

## ANDOSOLS (AN)

The Reference Soil Group of the Andosols accommodates soils developed in volcanic materials. Common international names are 'Andosols' (FAO, Soil Map of the World), 'Andisols' (USDA Soil Taxonomy), 'Andosols' and 'Vitrisols' (France) and 'volcanic ash soils'.

### Definition of Andosols

Soils

- 1 having a [vitric](#) or an [andic](#) horizon starting within 25 cm from the soil surface; **and**
- 2 having no diagnostic horizons (unless buried deeper than 50 cm) other than a [histic](#), [fulvic](#), [melanic](#), [mollic](#), [umbric](#), [duric](#) or [cambic](#) horizon.

*Common soil units:*

[Vitric](#), [Silandic](#), [Aluandic](#), [Eutrisilic](#), [Melanic](#), [Fulvic](#), [Hydric](#), [Histic](#), [Leptic](#), [Gleyic](#), [Mollic](#), [Duric](#), [Luvic](#), [Umbric](#), [Arenic](#), [Placic](#), [Pachic](#), [Calcaric](#), [Skeletalic](#), [Acroxic](#), [Vetic](#), [Sodic](#), [Dystric](#), [Eutric](#), [Haplic](#).



## Summary description of Andosols

*Connotation:* black soils of volcanic landscapes; from Jap. an, black, and do, soil.

*Parent material:* mainly volcanic ash, but also tuff, pumice, cinders and other volcanic ejecta.

*Environment:* undulating to mountainous, humid, arctic to tropical regions with a wide range of vegetation types.

*Profile development:* AC- or ABC-profile. Rapid weathering of porous volcanic material resulted in accumulation of stable organo-mineral complexes and short-range-order minerals such as allophane, imogolite and ferrihydrite.

*Use:* many Andosols are intensively cultivated with a variety of crops, their major limitation being their high phosphate fixation capacity. In places, steep topography is the chief limitation.

## Regional distribution of Andosols

Andosols occur in volcanic regions all over the earth. Important concentrations are found around the Pacific rim: on the west coast of South America, in Central America, the Rocky Mountains, Alaska, Japan, the Philippine Archipelago, Indonesia, Papua New Guinea and New Zealand. They are also prominent on many islands in the Pacific: Fiji, Vanuatu, New Hebrides, New Caledonia, Samoa and Hawaii. In Africa, major occurrences of Andosols are found along the Rift Valley, in Kenya, Rwanda and Ethiopia and on Madagascar. In Europe, Andosols occur in Italy, France, Germany and Iceland. The total Andosol area is estimated at some 110 million hectares or less than 1 percent of the global land surface. More than half of this is situated in the tropics. Figure 1 shows the worldwide distribution of Andosols. Note that the small scale of this map permits only to show the largest Andosol areas.



Legend:

- Dominant
- Associated
- Inclusions
- Miscellaneous lands

**Figure 1.** Andosols worldwide.



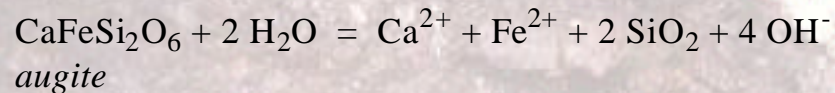
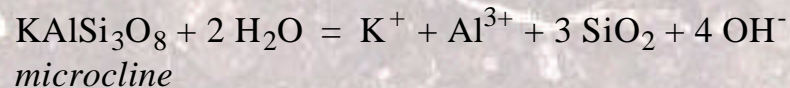
## Associations with other Reference Soil Groups

Andosols are azonal soils occurring in all climates and at all altitudes. Consequently they occur together with almost any other Reference Soil Group. A typical configuration on mountain slopes would have Andosols at the higher end of the slope, [Cambisols](#) and [Luvisols](#) at mid-slope positions and [Vertisols](#) (basic volcanic materials) or [Acrisols](#) (acidic materials) near the foot of the slope. In tropical highlands, e.g. in Kenya and Ethiopia, Andosols are often associated with [Nitisols](#).

## Genesis of Andosols

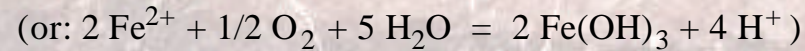
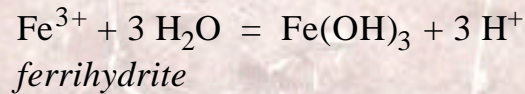
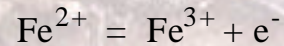
Andosols are characterised by the presence of either an '[andic](#)' horizon or a '[vitric](#)' horizon. Andic horizons are rich in allophanes<sup>1</sup> (and similar minerals) or aluminium-humus complexes whereas the vitric horizon contains an abundance of 'volcanic glass'.

Andosol formation depends essentially on rapid chemical weathering of porous, permeable, fine-grained mineral material in the presence of organic matter. Hydrolysis of the primary minerals 'microcline' and 'augite' may serve to illustrate this type of weathering ('glass' is actually an amorphous mixture but reacts in the same way):



The liberated  $\text{Fe}^{2+}$  and (particularly)  $\text{Al}^{3+}$  ions are tied up in stable complexes with humus. The ferrous iron is first oxidised to the ferric state after which it precipitates for the greater part as ferrihydrite<sup>2</sup>:

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1. *allophanes* are non-crystalline (short-range-order) hydrous aluminosilicates with Al/Si molar ratios typically between 1 and 2 (the Al/Si ratio of kaolinite is 1). They consist of hollow spherules with a diameter of 3.5 - 5 nm and have a very large (reactive) specific surface area.
  2. *ferrihydrite* represents the short-range-order hydrous iron oxides previously termed 'amorphous ferric oxide' or 'iron oxide gel'. Neither its structure nor its composition has yet been established beyond doubt; a good approximation is probably:  $\text{Fe}_2\text{O}_3 \cdot 2\text{FeOOH} \cdot 2.6\text{H}_2\text{O}$ . Ferrihydrite is the dominant iron oxide mineral of most volcanic soils and some of the properties ascribed to allophane may in part be caused by ferrihydrite. Recent evidence suggests that much, if not all, organically bound iron (as extracted by pyrophosphate) is ferrihydrite-Fe.



Aluminium protects the organic part of Al-humus complexes against bio-degradation. The mobility of these complexes is rather limited because rapid weathering yields sufficient Al and Fe to produce complexes with a high metal/organic ratio that are only sparingly soluble. This combination of low mobility and high resistance against biological attack promotes accumulation of organic matter in the topsoil culminating in the formation of a 'melanic' surface horizon that has an intense dark colour and a high content of organic matter.

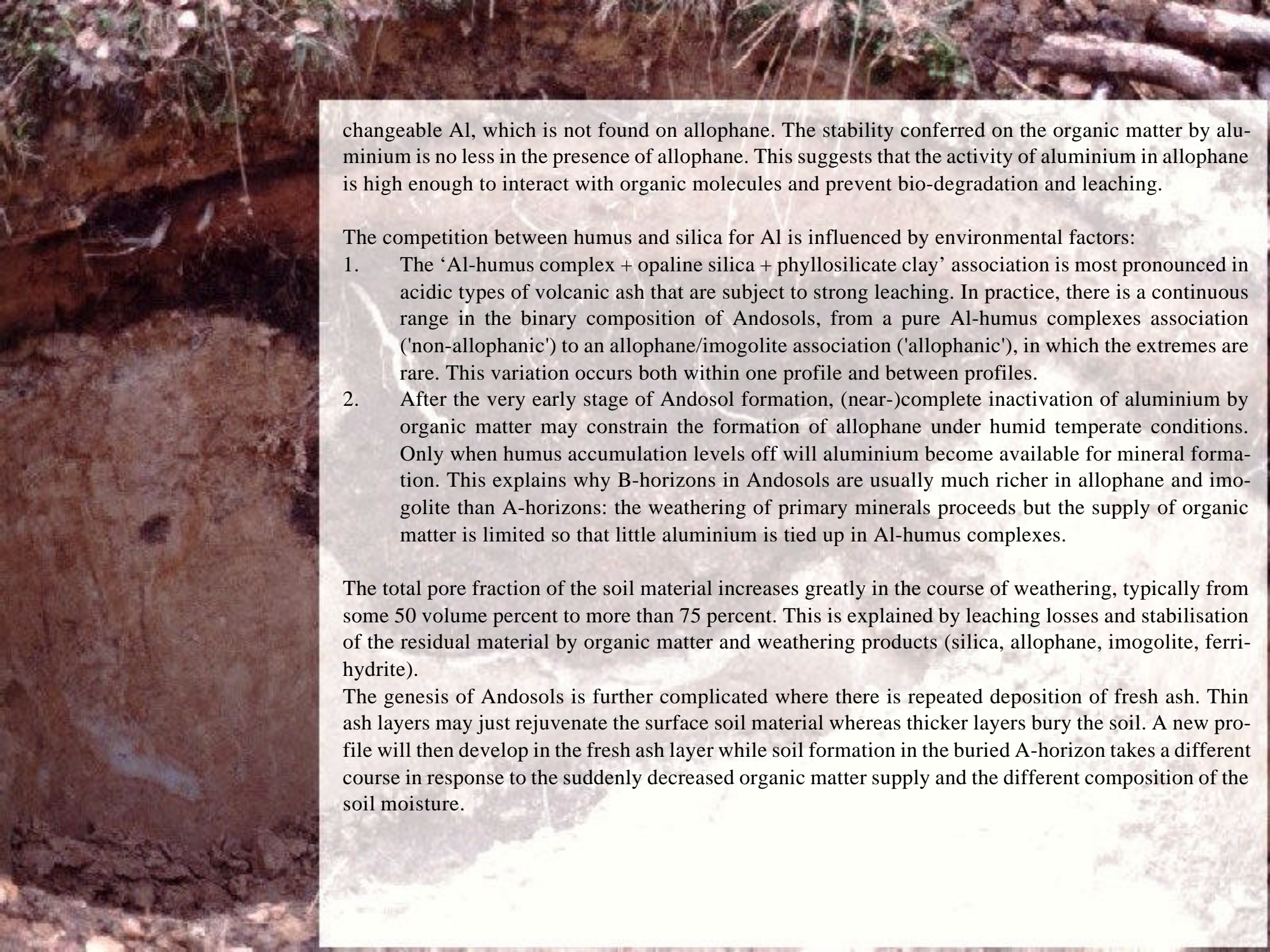
The fate of the liberated silica depends largely on the extent to which aluminium is tied up in Al-humus complexes. If most or all aluminium is 'fixed', the silica concentration of the soil solution increases and while part of the silica is washed out, another part precipitates as opaline silica. If not all aluminium is tied up in complexes, the remainder may co-precipitate with silicon to form allophanes of varying composition, often in association with imogolite<sup>1</sup>.

Note that formation of Al-humus complexes and formation of allophane associations are mutually competitive. This is known as the 'binary composition' of Andosols. It seems that allophane (and imogolite) are stable under mildly acid to neutral conditions (pH>5) whereas Al-humus complexes are dominant in more acid environments. If there is still aluminium available under the latter conditions, this may combine with excess silicon to form 2:1 and 2:1:1 type phyllosilicate clay minerals (e.g. chlorite), often found in association with Al-humus complexes. Under such acid conditions, these soils may have ex-

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1. *imogolite* is a paracrystalline aluminosilicate consisting of smooth and curved threads with diameters varying from 10 to 30 nm and several thousands of nm in length. The threads consist of finer tube units of 2 nm outer diameter; their outer wall consists of a gibbsite (Al) sheet and the inner wall of a silica sheet.

The Al/Si molar ratio is 2.



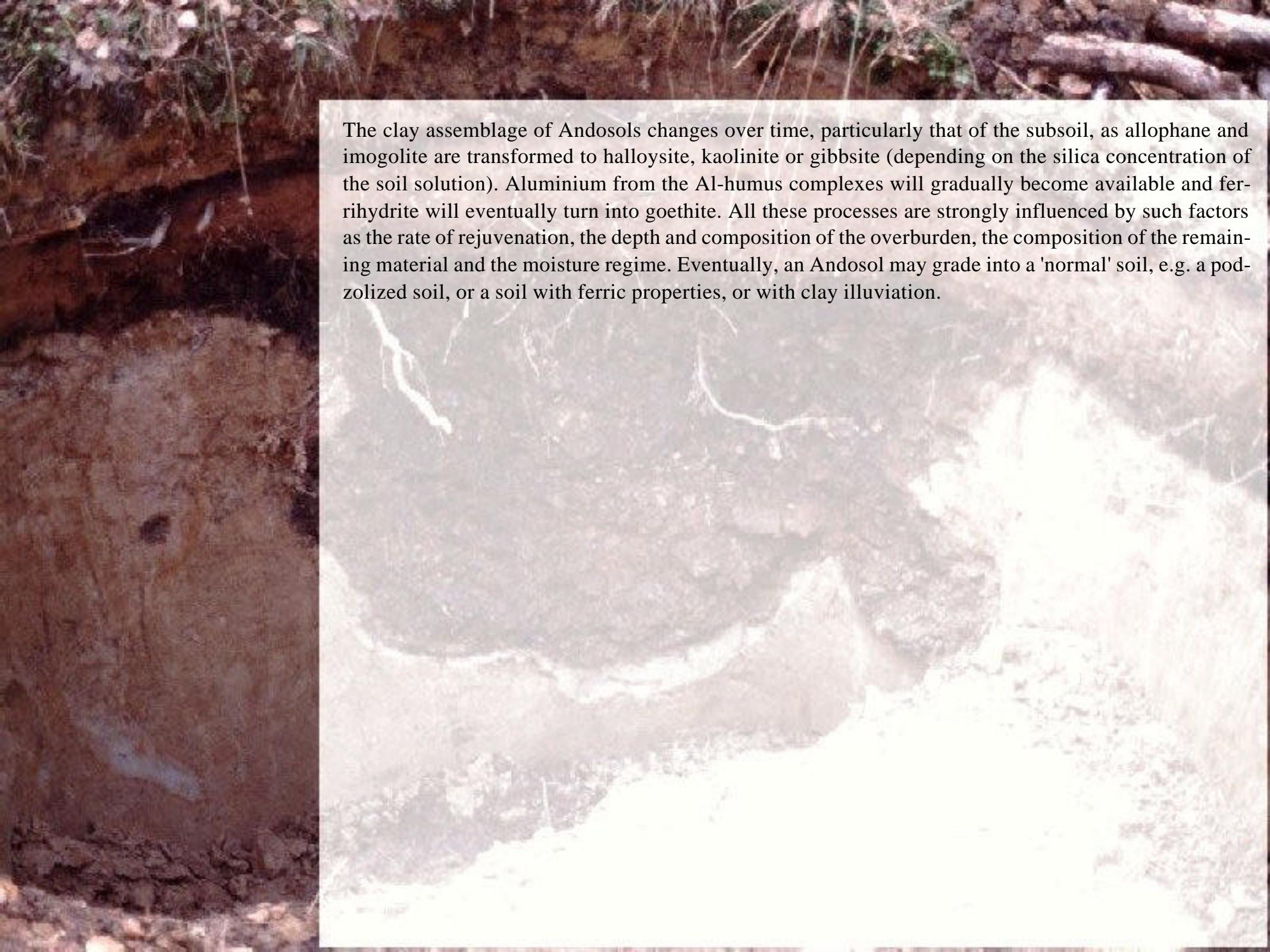
changeable Al, which is not found on allophane. The stability conferred on the organic matter by aluminium is no less in the presence of allophane. This suggests that the activity of aluminium in allophane is high enough to interact with organic molecules and prevent bio-degradation and leaching.

The competition between humus and silica for Al is influenced by environmental factors:

1. The 'Al-humus complex + opaline silica + phyllosilicate clay' association is most pronounced in acidic types of volcanic ash that are subject to strong leaching. In practice, there is a continuous range in the binary composition of Andosols, from a pure Al-humus complexes association ('non-allophanic') to an allophane/imogolite association ('allophanic'), in which the extremes are rare. This variation occurs both within one profile and between profiles.
2. After the very early stage of Andosol formation, (near-)complete inactivation of aluminium by organic matter may constrain the formation of allophane under humid temperate conditions. Only when humus accumulation levels off will aluminium become available for mineral formation. This explains why B-horizons in Andosols are usually much richer in allophane and imogolite than A-horizons: the weathering of primary minerals proceeds but the supply of organic matter is limited so that little aluminium is tied up in Al-humus complexes.

The total pore fraction of the soil material increases greatly in the course of weathering, typically from some 50 volume percent to more than 75 percent. This is explained by leaching losses and stabilisation of the residual material by organic matter and weathering products (silica, allophane, imogolite, ferrihydrite).

The genesis of Andosols is further complicated where there is repeated deposition of fresh ash. Thin ash layers may just rejuvenate the surface soil material whereas thicker layers bury the soil. A new profile will then develop in the fresh ash layer while soil formation in the buried A-horizon takes a different course in response to the suddenly decreased organic matter supply and the different composition of the soil moisture.



The clay assemblage of Andosols changes over time, particularly that of the subsoil, as allophane and imogolite are transformed to halloysite, kaolinite or gibbsite (depending on the silica concentration of the soil solution). Aluminium from the Al-humus complexes will gradually become available and ferrihydrite will eventually turn into goethite. All these processes are strongly influenced by such factors as the rate of rejuvenation, the depth and composition of the overburden, the composition of the remaining material and the moisture regime. Eventually, an Andosol may grade into a 'normal' soil, e.g. a podzolized soil, or a soil with ferric properties, or with clay illuviation.





## Characteristics of Andosols

### *Morphometric characteristics*

The 'typical' Andosol has an AC- or ABC-profile with a dark Ah-horizon, 20 to 50 cm thick (thinner or thicker occurs) on top of a brown B- or C-horizon. Topsoil and subsoil colours are distinctly different; colours are generally darker in humid, cool regions than in tropical climates. The average organic matter content of the surface horizon is about 8 percent but the darkest profiles may contain as much as 30 percent organic matter. The surface horizon is very porous, very friable, and has a crumb or granular structure. In some Andosols the surface soil material is smeary and feels greasy or unctuous; it might become almost liquid when rubbed as a consequence of sol-gel transformations under pressure (*thixotropy*).

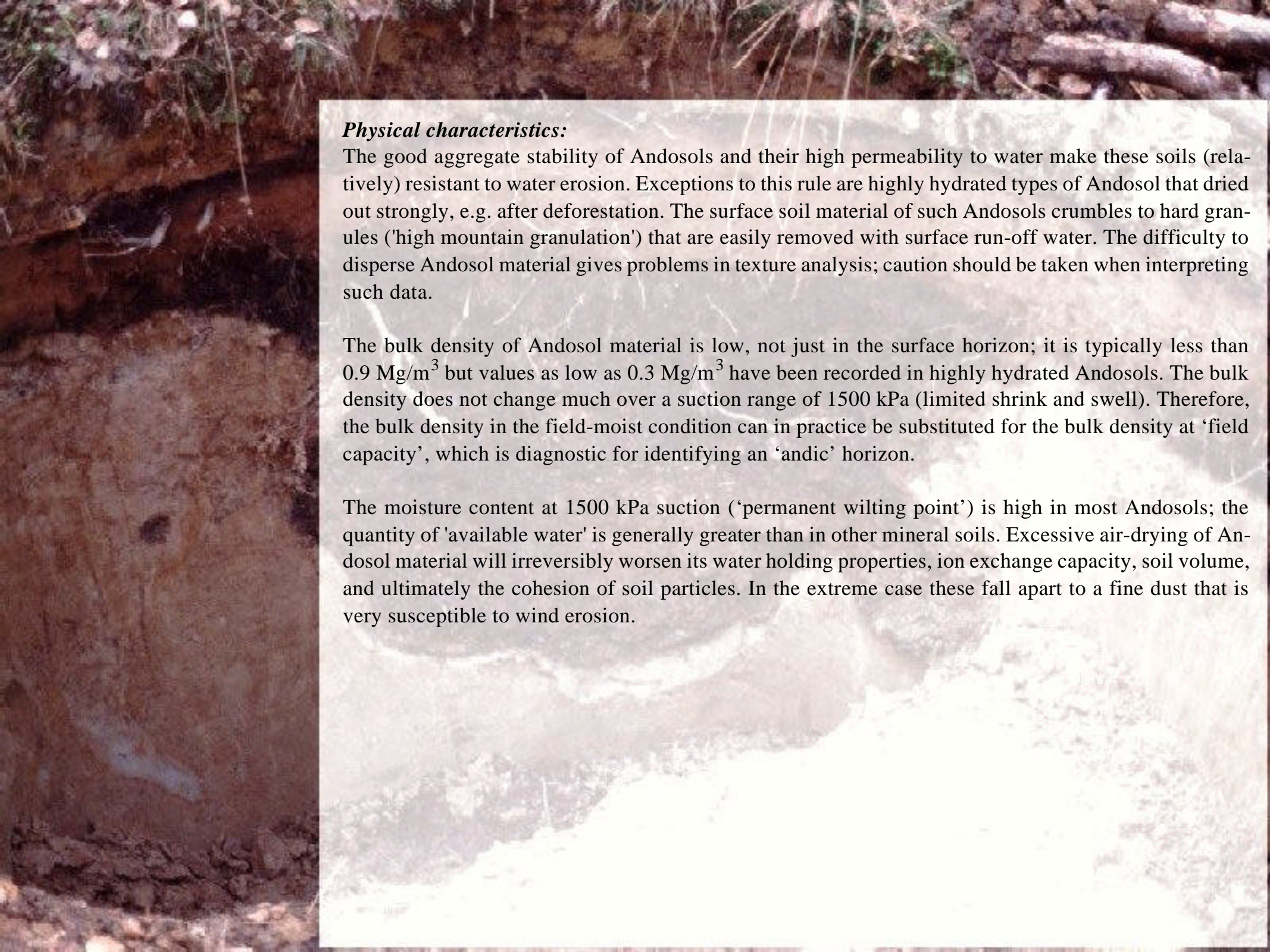
### *Hydrological characteristics:*

Most Andosols have excellent internal drainage because of their high porosity and their occurrence in predominantly high terrain positions. Gleyic soil properties develop where groundwater occurs at shallow depth; stagnic properties are particularly prominent in paddy fields on terraced volcanic slopes, e.g. on Java and Bali (Indonesia).

### *Mineralogical characteristics:*

Quantities of volcanic glass, ferromagnesian minerals (olivine, pyroxenes, amphiboles), feldspars and quartz in the silt and sand fractions of Andosol material differ between sites. Some of the mineral grains may have acquired a coating of volcanic glass when the temperature was still high.

The mineral composition of the clay fraction of Andosols varies with such factors as genetic age of the soil, composition of the parent material, pH, base status, moisture regime, thickness of overburden ash deposits, and content and composition of soil organic matter. The clay fraction of Andosols contains typical 'X-ray amorphous materials' such as allophane and imogolite, and/or humus complexes of Al and Fe together with opaline silica. Allophane/imogolite and Al-humus complexes may occur together even though the two groups have conflicting conditions of formation. Besides primary minerals, ferrihydrite, (disordered) halloysite and kaolinite, gibbsite and various 2:1 and 2:1:1 layer silicates and intergrades can be present.



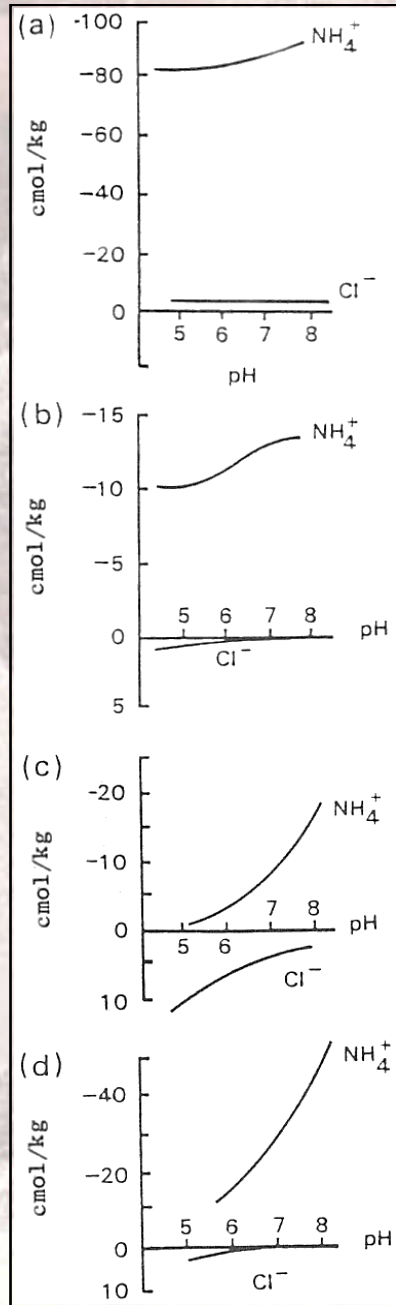
***Physical characteristics:***

The good aggregate stability of Andosols and their high permeability to water make these soils (relatively) resistant to water erosion. Exceptions to this rule are highly hydrated types of Andosol that dried out strongly, e.g. after deforestation. The surface soil material of such Andosols crumbles to hard granules ('high mountain granulation') that are easily removed with surface run-off water. The difficulty to disperse Andosol material gives problems in texture analysis; caution should be taken when interpreting such data.

The bulk density of Andosol material is low, not just in the surface horizon; it is typically less than  $0.9 \text{ Mg/m}^3$  but values as low as  $0.3 \text{ Mg/m}^3$  have been recorded in highly hydrated Andosols. The bulk density does not change much over a suction range of 1500 kPa (limited shrink and swell). Therefore, the bulk density in the field-moist condition can in practice be substituted for the bulk density at 'field capacity', which is diagnostic for identifying an 'andic' horizon.

The moisture content at 1500 kPa suction ('permanent wilting point') is high in most Andosols; the quantity of 'available water' is generally greater than in other mineral soils. Excessive air-drying of Andosol material will irreversibly worsen its water holding properties, ion exchange capacity, soil volume, and ultimately the cohesion of soil particles. In the extreme case these fall apart to a fine dust that is very susceptible to wind erosion.

### Chemical characteristics:



Andosols have highly variable exchange properties: the charge is strongly dependent on pH and electrolyte concentration. This is also the case with some other soils, e.g. Ferralsols, but the overriding difference is that the negative charge of Andosols can reach much higher values because of the high contents of soil organic matter and allophane. Figure 2 shows, for some Andosol components, the variation in charge as a function of pH (the clay minerals halloysite and montmorillonite, having a dominantly permanent charge, are included for comparison). With charge properties variable, base saturation values are also variable. Base saturation values are generally low because of strong leaching, except in some very young Andosols and in Andosols in dry regions.

The strong chemical reactivity of Andosols has long been attributed to X-ray amorphous compounds. It is more appropriate, however, to ascribe this Andosol characteristic to the presence of 'active aluminium' which may occur in various forms:

1. in short-range-order or paracrystalline aluminosilicates such as allophane and imogolite.
2. as interlayer Al-ions in 2:1 and 2:1:1 layer silicates.
3. in Al-humus complexes, and
4. as exchangeable Al-ions on layer silicates.

The role of active iron may often not be ignored but is generally considered of less importance than that of active aluminium.

**Figure 2.**  $\text{NH}_4^+$  and  $\text{Cl}^-$  retention curves measured in 0.01 M  $\text{NH}_4\text{Cl}$  (0.1 M  $\text{NH}_4\text{Cl}$  for montmorillonite). (a) montmorillonite; (b) halloysite; (c) allophane 905 (Al:Si=2:1, containing some imogolite); (d) allophane PA (Al:Si=1:1). Wada & Okamura, 1977.

## Management and use of Andosols

Andosols have a high potential for agricultural production but many of them are not used to their capacity. By and large, Andosols are fertile soils, particularly Andosols in intermediate or basic volcanic ash and not exposed to excessive leaching. The strong phosphate fixation of Andosols is a problem. Ameliorative measures to reduce this effect (caused by active Al) include application of lime, silica, organic material and 'phosphate' fertilizer. Andosols are easy to cultivate and have good rootability and water storage properties. Strongly hydrated Andosols are difficult to till because of their low bearing capacity and their stickiness.

Andosols are planted to a wide variety of crops including sugarcane, tobacco, sweet potato (tolerant of low phosphate levels), tea, vegetables, wheat and orchard crops. Andosols on steep slopes are perhaps best kept under forest. Paddy rice cultivation is a major landuse on Andosols in lowlands with shallow groundwater. Elsewhere, continued paddy rice production has resulted in formation of a dense hardpan over accumulation layers of iron and manganese oxides; these hardpans reduce percolation losses of (irrigation) water.