

Figure A21 The alkaline soils field of Figure A19, magnified to show the approximate ranges of precipitation of carbonates, sulfates, halides and silicates in soils. The pH of an evaporating soil solution depends mainly on the concentrations of carbonate species in the system. The precipitation of neutral salts such as gypsum and halite is not pH dependent. The lower pH limits of sulfate and halide precipitation ranges shown in the diagram are based simply on empirical observation. A good deal of variability is possible depending principally on the initial composition of the soil solution.

Cross-references

Calcisols
Gypsisols
Solonchaks
Solonetz

ALKALIZATION

Generally used for processes which increase the pH of soils such that they become alkaline (pH greater than 7) or alkali (pH greater than 8.5). Synonym: alkalization. McBride (1994, p. 274) states that mineral dissolution and the release of ions into solution are invariably involved in the generation of alkalinity.

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ALLITIZATION

An advanced stage of weathering in which Al and Fe accumulate at the expense of other ions and species such as the alkalis, alkaline earths and silica, which are removed from the soil in the aqueous phase (Pedro, 1983, table 1).

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ALLOGENIC

Describes components transported into the soil from some external place of origin. Equivalent to the geological term allochthonous. See *Authigenic*.

ALLUVIUM

Alluvial sediment deposited from flowing water; or pertaining to a deposit formed in that way. The parent material of alluvial soils.

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ANDOSOLS

Introduction

Andosols are soils of active volcanic areas. They exhibit unique soil properties that place them apart from other soils. The term 'andosol' is derived from Japanese, 'an' meaning dark, and 'do' connotating soil (Figure A22). Andosols are also found outside active volcanic regions when environmental conditions favor their formation. Andosols have a limited extent (1–2%) of Earth's land surface, but many such areas are densely populated.

The discussion of this entry follows the terminology of the World Reference Base for Soil Resources (WRB, FAO, 1998). Andosols are termed slightly different, or andisols according to the U.S. Soil Taxonomy (Soil Survey Staff, 1998). The soils discussed in this entry include tephra-rich soils, many of which are not considered Andosols, according to the WRB or Soil Taxonomy, but have various notations in international soil literature, such as vitrisols, (Iceland), vitrandosols (France), Pumice Soils (New Zealand), and vitrons (FitzPatrick's system).

Andosols were the subject of a book edited by Shoji et al. (1993a), which is the most comprehensive discussion of Andosols to date. Other publications devoted to Andosols include three special issues of scientific journals (Fernandez Caldas and Yaalon, 1985; Bartoli et al., 2003; Arnalds and Stahr, 2004), overview chapters, for example by Wada (1985) and Kimble et al. (2000), a monograph by Dahlgren et al. (2004), and a compilation of benchmark papers about Andosols (Tan, 1984).

The concept of Andosols

The development of the concept of Andosols has roots in the U.S. Soil Taxonomy, first presented as the andept suborder of inceptisols (Smith, 1986), but from 1990 as andisols, based on a work of international working group (ICOMAND), as was reviewed by Parfitt and Clayden (1991). The concept of the Andosol soil group, as used in the WRB, is similar to that of Soil Taxonomy (see Shoji et al., 1996).



Figure A22 Andosol in Iceland. The profile is about 190 cm thick. Many distinct tephra layers are evident, disturbed by cryoturbation. Basaltic and andesitic tephra are dark, but thin light colored rhyolitic tephra are also seen near the middle and near the bottom of the profile. The soil contains considerable carbon in most horizons, also at depth.

The concept of andosols is tied to soils that develop in volcanic ejecta. The rapid weathering of volcanic tephra results in precipitation of short-range order minerals and/or metal–humus complexes, a process that is sometimes referred to as ‘andosolization’ (e.g., Duchaufour, 1977). These colloidal constituents provide the soils with properties that distinguish Andosols, such as low bulk density, variable charge characteristics, thixotropy, and strong phosphate retention. The measure of Andosol colloidal constituents is used for the identification of Andosols. However, the term not only reflects products of soil genesis, as vitric parent materials are also used as a diagnostic criterion for these soils according to the WRB and Soil Taxonomy.

Mineralogy and metal–humus complexes

The parent materials

The most common parent material of Andosols is *tephra*. It should be noted, however, that Andosols do form in other types of materials, as will be discussed later.

Tephra. This is a collective term for all airborne volcanic ejecta, regardless of morphology, size, and composition. Volcanic ash is tephra which is <2 mm in diameter (MacDonald, 1972). The nature of tephra materials varies substantially according to the nature of the volcanic eruption that produces the tephra and it can be differentiated on several criteria. *Volcanic glass* is a term commonly applied to tephra but strictly speaking it refers to the part of the tephra that has cooled rapidly. The term *vitric* refers to glass (from Latin ‘vitr’ = glass) and it is used as a diagnostic criterion for poorly developed Andosols/Andisols (FAO, 1998; Soil Survey Staff, 1998), and to coin the terms such as vitrisols and Vitric Andosol. It should be noted that Andosols form in the bulk of parent materials, not only in the Vitric component. Fisher and Schmincke (1984) and Heiken and Wohletz (1985) provided discussion on tephra materials.

Composition. The differentiation of tephra by silica content is perhaps the most useful division of the tephra (basalt, andesite, dacite, rhyolite) and is widely used in geology. It affects weathering rates and the genesis of Andosols as discussed later.

Morphology and mineralogy. Many terms are applied to the morphology of tephra, such as glass, lapilli, cinders, and pumice. Grain size is an elusive term for tephra, as it is often quite porous and has a large active surface area. It is also difficult to determine the mineralogy of tephra because of microcrystallinity and/or non-crystalline nature of the materials. Such terms as colored glass (basaltic-andesitic and some dacite tephra) and non-colored glass (rhyolitic) are commonly used (e.g., Dahlgren et al., 1993).

Genetic mineral components

The dominant clay minerals in Andosols are allophane, imogolite, ferrihydrite, and halloysite. Notable publications on allophane and imogolite include those of Wada (1989), Harsh et al. (2002), Dahlgren et al. (1993), and Dahlgren (1994). These are not layered lattice clay minerals such as smectite and kaolinite, but are described by terms such as ‘spherical’, ‘tubular’ and ‘gel-like’. Their crystallinity has been subject to debate and these constituents have been described as ‘amorphous’, ‘X-ray amorphous’, ‘poorly crystalline’, ‘noncrystalline’, and ‘short-range order’.

The tephra parent materials of Andosols weather rapidly, resulting in high concentrations of Al, Fe, and Si. The poorly crystalline (short-range order) morphological forms of these minerals are the result of rapid crystallization of Al and Si (allophane and imogolite) and Fe (ferrihydrite) from such soil solution. However, these minerals are not exclusive to Andosols as they are also commonly found in Podzols, but to a lesser degree.

Allophane and imogolite

Allophane is an aluminum and silica mineral that forms hollow spherules which are about 5 nm in diameter. The ratio between Al and Si is somewhat variable, most commonly 1–2, but values <1 have been recorded (Parfitt and Kimble, 1989). These minerals have an extremely large surface area and a high

negative charge that is pH-dependent (variable charge), which increases rapidly with pH. In addition, allophane has considerable anion exchange properties.

Imogolite is tubular and often appears thread-like viewed with a transmission electron microscope. It usually has an Al/Si ratio close to 2, but similar properties to allophane.

Ferrihydrite

Ferrihydrite is a poorly ordered Fe^{III} mineral (Schwertmann, 1985), consisting of well aggregated spherical particles (Bigham et al., 2002) which often appear with gel-like structure. Its structure has been debated and ideas about the nature of ferrihydrite are still evolving. Ferrihydrite is very common in Andosols, especially where the parent materials are rich in iron, as in Iceland. It has a large surface area and a pH dependent cation and anion exchange capacity (Bigham et al., 2002).

Halloysite and other clay minerals

Halloysite is a common mineral in Andosols, especially in Si-rich environments, and is often associated with dry environments (Dahlgren et al., 1993, 2004) with distinct dry season. Its morphology varies, but it is believed to be closely related to kaolinite (see White and Dixon, 2002). Halloysite is often reported as representing more weathered environment than allophane dominated soils (e.g., Ndayiragije and Delvaux, 2004). Other minerals are found in many Andosols, especially when Andosols become mature, with the Andosol minerals being transformed to other minerals, such as kaolinite, smectite and Al/Fe oxides and chloritized 2 : 1 minerals (e.g., Shoji et al., 1985). Opalline silica is also often reported in Andosols, especially under grassland vegetation (e.g., Shoji et al., 1993b).

Allophane–humus and metal–humus complexes

The original concept of Andosols ('an-do') reflects the dark color of many andosols, which mainly results from the accumulation of organic matter. Large contents of organic matter characterize well-developed andosols. Appreciable amounts of carbon are found at depths, and the distribution is often quite erratic. There are two main pathways of organic accumulation in Andosols: the formation of allophane–organic matter complexes and metal–humus complexes.

Allophane and organic matter form bonds that are relatively stable, which results in soils that commonly have >6% C in both A and B horizons. This effect is enhanced when Al^{3+} and Fe^{3+} form stable bonds with organic matter by ligand exchange (metal–humus complexes). This means of carbon accumulation is effective at a relatively low pH. Research has confirmed the stability of these constituents, which can be >100 000 yr old in Hawaii (Torn et al., 1997).

In some areas, other environmental factors can enhance the accumulation of organic materials in Andosols, such as poor drainage and cold climate resulting in OC 12–20% (Arnalds, 2004).

Genesis

The rapid weathering of tephra constituents is perhaps what distinguishes the genesis of Andosols the most. It leads to a soil solution oversaturated with regard to Al, Si, and frequently Fe or organic molecules, which results in the precipitation of the colloidal Andosol constituents. The nature of the parent materials (most often tephra) and climate, which influences the rate of weathering and therefore the release of Al, Fe and Si, are the dominant factors shaping the formation of Andosols. Humid climate

enhances the weathering of tephra and the majority of the world's Andosols are therefore found under humid conditions, but <10% under arid or xeric moisture conditions (Wilding, 2000).

Andosols are most commonly considered youthful soils. Soils on slopes of volcanoes often show a trend from less weathered vitric or andic soils at high elevations (young PM/cold/coarse tephra) to allophanic soils, metal–humus complex dominated soils, and finally to more weathered soils of other types, such as Vertisols (warm, less tephra inputs, fine tephra). A range of soils can develop from Andosols, including Podzols, Mollisols, Vertisols, and Oxisols, (e.g., Dahlgren et al., 2004; Yerima et al., 1987). However, if the climate is dry and especially when the parent materials are silicious, vitric characteristics may dominate for a long time. Andosols also form in tephra redistributed by wind long distances away from where the volcanic materials were originally deposited, as in Iceland (Arnalds et al., 1995).

The nature of Andosols implies that these soils often become buried by new volcanic materials, both tephra and lava.

Allophanic, vitric and metal–humus complex andosols

Vitric (*vitrandic*), allophanic (*silandic*) Andosols, and Andosols dominated by metal–humus complexes (*aluandic*) can be viewed as three 'end-members' of Andosols (Shoji et al., 1996). The rate of cation release and the pH of the soil solution largely determine whether allophanic Andosols or soils dominated by metal–humus complexes are formed. Allophane formation is favored by a high pH, while it does not form when pH is under 5 (Figure A23a). Under such acidic pH conditions, the formation of metal–humus complexes becomes a dominant process (Figure A23b). The 'aluandic' soils often contain considerable amounts of phyllosilicates, such as chloritized 2 : 1 minerals (Shoji et al., 1985), under a variety of climatic conditions, which contribute to their physical and chemical behavior (see also Ndayiragije and Delvaux, 2003).

The weathering of basaltic tephra is rapid, resulting in areas of high chemical denudation (Stefansson and Gislason, 2001), rapid formation of allophane and ferrihydrite. The surface area of basaltic tephra can be quite high or >10 m² g⁻¹ (Wolff-Boenisch, 2004). Young basaltic tephra soils, which appear to have not been subjected to much weathering, can therefore meet criteria for Andosols (Arnalds and Kimble, 2001).

The weathering of basaltic or andesitic tephra releases an abundance of cations, which maintain the pH. The system can be continuously recharged with cations by weathering of new materials deposited by repeated volcanic eruptions. If not, the soil pH will eventually become low with depletion of tephric materials, and the formation of metal humus complexes becomes a dominant process.

Weathering rates of silicious (rhyolitic) tephra are slower than in basalt with less abundance of cations released to maintain the pH. Weathering often results in more acidic soils, especially in humid-wet areas. Dry climates can alternatively result in relatively unaltered parent materials.

The formation of metal–humus complexes becomes dominant at pH < 5, when humic substances form bonds with Al and Fe (predominantly). Their formation is influenced by the rapid release of Al (and Fe), as in the formation of the mineral colloids (allophane, imogolite and ferrihydrite). In Iceland, both mineral colloids and metal humus complexes seem to form when pH is 5–6 (Agricultural Research Institute, unpublished data). Metal–humus complexes have been shown to be quite stable against biodegradation (e.g., Nanzyo et al., 1993), and more stable than allophane–

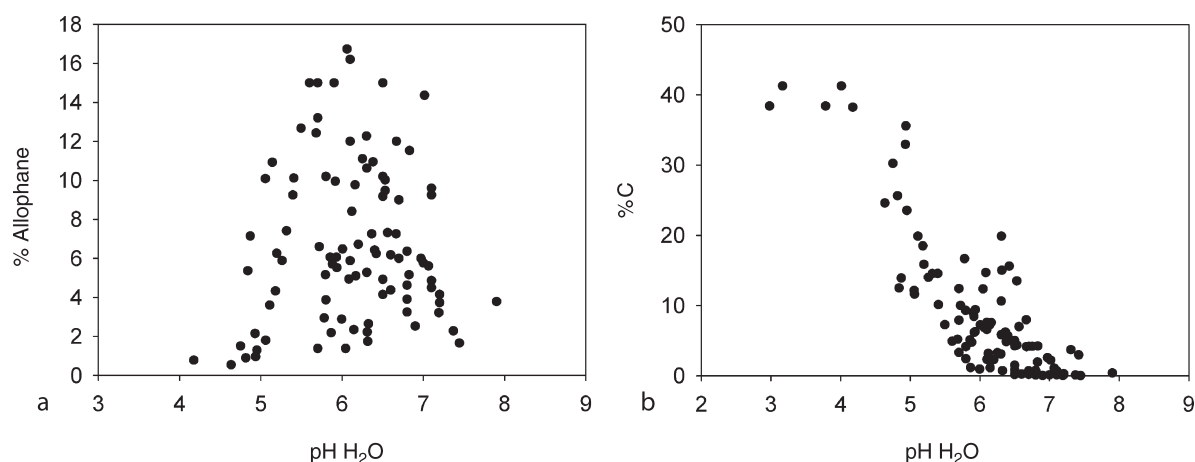


Figure A23 Allophane and organic carbon as a function of soil reaction in Icelandic Andosols and Histosols (surface horizons). Allophane does not form when pH becomes lower than 4.9 (a) and reaches a maximum around pH 6. Organic content rises rapidly with decreased pH, which also represents less tephra input in Iceland (b). With less tephra, there is less release of cations by weathering to maintain the pH. The gradient continues into Histosols, which have >20% organic carbon (figure based on O. Arnalds, unpublished data).

humus complexes (Boudot, 1992). Metal–humus complexes can be stable for >20 000 yr, and even >100 000 yr as exemplified by old soils in Hawaii (Torn et al., 1997).

The effect of vegetation on Andosol formation is often emphasized (e.g., Shoji, 1988), with darker soils rich in organic matter (melanic horizons) forming under grassland vegetation, but lighter colored fulvic horizons under woodlands.

Formation in redistributed volcanic rocks and other parent materials

Andosols have been reported to form in other materials than volcanic when environmental conditions result in a weathering environment characteristic of andosols. Andosols have formed in gabbros and amphibole parent materials in Galicia, Spain (Garcia-Rodeja et al., 1987), in low-activity clay regolith in India (Caner et al., 2000), in granite in Austria (Delvaux et al., 2004), and in non-volcanic materials in Nepal (Baumler and Zech, 1994). Old volcanic rocks, often reworked by glaciers or redistributed as sediments, can also serve as parent materials for Andosols, such as reported in Washington (Hunter et al., 1987) and France (reviewed by Quantin, 2004).

Properties

Morphology

When considering the horizonation and morphology of Andosols, it is important to bear in mind that the soil environment is characterized by deposition of parent materials, with the youngest materials on top, gradually or repeatedly being buried under new fresh vitric materials. However, some Andosols also form in volcanic bedrocks that for example have been reworked by Quaternary glaciers (see Quantin, 2004).

Andosols are usually dark soils rich in organic matter, but the morphology varies considerably according to the type of andosols. The color of Vitric Andosols is partly determined by the nature of the tephra materials, which range from black basaltic to light colored rhyolitic materials.

Horizonation typically follows an A–Bw–C sequence, but often with buried sequences due to repeated deposition events.

Argillic horizon is usually not present. Clear tephra layers result in abrupt horizon boundaries. Tephra layers are sometimes distinct and can be important markers for dating.

While the surface horizon commonly has well expressed granular structure, the structure of the B horizon is usually poorly developed and difficult to identify. Young or poorly developed Andosols can contain various types of coarse fragments, which are described by specific terminology such as ashy, pumiceous, and cindery (see Shoji et al., 1993c).

Andosols tend to be very friable when lacking phyllosilicates, and non-plastic. Roots often extend far into the soils. However, hard-pans are also common under moist climates, which impede both root growth and water transport.

Physical properties

The many peculiar physical properties characterize Andosols such as strong silt sized aggregation and thixotropic nature, as was reviewed by Maeda et al. (1977). Vitric materials do not show these properties as clearly as allophanic or metal–humus Andosols, but their physical behavior depends on their type and degree of weathering (see Warkentin and Madea, 1980).

Aggregation and bulk density

Low bulk density is one of the diagnostic criteria for Andosols. Density of <0.9 g cm⁻³ is required. This low bulk density is a result of high organic content, aggregation of soil materials, and sometimes low density vitric materials. Icelandic research points to two main axes of influence, with density slowly decreasing with increased allophane content, but organic matter having more influence on bulk density with lowest values (0.2 g cm⁻³) recorded in Histic Andosols (>12% C). The mineral colloidal fraction also forms stable silt-sized aggregates, which greatly influence the physical properties of Andosols (Maeda et al., 1977), and make conventional mechanical particle size determinations useless for Andosols. Drying can cause irreversible decrease in water retention and increase in bulk density.

Water retention and transport

Great water retention is one of the main characteristics of Andosols, hence the low bulk density. Common 1.5 MPa tension water contents are >60%, but the term 'hydric' is used to describe Andosols when water retention is >100% at this tension based on dry weight of the soil. While allophane, imogolite and ferrihydrite contribute to this strong water retention, the effect of organic matter (metal–humus complexes, allophane–humus and humus alone) is much greater, following the two line pattern shown earlier for bulk density. Andosols have a large proportion of both large and intermediate pores, which allow for rapid water transport. Water infiltration, and both saturated and unsaturated hydraulic conductivity are rapid compared to most other soils (see Warkentin and Maeda, 1985; Basile et al., 2003). The silty aggregate behavior of the clay constituents and extremely high water retention leads to high frost susceptibility of Andosols (Arnalds, 2004).

Vitric materials can also have substantial water holding capacity, and extremely high infiltration rate and saturated hydraulic conductivity, enhancing their use for agriculture.

Atterberg limits and thixotropy

Andosols possess a special property, which has been called thixotropy. The soils can contain large amounts of water and yet appear relatively dry. When disturbed, the water is released. In other words, the soil can reach the liquid limit upon disturbance (Figure A24). This property is also expressed by very high liquid limits but a low range where the soil is plastic, resulting in very low plasticity index (often near 0). This property explains in part why andosols are quite susceptible to slope failures when disturbed.

Chemical properties

pH

Andosols can have a range of soil pH (H₂O). Metal–humus-dominated soils tend to be acid (<5) with low base saturation and they can show signs of Al toxicity. Soils dominated by allophane often have pH 5.5–6.5 (Nanzoyo et al., 1993). If fresh basic parent materials are still present, pH is maintained by recharge of basic cations during weathering, which in Iceland sometimes leads to pH > 6.5 (Arnalds, 2004). Older, mature Andosols tend to have lower pH than younger soils, and can be quite acid. Soil reaction measured in KCl tends to be 0.5–1.5 units or more lower than the pH H₂O, the greatest difference between the two appears where metal–humus complexes are present (Nanzoyo et al., 1993). Soil reaction measured

in KCl provides important information about soil acidity in acid Andosols.

Soil reaction of Andosols rises rapidly when NaF is added to the soil solution, with F[−] replacing OH[−] from active surfaces. This is sometimes used to identify the presence of andic soil materials, both in laboratory and in the field.

Ion exchange

One of the most distinguishing features of Andosols is their pH-dependent charge. Allophane, imogolite, ferrihydrite and metal–humus complexes all have large reactive surface areas, but cation exchange capacity rises rapidly with increasing pH (see Wada, 1985). Determination of CEC is therefore very dependent on the pH used in any particular method and care should be taken when interpreting both CEC and base saturation values (see Madeira et al., 2003). Common CEC values reported for Andosols range between 10–40 cmol_c kg^{−1}. Andosols also exhibit anion exchange properties, which can be important for nutrient retention (e.g., Cl[−], NO^{3−}, SO₄^{2−}).

Exchange characteristics make Andosols susceptible to heavy metal and Cs¹³⁷ pollution (e.g., Adamo et al., 2003) by retaining the pollutants quite effectively, especially when soils are not very acid (Nanzoyo et al., 1993). Andosols often sustain dense populations, and pollution problems have been recorded in many areas, such as near Napoli, Italy (Adamo et al., 2003).

Classification

The development of early concepts and selection of classification criteria were reviewed by Parfitt and Clayden (1991) for Soil Taxonomy, and the subsequent evolution of the WRB criteria was discussed by Shoji et al. (1996). The colloidal constituents of Andosols, clays and metal–humus complexes, provide them with their distinctive characteristics. The identification of Andosols is therefore primarily based upon the measure of these constituents and their accessory properties.

Diagnostic properties

Identification of Andosols is based on the identification of an 'andic horizon' in WRB (FAO, 1998), but 'andic soil properties' according to Soil Taxonomy (Soil Survey Staff, 1998). Acid ammonium oxalate preferentially extracts the poorly ordered colloid constituents of Andosols and can be used to calculate the amount of allophane, imogolite and ferrihydrite (Parfitt and Childs, 1988; Parfitt and Wilson, 1985). The treatment also extracts Al and Fe associated with metal–humus

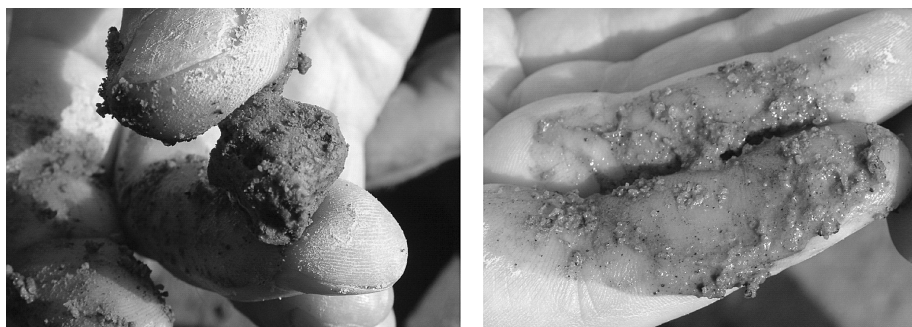


Figure A24 Thixotropy. Undisturbed clod is shown on to the left, but disturbed clod to the right. The soil reaches the liquid limit when disturbed with gentle pressure, even though the clod appears relatively dry. The soil is hydric andosol from the Azores (Portugal).

complexes. The primary diagnostic criteria for andic horizon is that it has $\geq 2\%$ oxalate extractable Al and $\frac{1}{2}\text{Fe}$ ($\text{Al} + \frac{1}{2}\text{Fe}$)_o. Additional criteria used for identifying andosols are bulk density $< 0.9 \text{ g cm}^{-3}$, P-retention $\geq 70\%$, and thickness of $\geq 30 \text{ cm}$. WRB also defines a 'vitric horizon', which is at least 30 cm thick, containing $> 10\%$ volcanic glass in the fine earth fraction and has either ($\text{Al} + \frac{1}{2}\text{Fe}$)_o of $> 0.4\%$, or bulk density $> 0.9 \text{ g cm}^{-3}$, or P-retention $> 25\%$. Soil Taxonomy uses similar criteria for vitric materials, which are included with andic soil properties, by decreasing the requirements for ($\text{Al} + \frac{1}{2}\text{Fe}$)_o with increasing amount of vitric materials (0.4% ($\text{Al} + \frac{1}{2}\text{Fe}$)_o when vitric glass $> 30\%$). In addition, tephric material (un-weathered) is defined by the WRB.

It should be noted that the tendency of Andosols to accumulate large amounts of organic matter is given special consideration by allowing andic soil horizons to have up to $20\% \text{ C}$, while under other conditions $> 12\% \text{ C}$ (no clay) would normally result in Histosol classification (FAO, 1998). This breakpoint is at $25\% \text{ C}$ in Soil Taxonomy (Soil Survey Staff, 1998).

Andosols, subclasses

The WRB separates Andosols based on many criteria. Andic horizons are divided depending on whether they are allophanic (silandic), metal-humus complex dominated (aluandic) or vitric. Melanic and fulvic horizons are andic horizons with $> 6\% \text{ C}$, but the melanic horizon is darker than the fulvic, but a distinction between the two is also based on the so-called melanic index (see FAO, 1998; Shoji, 1988). The term 'hydic' is used for Andosols with $> 100\%$ water at 1.5 MPa tension. Andosols also include vitric and silic (allophane rich) subgroups. There is a range of other subunits of Andosols based on criteria common to other soil groups of the WRB, such as histic, mollic and gleyic. Tephric soil material is also used by the WRB for vitric soils.

Distribution

Andosols are found in volcanic regions, which are widespread on Earth, in all climatic regimes but more commonly in humid areas than dry (Wilding, 2000). Vitric soils are also widespread, but are not recognized as Andosols according to the WRB.

Reviews by Kimble et al. (2000), Dahlgren et al. (2004) and FAO (2001) provided good accounts of aerial distribution of Andosols. They are common along the Pacific coast of the Americas, with notable areas are in Alaska ($100\,000 \text{ km}^2$, Kimble et al., 2000) the Pacific North-West USA, Mexico, Peru and Chile. Andosols are found in volcanic areas of Africa, e.g., Ethiopia, Rwanda, Kenya and Tanzania (FAO, 2001). Large areas are found in Asia, including the Kamchatka Peninsula (Russia), Japan, Indonesia and the Philippines, and New Zealand. Andosols are also found in active volcanic areas of mainland Europe (e.g., Italy, France). They are major soils of the volcanic islands in the Atlantic, including the Azores, Madeira the Canaries, and in Iceland. FAO estimate (2001) for global distribution of andic soils is 1.1 million km^2 , but recent USDA-NRCS estimates are 1.2 million km^2 (Kimble et al., 2000) and $0.91 \text{ million km}^2$ (Wilding, 2000) (see Figure A25).

Areas affected by volcanic ash are much larger than the close vicinity of volcanoes, as volcanic materials can be transported long distances during eruptions or by aeolian/fluvial redistribution.

Andosols and land use

The low bulk density and lack of cohesion make Andosols susceptible to disturbance, such as made by heavy machinery. The soils are susceptible to failure when disturbed on slopes, which can cause them to reach the liquid limit (thixotropic property). Landslides are therefore common on slopes covered by Andosols, and this has caused many catastrophes in volcanic areas such as near Napoli, Italy in 1998 (e.g., Basile et al., 2003). Mantling of harder bedrock by andic soils and the platy character arising from tephra layers can form planes of failures. Considerable resources are spent on stabilizing Andosols (Figure A26).

Andosols are light and easy to plow, which favors their cultivation. The high water holding capacity and good hydraulic conductivities enhance their use for agriculture, but coarse layers of tephra can, however impede unsaturated water flow. Good quality products are often associated with Andosols, such as of wine and coffee. However, fertility varies greatly between Andosol types, especially between the acid metal-humus complex Andosols and the allophanic soils. Vitric soils are

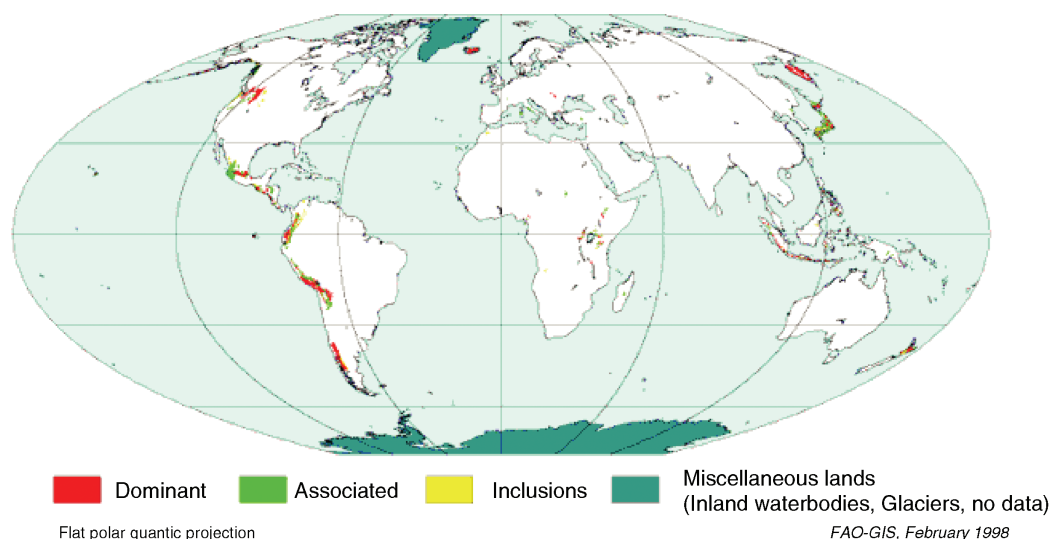


Figure A25 Andosols of the world.



Figure A26 Road construction in Hokkaido, Japan. Much effort is made to stabilize the slopes, but landslides are common in Andosol areas.

widespread, especially under dry temperature regimes (e.g., Africa, Mediterranean), and are successfully used for various crops, depending on local conditions, such as seasonal rainfall pattern and possible source of irrigation water.

Extreme examples of the value of Andosols and vitric materials for cultivation is the transport of andic soil materials to the lowlands of the Canary Islands for intensive cultivation (*sorriba*) (see Armas-Espinel et al., 2003) and the use of tephra as mulch for water conservation in the Canaries (Tejedor et al., 2003).

Hard pans commonly form in Andosols, which greatly affect their management possibilities, such as Mexico's *tepetates* (Servenay and Prat, 2003) and in the Azores (Pinheiro et al., 2004). Andosols have an especially strong tendency to retain phosphate, hence the P-retention classification criterion, and often require phosphorous additions for intensive crop production. Allophanic soils in the tropics are often heavily populated as a result of their fertility. Heavy land use can lead to pollution of these soils, enhanced by their colloid charge characteristics.

Much of the organic carbon in global cycling is retained in soils. The tendency of andosols to accumulate more carbon than other mineral soils (Eswaran et al., 1993) make them important in relation to the global carbon cycle and climate change, in spite of their limited distribution.

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Cross-references

Acid Soils

Classification of Soils: World Reference Base (WRB) for Soil Resources

Classification of Soils: World Reference Base (WRB) Soil Profiles

Geography of Soils

Iron Oxides

ANTHROPOGENIC

Used of soils, landscapes, or ecological systems generally, to indicate modification by human activities. Recognized as the group Anthrosols in the WRB System of Soil Classification, in terms of diagnostic anthropogenic horizons:

A terric horizon (from *L. terra*, earth) results from addition of earthy manure, compost or mud over a long period of time. The terric horizon has a non-uniform textural differentiation with depth. The source material and/or underlying substrates influence the color of the terric horizon. Base saturation (in 1 M NH_4OAc at pH 7.0) is more than 50%.

An irrigric horizon (from *L. irrigare*, to irrigate, and *agricolare*, to cultivate) is a light colored (Munsell color value and chroma, moist, both greater than 3), uniformly structured surface layer, developed through long-continued irrigation with sediment-rich water. Clay and carbonates are evenly distributed and the irrigric horizon has more clay, particularly fine clay, than the underlying soil material. The weighted average organic carbon content exceeds 0.5%, decreasing with depth but remaining at least 0.3% at the lower limit of the irrigric horizon.

A plaggic horizon (from Dutch plag, sod) has a uniform texture, usually sand or loamy sand. The weighted average organic carbon content exceeds 0.6%. The base saturation (in 1 M NH_4OAc at pH 7.0) is less than 50%. The content of P_2O_5 extractable in 1% citric acid is more than 0.25% within 20 cm of the surface (frequently more than 1%).

A hortic horizon (from *L. hortus*, garden) results from deep cultivation, intensive fertilization and/or long-continued application of organic wastes. It is a dark colored horizon with Munsell color value and chroma (moist) of 3 or less. The hortic horizon has a weighted average organic carbon content of 1% or more, and more than 100 mg kg^{-1} (0.5 M NaHCO_3 extractable) P_2O_5 in the fine earth fraction of the upper 25 cm layer. Base saturation (in 1 M NH_4OAc at pH 7.0) is 50% or more.

An anthraquic horizon (from Gr. anthropos, human, and *L. aqua*, water) represents a puddled layer or a plow pan. Characteristically, plow pans have a platy structure; they are compacted and slowly permeable to water. Yellowish-brown, brown or reddish-brown rust mottles occur along cracks and root holes. The bulk density of the plow pan is at least 20% greater than that of the puddled layer, whereas its porosity is 10 to 30% less than that of the puddled layer. Non-capillary porosity is 2 to 5%.

A hydric horizon (from Gr. hydros, water, and *L. agricole*, to cultivate) is a subsurface horizon with characteristics associated with wet cultivation:



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