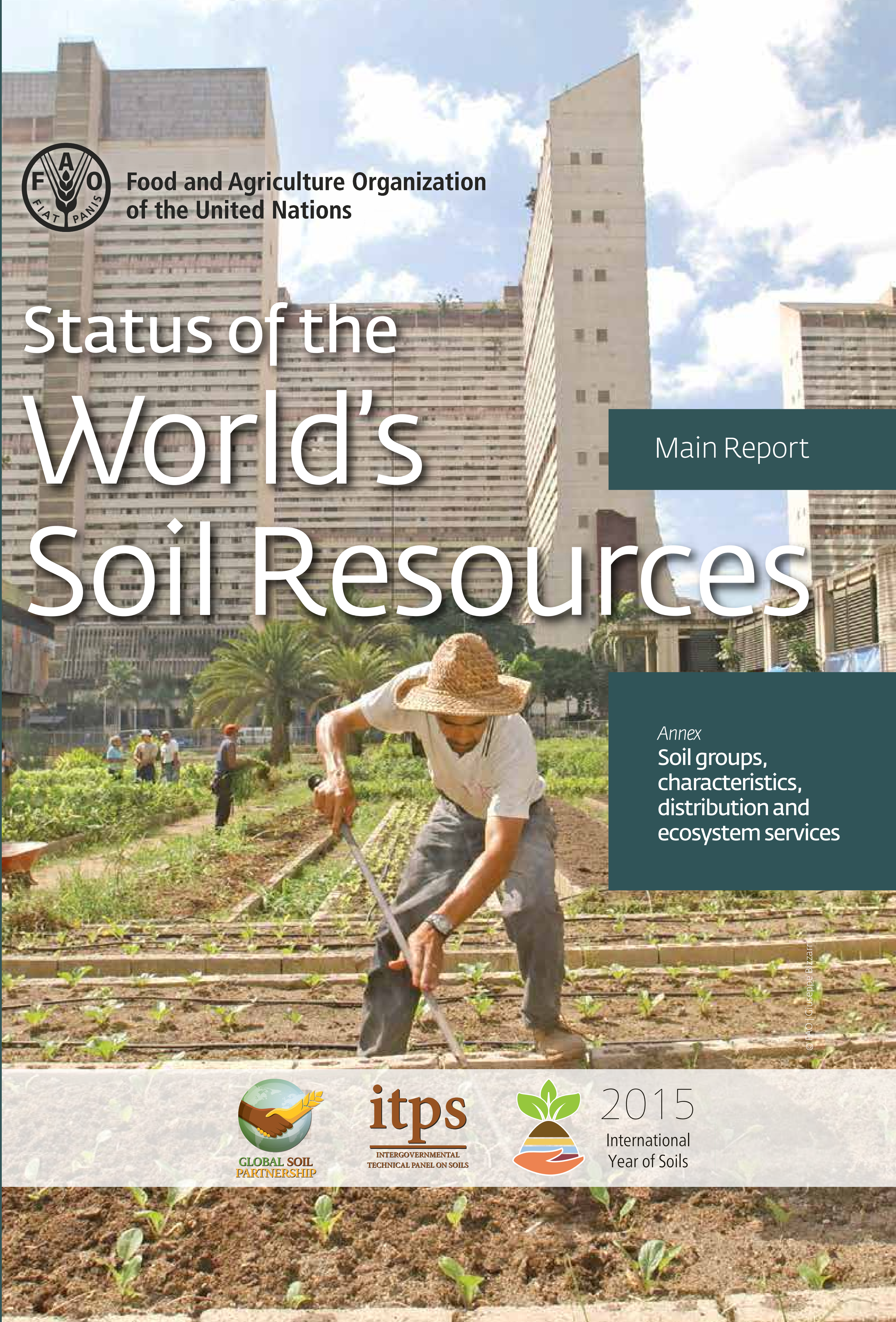
Food and Agriculture Organization
of the United Nations

Status of the World's Soil Resources

Main Report

Annex
Soil groups, characteristics, distribution and ecosystem services



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INTERGOVERNMENTAL TECHNICAL PANEL ON SOILS

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Annex | Soil groups, characteristics, distribution and ecosystem services

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1 | Soils with organic layers

HISTOSOLS[1]

In most Histosols organic materials are deposited in a wetland environment to form peat. The waterlogged conditions, oxygen deficiency and, very often in the north, low temperatures, and acidic conditions, inhibit decomposition and lead to accumulation of organic matter (Kolka *et al.*, 2012). In some Histosols the organic material is derived from upland forest vegetation under cool, wet high rainfall conditions.

The soil profile features of Histosols reflect the origin of the organic material and the degree of decomposition, while the occurrence of permafrost is a common feature in these soils in arctic landscapes (FAO, 2014; Figure A1). The soil materials in Histosols are generally dark brown to almost black reflecting the high organic matter content. These soils support forest, sedge and shrubby-moss types of vegetation and occupy a poorly-drained, level topography. However, some Histosols in the coastal areas are found on slopes or form a continuous cover on the terrain, such as blanket bogs. Most of these soils developed during the Holocene Epoch. The age of the basal peat (the peat layer just above the mineral contact) is usually five to nine thousand years old.

Histosols are common soils in the Boreal and Arctic landscapes of the Northern hemisphere, although they may also occur in temperate and some tropical regions. Globally, peat lands (organic soils developed on peat) cover approximately 4 million km^2 (World Energy Council, 2013). However, most of the Histosols (3.5 million km^2) are found in the Northern Circumpolar Permafrost Zone where 76 percent of these soils are perennially frozen (Tarnocai *et al.*, 2009). Nearly 80 percent of all Histosols occur in Russia, Canada and the United States.

The global significance of Histosols is that they store huge amounts of organic carbon. It has been estimated that they represent a carbon pool of 500 billion tonnes of organic carbon (Strack, 2008). In addition, the present rate of annual carbon sequestration is approximately 100 million tonnes (Strack, 2008), which exceeds the present carbon loss from these soils due to agriculture, peat extraction and other human-made disturbances. Due to climate change, however, the water-saturated Histosols could be a source of greenhouse gases, mainly in the forms of methane (Couwenberg *et al.*, 2010), but they also could be the source of carbon dioxide if these soils dry out and are affected by wildfires.

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[1] The Reference Soil Group names of the World Reference Base developed by the IUSS Working Group RB (FAO, 2014) are used. Where the approximate equivalent name in the USDA Soil Taxonomy (Soil Survey Staff, 2014) is different, the USDA name is cited in brackets.

Photo by C. Tarnocai

Photo by S. Khokhlov

Figure A1 | (a) A Histosol profile and (b) a peatbog in East-European tundra.

ANTHROSOLS (Plagganthrepts, Haplanthrepts, some Orthents)

Anthrosols (Figure A2) are soils formed, altered or influenced by intense human agricultural activities. They are associated with long-term agricultural management in many parts of the world, especially where ancient civilizations were present. Technosols (see below) are also human-influenced but are connected with more recent human activities in industrial and urban environments resulting in the presence of artificial and man-made objects in the soil.

The formation of Anthrosols is termed anthropedogenesis. This formation includes various processes induced by human activities in ancient agricultural systems, such as periodic irrigation and drainage, continuous build-up by applying transported manure or other soil materials, and long-term fertilization. These soils are often enriched with phosphorus and carbon, and are characterized by movement and accumulation of clay and clay-organic complexes, reduction and oxidation of iron-manganese oxides and even physical compaction, processes that occur at an accelerated rate compared with that of natural soil changes. This results in a special soil morphology and soil horizon development, such as the formation of a surface horizon with a high organic matter content, the development of compacted plough-pans and the formation of redoximorphic features, all of which represent the outcome of anthropedogenesis.

Anthrosols occur widely across the globe. They appear, for example, in ancient agricultural regions under paddy cultivation, or in semi-arid and arid regions where irrigation and sedimentation have occurred. Anthrosols may also show a long-term build-up of elements from long-term manure application and phosphorus enrichment. Globally, the total extent of Anthrosols is estimated at more than 200 million ha, of which 80 percent are cultivated paddy fields.

Anthrosols make up the most fertile agricultural land in the world and provide food as an essential ecosystem provisioning service. They often are an inherent part of unique agricultural systems and as such have a cultural function as well.

Figure A2 | (a) An Anthrosol (Plaggen) profile and (b) associated landscape in the Netherlands.

TECHNOSOLS (Non soils)

Technosols (Figure A3) are common soils on all continents. They are dominant in urban areas, where there are only remnants of natural soils and where soils radically transformed by different human activities dominate together with 'new soils'. The development of particular horizons and layers in such soils is not reflected in natural conditions of the system (Charzyński *et al.*, 2013). Technogenic activities lead to the construction of artificial soil, soil sealing or extraction due to mining of materials not affected by surface processes in natural landscapes. The largest areas of Technosols in comparison to country total area can be found in countries with an extremely high percentage of urbanization such as Belgium and the United Kingdom. The largest areas dominated by Technosols are located within the largest mega-cities, for example the Yangtze River Delta Megalopolis in China (population of about 90 million); the Taiheiyō Belt in Japan, also known as Tokaido corridor (population of nearly 80 million); and the Great Lakes region in the United States (60 million).

Technosols are soils of urban, industrial, traffic, mining and military areas.

There are four main varieties of Technosols:

- soils sealed by *technic hard* material (hard material created by humans in industrial processes) e.g. asphalt or concrete.
- soils containing a large amount (more than 20 percent in the upper 1 m of soil) of *artefacts*. Artefacts are objects in the soil formed or strongly transformed by human activity or excavated from beneath the earth. Examples of artefacts are mine spoils, dredgings, rubbles, organic garbage, cinders, industrial dust, synthetic solids and liquids (e.g. petrol, kerosene)
- soils with geomembranes or synthetic membranes made, for example, of polyvinyl chloride (PVC) laid on the surface or into the soil.
- constructed or naturally developed shallow soils on buildings, without any contact to other soil material.

The soil profile features of Technosols are usually weak. Beneath technogenic deposits occasionally a natural soil profile can be observed. Also original profile development may still be present in contaminated natural soils.

In the urban ecosystem, soils play an essential role with their functions and ecosystem services. However, the ability of Technosols to provide ecosystem services differs from the services secured by natural soils and is often impaired (Morel *et al.*, 2015; Stroganova *et al.*, 1998). Technosols are more likely to contain toxic substances than other types of soils and should be treated with care (FAO, 2014). The benefits of Technosols and other urban soils are nonetheless numerous. They provide groundwater recharge for water supply, plant products for food supply, a medium for alternative storm-water management, sites for recreational activities, and buffering of temperature and humidity. They serve as a medium of retention, decomposition and immobilization of contaminants, and for dust entrapment to reduce dust content in the air. Technosols can be also considered as historical archives (Lehmann and Stahr, 2007).

Figure A3 | (a) A Technosol profile and (b) artefacts found in Technosol.

CRYOSOLS (GELISOLS)

Due to the presence of perennially frozen conditions, Cryosols have unique processes and properties different from other soil groups. Cryogenic processes, which dominate the development of these soils, are driven by the mobility of unfrozen soil water as it migrates along the thermal gradient from warm to cold. This unfrozen water then moves into the frozen soil system, and feeds the ice bodies. The increase of ice volume and the volume increase from water to ice lead to differential frost heave. This then results in cryoturbation and the formation of cryogenic macro and micro soil structures (Figure A4).

Cryosols are the major soils in the permafrost areas of the Northern Circumpolar Arctic and Subarctic as well as a large part of the Boreal Region. They also occur in the ice-free areas of Antarctica and in the subalpine and alpine areas of the mountainous regions. They cover approximately 10.2 million km^2 in the Northern Circumpolar Region (Tarnocai *et al.*, 2009) and approximately 46 thousand km^2 in the Antarctic Region (Tarnocai and Campbell, 2002). Globally, most Cryosols occur in Russia and Canada. Cryosols support forest vegetation in the Boreal and Subarctic regions and tundra vegetation in the Arctic and Alpine Regions. Most Cryosols in Antarctica are unvegetated.

Cryosols, especially those affected by cryoturbation, contain large amounts of organic carbon. Cryoturbation moves organic materials from the surface into the subsoil where it is preserved for thousands of years because of the cold soil temperatures. Cryosols in the Northern Circumpolar Permafrost Zone contain approximately 351.5 Gt of carbon in the 0-100 cm depth and 818 Gt in the 0-300 cm depth (Tarnocai *et al.*, 2009). Due to climate change and the resulting thawing of these high carbon content Cryosols, they could be the source of greenhouse gases (carbon dioxide and methane), which would then further increase climate warming.

Figure A4 | (a) A Cryosol profile and (b) associated landscape in West Siberia, Yamal Peninsula.

LEPTOSOLS (lithic sub-groups of the Entisol order)

Leptosols include soils that are very shallow (less than 25 cm) with continuous rock occurring at or near the surface, and soils that are very gravelly (with less than 20 percent soil particles). Bare rock at the surface is included in the concept of Leptosols (FAO, 2014; Figure A5). These are generally young soils with little or no soil profile development. When Leptosols form in calcareous materials, dissolution and removal of carbonates may occur and biological activity may be high.

Leptosols may occur everywhere where rocks are near the surface. They are particularly prevalent in strongly eroding areas in mountainous land at high and medium altitude with a strongly dissected topography. Minor occurrences are also along rivers where gravelly deposits have accumulated without substantial admixture of fine earth material. Leptosols are the most extensive soils in the world with an estimated extent of more than 1 600 million ha. They are associated with mountain ranges, with the Sahara and the Arabian Desert.

In spite of their considerable extent, Leptosols have largely been ignored in soil studies mainly because of their very limited interest for agriculture and the general lack of profile development. This may not be fully justified as more than 12 percent of the world's population lives in a mountainous environment where Leptosols are common (Nachtergaele, 2010).

Leptosols have a potential for seasonal grazing and as forest land. Erosion is the greatest threat in montane Leptosol areas of the temperate zone where population pressure (for example from tourism), over-exploitation and environmental pollution lead to the increasing deterioration of the natural vegetation and to soil erosion.

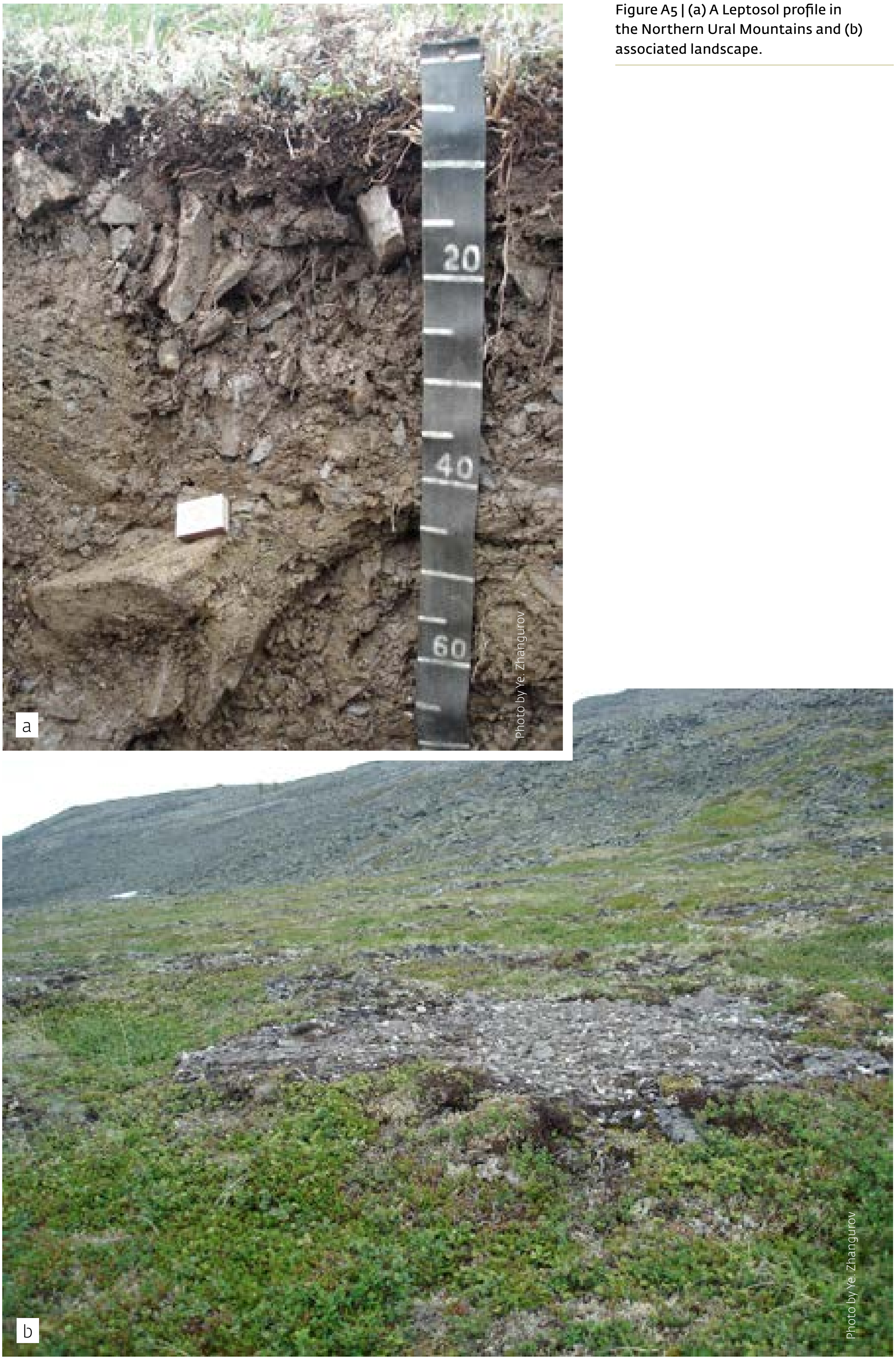

Figure A5 | (a) A Leptosol profile in the Northern Ural Mountains and (b) associated landscape.

VERTISOLS

Vertisols (Figure A6) are expansive clayey soils that shrink and swell extensively with changes in moisture content. Cracking, gilgai microrelief, and high clay content are common attributes of Vertisols, but these properties are not exclusive to them. Slickensides are the common morphogenetic link to Vertisols and Vertic intergrades (Ahmad, 1983; Coulombe *et al.*, 1996a and 2000; Soil Survey Staff, 1999). The soil mechanics model of shear failure, slickenside formation, and oblique thrusting appear to better fit observed morphological properties, systematic soil property depth functions, and leaching vector transfers than the traditional inversion pedoturbation model (Ahmad, 1983; Coulombe *et al.*, 1996a; Wilding and Tessier, 1988). Shrink-swell in Vertisols is due mainly to inter- and intra-particle pore volume changes that occur under field conditions at high matric potentials (-1/3 to -10 bars). This is in contrast to the commonly held interlayer clay dehydration/rehydration mechanism invoked for shrink/swell dynamics (Wilding and Tessier, 1988). While smectite is a clay mineral component commonly found in Vertisols, many other clays including kaolinite, halloysite, mica and mixed layer assemblages of vermiculite, smectite and chlorite may occur as dominant or co-dominant associates (Coulombe *et al.*, 1996b). Mineralogy controls shrink-swell phenomena by the presence of fine-grained particles which have high external surface areas, high flexibility and a packing geometry that favours micropores a few micrometres in diameter or less (Wilding and Tessier, 1988; Coulombe *et al.*, 1996b).

Vertisols commonly occur in regions of grasslands and savannas, but may also be found under mixed pine and deciduous forests. Parent materials may originate from sedimentary, igneous or metamorphic origins but must provide, either from inheritance or weathering, a high content of clay with high surface area. Soil moisture conditions vary widely from aridic to aquic with the caveat that soil moisture stress, desiccation and cracking must occur at some time in most years. Topography controls gilgai patterns with normal gilgai commonly occurring on slopes < 4 percent, while linear gilgai occur on steeper landforms. Most Vertisols occur on Pleistocene-age or younger geomorphic surfaces that are several thousand to hundreds of thousands of years old (Coulombe *et al.*, 1996a and 2000).

Vertisols occur in over 100 countries and represent about 316 million km^2 or 2.4 percent of the global ice-free land area (Dudal and Eswaran, 1988; Ahmad, 1983; Coulombe *et al.*, 1996a; Wilding, 2000; Coulombe *et al.*, 2000). Over 75 percent of Vertisols are found in India, Australia, Sudan, United States, Chad and China. Forty-seven percent are in tropical regions, 52 percent in temperate zones, and 1 percent in cold boreal climates (Wilding, 2000; Coulombe *et al.*, 2000).

While Vertisols are very productive land resources in many parts of the world, especially in the developed world, they are among the most difficult resources to manage (Coulombe *et al.*, 1996a; McGarity *et al.*, 1984; Ahmad and Mermut, 1996). They require well above average managerial skills for success because of their high energy requirements, limited range of soil-water workability, high physical instability, susceptibility to seasonal flooding, fertility constraints, and susceptibility to wind and water erosion. They are best managed with shallow and infrequent tillage. Irrigation scheduling should be frequent with low application rates. Despite their resilience, Vertisols are subject to structural degradation, loss of macroporosity, loss of biological diversity and formation of tillage pans when used under continuous, long-term mechanical cultivation practices. Rejuvenation of native structural conditions can only be partially achieved after decades of fallow (Coulombe *et al.*, 1996a; McGarity *et al.*, 1984; Puentes and Wilding, 1990). Construction activities are constrained by the propensity of Vertisols for soil failure and high shrink/swell activity (Coulombe *et al.*, 2000; McGarity *et al.*, 1984; Ahmad and Mermut, 1996). High bioremediation and physical/chemical sorption capacities promote favourable habitats for land treatment of waste products because Vertisols when wet are slowly permeable, biochemically reduced, and have long mean residence times for intestinal fluids.

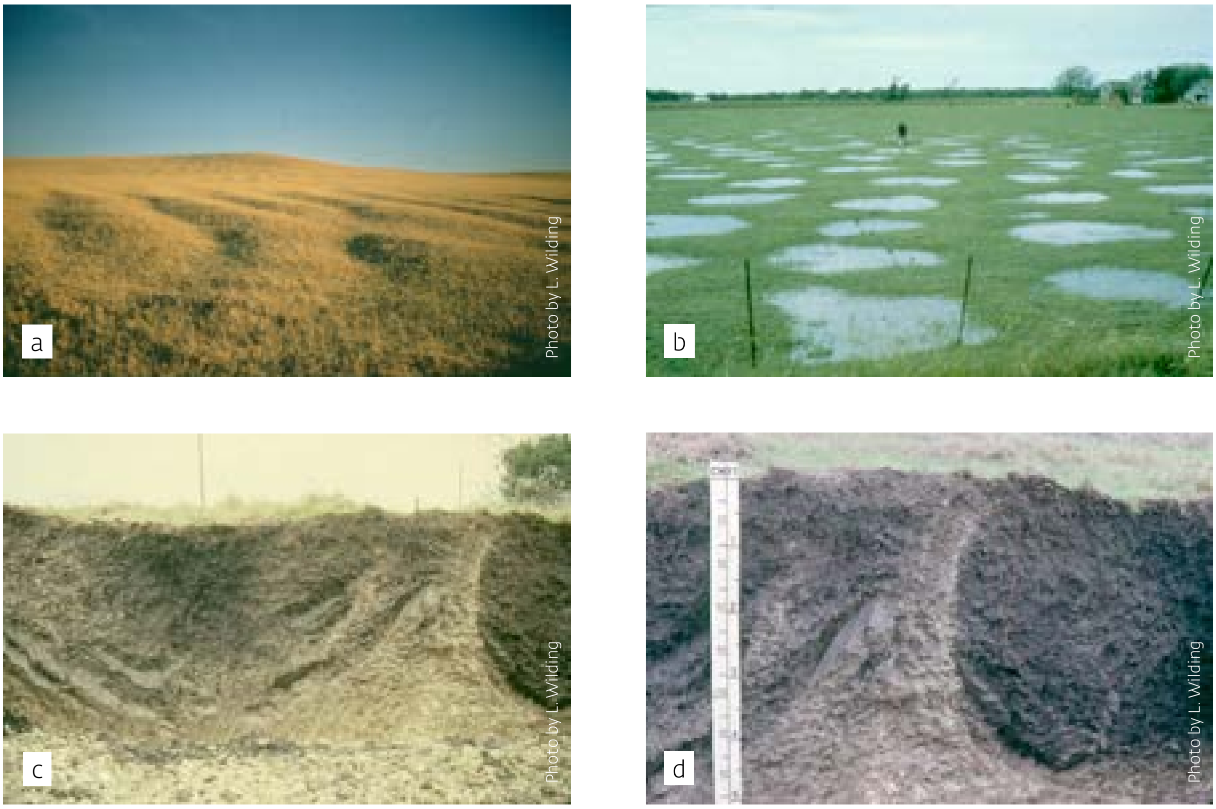

Figure A6 | Vertisol gilgai patterns and associated soils: (a) linear gilgai pattern located on a moderately sloping hillside in western South Dakota. Distance between repeating gilgai cycle is about 4 m. (b) Normal gilgai pattern occurring on a nearly level clayey terrace near College Station, TX. After a rainfall event microlows have been partially filled with runoff water from microhighs - repeating gilgai cycle about 4 m in linear length. (c) Trench exposure of soils excavated across normal gilgai pattern - repeating gilgai cycle about 4 m in linear length. Dark-colored deep soil in microlow (leached A and Bss horizons) with light-colored shallow calcareous soils associated with diaper in microhigh (Bssk and Ck horizons). The diaper has been thrust along oblique slickenside planes towards soils surface. Vertical depth of soil trench in about 2 m. (d) Close up of dark-colored soil associated with microlow and light colored diaper associated with microhigh of the trench in (c).

SOLONETZ (Natric great groups of several different orders)

Solonetz (figure A_7) are formed by salt accumulation and the leaching of the surface horizon. The dominant soil processes involved in Solonetz formation are leaching of the surface horizon combined with argilluviation and sodification manifested in the formation of columnar/prismatic structural elements.

Solonetz generally occur in flat plains that have a source of soluble salts, such as salt-bearing parent material or a shallow saline water table in semi-arid, temperate and subtropical climates that receive less than 500 mm of rainfall per year. The vegetation is commonly dominated by short grasses. The formation of these soils takes generally more than 5 000 years.

The extreme physical characteristics (high water retention, low hydraulic conductivity, strong swelling-shrinking, great plasticity) of Solonetz are linked with the high concentration of sodium in the exchange complex of the soil. Solonetz show strong profile differentiation in terms of colour, texture, structure, sodicity, salinity, alkalinity and calcareousness. Because of the high sodicity, Solonetz have a very short time window between snow melt and the following dry period for optimal ploughing. Plastic wet or dry Solonetz surface horizons cause a number of problems for cultivation. Only Solonetz with a thick surface horizon can be cropped successfully. Other Solonetz may be used for livestock farming. After reclamation, when the adsorbed sodium is replaced by calcium (by applying gypsum) and drainage, these soils can be turned into cropland.

The extent of Solonetz is estimated at about 135 million ha. They are mainly located in North America, Eurasia and Australia.

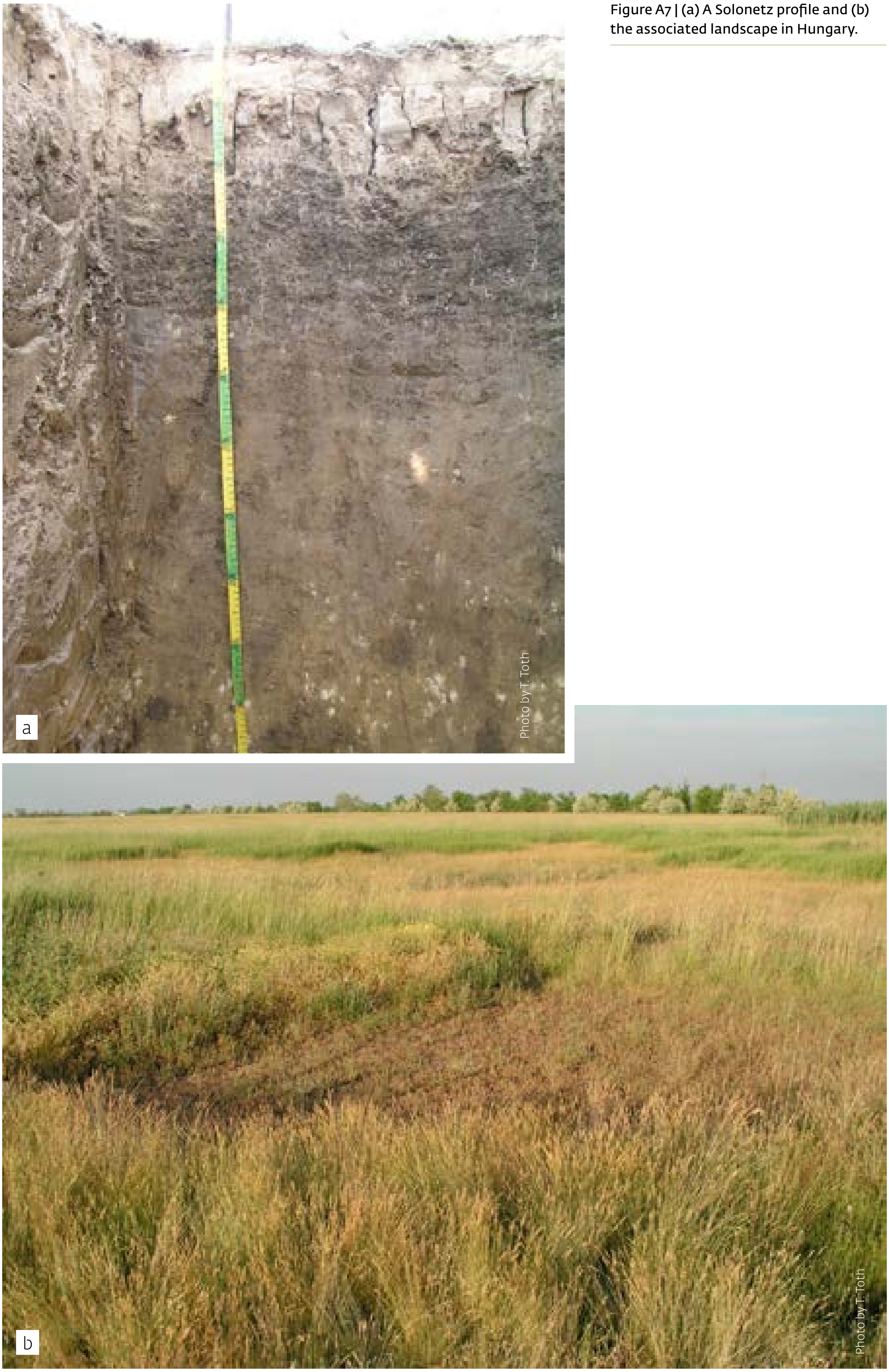

Figure A7 | (a) A Solonetz profile and (b) the associated landscape in Hungary.

SOLONCHAKS (Salids)

Solonchaks (Figure A8) are characterized by their high salt concentration, expressed by the electrical conductivity of the saturation extract (ECe) that exceeds 15 dS m^{-1} (or > 8 dS m^{-1} when the pH is ≥ 8.5). The presence of salt crystals and hydromorphic features are indicators of Solonchaks. The dominant soil processes involved in Solonchak formation are salt accumulation and the development of hydromorphic features.

These soils generally occur in inland river basins and very flat or depressed areas which have a source of soluble salts, such as salt-bearing parent material or a shallow saline water table. They also occur in coastal lowlands. Generally they are formed in arid, semi-arid and sub-humid climates where rainfall is less than 500 mm yr^{-1} and the evaporation exceeds the rainfall. The vegetation consists of salt tolerant grassland, bushes or mangroves.

Globally the extent of Solonchaks has been estimated at 260 million ha; they occur mainly in the drier parts of North America, northern Africa, the Middle East and central Asia, South America and Australia.

Solochaks are typically used for livestock farming or highly adapted irrigation farming. The vegetation on Solonchaks provides ecological services such as coast protection, grazing land and a source of wood. After leaching the salts and with drainage, these soils can be turned into cropland.

Figure A8 | (a) A Solonchak profile and (b) a salt crust with halophytes.

PODZOLS (SPODOSOLS)

The majority of Podzols (total area 4.8 million km^2) occur in humid boreal and temperate climates on light-textured rocks or quartz sands, on outwash plains and river terraces under pine forests, and on siliceous hard rocks in the mountains (Figure A9). Smaller areas occur under equatorial evergreen forests.

Podzol is a Russian folk name introduced by Dokuchaev (1879) into scientific language. It means either 'similar to ash' or 'under ash', implying that the ash is white or dark, respectively. Hence Podzols initially were mostly identified by their whitish (albic) subsurface layer resulting from the loss of iron-organic compounds. The thickness of the albic material (and of the whole Podzol solum) depends on climate and ranges from 2 m in equatorial 'giant Podzols' (Sombroek, 1966; Figure A10) to 5-10 cm in 'dwarf Podzols' on the Baltic Shield. Equatorial Podzols are confined to areas with annual rainfall from 1 800 to 3 000 mm without a marked dry season, to the weathering products of granites or gneisses, claystone and sandstone in the Amazon basin, and to marine sediments on the coastline of Brazil (Sombroek, 1966: Lucas *et al.*, 2012). A particular combination of environmental factors favours the development of acid hydrolysis and downward migration of its products immobilized at a varying depth to form a spodic horizon. The mechanism of podzolization has been discussed by many researchers. The most recent ideas summarized by Sauer *et al.* (2007).

The properties of spodic horizons and both the regional and local distribution of Podzols are in good agreement with moisture regimes: the spodic horizon is dominated by iron oxide compounds in drier conditions and by dark organic matter in humid ones. This differentiation is distinct at regional and local levels. Giant Podzols have a high organic carbon content in the spodic horizon, indicating that unusually large quantities of dissolved organic carbon were transferred from the topsoil. This is attributed to high volumes of water percolating through the soil, the chemical quality of the organic matter, and the long time for soil evolution (Lucas *et al.*, 2012). The subsoils of Podzols under a continental climate or strong drainage are commonly dominated by iron, while in other more temperate areas or less drained areas they are dominated by organic carbon (Friedland *et al.*, 1988).

Podzols may be young soils, just a few centuries old, or they may have been formed over millennia (Sauer *et al.*, 2007). Podzols buried almost 8 000 years ago were described under Histosols 2-3 m thick in West Siberia (Karavaeva, 1982).

Podzols are unstable soils even without human intervention: tree windfalls or fires induce wind erosion. Their most efficient ecological services are supporting coniferous forests, often of high quality, regulating the water balance in landscapes, and retaining some pollutants. In northern Europe, Podzols on heathlands are poorly preserved if they have been part of a Plaggen ecosystem (Blume and Leinweber, 2004).

Figure A9 | (a) A Podzol profile and (b) an associated landscape, West-Siberian Plain.

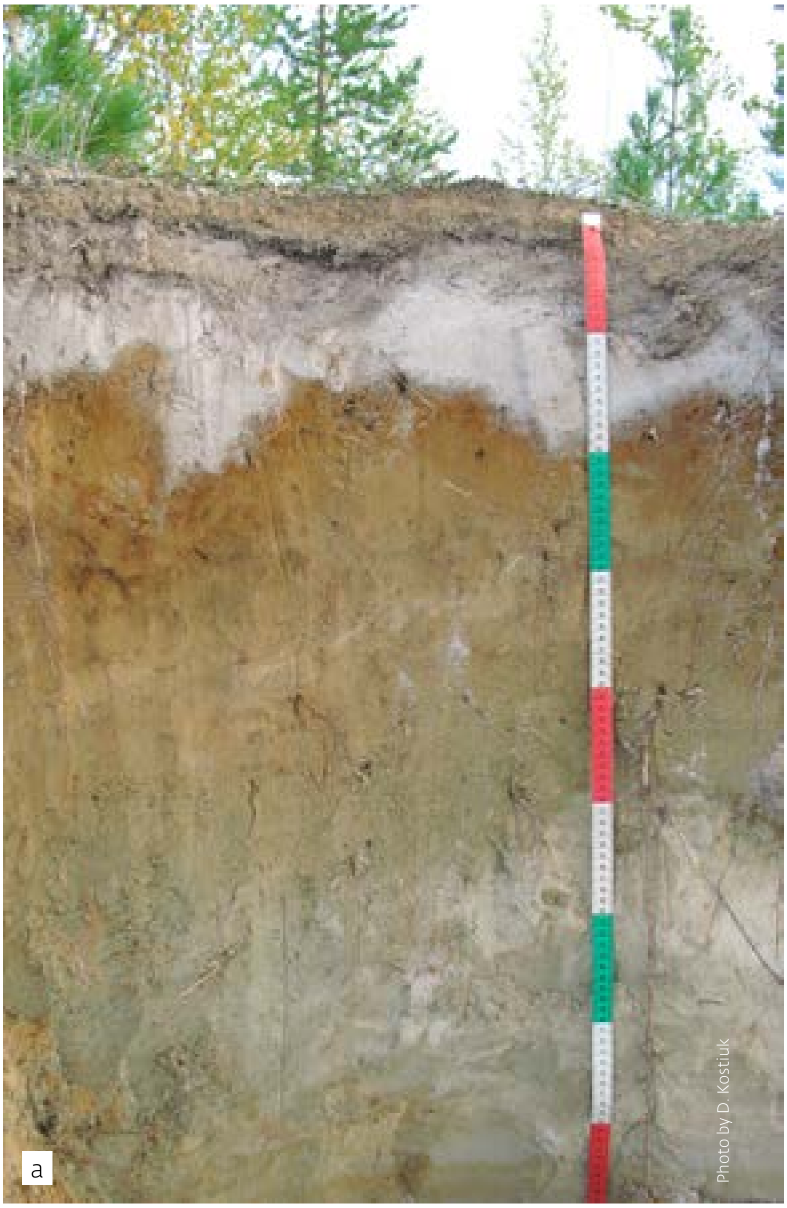

Figure A10 | (a) A giant Podzol profile and (b) an associated landscape, Brazil.

FERRALSOLS (OXISOLS)

Ferralsols (Figure A11) form where the weathering conditions are very intense, usually under tropical and subtropical humid conditions, with intense leaching of silica and alkaline and alkaline-earth cations, resulting in the relative accumulation of kaolinite and various amounts of resistant minerals such as (hydr-)oxides of Fe, Al, Mn and Ti. The distribution of clay in the soil profiles is uniform, without marked clay increase with depth. Ferralsols have low-activity clays throughout the lower horizons, and the base saturation is frequently low. Ferralsols have a distinct granular microstructure, due to the strong interaction among kaolinite and (hydr-) oxides of Fe and Al.

These soils show no large variation of clay content or evidence of clay illuviation, and the horizons are marked only by a higher content of organic carbon in the topsoil, which reduces with depth. The subsurface horizons show gradual to diffuse boundaries. The chemical characteristics reflect the leaching of base cations and advanced weathering resulting in low-activity clays. Some Ferralsols formed from basic rocks such as basalt may have better nutrient reserves, although the high iron content will result in strong phosphorus 'fixation'. The structure is usually of granular type, although some Ferralsols may develop a weak subangular block structure. They vary in the colour of their subsurface horizon from red to yellow, mainly according to the iron content in the parent material and to hydrological conditions.

Ferralsols are reported on weathering products of acid and basic rocks, and unconsolidated sediments on old and stable surfaces. They are most common on interior plateaus or slowly undulating topography in humid tropical, humid subtropical and monsoon climates. Because many climatic changes occurred since these soils were formed or the parent materials deposited, they may lack a relationship with the present vegetation, which may vary from Amazon forest to dry savannah.

The most extensive occurrences of Ferralsols are in South America, mainly in Brazil. They cover about 17 percent of Latin America and the Caribbean (Gardi *et al.*, 2014). Ferralsols are also distributed in eastern and central Africa (10 percent of the continent, Jones *et al.*, 2013) and Madagascar, in some areas of Australia and in the United States (Hawaii).

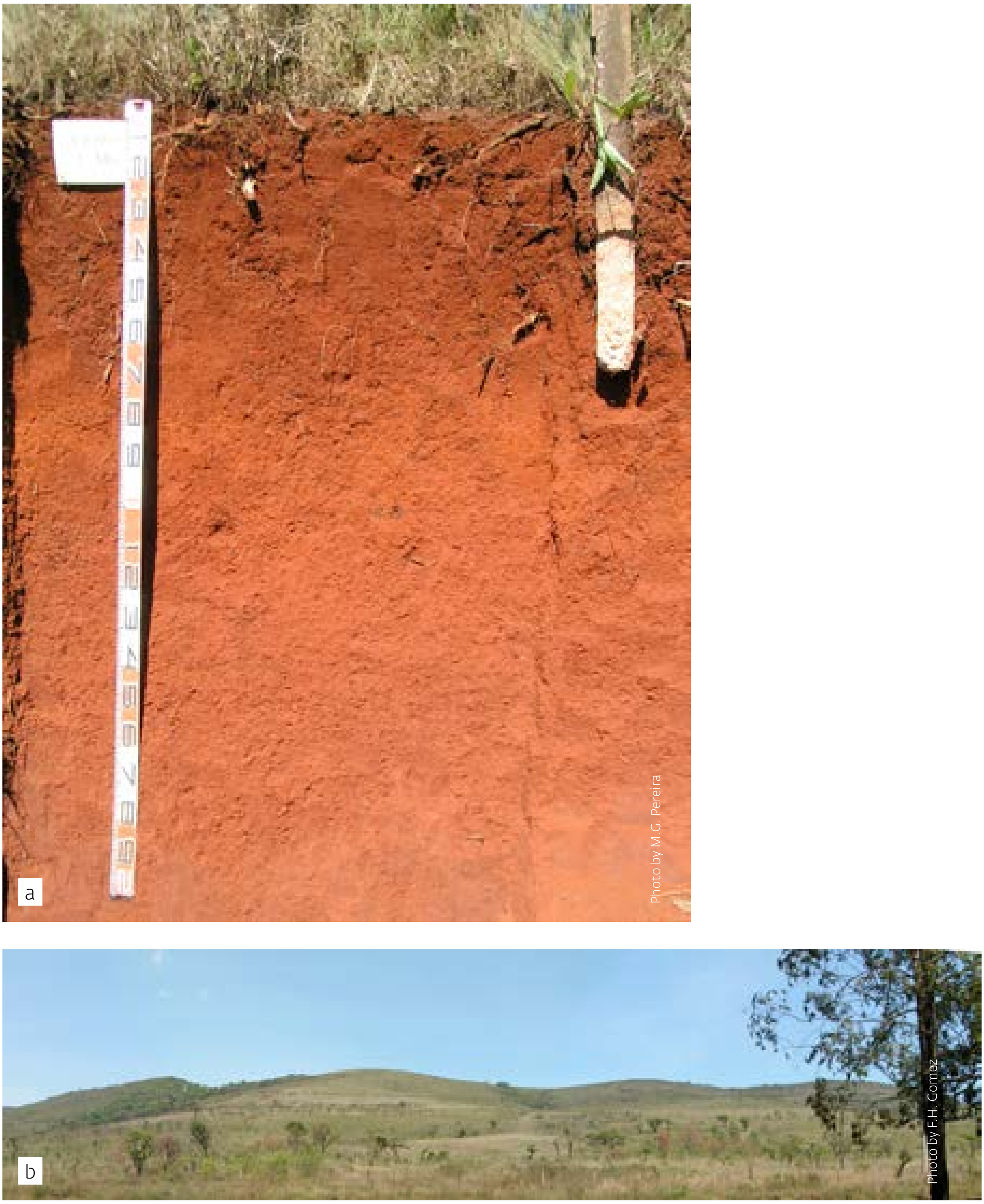

Figure A11 | (a) A Ferralsol profile and (b) an associated landscape, Brazil.

NITISOLS (Alfisols, Ultisols, Inceptisols and Oxisols Great groups)

Nitisols are well drained clayey soils with deep profiles. They are characterized by the strong development of structure, frequently with shiny aggregate faces (Figure A12). They originate from basic and intermediate rocks or sediments derived under relatively intense weathering conditions in tropical and subtropical climates. This leads to the predominance of low activity clays (kaolinite) and (hydr-) oxides of Fe, Al and titanium (Ti). Some Nitisols have high base saturation and high potential for crop production. Others have very high amounts of iron and strong P fixation, or a very low sum of exchangeable bases and high aluminium. Both these latter classes are limiting to crops.

The texture is clay loam or finer, with no large variation of clay content within the soil. The profile development shows intense weathering, with the prevalence of kaolinite and high iron in the nitic horizon, resulting in the strong stability of the aggregates, and the common angular and/or subangular blocks combined in a prismatic structure. The nitic horizon may show clay coatings indicating an illuviation process. The Nitisols are usually red or reddish-brown, and there is no distinct colour variation in the profile, except for the topsoil, due to the higher content of organic carbon. The subsurface horizons show gradual to diffuse boundaries. Nitisol classes vary largely according to base saturation, clay activity (usually low), iron and aluminium content. However, Nitisols formed from basalt may have high base saturation and, due to their good drainage and structure, may have high potential for both intense and low input agriculture.

Nitisols are mainly formed from weathering products of intermediate and basic igneous rocks (basalt and diabase). They may also have originated from clayey sediments in karstic areas (TerraRossa). They occur predominantly on high level plateaus and slightly undulating reliefs, originally under tropical and subtropical forest, or Cerrado (Brazil) and savannah vegetation.

Nitisols occur in eastern Africa and Madagascar (2 percent of the continent, Jones *et al.*, 2013). Although accounting for less than 1 percent of area on the Latin America and Caribbean soil map, Nitisols are prized lands in Southeastern and South regions of Brazil, and in neighbouring Argentina and Uruguay. They are cultivated with crops such as coffee, citrus, soybean, corn and sugarcane; and they play an important role in the agriculture of many tropical countries. Nitisols are also found in Australia (Ferrosol in Australian soil classification, formed from basalt), Europe (the Mediterranean) and the United States.

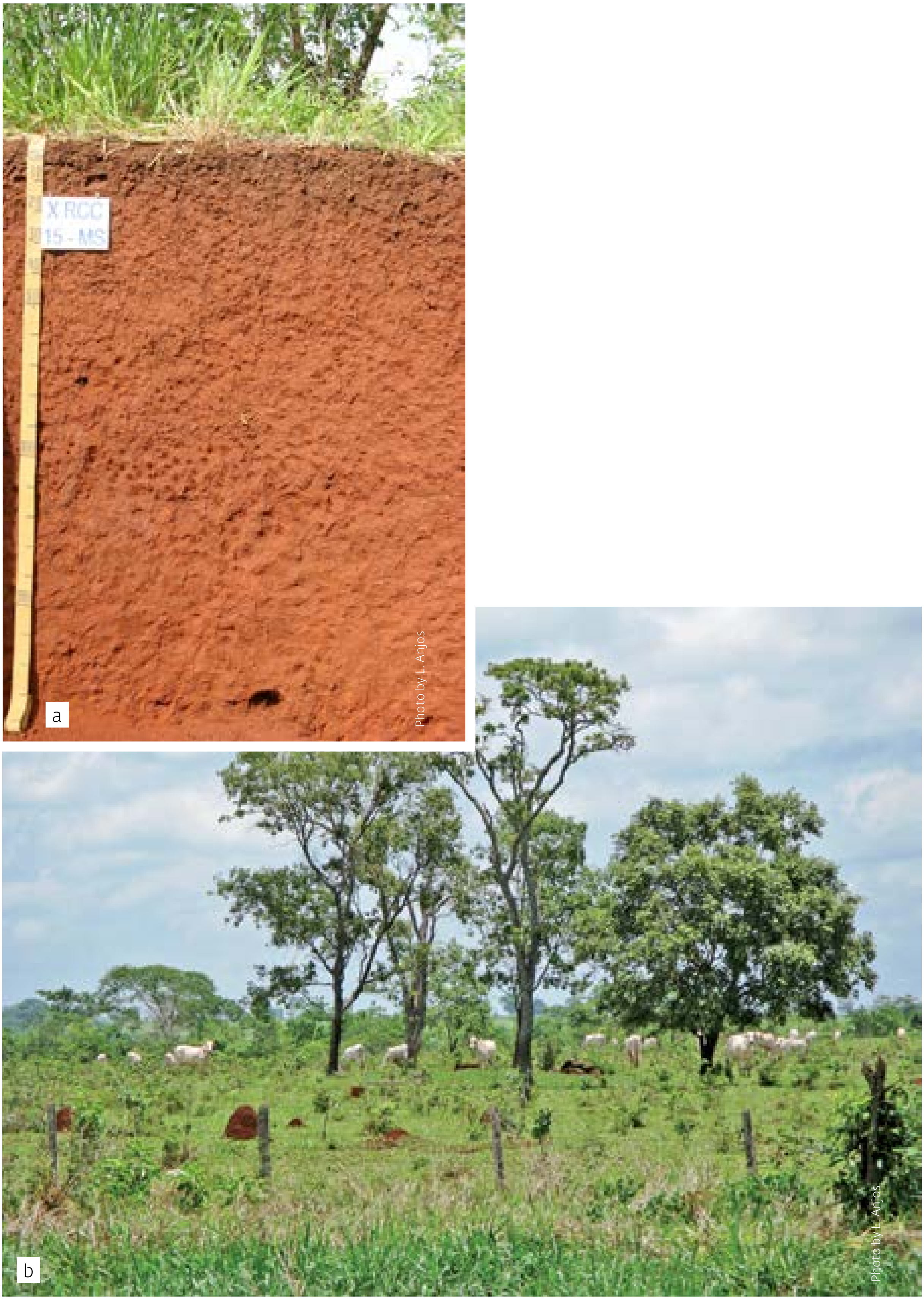

Figure A12 | (a) A Nitisol profile and (b) the associated landscape with termite mounds, Brazil.

PLINTHOSOLS (Plinthic sub-groups)

Plinthosols (Figure A13) are defined by the presence of plinthic, petroplinthic or pisoplinthic horizons, at a certain depth in the soil profile. Their formation is related to accumulation and redistribution of Fe under conditions of alternating wetting and drying cycles over long time periods. The landscape position - low lands with high groundwater or slopes with water seepage conditions - leads to chemical reduction of iron compounds in the parent material, which are redistributed and accumulated in the soil profile. The plinthite may be hard and irreversible (petroplinthite), forming a continuous and highly impermeable layer of ferruginous material (carapace or crust). The reduction, segregation and precipitation of iron (hydr-)oxides in the subsurface horizon forming the plinthite bodies, together with the dominance of kaolinite and other products of strong weathering such as gibbsite, indicate the conditions in which most Plinthosols formed. The profile may develop strongly bleached eluvial horizons and have evidence of clay illuviation; or show morphology associated to Ferralsols or to lesser development in recent sediments where reducing conditions are still present as indicated by gleyic properties. The subsurface horizon has platy, polygonal or reticulate patterns of distinct coloured (red, brown) plinthite bodies that are coherent enough to be separated from the surrounding soil matrix, which is usually of a pale colour. Hardening of the plinthite will form discrete concretions or nodules that characterize the pisoplinthic horizon. Further cementation and interconnecting of the pisoplinthic material will form the petroplinthic horizon, a layer of indurated material which may be continuous, broken or fractured.

Plinthosols are reported as formed from weathering products that have a high amount of Fe or where this element is accumulated due to water seepage or ascension of groundwater. They are most common on level to gently sloping topography, in areas with seasonal fluctuating groundwater in wet climates, humid and tropical, such as in the Brazilian Amazon Basin. However, in the Brazilian Cerrado and the savannahs of Africa, Plinthosols (with petroplinthic or pisoplinthic horizons) are also found on steeper slopes or as hard layers on plateau tops of old erosional surfaces.

Extensive areas of Plinthosols occur in West Africa, where they represent 5 percent of the total 30 million km^2 area of the continent (Jones *et al.*, 2013). Widespread in the Amazon Basin, they cover about 1 percent of Latin America's 22 million km^2, largely in Brazil, Colombia, Venezuela, Guyana and Bolivia, and in the Caribbean region, (Gardi *et al.*, 2014). Plinthosols are also found in Southeast Asia, India, Australia and the United States.

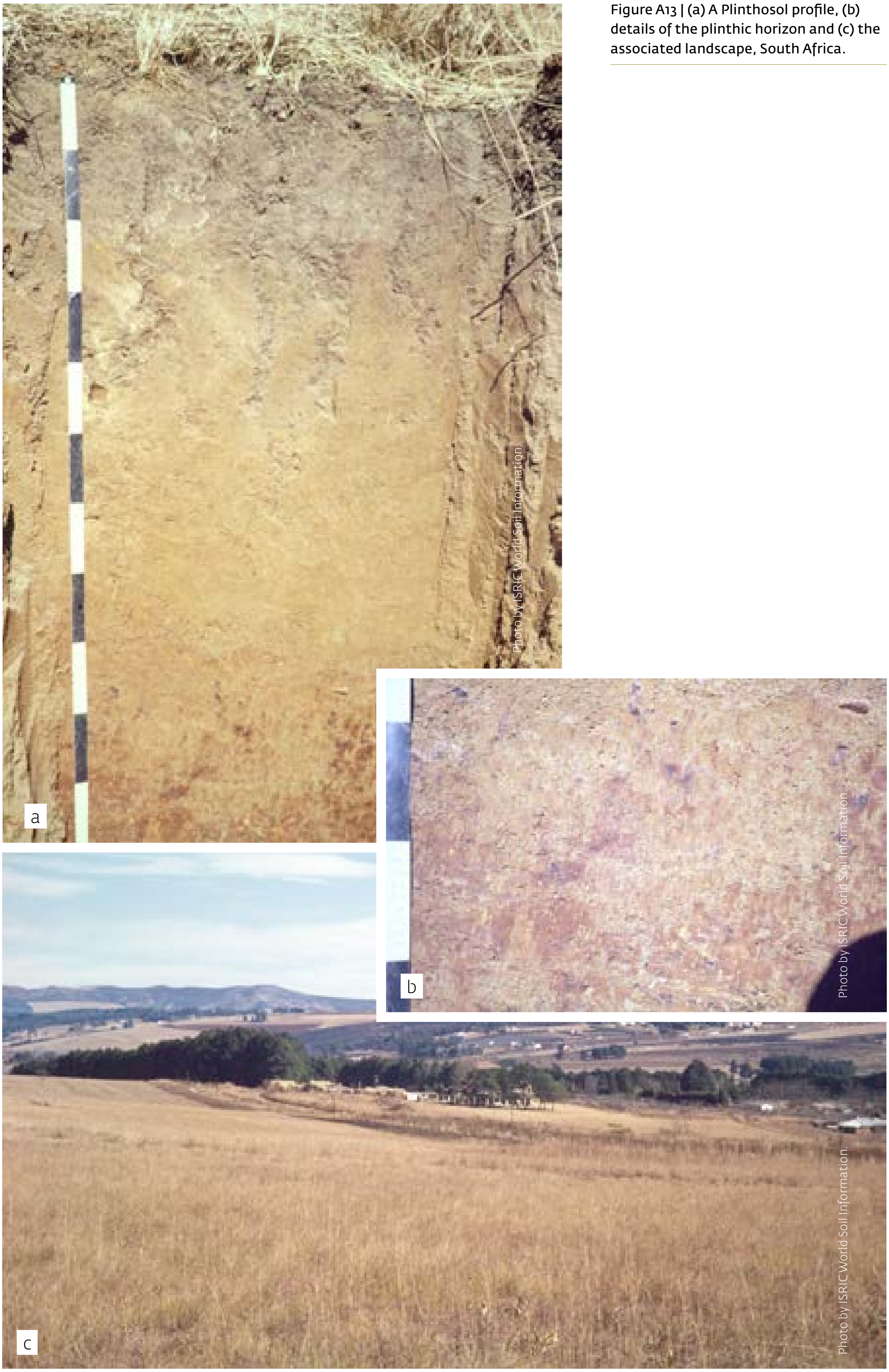

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Figure A13 | (a) A Plinthosol profile, (b) details of the plinthic horizon and (c) the associated landscape, South Africa.

PLANOSOLS (Albaqualfs, Albaquults and Argialbolls)

Planosols are seasonally water-saturated or flooded, poor acid soils with bleached, generally silty surface horizons with an abrupt transition to a dense subsoil with significantly more clay (Figure A14). There may be pore infillings of bleached material in the subsoil. Clay destruction and aluminium interlayering driven by periodic iron hydroxide reduction and reoxidation (ferrolysis) has been recognised as a process sometimes involved in the formation of the silty surface horizons (Brinkman, 1979; Van Ranst *et al.*, 2011).

Planosols occur in generally level areas in climates with contrasting wet and dry seasons, mainly in the subtropics but in temperate areas and the tropics as well. Their total extent is estimated at 1.3 million km^2. They are extensive in Latin America (southern Brazil, Paraguay, and Argentina) and Australia, and they also occur in Africa (Sahelian zone, East and southern Africa), the eastern United States, Siberia, China, and Southeast Asia (Bangladesh, Thailand).

Natural vegetation on Planosols is sparse grass with or without shrubs or small trees; extreme Planosols may be barren. They are generally used for grazing or for grain or root crops in temperate areas. In the subtropics and tropics, rainfed paddy (wetland) rice is grown on bunded fields; with irrigation, they can be double cropped with a second paddy rice or dryland crop. Yields are very low without fertilizers and remain sub-optimal even with fertilizers because of the poor physical and chemical soil conditions.

Figure A14 | (a) A Planosol profile and (b) the associated landscape, Argentina.

GLEYSOLS (Aquic suborder and Endoaquic great groups)

Gleysols are easily identified by bluish or greenish grey colours in their mineral horizons that are usually water-saturated, with only a weak or no structure (Figure A15). These horizons are formed under reducing conditions characterized by a low redox potential. In some Gleysols the smell of hydrogen sulphide or methane is noticeable. Iron compounds are easily mobilized in Gleysols, especially in the presence of organic matter and anaerobic microorganisms. These are partially removed or oxidized and may accumulate as iron segregations, nodules, iron pans, bog ores, etc. (Zaidelman, 1994). Above the layer with gleyic characteristics, a topsoil horizon relatively rich in organic matter occurs, that may show rusty root channels. The range in pH values in Gleysols is broad and may vary between 2.5 and 9. In coastal positions Gleysols may show sulphides oxidation resulting in high acidity (Zech *et al.*, 2014).

Globally the extent of Gleysols is estimated at 7.2 million km^2, of which approximately two thirds occur in boreal areas on unconsolidated parent rocks. In humid regions they often occupy depressions, river valleys and deltas, lake kettles and foot slopes. Subaqueous soils of shallow water bodies are also included with Gleysols. Large areas of Gleysols occur in tundra areas, in deltas of great rivers and in lowlands. They occur as associated soils almost everywhere, except in arid lands and on steep slopes.

In tundra regions the melting of the permafrost layer in summer causes excess of water in an environment already enriched in organic matter and induces seasonally reducing conditions and the formation of Gleysols. Water logging is the main prerequisite for the development of gleyic features and is due to high ground water table in depressions; additional water inflow there may contribute to gleying as well as flooding in the valleys and tides in coastal areas. There is no special plant community on Gleysols because they occur all over the world, but everywhere hygrophytes are dominant plants.

The main limitation for Gleysols management is surface water logging and/or shallow ground water hindering the growth of the roots of crops and trees. With artificial drainage the ground water table is lowered and the excessive moisture removed. When drainage is implemented efficiently, as it is in the Netherlands and Germany, Gleysols are productive soils for vegetables, beets and flowers. The main ecosystem threat is related to the Gleysols' low position in the landscape, where they may accumulate pollutants and could turn into 'chemical time bombs' (Stigliani, 1988).

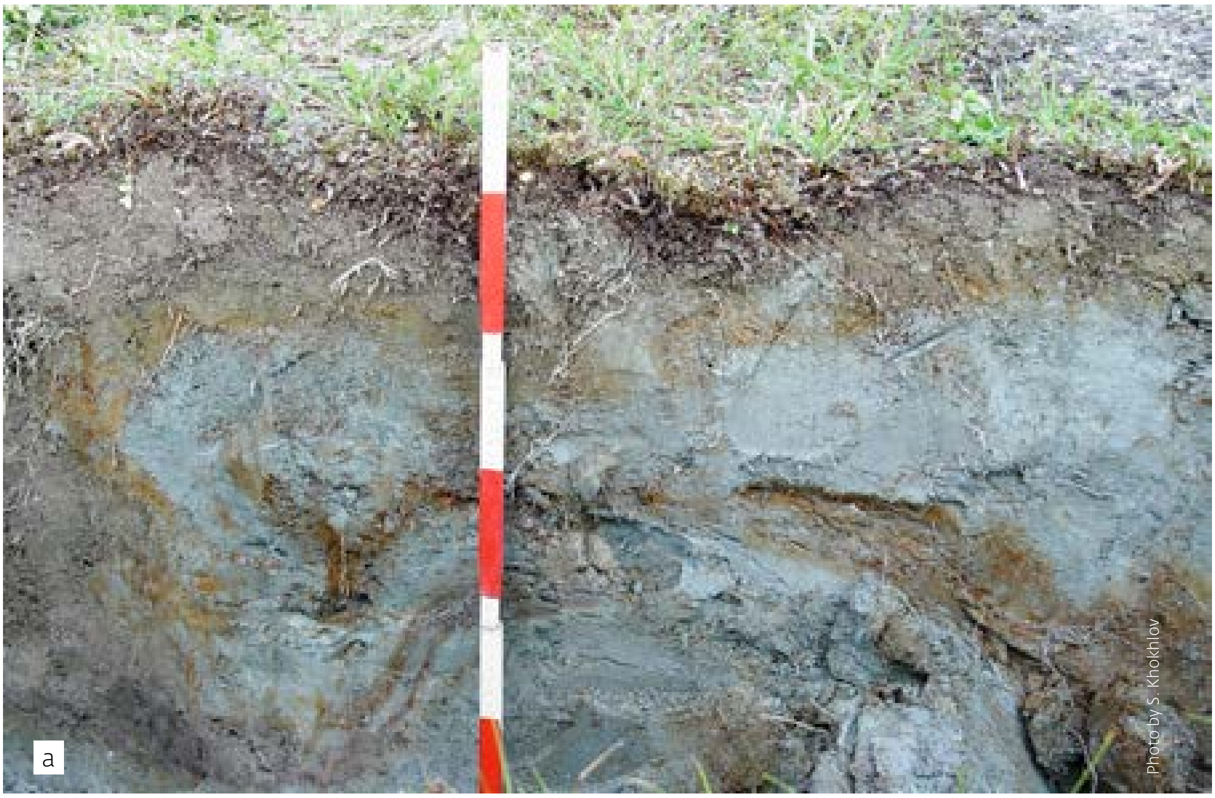

Photo by S. Khokhlov

Photo by S. Khokhlov

Figure A15 | (a) A Gleysol profile and (b) associated landscape in the East European tundra.

STAGNOSOLS
(Aquic Suborders and Epiaquic Great Groups in Alfisols, Ultisols, Inceptisols, Entisols, and Mollisols)

Stagnosols (Figure A16) have much in common with Gleysols, but are different in their source of waterlogging and in their manifestations in the soil profile. Periodical stagnation of atmospheric water accounts for the name of this soil (originating from the German Pseudogley and Stagnogley). Stagnosols are characterized by the difference in texture between topsoil and subsoil originated due either to illuviation or to initial parent material heterogeneity in areas with humid climate and flat topography. Stagnosols are identified by the colour pattern of the upper 0.5 m of their mineral horizon, where a combination of reductimorphic (bluish grey colours that do not last) and oximorphic colours (rusty, reddish brown mottles inside aggregates and root channels known as Rohrenstein) together with iron-manganic segregations or nodules occur. These pedofeatures may occur within the whole layer, or they may be confined to its lower part, whereas its upper part may be composed of albic material with reductimorphic features. A special case of stagnic properties is the 'marbled' colour pattern described in old German literature as 'Marmorierung' (Muckenhausen, 1963).

Stagnosols are mostly acid to weakly acid and have a low to medium base saturation. Humus accumulation is prominent in these soils with raw or moder humus types; the biological activity in these soils is weak and the physical properties are unfavourable for plant growth: low porosity, reduced water filtration and risks of drying out (Zech *et al.*, 2014). Stagnosols are often localized and do not occur in vast continuous areas. They are mostly associated with other soils - Cambisols, Retisols, Acrisols. They are confined to flat or weakly undulating plains with various unconsolidated parent materials, moderately or heavy-textured. When the textural difference between the top- and subsoil is large, they are replaced by Planosols.

Stagnosols have mostly been described in areas with humid temperate and subtropical climate under hardwood forests. They are most common in Western Europe and the Midwest of the United States. The total area of Stagnosols worldwide is estimated at 1.5^{-2} million km^2 (FAO, 2014). Stagnosols have a low fertility due to their poor physical properties and moisture regime along with the elevated acidity and aluminium toxicity. Applying artificial drainage is less efficient than in Gleysols, unless additionally deep loosening of the subsoil is applied to break the impermeable layer. The same weakly permeable and dense subsoil is a problem for silviculture as it is an obstacle for tree roots and results in a high probability of tree uprooting. Nevertheless, forests of wetness-tolerant tree species and meadows are a preferable land use option.

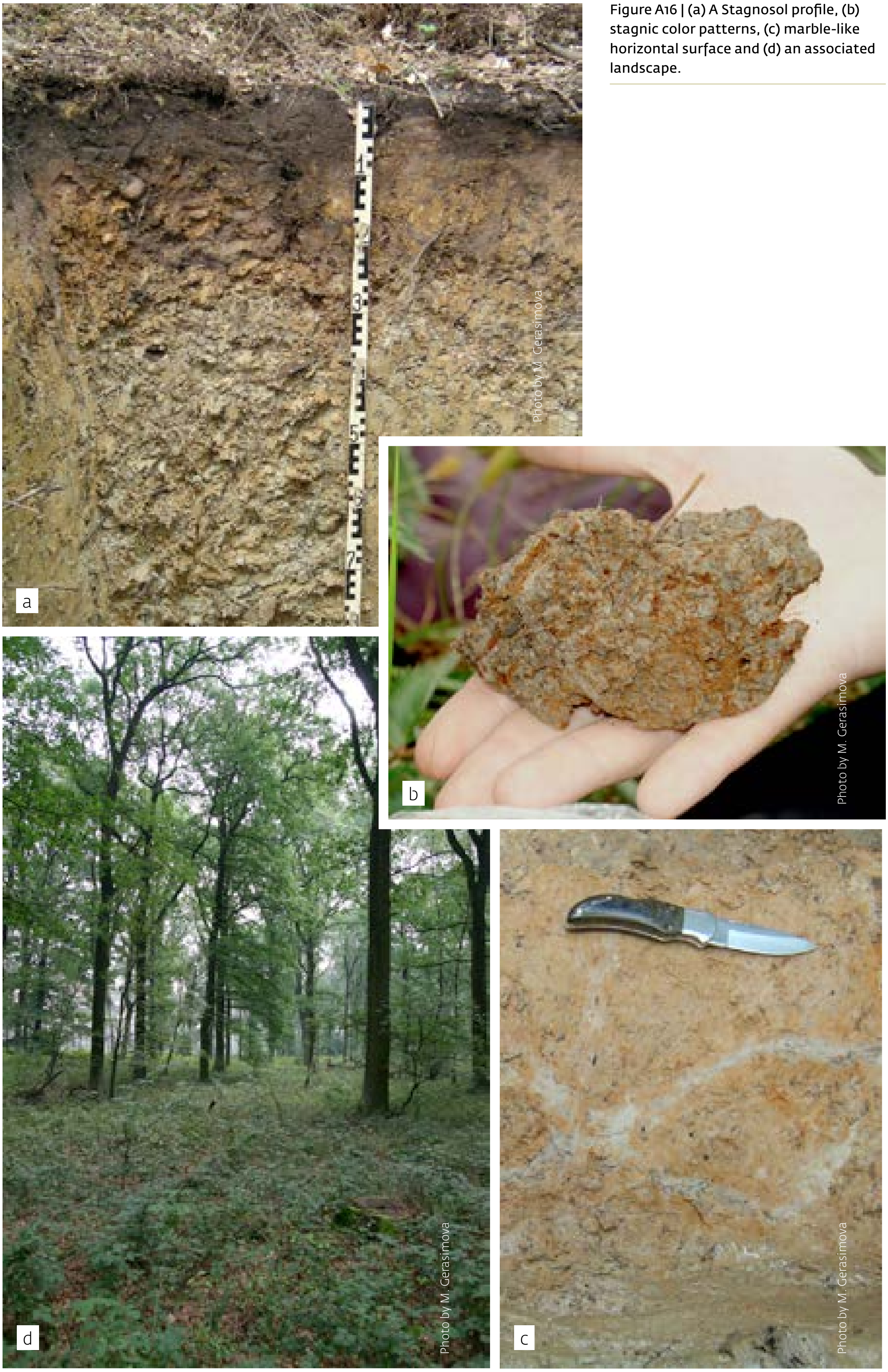

Figure A16 | (a) A Stagnosol profile, (b) stagnic color patterns, (c) marble-like horizontal surface and (d) an associated landscape.

Photo by M. Gerasimova

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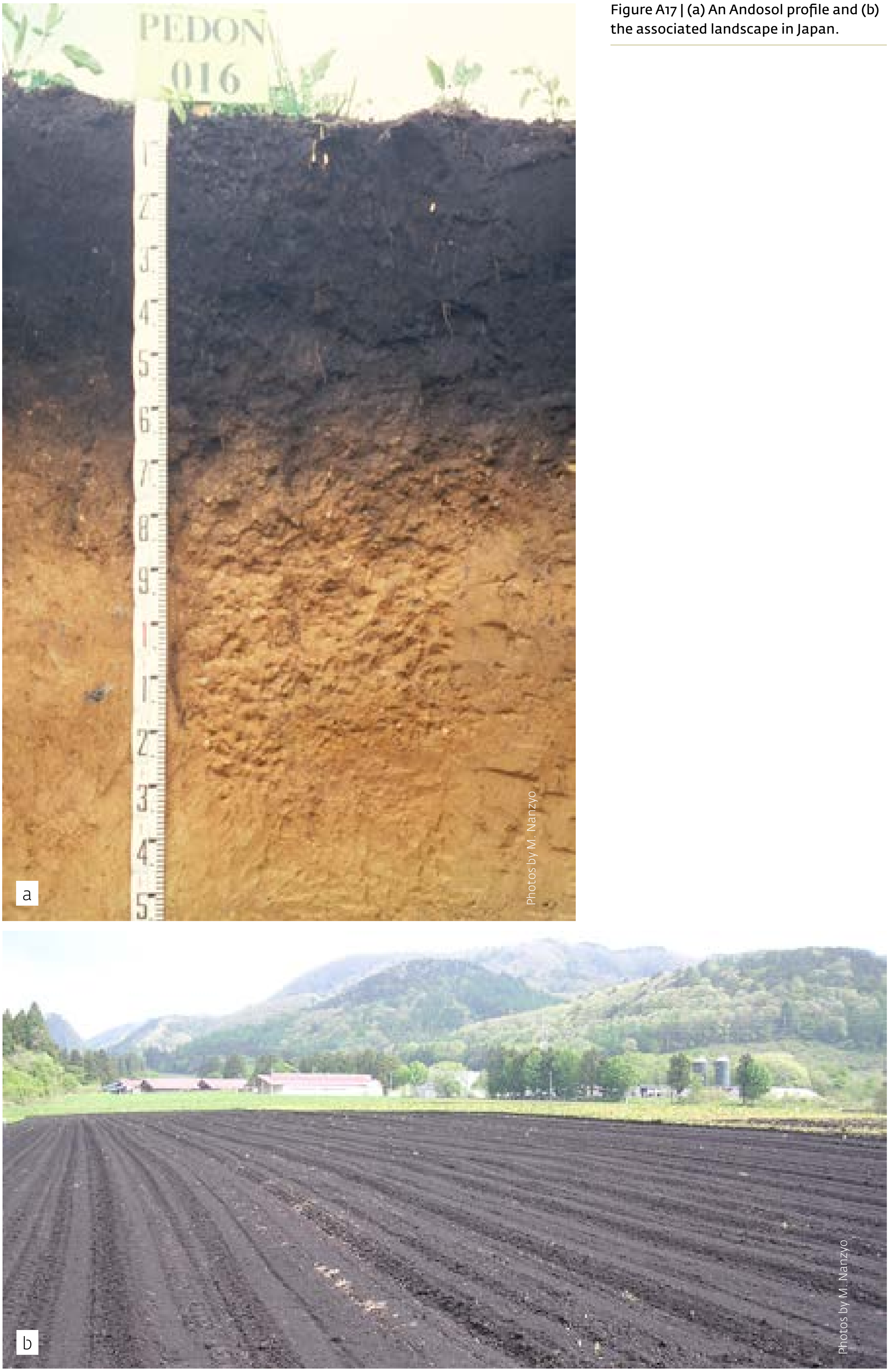
ANDOSOLS (ANDISOLS)

Andosols (Figure A17) form typically from volcanic tephra on uplands. Distinctive properties of matured Andosols are the high content of active Al and Fe materials, and the lowest bulk density among mineral soils. Volcanic glass, the major constituent of tephra, rapidly weathers to form allphane, imogolite, Al-humus complex (non-crystalline active Al materials) and ferrihydrite (poorly crystalline active Fe material), with leaching loss of a large amount of Si, Na, Ca, etc. Under plentiful vegetation a large amount of humus accumulates in the A horizon, forming the Al-humus complex. Halloysite tends to increase under semi-dry climate in addition to non-crystalline active Al materials. Translocation of clays, Al and Fe is minimal in the soil profile. Due to a porous, fluffy and highly aggregated microstructure, Andosols show low solid phase ratio, low bulk density, high water permeability, and high water holding capacity.

A humid climate and uplands are favourable for leaching loss of Si, Na, Ca, etc. and for formation of active Al and Fe materials. Tephra deposits in swamps tend to weather more slowly than those on uplands, and the weathering product is richer in halloysite. Weathering of tephra under arid soil moisture regime appears even slower. The rock type of tephra ranges from rhyolitic to basaltic. The colour of rhyolitic to Andisitic tephra is whitish to greyish and that of basaltic tephra, black.

Andosols cover less than 1 percent of the earth's land surface. The major occurrences of Andosols are in and around the volcanic areas along the circum-Pacific volcanic zone, the Alpine-Himalayan belt, and the great Rift Valleys of Africa. Others are on the Hawaiian Islands, Iceland, etc. Andosols are used as productive farmlands after appropriate improvement of chemical shortcomings.



Photos by M. Nanzyo

Photos by M. Nanzyo

Figure A17 | (a) An Andosol profile and (b) the associated landscape in Japan.

CHERNOZEMS (Udolls)

Chernozems are marked by their deep, dark and well-structured topsoil (FAO, 2014). The soil has an almost black colour (hue < 1, chroma ≤ 2.5), intricate pedality and strong water-stable structure, which is mostly due to the activity of earthworms. The (micro-)structure is granular or crumb-granular in the upper part of the topsoil and spongy in the lower one; density is close to 1 g cm^{-3}; the Corg content ranges between 2.9 and 3.5 percent in the upper 10 cm (with humates as predominant fraction), and exceeds 1.2 percent at the lower boundary of the chernic horizon (Lebedeva, 1974). Earthworms and burrowing mammals (mole rats, marmots, hamsters, ground squirrels) modify the horizons' boundaries, effervescence depth and the pathways of solution flows. They also perform the exchange of material between the top and subsoil, which contributes to the profile stability; dark and brown krotovinas are common. Calcic horizon and/or secondary carbonates are diagnostic for all Chernozems. Secondary carbonates comprise labile forms: pseudomycelium and impregnation mottles corresponding in thin sections to needle-shaped crystals in voids, micritic (quasi) coatings, sometimes with sparite grains. The labile forms of carbonates are in agreement with the data on current hydrothermal soil regimes. Soft segregations – beloglazka – and hard nodules occur in more arid variants of Chernozems transitional to Kastanozems, while micritic pendants are confined to materials with rock fragments. In Russia, Chernozems are differentiated in accordance with secondary carbonate pedofeatures reflecting the current pedoclimate (Figure A18).

Continental climate with summer rains, soil freezing for two to four months, rich forb-grass natural vegetation, mostly loess as parent material, good drainage and level to undulating topography all contribute to the development of most typical profiles. The radiocarbon age of the topsoil ranges within 2^{-3} kA in its upper part, and 5-8 kA in the lower part (Chichagova, 1985). Chernozems first appeared in the Late Miocene under grass ecosystems maintained by grazers (Retallack, 2001). However, most Chernozems have been cropped for at least the last two centuries. They are regarded as very fertile soils.

Chernozems occur as a continuous belt in steppe and forest-steppe landscapes in Russia and the Ukraine, in the Great Plains of the US, in northern Kazakhstan and locally in some countries of Central Europe. They cover approximately 230 million ha.

High fertility of Chernozems is provided by a unique combination of very favourable chemical and physical properties. More than half of their area is cropland - maize, wheat, sugar beet and sunflower are the main crops. In the drier parts of their area, the main limitations to agriculture are droughts with occasional dust storms, whereas in wetter parts both wind and water erosion are the main risks. Climate change along with water conservation measures and irrigation at the background of lithological discontinuity have resulted in the appearance of small wetlands in the steppe landscapes.

Figure A18 | (a) A Chernozem profile (Photo by J. Deckers) and (b) the associated landscape in the Central Russian Uplands.

KASTANOZEMS (Ustolls and Xerolls)

Kastanozems are humus-rich soils that were originally covered with early-maturing native grassland vegetation which produced a characteristic brown topsoil 20-40 cm thick in which the organic matter content ranges between 2 and 6 percent. Kastanozems have a brown topsoil with a granular or fine blocky structure. The rest of the profile is lighter in colour and is characterized by the secondary accumulation of calcite (Figure A19). Kastanozems are chemically rich soils with a pH slightly above neutral. Near the surface, soil pH may reach a value of 8.0.

These soils are found in relatively dry climatic zones (annual precipitation 200–400 mm). Kastanozems are mostly used for irrigated farming and grazing. Kastanozems have relatively high levels of available calcium ions and other nutrients. Carbonates weakly move down in the soil profile with percolating water to form layers of secondary carbonates; gypsum is also common in these soils. Kastanozems form in semi-arid regions under relatively sparse grasses and shrubs.

The total extent of Kastanozems is estimated to be about 465 million ha. Major areas are in the Eurasian short-grass steppe belt (southern Ukraine, the south of the Russian Federation, Kazakhstan and Mongolia), in the Great Plains of the United States of America, in Mexico, and in the southwestern pampas and Chaco regions of Argentina, in Paraguay and southeastern Bolivia (FAO, 2014).

The main obstacle to the agricultural use of these potentially rich soils is drought (Encyclopaedia of Soil Science, 2008). Irrigation, which brings the threat of secondary salinization, is nearly always necessary to obtain high yields. Another serious problem on Kastanozems is overgrazing (Wang and Batkhishig, 2014), extensive grazing being another important use for these soils. Overgrazing on light-textured soils often produces deflation, destroying the topsoil.

Figure A19 | (a) A Kastanozem profile and (b) the associated landscape in Mongolia.

PHAEOZEMS (Udolls and Albolls)

Phaeozems are soils with a mollic horizon which occur most frequently in the transitional areas between boreal forests and steppes, or in forest-free plains with temperate semi-humid climate (tall-grass prairies) on unconsolidated base-rich sediments, mostly loess or loess-like material. They may also occur locally under sparse herbaceous forests in the mountains (Figure A20). They cover approximately 2 million km^2, and their largest areas are found in the United States (Great Plains) and Canada, in the Argentinian Pampas, and in Manchuria. Mountainous variants were described in Southern Siberia and Northern Mongolia on gentle slopes with colluvium, under larch forests with a rich forb-grass cover (Zech *et al.*, 2014; Vostokova and Gunin, 2005). Phaeozems are formed under milder and more humid climates than Chernozems; the vegetation is mesophytic with less pronounced seasonal rhythms. Typically, natural grassland cover is mostly replaced by high-quality farmland, or may be modified by grazing. Phaeozems are among the most fertile soils owing to their favourable physical and chemical properties, along with moisture and thermic regimes (udic and mesic).

The most conspicuous feature of Phaeozems is their dark, mostly thick, mollic horizon with traces of burrowing mammal activity, weakly acid to neutral, base saturation ranging within 50-100 percent. Phaeozems include some of the traditional forest-steppe Chernozems with deep secondary carbonates, and in this case they have a chernic horizon with its coprogenic structure underlain by a cambic or argic horizon. In the rest of Phaeozems, the subsoil horizons may be diverse: argic, cambic, calcic and petrocalcic; the latter phenomenon is common in Argentinian Phaeozems – a specific hard *tosca* layer that may occur within 1 m from the soil surface and be a limitation for plant growth (Moscatelli, 1991; Pazos, 2012). Some other properties were described in Phaeozems as well: albic material and uncoated silt grains, clay coatings, stagnic colour pattern, and sodic features (FAO, 2014). This broad array of properties is explained by the occurrence of Phaeozems in different environments providing for the development of additional pedogenic processes, some of them being limitations for farming.

The global significance of Phaeozems is their high agricultural potential, as well as the prominent reserves of organic carbon accumulated in their topsoils. The limitations are not strong: they include wind erosion in dry years, water erosion on uplands, and water stagnation either during short rainy events or in case of high groundwater. In Manchuria, deep freezing and slow thawing are common. Local manifestations of sodicity have been recorded in Argentina and Western Siberia (Gerasimova, 2002).

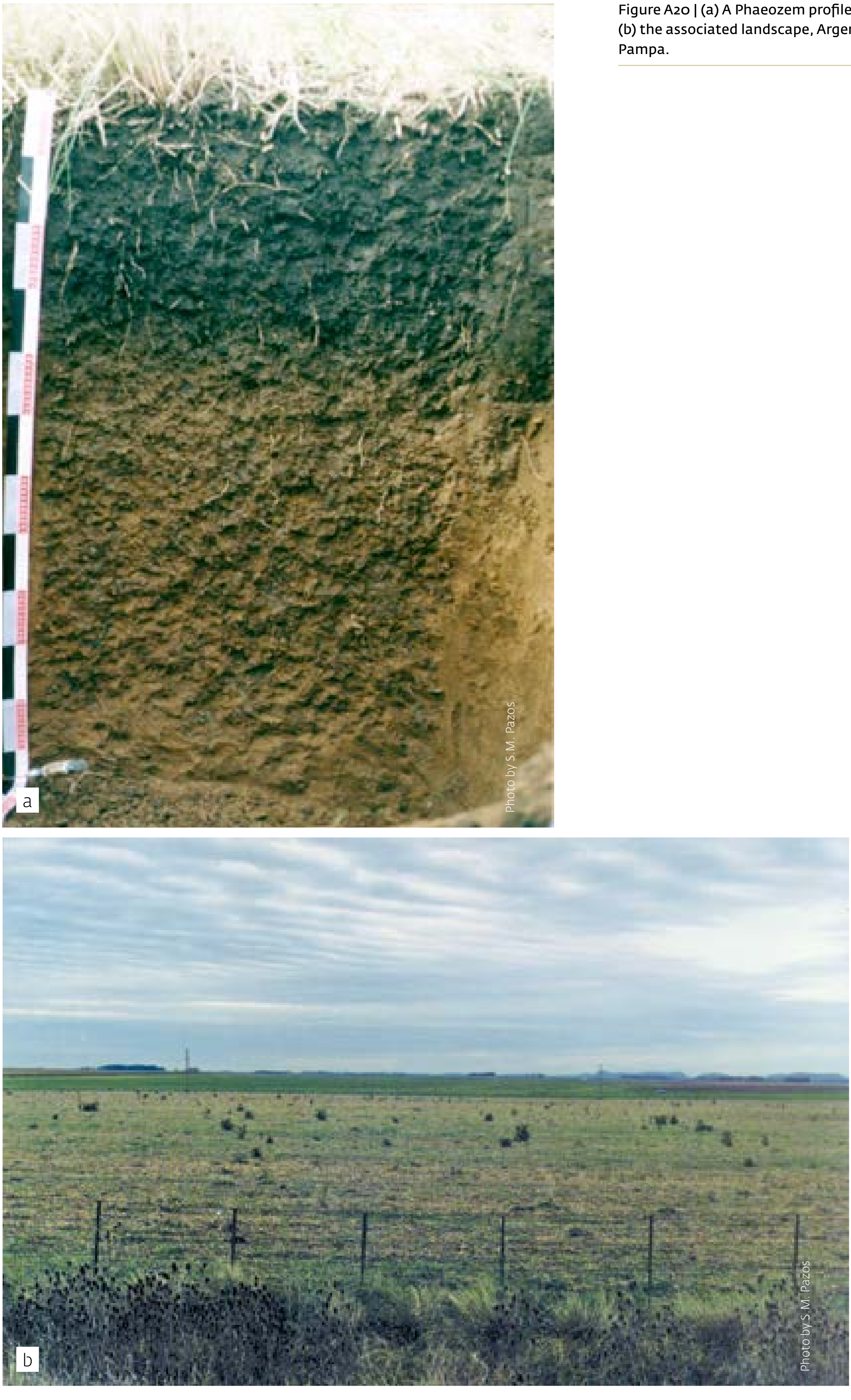


Figure A20 | (a) A Phaeozem profile and (b) the associated landscape, Argentinian Pampa.

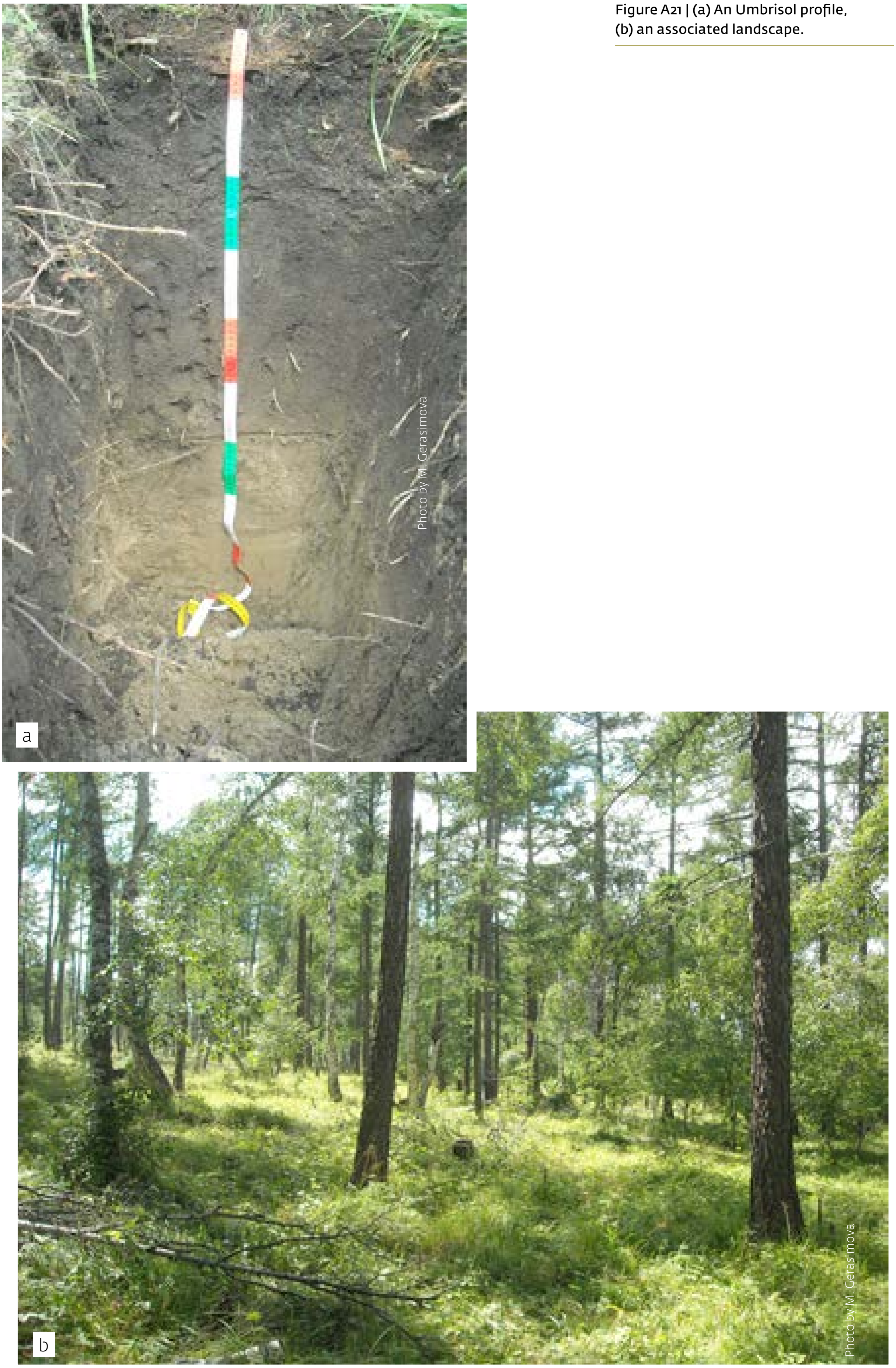
UMBRISOLS (Umbric Great Group in Aquept Suborder, Humic Subgroups in all Suborders of Inceptisols)

Umbrisols are mostly mountainous soils of cool humid climates covered by meadows or sparse forests. They are characterized by a dark, humus-rich and acid topsoil horizon with a low base saturation. A rather weak crumb structure is characteristic for the topsoil horizon (Figure A21).

Umbrisols are formed under dense forb-grass natural vegetation (subalpine meadows) or under deciduous forests with a prominent lower canopy, sometimes with shrubs. This produces a large volume of plant residues, which in part may not be strongly decomposed, and elements of a moder humus form may be identified (Zech *et al.*, 2014). Rather steep slopes and stony parent material provide sufficient drainage in spite of abundant precipitation and high air moisture; the soil is always moist, but stagnic or gleyic properties are absent. Typical examples of landscapes with Umbrisols are (sub-)tropical montane cloud forests in Mexico, Bolivia and Chile (Roman *et al.*, 2010), although Umbrisols also occur at higher altitudes in sub-boreal continental mountain ranges. Igneous and metamorphic rocks are almost always the parent material for Umbrisols. Worldwide, Umbrisols occupy approximately 10 million km^2 (Zech *et al.*, 2014).

The geographical location of Umbrisols poses serious limitations for agricultural activities. Chemical fertility is not low owing to high humus content but is restricted by soil acidity. Liming and mineral fertilizers are required. Another limiting factor is the risk of erosion because of the predominance of steeper slopes in areas of Umbrisols. Most Umbrisols are left under natural forests or forestation activity as hard rock or stony eluvium are not serious obstacles for tree roots. Grazing is less common. Only in New Zealand have high inputs made it possible to practice intensive dairy farming on these soils (FAO, 2014).

Figure A21 | (a) An Umbrisol profile, (b) an associated landscape.



DURISOLS (Durids)

Durisols may develop in arid and semi-arid conditions when a dissolution and accumulation of silica leads to the formation of a cemented hardpan that restricts the rooting depth of soils. These soils form mainly in alluvial and colluvial deposits in level or slightly sloping alluvial plains, terraces and piedmont plains. Stable landscapes occur where the Durisols have been eroded down to their resistant duripan, the material of which is often used in road construction. Durisols in low-lying areas may suffer from salt accumulation (Figure A22).

The duripan may range in thickness from 10 cm to more than 4 metres. There are two main types of duripans: those which are massive, and those with a platy or laminated structure that are coated with amorphous opal or microcrystalline silica.

Durisols are known to be relatively extensive in Australia, South Africa, Namibia and the drier parts of the southern United States. Minor extents have been observed in South America and Kuwait. No estimate of their global extent is available (FAO, 2014). The agricultural use of Durisols is mostly limited to extensive grazing. Arable cropping is limited to areas where irrigation water is available.

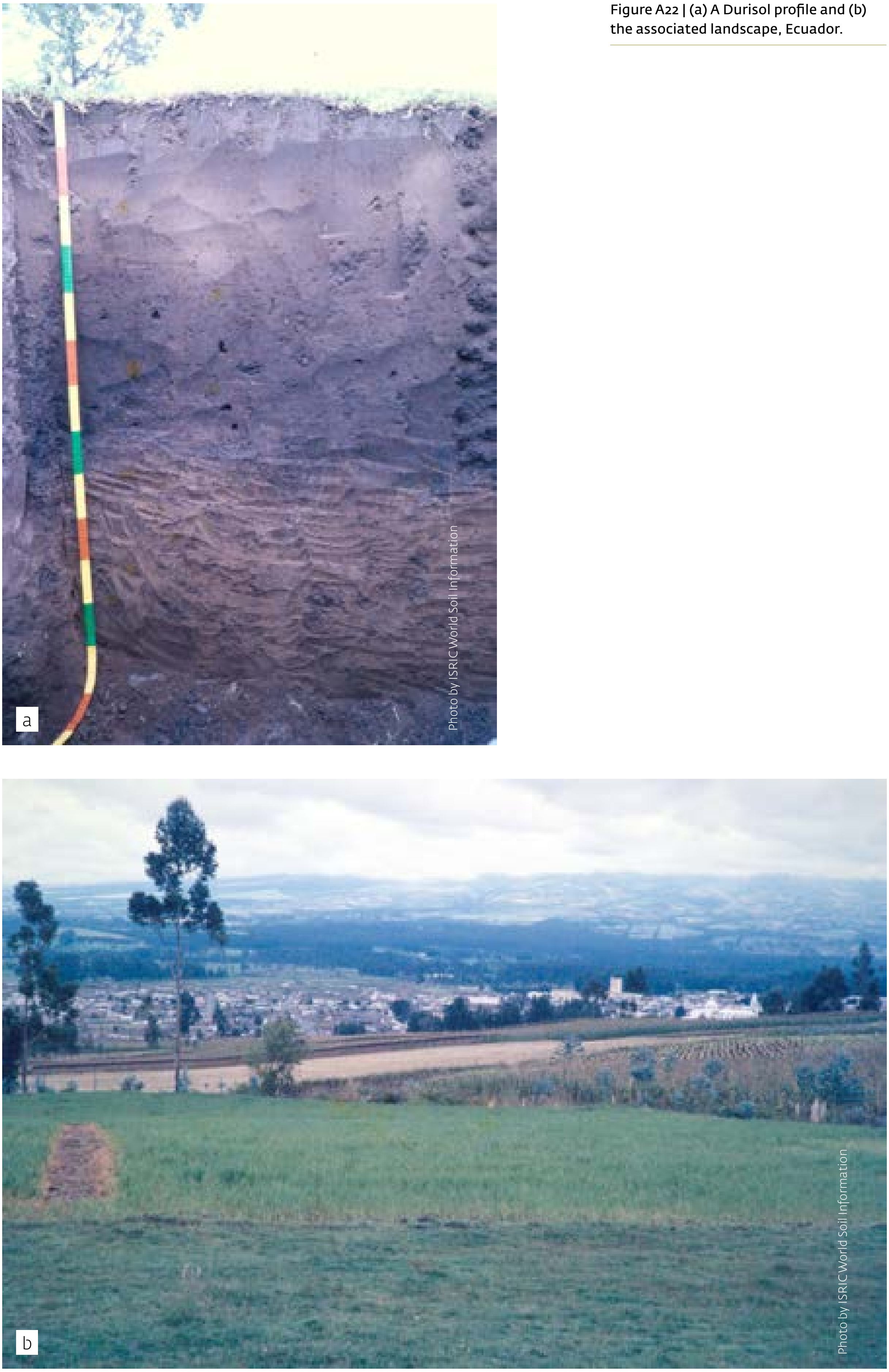


Figure A22 | (a) A Durisol profile and (b) the associated landscape, Ecuador.

Photo by ISRIC World Soil Information

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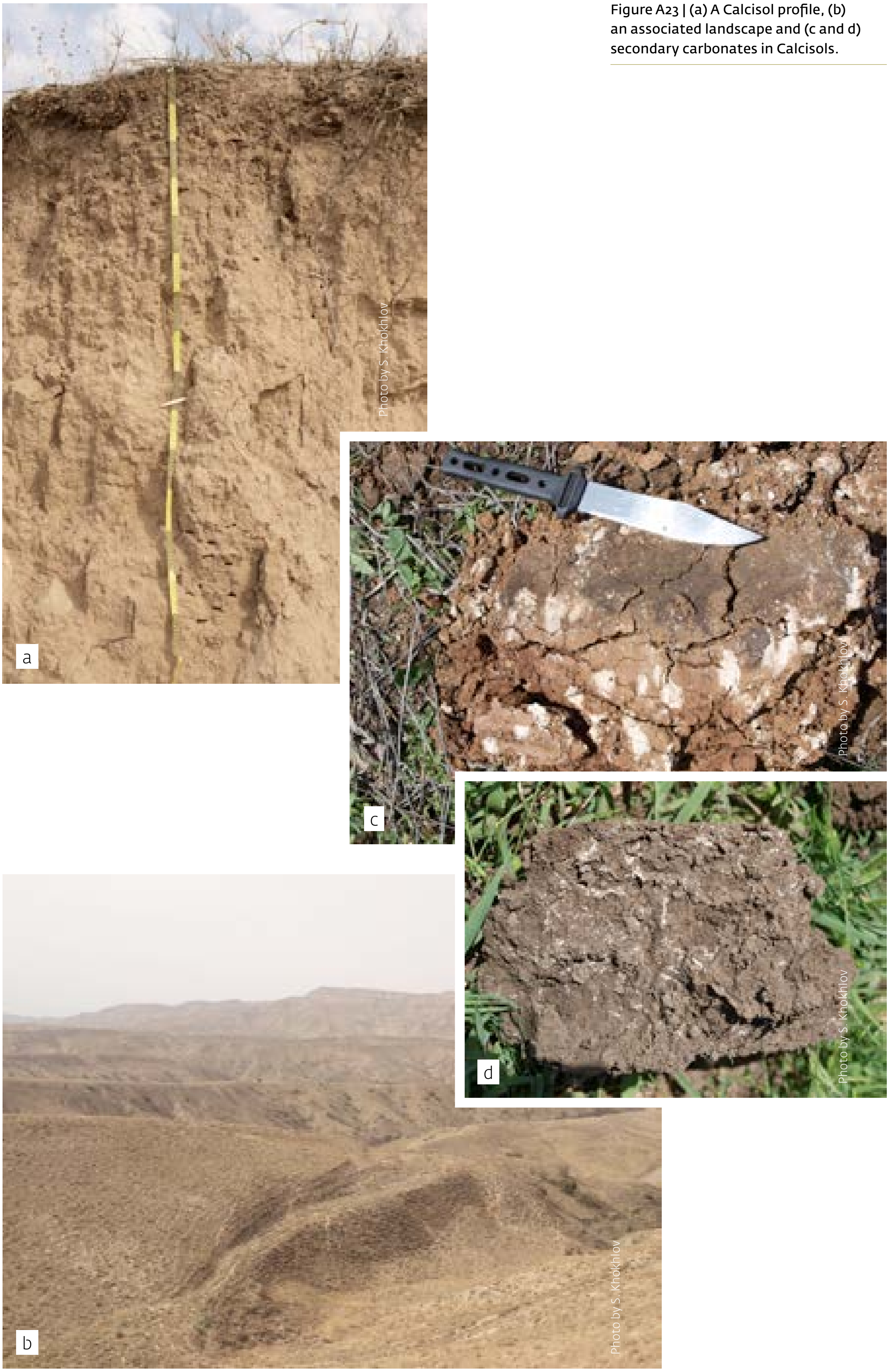
CALCISOLS (Calcids, Argids, Cambids, some Cryids)

Calcisols embrace a broad group of soils in arid and semiarid regions. Their name in the FAO-WRB system has been changed, with former Xerosols and sub-categories of Yermosols becoming Calcisols. Most national names for these soils comprise indications of their grey or brown colour and of the (semi-)desertic or aridic landscapes in which they occur (Figure A23). Calcisols are widely spread in Mediterranean countries, central-eastern and southern Africa, the Near East, Mongolia, Australia, and southwestern United States. Calcisols are very widespread and are fifth in importance by surface area of all classified soils - 1000 million ha (FAO, 2014).

Calcisols have light coloured topsoil, poor in humus, sometimes free of carbonates, and a diagnostic calcic horizon. If there is a petrocalcic horizon within the upper 100 cm, the soil is also qualified for Calcisol. Calcic horizon is identified in the profile either 'quantitatively' by an elevated content of calcium carbonate in the fine earth ($\geq$ 15 percent $CaCO_3$), or by an increase relative to the underlying horizon; or 'qualitatively' through the presence of secondary carbonates (FAO, 2014). Both criteria indicate mobilization and accumulation of carbonates in the soil (calcification). Both processes are known to depend on the moisture regime (Boettinger, 2002), which is dry almost all year round but with a short rainy period. Calcic horizon is formed in other soils (salt-affected, Chernozems, Kastanozems) but in Calcisols it is their major characteristic. High content of carbonates may be checked in the field by effervescence with 1M hydrochloric acid: it is quick with abundant foam formed. Secondary carbonates occur as soft nodules (beloglazka), pendants and coatings on stones, impregnation mottles, veins, single or coalescent – pseudomycelium, in the fine earth. Calcisols are always base-saturated, neutral to alkaline, have a narrow C:N ratio, and Corg content below 1-2 percent; the profile curve of $CaCO_3$ usually has a peak in the subsoil (Zech *et al.*, 2014).

Water deficit is a major limitation for using Calcisols, and extensive grazing is common in many lands dominated by Calcisols. Few areas are used for rainfed agriculture. Under irrigation, grain crops, cotton and vegetables are efficiently grown.

Figure A23 | (a) A Calcisol profile, (b) an associated landscape and (c and d) secondary carbonates in Calcisols.



GYPSISOLS (Gypsids)

Gypsisols are characterized by a significant secondary accumulation of calcium sulphate. Accumulation of gypsum takes place initially as crystal aggregates in the voids of the soils. These aggregates grow by accretion, displacing the enclosing soil material. When the gypsic horizon occurs as a cemented impermeable layer, it is recognized as the petrogypsic horizon. These soils occur in the driest part of the arid climatic zone in unconsolidated deposits of base-rich weathering material on level land and in depressions. Natural vegetation on these soils is sparse and limited to xerophytes and ephemeral grasses and herbs (Figure A24).

The worldwide extent of Gypsisols has been estimated at about 100 million ha, exclusively occurring in desert areas. Major occurrences are found in the Near East, Kazakhstan, Turkmenistan, Uzbekistan, the Libyan and Namib deserts, in southern and central Australia and in the southwest of the United States.

Large areas of Gypsisols are used for extensive grazing. When irrigation water is available these soils can be very productive, but the dissolution of gypsum results in the irregular subsidence of the land surface, caving in canal walls, and in the corrosion of concrete structures (FAO, 2014).

Figure A24 | (a) A Gypsisol profile and (b) an associated landscape.

RETISOLS (Glossic great groups of Alfisols and Ultisols)

The clay illuviation within Retisols is typically manifested by an interfingering of bleached coarser-textured soil material into the illuvial horizon, forming a net-like pattern (e.g. a glossic horizon). The dominant soil processes involved in Retisol formation are argilluviation and biological enrichment of base cations. They are often characterized by 'waxy' argillans; a subangular blocky structure; silty or loamy textural classes; active and superactive CEC (cation-exchange capacity) classes; and the occurrence of lithologic discontinuities (Figure A 25).

Retisols occur in climates where winters are cold and summers are short and cool with an annual precipitation between 500 and 1000 mm. They typically carry a temperate needle-leaf evergreen forest/woodland on often steeply sloping land. Their parent material is variable and includes loess, till, lacustrine and alluvium. Retisols are dated from the mid-Holocene or older e.g. > 5 000 years old. These soils generally exist in 'tension zones' (ecotones), reflecting a change in climate and/or vegetation.

Regional distribution of the 320 million ha of Retisols is mainly in Europe and northern and central Asia. There are about 85 000 ha in the United States. Retisols are important for forestry, recreation, and limited livestock farming and they provide ecological services such as watershed protection and ecological sustainability

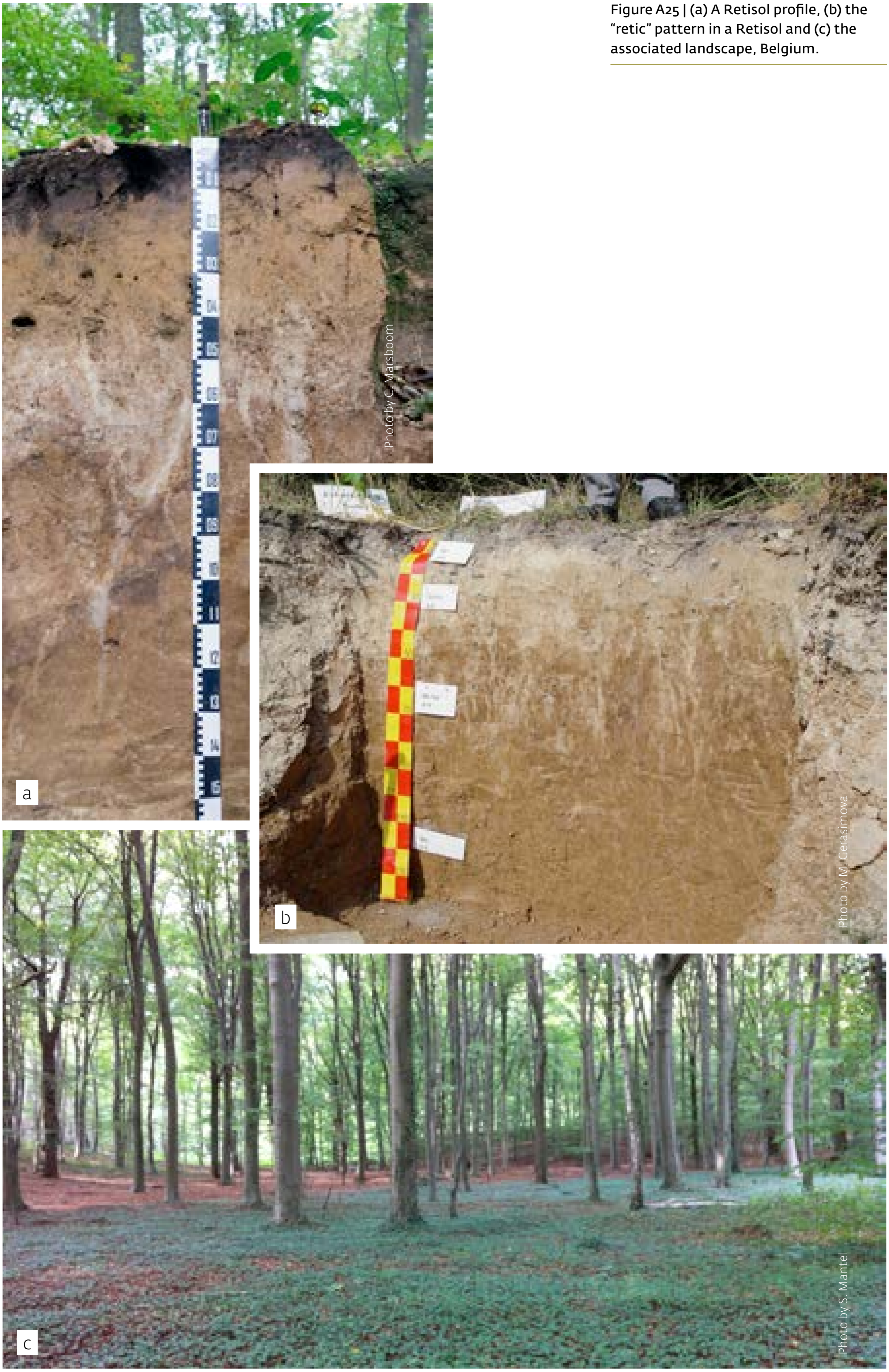


Figure A25 | (a) A Retisol profile, (b) the "retic" pattern in a Retisol and (c) the associated landscape, Belgium.

ACRISOLS (Kan- great groups of Ultisols, e.g. with a kandic horizon)

Acrisols are characterized by movement and accumulation of low-activity clays (cation-exchange capacity < 24 cmolc kg^{-1} clay) and a low base saturation (< 50 percent). The dominant soil processes involved in Acrisol formation include argilluviation and base-cation leaching (Figure A 26).

Acrisols occur under equatorial or warm climates, fully humid or winter-dry with an annual precipitation exceeding 1 200 mm. They typically carry a tropical deciduous or tropical evergreen forest or are under savannah. They occur on old hilly land surfaces where the relief is variable but often steeply sloping. Their parent material is saprolite or colluviums. These soils are commonly more than 200 000 years old.

Acrisols are used for forestry, recreation, agroforestry and shifting cultivation. They provide ecosystem services such as water protection and biotechnology for human health.

Regional distribution is some 1 000 million ha worldwide, mainly in southeast Asia, the southern fringe of the Amazon Basin, southeastern United States, and east and west Africa.

Figure A26 | (a) An Acrisol profile and (b) the associated landform in Kalimantan, Indonesia.

LIXISOLS (Kan - great groups of Alfisols, e.g. with a kandic horizon)

Lixisols are characterized by the movement and accumulation of low-activity clays (cation-exchange capacity < 24 cmolc kg^{-1} clay) and a high base saturation (> 50 percent). The dominant soil processes involved in Lixisol formation include argilluviation and biological enrichment of base cations. These soils are often polygenetic and have strong textural differentiation and advanced weathering but with abundant base cycling (Figure A 27).

Lixisols occur in the drier parts of the tropics and sub-tropics with a precipitation more than 1 200 mm annually. They typically carry a savannah vegetation. They occur on variable reliefs, while their parent material is saprolite or colluviums. These soils are commonly more than 200 000 years old.

Regional distribution is 435 million ha worldwide, mainly in sub-Sahelian and east Africa, Central and South America, the Indian Subcontinent, and southeast Asia and Australia

Lixisols are used for forestry, low-volume grazing and agro-forestry and provide ecological services such as water protection and ecological sustainability.

Figure A27 | (a) A Lixisol profile and (b) the associated landscape, Brazil.

Photo by ISRIC World Soil Information

Photo by ISRIC World Soil Information

ALISOLS (Ultisols with an argillic horizon)

Alisols are characterized by movement and accumulation of high-activity clays (cation-exchange capacity > 24 cmolc kg^{-1} clay) and a low base saturation (< 50 percent). The dominant soil processes involved in Alisol formation include argilluviation and base-cation leaching. Alisols have high Al and very low plant nutrients (Figure A 28).

Alisols occur under equatorial or warm climates, fully humid or winter-dry with an annual precipitation exceeding 1 200 mm. They typically carry a tropical deciduous forest or tropical evergreen forest. They occur where the topography is variable but often hilly or undulating, while their parent material is strongly weathered basic rocks and unconsolidated sediments. These soils are commonly more than 200 000 years old.

Regional distribution of the approximately 100 million ha of Alisols globally is mainly in Central and South America, the Caribbean, west and east Africa, southeastern Asia, and northern Australia. Alisols are used for forestry, low-volume grazing and, to a limited extent, for agriculture.

Figure A28 | (a) An Alisol profile and (b) the associated landscape, Belgium.

Photo by ISRIC World Soil Information.

Photo by ISRIC World Soil Information.

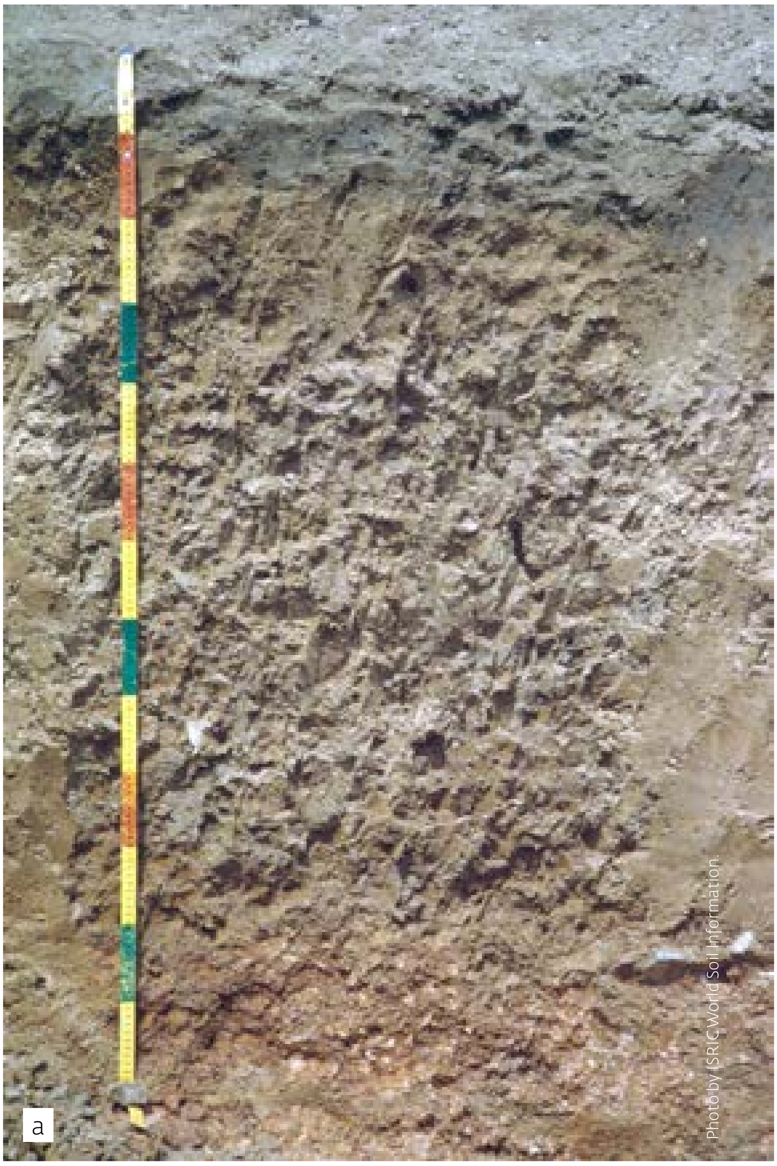
LUVISOLS (Alfisols with an argillic horizon)

Luvisols are characterized by clay movement, accumulation of high-activity clays (CEC > 24 cmolc kg^{-1} clay) and a high base saturation (> 50 percent). The dominant soil processes involved in Luvisol formation include argilluviation and biological enrichment of base cations. They are either derived from base-rich materials or have not been subject to strong weathering (Figure A 29).

Luvisols occur in humid climates with warm summers and snowfall during winter. They typically carry a vegetation of deciduous forest or woodland. They occur on flat or gently sloping topography. Their parent material is till, loess, alluvium or colluvium. These soils are commonly more than 5 000 years old.

There are 500-600 million ha of Luvisols worldwide, mainly in the Eastern European Plain, Western Siberian Plain, north central and northeastern United States, central Europe, and South Australia. Luvisols are used for agriculture, forestry and grazing. They are among the most productive soils worldwide and provide ecological services such as food and energy security, water protection, and ecological sustainability.

Figure A29 | (a) A Luvisol profile and (b) the associated landscape, China.



8 | Soils with little or no profile development

These soils have little or no profile development due to age, parent material, soil depth, transport, or deposition.

CAMBISOLS (Inceptisols)

Cambisols are young soils with beginning subsurface soil development. Characteristics that are more easily modified include structure, colour and bulk density. Structure begins to develop as wetting and drying cycles occur. Colour is modified through additions and removals such as carbonates and silica. Bulk density decreases as elements are weathered and organisms create voids. Typical soil horizonation is A-Bw-C (Figure A 30).

Cambisols are found in a wide range of climates, in all vegetation types, and level to steep reliefs. The typical parent material is medium and fine-textured, derived from a wide range of rocks, mostly in colluvial, alluvial or aeolian deposits. Cambisols form in almost all environments except permafrost.

The spatial distribution of Cambisols is estimated to be 1 500 million ha worldwide. Countries with more than 50 million ha are Russia, China, Canada and India. Cambisols are the dominant soil in San Marino, Saint Lucia, Grenada, Saint Vincent and the Grenadines, Jersey, Fiji, Belize, Italy, Luxembourg, Samoa, Guernsey, Anguilla, Czech Republic, Georgia, Haiti, American Samoa, Solomon Islands, Bosnia and Herzegovina, and New Zealand.

REGOSOLS (Orthents)

Photo by ISRIC World Soil Information.

Photo by ISRIC World Soil Information.

Figure A30 | (a) A Cambisol profile and (b) the associated landscape, China.

Regisols are the youngest soils with no pedogenic horizons and no evidence of soil forming processes. They may, nonetheless, support vegetation but do not meet criteria to be classified as another soil. They are located in inert or slowly soluble parent material, recent deposits, or excavation spoils. The profile horizons are usually A-C (Figure A 31).

Regisols exist in all climates and vegetation. They occur on level terrain to steep slopes.

Countries with more than 500 000 km$_2$ are Canada, Russia and Mexico. These are dominant soils in Curacao, Aruba, Bahamas, Bonaire, Saint Eustatius, Saba, Cayman Islands, Norway and El Salvador.

ARENOSOLS (Psamments)

Figure A31 | (a) A Regosol profile and (b) the associated landscape, China.

Arenosols are sandy soils that may have diagnostic horizons below meter. These soils have low water holding capacity and where there is no plant cover they are subject to wind transport. Profile horizonation is A-C (Figure A 32).

Arenosols occur in any climate except permafrost. Vegetation varies widely with climate. They are found on level to steep slopes. Typical textures are sandy or loamy sand on dunes, beaches, lacustrine deposits or weathered sandstone or coarse granite. The age can be recent to Pliocene or older.

Arenesols occupy approximately 1 300 million ha or about 10 percent of the land surface of the globe. Countries with more than 400 000 km_2 are Australia, Sudan, China, Angola and Botswana. These are the dominant soils in Botswana and Angola.

FLUVISOLS (Fluvents, Fluv-Subroups)

Figure A32 | (a) An Arenosol profile in South Korea and (b) an Arenosol profile in New Mexico.

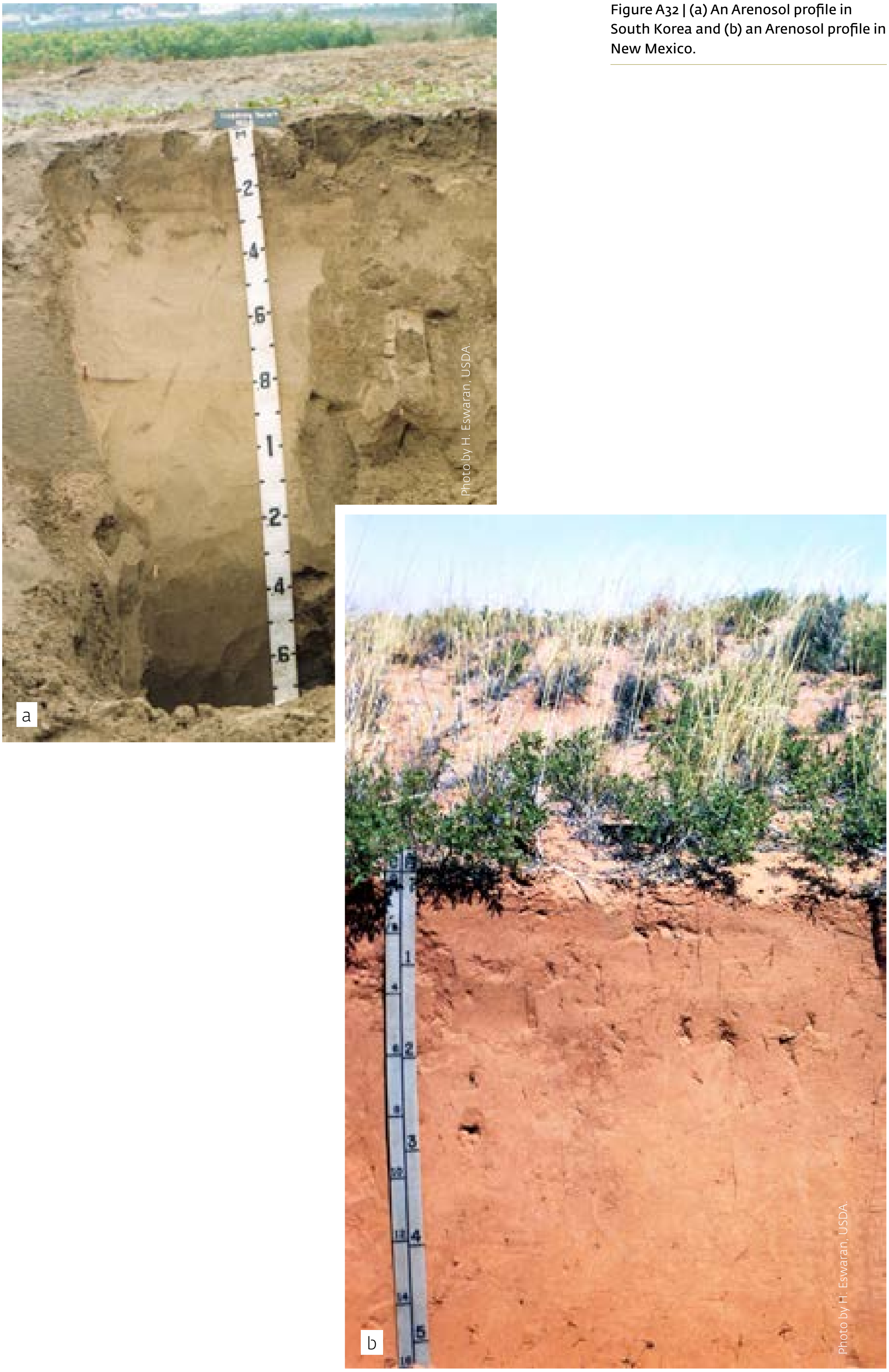


Photo by H. Eswaran, USDA.

Photo by H. Eswaran, USDA.

Fluvisols are soils developedin fluvial, lacustrine or marine deposits A noted characteristic is an irregular decrease in organic carbon. In fact, significant soil organic carbon is buried by depositional events. Typical horizonation is A-C_2-C_3-Ab (Figure A 33).

Fluvisols are found in all climates except permafrost. Vegetation depends on climate and proximity to water. The relief is usually level. Most of the soils are of recent origin.

Fluvisols occupy approximately 350 million ha of the land surface of the globe. Countries with more than 20 million ha are Russia, China and Indonesia.

9 | Permanently flooded soils

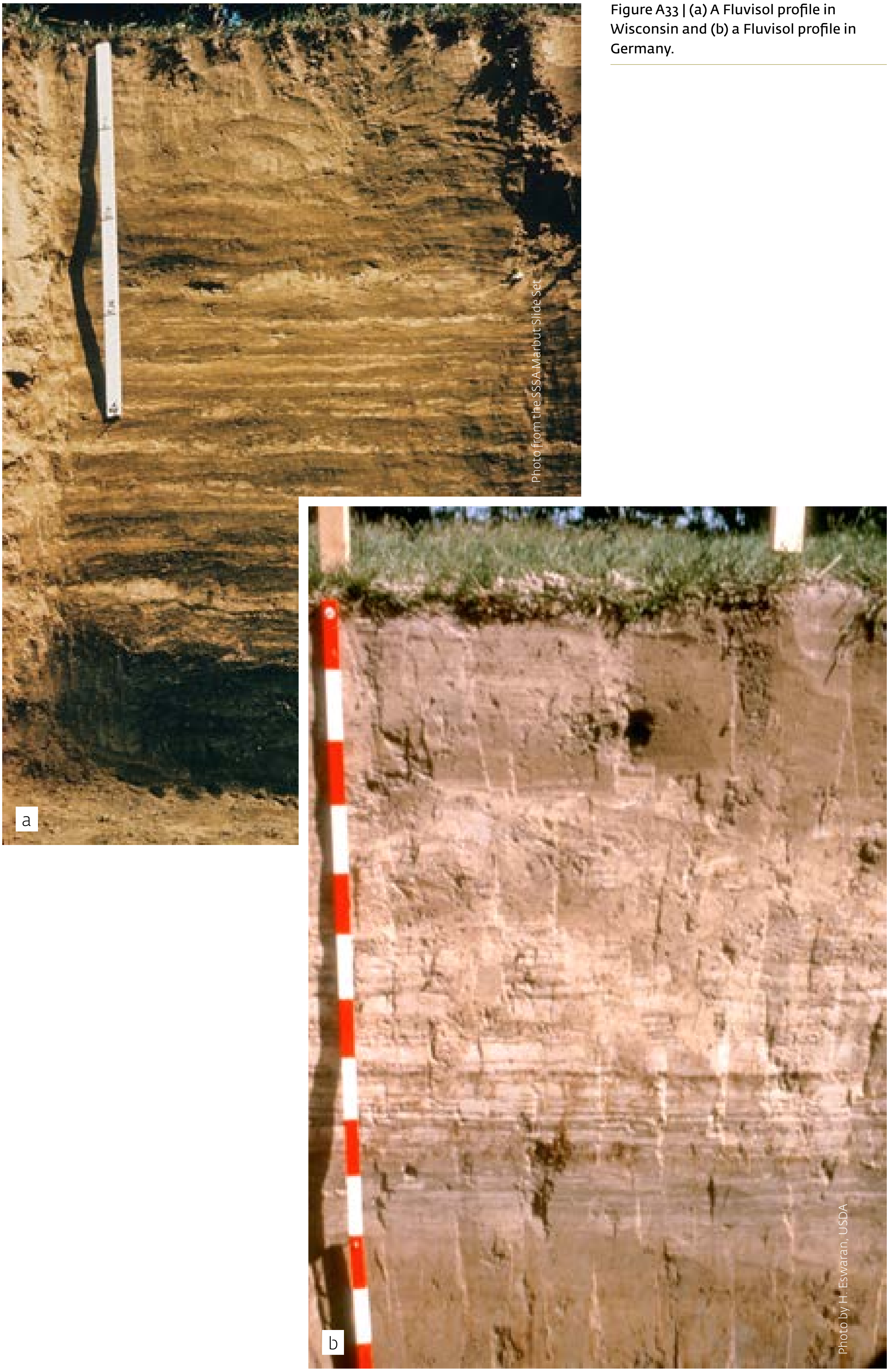


Figure A33 | (a) A Fluvisol profile in Wisconsin and (b) a Fluvisol profile in Germany.

Photo from the SSSA Marbut Slide Set

Photo by H. Eswaran, USDA

WASSENTS, WASSISTS (subaquatic in Histosols and Fluvisols)

Diagnostic horizons are typically absent from subaqueous soils. The exception is horizons formed from the accumulation of organic materials derived from submerged aquatic vegetation. Buried horizons have been observed because of sea level rise. In estuarine subaqueous soils, sulphides typically accumulate in low energy environments (sulphidization). Another important process is pedoturbation (faunal). This is especially the case in estuarine subaqueous soils where benthic organisms such as clams and worms burrow and mix the upper soil materials.

Subaqueous soils are found in shallow areas of lakes, ponds and estuarine systems such as bays and lagoons in any climate. The distribution of the different subaqueous soil types typically follows the submerged landscape which is broken into different units such as submerged beach, bay bottom, wash-over fan, or flood-tidal delta. The parent materials are marine or lake sediments that have been brought in by streams and rivers emptying into the system or through inlets bringing in tidal water and sediment, or sediments brought in during storm events where over-wash events move materials from the barrier island into the lagoon. These are young soils, similar to floodplains in the subaerial system, and having little profile development. Buried horizons are common (figure A 34).

Subaqueous soils provide the structure and habitat for the range of benthic organisms that live in these systems. Submerged aquatic vegetation is rooted in these soils and obtains some nutrients from the soils. Recent studies have shown that subaqueous soils store and sequester equivalent amounts of soil organic carbon as their subaerial counterparts. These soils serve as sinks for heavy metals and under certain conditions are important for water quality, storing N and providing denitrification. Shellfish aquaculture for species such as hard clams and oysters is a common practice on shallow estuarine subaqueous soils.

A range of submerged aquatic vegetation can be found rooted in these soils, depending on the location, climate and water quality. Common species in estuarine systems include eelgrass (*Zostera marina*), turtle grass (*Thalassia sp.*), and widgeon grass (*Ruppia sp.*). In freshwater systems pondweed (*Potamogeton sp.*), watermilfoil (*Myriophyllum sp.*), and fanwort (*Cabomba sp.*) are commonly found.

Figure A34 | (a) A Wassent profile and (b) the associated landscape, the Netherlands.

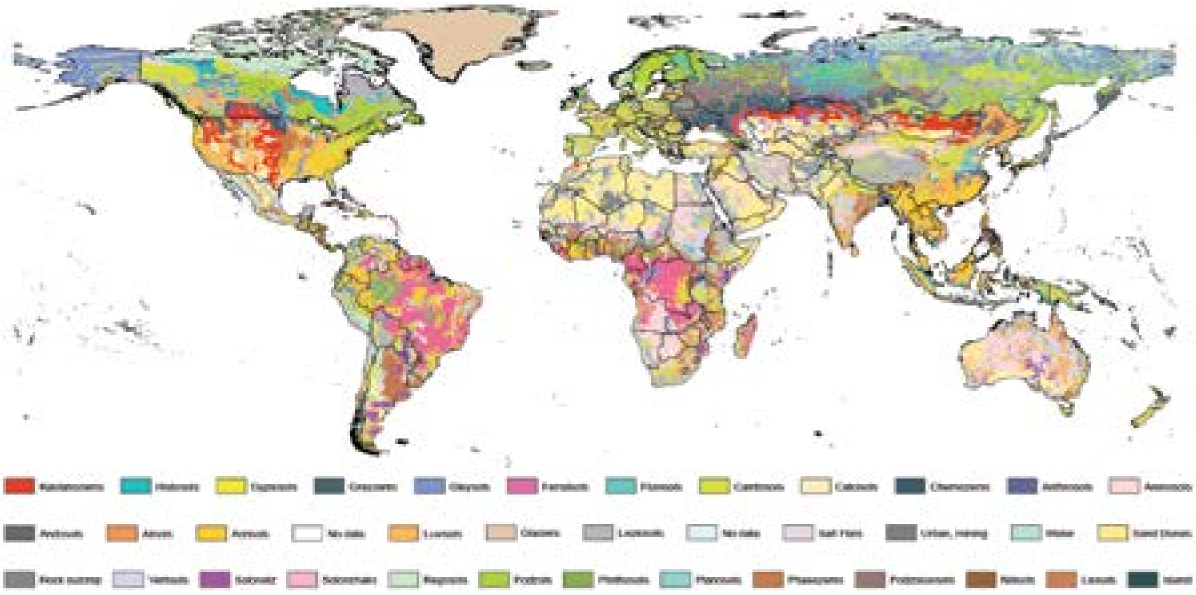


Figure A35 | Global Soil Map of the World based on HWSD and FAO Revised Legend (Nachtergaele and Petri, 2008)

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