# SOME CHARACTERISTICS OF ANDOSOLS IN JAPAN

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## Distribution of Andosols in Japan

The Japan Island Arc, located in the northwestern part of the circum-Pacific volcanic belt, has 8% of Quaternary volcanoes of the world. The volcanic ejecta are widely spread over Japan. The ejecta alter and form Andosols, which account for 1/4 of arable land and play an important role in the agriculture of Japan (Matsuzaki, 1977).

Volcanoes eject pyroclastics usually up to the stratosphere at altitudes ranging from 10,000 to 20,000 m at the time of eruption. The pyroclastics extend by the westerly jet current which is blowing in the stratosphere in the mid-latitude of the northern hemisphere. The pyroclastics thin away from their sources of eruption. Some examples are shown in Fig. 1 (Seo et al., 1968).

Thickness-contour lines of ejecta layers are commonly ellipses with major axes extending to the eastern sector of craters (Yamada, 1958). The texture of ejecta becomes finer and relative contents of heavy minerals decrease with increase in distance from volcanoes.
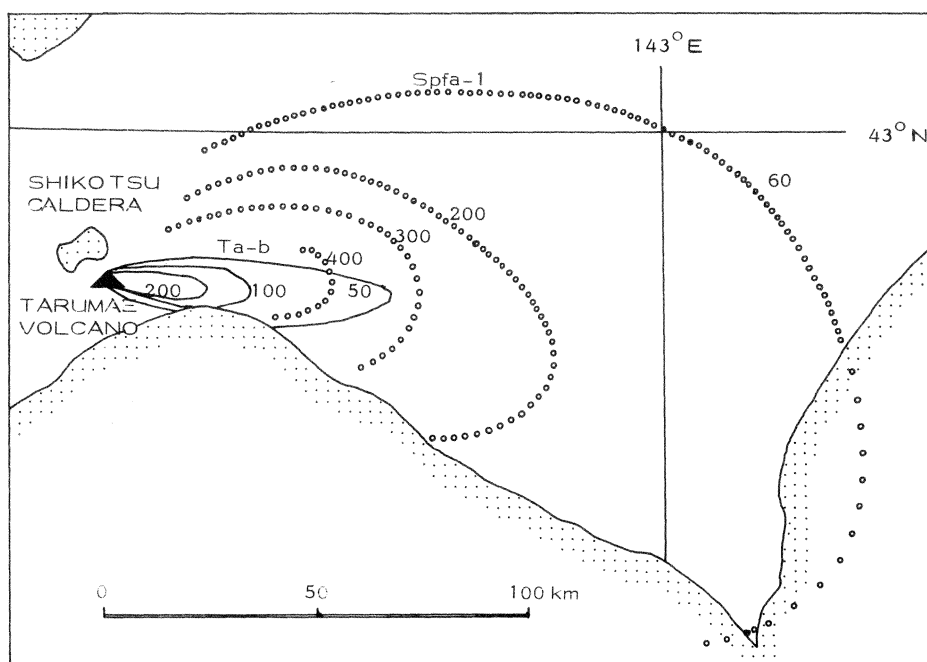


**Fig. 1** Distribution of volcanic ejecta.
Ta−b = Tarumae−b volcanic ejecta; Spfa−1 = Shikotsu pumice−fall deposit−1;
Thickness-contour line = (cm); Study site = southern part of Hokkaido in Japan.
(Seo et al.)

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As volcanoes of Japan are situated outside the so-called "andesite line," most volcanic ejecta are andesitic and a few of them basaltic or rhyolitic. The sand fractions of Andosols include such light minerals as quartz, plagioclase, pumice or volcanic fragments, biotite and plant opal as well as such heavy minerals as pyroxene, hornblende, olivine, magnetite, etc. Ejecta, most commonly found in Japan, contain chiefly pyroxenes in heavy mineral fractions (Kobo and Oba, 1973).

## Genesis of Andosols

Volcanic ejecta are commonly composed of finely crushed fragments and, moreover, they are usually porous. Their weathering is very rapid due to large specific surface, Marked loss of silica and bases, formation of clays rich in hydrous sesquioxides, decrease of volcanic glass, and accumulation of organic matter arise simultaneously from the deposition of ejecta. The high porosity of Andosols results in low bulk density and high water-holding capacity. Bulk density of 90% of Andosols is in the range from 0.5 to 1.0 (Kobo and Oba, 1973). These characters partly explain their erodibility by wind and water, and frost damage of plant on Andosols.

Andosols undergo modifications with age. In the surface layers of Andosols, hydroxy-Al (Fe) complexed with humus (Arai and Kumada, 1981) are present from the early (up to 2,500 BP) to late (7,500 BP or more) stages of weathering. Complexes of allophane-like constituents and allophane with humus seem to appear from the middle to late stages, as summarized in Fig. 2 (Wada and Aomine, 1973; Wada, 1977). Opaline silica is dominant in the early stage of soil formation (Shoji and Masui, 1972).
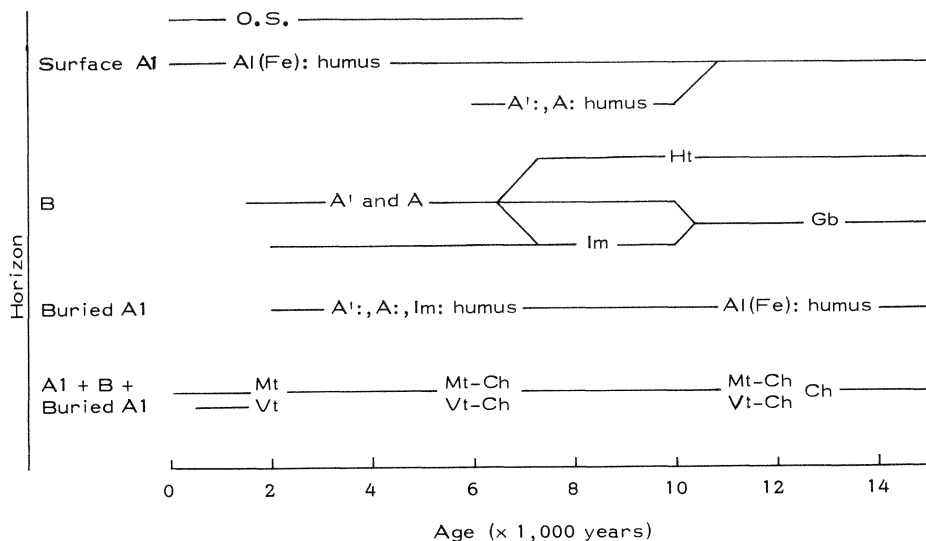


Fig. 2    Major soil components formed in Andosols.
O.S. = opaline silica, Al (Fe); humus = aluminum (iron): humus complex,
A' = allophane-like constituents, A = allophane, Ht = halloysite, Gb = gibbsite,
Im = imogolite, Mt = montmorillonite, Vt = vermiculite, Ch = chlorite,
Mt-Ch = montmorillonite-chlorite intergrades, Vt-Ch = vermiculite-chlorite
intergrades. (Wada).

B horizons contain allophane, allophane-like constituents and imogolite in the early to middle stages, and halloysite and gibbsite in the late stage. In buried A horizons, allophane, allophane-like-constituents, and imogolite-humus complexes dominate in the early and middle stages and Al(Fe)-humus complex in the late stage. High aluminum activity causes hydroxy-Al interlayering

in expandable 2:1 layer silicates irrespective of horizons.

## Composition of allophanic clay

Studies of allophanic clay in Andosols have registered remarkable progress of late (Aomine and Mizota, 1972; Kato, 1970; Wada, 1966; Wada and Aomine, 1973; Wada and Wada, 1977; Wada; 1977; Yoshinaga and Aomine, 1962a; 1926b). Ross and Kerr used the word allophane as a group-name of X-ray amorphous clays which are often associated with halloysite and consist of a solid solution of silica, alumina and water. At present, allophane is used as a series name of naturally occurring hydrous aluminosilicate clays characterized by short range order and by the predominance of Si-O-Al bonds (van Olphen, 1971).

From Andosols are separated imogolite (a paracrystalline mineral), allophane, and allophane-like constituents including non crystalline aluminum and iron oxides. The allophane-like constituents are dissolved by dithionite-citrate-bicarbonate and subsequent sodium carbonate treatment. They have low silica/alumina ratio ranging between 0.2 and 1.4, while allophane has a ratio ranging between 1.0 and 2.5. Approximate chemical composition of allophane is as follows: (Yoshinaga and Aomine, 1962a)

$$Al_2O_3 \cdot 1.5SiO_2 \cdot 2.5H_2O$$

Approximate chemical composition of imogolite is as follows:

$$Al_2O_3 \cdot SiO_2 \cdot 5H_2O$$

Aluminum in allophane is partly in four-fold coordination and partly in six-fold coordination, while aluminum in imogolite is only in six-fold cordination (Egawa, 1964). The presence of aluminum in four-fold coordination has great significance in the negative charge and surface acidity of allophane.

Recent progress has thrown new light on the structure of allophane and imogolite (Kitagawa, 1971; Wada and Wada, 1977). Electron microscopy indicates that allophane has a unique structure
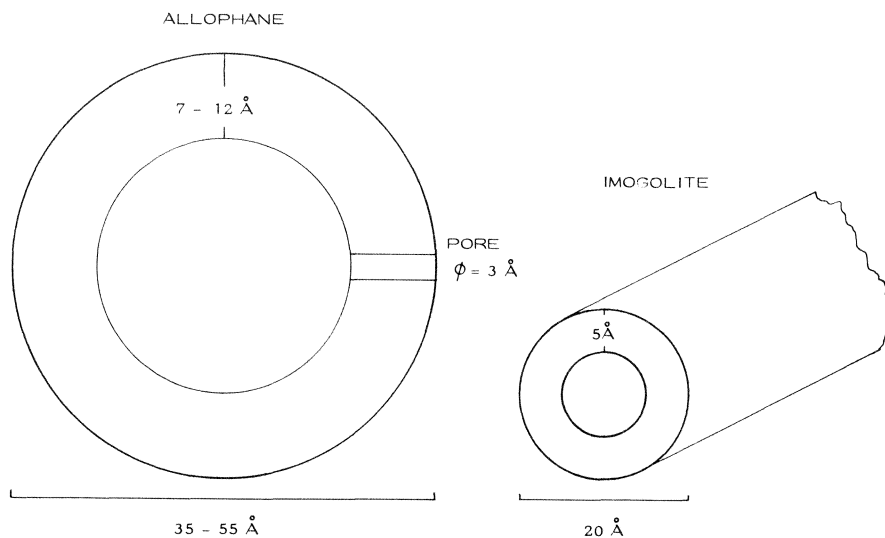


Fig. 3   Schematic structure of allophane and imogolite. (Wada and Wada).

of a spherule with hollow formations. As shown in Fig. 3, the external diameter of the spherule ranges from 35 Å to 55 Å. Its wall is 7 Å to 10 Å thick, containing many openings which allow passage of water molecules (Wada, 1966). The space in the spherule is filled with strongly-retained water.

Imogolite has a smooth and curved thread-like structure ranging from 100 Å to 300 Å in diameter and several $\mu$m in length. High resolution electron microscopy shows that the threads of imogolite consist of fine tubes with an external diameter of 20 Å and an internal diameter of 10 Å.

## Active aluminum

Allophane-like constituents, allophane and imogolite form complexes (Inoue and Wada, 1971) with humus whenever organic matter is supplied. Allophane-like constituents have more highly active aluminum than imogolite and allophane. Montmorillonite-chlorite- and vermiculite-chlorite-intergrade minerals have hydroxy-Al interlayering, which is important for the properties of Andosols rich in layer-silicates. On the surface horizons, aluminum released from volcanic ashes reacts quickly to form a complex with humus (Wada, 1977).

Andosols show high cation-exchange capacity due to the presence of negative charges of humus, allophane-like constituents, allophane and imogolite. However, a large part of the charge is pH-dependent, i.e., cation-exchange sites increase with increasing pH (Iimura, 1966). The negative charges are of two types, namely, "i-charge" (charges inside crystalline structure) and "o-charge" (outside, or external charges related to organic matter and allophanic clay) (Yoshida, 1956). As shown in Table 1, Andosols are characterized by higher values of o-charge.

Table 1   Proportions of i- and o-charge in soils (Yoshida)

| Specimen | i-charge (a) | o-charge (b) | $\dfrac{100a}{a + b}$ |
|---|---|---|---|
| | meq/100g | | % |
| Soil 133 (Andosol) | 4 | 44 | 8 |
| Soil 134 (Alluvial soil) | 11 | 11 | 50 |
| Kanto bentonite | 44 | 17 | 72 |
| IR-120 resin | 0 | 100 | 0 |

A method using pH (KF) has been proposed for the determination of active aluminum (Kawaguchi and Matsuo, 1955). Later, pH (NaF) has been proposed for the differentiation of Andosols (Fieldes and Perrot, 1966). However, the reaction of KF is much more rapid than that of NaF. The KF method may be used for semi-quantitative analyses of active aluminum in Andosols as well as in Podzols.

## Phosphorus in Andosols

Phosphate sorption of Andosols due to the presence of active aluminum has been a serious problem in agriculture and agricultural production from Andosols has markedly increased by application of phosphate fertilizers since the beginning of the 20th century in Japan. Many workers have studied phosphorus for higher crop production (Haneda, 1973; Miyazawa, 1980) to identify methods of its determination, its available form, and physico-chemical equilibrium with soil (Watanabe, 1966), especially fixation of phosphorus by Andosols (Kawai, 1980; Miyauchi and Nakano, 1971; Mizota, 1977; Yoshida and Miyauchi, 1975).

Phosphate fixation is also called phosphate sorption, absorption or retention. A method using ammonium phosphate, $2.5\%\,(NH_4)_2HPO_4$ at $pH = 7.0$ has long been applied in Japan for the determination of phosphate sorption. The phosphate sorption of Andosols by this method is usually above $1{,}500$ mg $P_2O_5/100$ g soil.

Fig. 4 shows a comparison of the traditional method with Blakemore's method (Blakemore
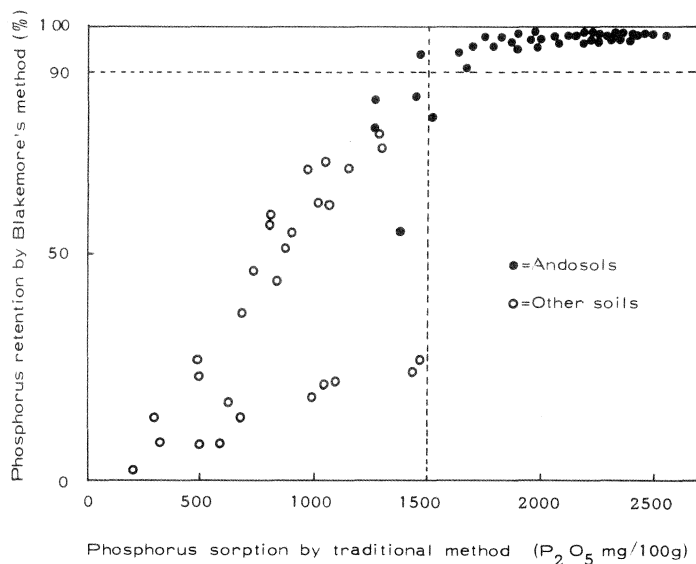


Fig. 4 Phosphate sorption of **Andosols.** (A comparison of the traditional method of Japan with Blakemore's method).

*et al.,* 1977) using sodium acetate buffer solution which has been proposed lately. Phosphate retention of Andosols by the method is mostly higher than 90%. Andosols react with large amounts of phosphates, particularly under acid conditions. The availability to plants of phosphates applied as fertilizers decreases rapidly and approximately only 10% of the applied phosphorus is utilized by most upland crops (Egawa and Sekiya, 1959). About 70% of phosphorus in potassium phosphate added to Andosols was converted to aluminum phosphate and 9 to 19% to ferric phosphate in the experiment carried out by Sekiya and Egawa. Al (Fe)-humus complex, allophane-like constituents, allophane and imogolite seem to play an important role in phosphate sorption. Allophane and imogolite react with and retain pyrophosphate, although Al-humus complex is dissolved by them (Wada, 1977).

## The fate of phosphorus in Andosols

The total contents of phosphorus in Andosols depend on their parent materials under natural conditions (Amano, 1981). Andosols from basaltic ejecta are rich in phosphorus, whereas those from dacitic or rhyolitic ejecta are relatively poor, and those from andesitic ejecta are intermediate between them. In other words, the higher the content of silicon in parent materials is, the lower is the content of phosphorus. The total phosphorus contents are also related to the water regime of Andosols and are higher in poorly drained Andosols than well drained ones. Inorganic fractions of phosphorus show limited variation in each soil profile as shown in Fig. 5, as well as among soils with different drainage conditions. In contrast, phosphorus contents are extremely high in poorly drained Andosols. The higher values of total phosphorus are related to the accumulation of organic matter.
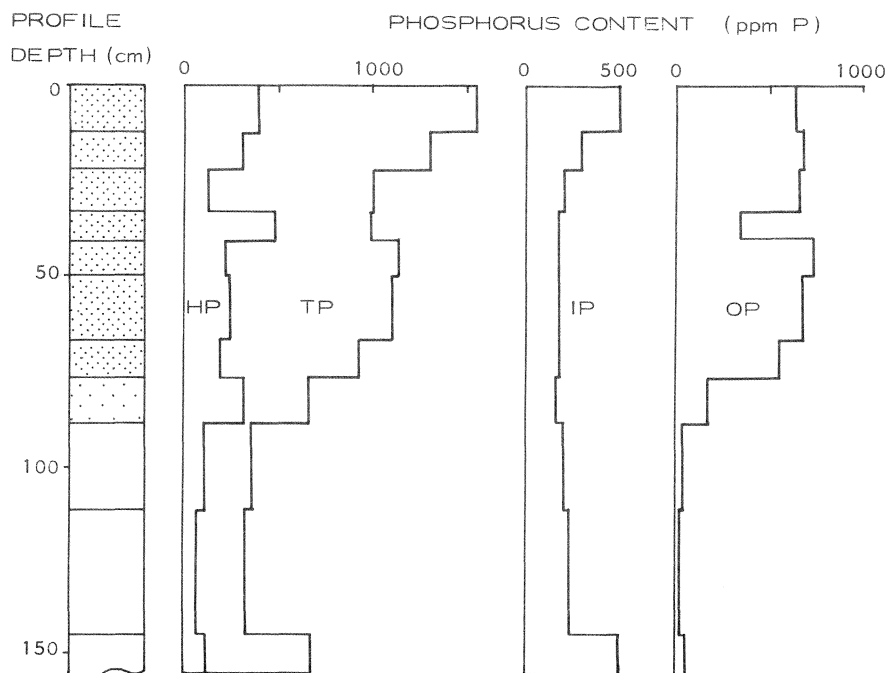
Fig. 5  Vertical distribution of phosphorus in a thick high-humic Andosol.
The site of sampling = Imaichi, in Tochigi Prefecture.
TP = total amount of phosphorus in soils,  IP = inorganic phosphorus,
OP = organic phosphorus,  HP = TP − (IP + OP)  =  hardly soluble
phosphorus.

Results of fractionation of phosphorus in a thick high-humic wet Andosol (The Third Division of Soils, National Institute of Agricultural Sciences, 1977) (Aquic Dystrandept) are presented in Table 2. Specimen A represents the A horizon of the layer of volcanic ejecta de-

Table 2  Subdivision of phosphorus in a thick high-humic
wet Andosol (Aquic Dystrandept)

| Sample | Easily-sol. P | Ca-P | Al-P | Fe-P | Occluded P | Organic P |
|--------|---------|------|------|------|------------|-----------|
| | | | | ppm P | | |
| A | 22 | 115 | 90 | 45 | 51 | 116 |
| IIA | 1 | 34 | 35 | 49 | 166 | 847 |

posited in 1667 AD., and IIA represents the buried A horizon from the ejecta deposited approximately in 1,300 BP. as estimated by radiocarbon dating. The period of soil development of the IIA horizon is about 1,000 years longer than that of A. The accumulation of organic phosphorus (Legg and Black, 1955) seems to be parallel to the period of weathering at the earth surface, i.e., appreciable amounts of phosphorus seem to have been retained in the organic fraction during the

intervals between eruptions. Small amounts of easily soluble phosphorus extracted by $NH_4Cl$ can be found in the surface-A, but vey little of it in the buried IIA horizon. The calcium-bound phosphorus extracted by HCl is relatively high in A and low in IIA. The amount of aluminum-bound phosphorus extracted by $NH_4F$ and iron-bound phosphorus extracted by NaOH increases at the early stage of weathering, and then, gradually decreases with time. The occluded phosphorus extracted by dithionite-citrate-bicarbonate and subsequent NaOH treatment gradually increases with the increase in the degree of soil development.

Organic phosphorus in Andosols accumulated proportionally to time up to about 8,000 BP. Consequently, age of Andosol can be estimated from organic phosphorus accumulation in situ, based on standard ejecta of a given age, if they are younger than 8,000 BP., and have never been subjected to erosion (Amano, 1981). It appears that this technique could be used for the study of the genesis of Andosols.

The conversion rates of various forms of phosphorus are likely to show considerable variations (Wada, 1978) due to the difference in climate in other countries. Detailed studies on the long-term behavior of phosphorus in Andosols should be carried out in future.

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## Discussion

**Wada, K.** (Japan): In your last slide you showed that there is a high amount of easily soluble phosphorus in the $A_1$ horizon. Are such high amounts usually observed in these soils?

**Answer:** This soil sample was taken in a deciduous forest. Such high amounts are rather unusual but can be ascribed to the fact that this soil contained recently erupted volcanic ash (1667 A.D.). I have observed similar high levels in soils with young ash. For example, phosphorus extracted by Bray II method in volcanic ash from Mount Ontake which had erupted in 1979 amounted to 210 ppm.

**Shoji, S.** (Japan): 1) Your data showed a very high specific surface (200 $m^2/g$) in the Tarumae pumice suggesting a high level of weathering. 2) You illustrated the relationship be-

tween the age and genesis of present-day Andosols. However, as you may know, Andosols are so-called transported soils having several or many A and B horizons. Therefore I think that the very old Andosols are mostly truncated soils. What is your opinion about the influence of repeated ash fall on the genesis of Andosols?

**Answer**: 1) I agree with you. Red pumice is usually highly weathered, while a yellow one is intermediate and a grey one is a pumice with little weathering. 2) The rejuvenation of Andosols by addition of newly erupted material is the most important problem for the classification of Andosols in Japan and more research is needed in this respect. It is thus difficult to apply the U.S. Soil Taxonomy to the rejuvenated volcanic ash soils of Japan as the criteria applied in the taxonomy chiefly use characteristics of the B horizon.

**McIntosh, J.L.** (IRRI): Some of the soils in your studies appear to have rather high contents of phosphorus in the topsoil. Do these soils respond, in terms of improved crop growth, to phosphorus fertilizer applications?

**Answer**: Actually I often observed that the effect of phosphorus was not so pronounced in this soil as in typical volcanic ash soils because this surface soil is too young to have a high phosphorus sorbing capacity. Phosphorus content of the soil can be considered to be high when compared with that of tropical soils but not when compared with volcanic ash soils in Japan. The soil was sampled not as being representative of volcanic soil in Japan but to show phosphorus transformation in the weathering process of volcanic ash soil with a well determined age.