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THE MORPHOLOGICAL CHARACTERISTICS OF ANDISOLS

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I. INTRODUCTION

Soils formed on materials of volcanic origin have commanded particular attention for many reasons, among which are their specific geographic distribution, their readily identifiable origin and their distinctive properties. Most studies have been devoted to soils formed on volcanic ash (e.g., Ministry of Agriculture and Forestry, Japanese Government, 1964; World Soil Resources Report 14, 1965; Gibbs, 1968; Inter-American Institute of Agricultural Sciences, 1969). In this chapter we attempt to summarize the main morphological characteristics common to most soils which, because of their assemblage of distinctive properties, are recognized as having a common genetic derivation from volcanic materials. We will first outline some of the developments in soil classification which have led to the current proposal to provide an Order of Andisols for at least those soils that are now identified in Soil Taxonomy (Soil Survey Staff, 1975) as Andepts. This is not intended to compromise or restrict ongoing discussion on a proposal which is still being debated and which cannot yet be finalised (International Committee on the Classification of Andisols (ICOMAND), Circular 1, p.2, 1979).

A. Nomenclature and Classification

The name "Ando", which has commonly been associated with volcanic ash soils, was introduced in 1947 during reconnaissance soil surveys in Japan by American soil scientists (Simonson, 1979). The name was connotative of soils formed on volcanic ash which had thick, dark surface horizons and were acid in reaction. It is derived from the Japanese *Anshokudo* which was a descriptive term in common use, meaning dark *(an)*, coloured *(shoku)*, and soil *(do)*.

Part of the name was retained as a formative element in new systems of nomenclature defined in soil classifications developed by F.A.O. (FAO-Unesco, 1974) for the World Soil Map project, and in the U.S.A. as Soil Taxonomy (Soil Survey Staff, 1975).

The legend for the FAO-Unesco World Soil Map identified these soils as Andosols and described them as "soils formed from materials rich in volcanic glass and commonly having a dark surface horizon" (FAO-Unesco 1974).

In Soil Taxonomy (Soil Survey Staff, 1975), the Andept suborder of Inceptisols accommodates soils formed predominantly in volcanic ash. These soils have a low bulk density, an appreciable amount of allophane of high exchange capacity, or consist mostly of pyroclastic materials.

Subsequent testing and use of Soil Taxonomy has revealed a number of serious defects in the classification of Andepts.

1. The definition of the suborder excludes a number of soils that should be included. Andepts are required to have an exchange complex dominated by amorphous materials throughout the upper 35 cm and to have low bulk densities, or to have more than 60% (by weight) vitric volcanic ash, cinders or other pyroclastic material. Some Andepts have a surface horizon of 15 to 25 cm thickness that does not react to NaF as is required by the definition of domination by amorphous materials. Such soils conform to the definition at depth and probably should not be excluded at the highest categoric level. Studies on the interactions between humus and inorganic constituents in volcanic ash soils have indicated that humus evolves from forms with a very low complexing ability for Al and Fe to forms that complex Al and Fe in A1 horizons (Wada & Higashi, 1976). Recent Japanese work has highlighted the importance of "active" Al in volcanic ash soils (Wada, 1977; Wada & Gunjigake, 1979). In some cases (Mizota & Wada, 1980) it is concluded that the NaF reaction is not specific for allophane and a reaction is obtained with any "active" Al even if bound with humus. More data on the fluoride reactivity of the upper horizons of volcanic ash soils are clearly required before clear taxonomic parameters can be derived.

   In addition, the 60% limit of vitreous materials has been interpreted in some cases to mean that any soil formed in ash and having less than 40% clay must be classified as an Andept unless it has a diagnostic horizon prohibited in Inceptisols. Such an interpretation includes soils more properly classified as Entisols.
2. Base saturation by NH_4OAc has been used as a differentia with a limit of 50%, the same limit used for mineral soils that have crystalline clays. The significance of this limit in Andepts is open to very serious question because the clays are mostly amorphous and the cation exchange capacity (CEC) is largely pH dependent.
3. Thixotropy has been used as a differentia, but the decision that a given horizon is, or is not thixotropic, is very subjective and cannot be made uniformly.
4. The soil moisture regime has not been used as a differentia for Andepts as it has for all other soils. Interpretations for a given family cannot be made without the use of climatic phases.
5. The darkness of the epipedon is weighted heavily in subgroup definitions, but in warm intertropical areas there seems to be little or no relation between colour and carbon content, degree of weathering, or any other property.
6. For most mineral soils a fragmental particle size class is provided, but not for Andepts. Coarse pumice falling from the air commonly has a basal layer without appreciable fine earth.
7. Inadequate emphasis was given to the unique moisture retention properties of the Andepts. The irreversible drying effect was used only to define the Hydrandepts. New data require reconsideration of the effects of drying. For instance, Rousseaux & Warkentin (1976) have suggested that for some allophane soils from the West Indies and Japan the chemical composition of the allophane component determines the micropore size distribution, which in turn determines the water retention properties. Colmet-Daage *et al.* (1967) have documented water retention properties and the effects of drying on Andepts of Ecuador. Such properties could possibly be substituted for the present unsatisfactory property of thixotropy.

The identification of these taxonomic defects has resulted in the preparation, by G. D. Smith, of an unpublished document dated 10 April 1978, subsequently amended slightly by letter of 13 February 1979, titled "A Preliminary Proposal for Reclassification of Andepts and some Andic Subgroups". In this document the name Andisol was introduced. This name, rather than Andosols, was proposed because the latter is currently used elsewhere with other definitions (FAO-Unesco 1974), and because the connecting vowel o is supposed to be restricted to Greek formative elements.

This proposal is the basis for the discussions and operations of ICOMAND which currently has about 100 members throughout the world receiving correspondence by way of circulars (ICOMAND Circular No. 1, 3 April 1979; ICOMAND Circular No. 2, 25 January 1980; ICOMAND Circular No. 3, 30 April 1980).

Because it has not been formally published, the proposal is not widely accessible and for this reason as well as its central relevance to a discussion of the morphology of Andisols, that part dealing with the Order definition is reproduced here.

B. Definition

Andisols are defined as mineral soils that do not have an aridic* moisture regime or an argillic, natric, spodic, or oxic horizon unless it is a buried horizon, but have one or more of a histic, mollic, or umbric epipedon, or a cambic horizon, a placic horizon, or a duripan; or, the upper 18 cm, after mixing, have a colour value, moist, of 3 or less and have 3% or more organic carbon in the fine earth; and, in addition, have one or more of the following combinations of characteristics:

1. Have, to a depth of 35 cm or more, or to a lithic or paralithic contact that is shallower than 35 cm but deeper than 18 cm, a bulk density of the fine earth fraction of less than 0.85 g/cm^3 (at 1/3 bar water retention of undried samples) and the exchange complex is dominated by amorphous materials.
2. Have, in the major part of the soil between a depth of 25 cm and 1 m or a duripan, a placic horizon, or a lithic or paralithic contact that is deeper than 35 cm but shallower than 1 m, a bulk density of the fine earth fraction of less than 0.85 g/cm^3 (at 1/3 bar water retention of undried samples) and the exchange complex is dominated by amorphous materials.
3. Have 60% or more, by weight, of noncalcareous vitric volcanic ash, pumice or pumice-like fragments, cinders, lapilli, or other vitric volcaniclastic materials either to a depth of 35 cm or more, or in the major part of the soil between 25 cm and 1 m or a lithic or paralithic contact that is shallower than 1 m, and the pH in the major part of these horizons of 1 g of fine earth in 50 ml of 1N NaF is 9.2 or more after two minutes.
4. Have a weighted average (by thickness of subhorizons) in the major part of the soil between a depth of 25 cm and 1 m or a duripan or paralithic or lithic contact shallower than 1 m, a water retention of undried fine earth at 15 bar pressure of 40% or more; an ustic moisture regime, and a bulk density of the fine earth fraction of less than 0.9; and either a ratio of 15 bar water percentage (undried) to the meq of exchangeable bases is 1.5 or less, or the pH of 1 g of fine earth in 50 ml of 1N NaF is 9.4 or more after two minutes, or both.

Explanation of Definition

The opening paragraph transfers the present requirements of Andepts from Inceptisols to Andisols, and, for the vitric great groups (item 3), presently Vitrandepts, eliminates problems about cambic horizons (which may not have sandy particle size) and

* During the 3rd International Soil Classification Workshop, 1980, soils with andic properties were tentatively identified in Syria (H. Eswaran, pers. comm.). Substantiation and testing may lead to the deletion of this requirement.

the thickness of the umbric epipedon. The concept of a sandy particle size does not apply well in Andisols, particularly those in rhyolitic ash because of their high water holding capacity. The carbon limit is intended to eliminate problems with basaltic or andesitic ash, cinders, and lapilli, all of which are nearly black.

Item 1 is intended to bring into Andisols the soils formed in thin deposits of ash. It does not differ significantly from the present definition of Andepts.

Item 2 is intended to bring into Andisols the soils formed in thicker deposits of ash but lacking allophane in the surface horizon. In the West Indies and South America, soils that should be grouped with Andisols commonly do not react to NaF in the upper 15 to 25 cm but react strongly below. The Japanese literature reports the absence of allophane in some surface horizons, although it is identified below (Tokashiki & Wada, 1975). (The ICOMAND deliberations currently include discussion on the role and significance of "active" Al, particularly in upper horizons (ICOMAND Circular No. 2, 1980)).

Item 3 is intended to clarify the classification of soils formed in ash but belonging to other orders. If a soil with a bulk density greater than 0.85 g/cm^3 is classified as an Andisol because it has formed in ash, and glass is thought to be present, it must react to NaF. However, some soils such as the yellow-brown pumice soils of New Zealand have coarse textures, vesicular particles and small surface area (N.Z. Soil Bureau, 1968). Because of this, the pH is required to rise only to 9.2 instead of the 9.4 required for domination by amorphous materials. Not all of the yellow-brown pumice soils reach a pH as high as 9.4 (unpublished data, N.Z. Soil Bureau).

Item 4 is intended to clarify the classification of the present Eutrandepts of Hawaii. Some are calcareous in the lower horizons. Water retention, bulk densities, and CEC are appropriate for Andisols, but not all react adequately to NaF, or they are calcareous and the test is meaningless. Exchangeable bases are very high, so the ratio of 15 bar water to bases is low (unpublished data, U.S. Soil Conservation Service).

Not all soils on volcanic ash are intended to be classified as Andisols. Entisols may form in recent historic ash, and if conditions are suitable, Spodosols and Mollisols occur on volcanic materials. In strongly weathered volcanic ash Ultisols, Alfisols and Oxisols may be developed.

C. Distribution

The distribution of Andisols clearly cannot be outlined beyond general statements while the proposal is still being tested. However, the FAO-Unesco (1974) Soil Map of the World reveals that soil associations dominated by Andosols occupy about one hundred million hectares, or 0.76% of the world land area (Dudal, 1976). However, soils formed on volcanic material are not distributed in wide zonal regions, but are associated with occurrences of volcanoes which, on a global scale, do not occupy large areas in any one place. A more detailed analysis of the sheets of the Soil Map of the World, with the exception of those for South-East Asia and Europe where area measurements are currently not available, shows that more than 124 million hectares, or 0.84% of the world's land surface is occupied by soil associations which have some Andosol content (Fig. 1).

Volcanic ash soils occur primarily in association with the major global tectonic zones. The circum-Pacific zone of volcanic and tectonic activity is an example of this pattern. The distribution and properties of volcanic ash soils in the Pacific region have been documented from Japan (Yamanaka & Yamada, 1964; Yamada, 1977), Korea (Shin, 1965) and Kamchatka (Liverovskii, 1971) in the north-western Pacific; from Alaska (Simonson & Rieger, 1967) the U.S.A. (Flach, 1965) and Mexico (Aguilera, 1969) in North America; in central America (Rico, 1965; McConaghy, 1969; Martini, 1969; Colmet-Daage *et al.*,

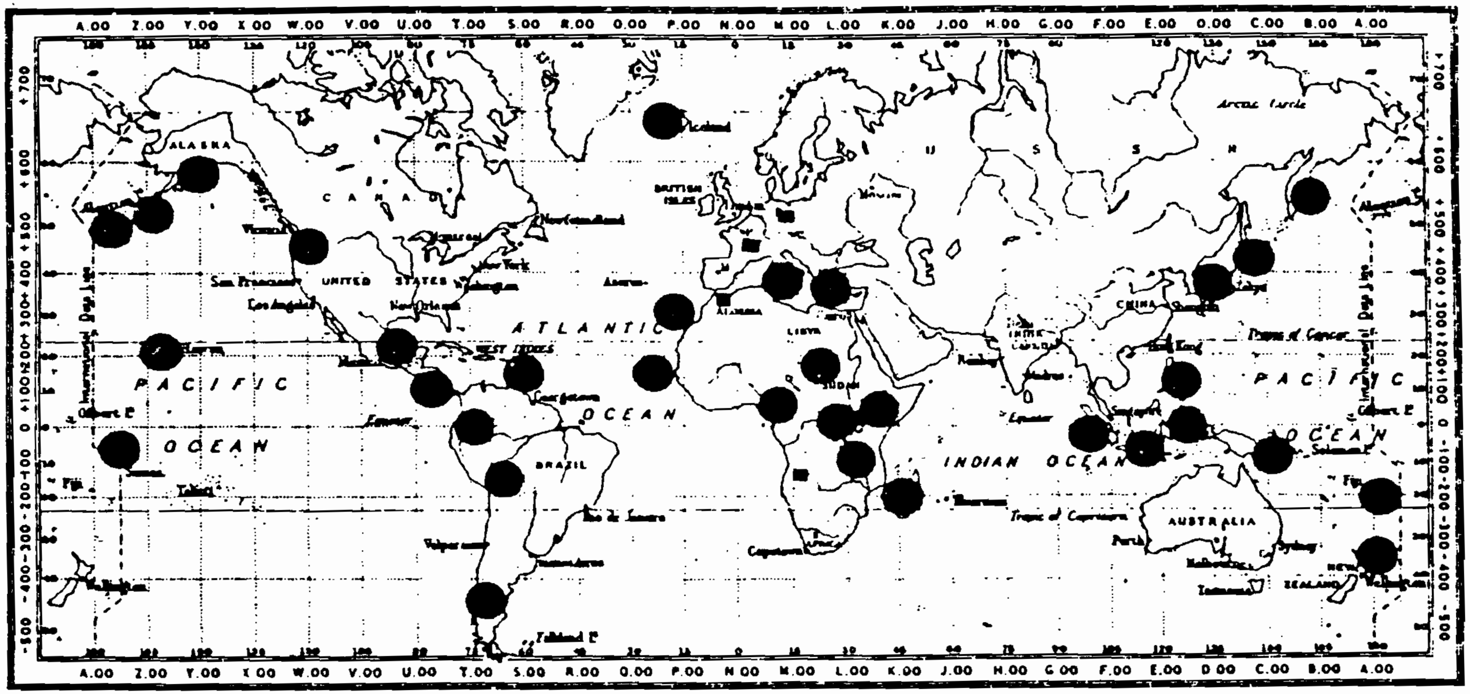

Fig. 1 : Diagrammatic global distribution of Andisols. Areas of major occurrence are indicated by circles, and those of minor occurrence by squares.

1970; Alvarado & Buol 1975); and from Ecuador (Colmet-Daage *et al.*, 1967); Colombia (Luna, 1969); Peru (Zavaleta, 1969); Chile (Valdés, 1969) and Argentina (Wright, 1965) in South America. In the southern and south-western Pacific, occurrences are documented from New Zealand (N.Z. Soil Bureau, 1968), Fiji (Twyford & Wright, 1965), Samoa (Wright, 1963), Vanuatu (Tercinier & Quantin, 1968), and Papua-New Guinea (Haantjens *et al.*, 1967), while in the western and central Pacific the distribution includes Indonesia (Tan, 1965), Taiwan (Lai & Leung, 1967), the Phillipines (Mariano, 1965) and Hawaii (Swindale & Sherman, 1965).

Data from Africa include East Africa (Frei, 1978), Sudan (White, 1967) and Cameroun (Sieffermann, 1969); and from Europe, Italy (e.g. Buondonno, 1964; Lulli, 1971; Violante & Violante, 1973; Eschena & Gessa, 1967), France (e.g., Duchaufour & Souchier, 1966; Hetier, 1973), Spain and the Canary Islands (e.g., Gallardo *et al.*, 1973; Fernandez-Caldas, 1975) and Rumania (Conea, 1972).

II. MORPHOLOGY

The definition of Andisols allows the following diagnostic horizons: umbric, histic, mollic, ochric, cambic, placic and a duripan. The following horizons are not permitted: argillic, natric, spodic, or oxic. There is thus no distinctive, defined diagnostic horizon central to the concept of the Order. And yet, it is not uncommon for these soils to have attracted a local name, such as *Trumao* in Chile, or *Kurobokudo* in Japan – literally meaning "soil from volcanic ash with light stones breaking down in time to a black acid soil". These names often derive from a distinctive feature of soil morphology. The obvious example is "Ando", connotative of a dark colour, but they are also referred to as "soapy hill" in the West Indies which seems to be a clear reference to a characteristic of their morphology and behaviour; and many in New Zealand are known as yellow-brown loams, inferring a distinctive combination of loamy texture and specific colours.

Such names identify properties which distinguish volcanic ash soils from soils with which they are associated in many parts of the world. They do not necessarily identify properties common to all Andisols everywhere, and it is clearly not possible to compile a detailed morphological specification at Order level. However, the following generalizations do capture the essential morphological characteristics of many of these soils as discerned by investigators in Japan, New Zealand, U.S.A. and Latin America (Wright, 1965; Forsythe *et al.*, 1969). They are deep soils, often stratified as a result of periodic accumulation. The upper horizons are in many cases darker coloured and thicker than those of associated soils on non-volcanic materials; subsoils are brown to yellow and have a slippery consistence; textures are predominantly loamy; structures are crumb or granular in topsoils and blocky in subsoils.

Some of the ICOMAND discussions, and particularly submissions from Costa Rica and New Zealand, have strongly advocated the identification of an andic diagnostic horizon or andic materials, which would become the main thrust of the Order definition (ICOMAND, Circular No. 2, 1980).

Clearly, Andisols do have some quite extraordinary morphological characteristics which are most uncommon in other Orders.

A. Colour

Despite the pre-eminence of the formative elements "And-", not all Andisols have deep, dark topsoils. Certainly, the upper horizons often have a very dark colour (very dark grey to black) and great thickness particularly in Japan, especially Hokkaido, and the

Altiplano of the Andes. On very recent volcanic formations, the colour is equally very dark but the thickness can be less. In a tropical climate, the colour appears less dark and more vivid (dark brown to dark red-brown) and the accumulation of humus less important than in a cold climate, although it is clearly greater than is observed in other tropical soils (Quantin, 1972).

In young Andisols with low allophane content, colour tends to be dictated by the parent material. Soils on basic volcanic ash include many dark coloured minerals such as hypersthene, hornblende, augite, olivine, and magnetite. The volcanic ash is thus dominantly black and is low in organic matter (O.M.) or allophanic material. Other volcanic parent materials such as pumice and some dacitic rocks are almost white. A small quantity of O.M. will, however, turn these materials very dark, at least in the surface horizon.

In the hot, isohyperthermic regions, and in the temperate, thermic regions in Central Chile, fulvic acid extracted by pyrophosphate solution clearly dominates. The soils are dark brown on the surface and yellow at depth.

On the other hand, in cool isomesic regions, or in the cooler isothermic regions with an almost constant temperature, humic acid dominates. The soils are black throughout the profile, sometimes up to several metres. There is thus a clear relationship between colour and the nature of the O.M., for there is virtually no difference in soil mineralogy.

Deep, dark topsoils are most commonly and consistently reported from Japan (e.g., Egawa, 1977). Characteristics of the *Kurobokudo*, which are extensive on Hokkaido, Tohoku, Kanto, and Kyushu are that A horizons are blackish in colour, very rich in humus (15-30%) and 30-50 cm in thickness. Occasionally they may be as thick as 100 cm because of redeposition or intermittent thin ash fall. B horizons are brown to yellowish brown. In thick A horizons the average content of humus in virgin soils is 20%. From a global viewpoint, this is the highest content of humus consistently found in terrestrial soils. As in chernozems, herbaceous plants are assumed to be the main source of humus. In herbaceous plants the Gramineae family such as Susuki *(Miscanthus sinensis)* is considered to be the most important source, because a large quantity of plant opal derived from the Gramineae family is found in A horizons. High water-holding capacity may have accelerated the vigorous growth of herbaceous plants from the beginning of pedogenesis. Humus has been preserved in association with amorphous material, especially soluble aluminium, formed in the course of weathering of the mineral constituents (cf. Chapter 6). The accumulated humus has a higher content of humic acid than found in other genetic soil types and the ratio of humic acids to fulvic acids usually exceeds 1. Because of the dominance of humic acid the C/N ratios of A horizons are as high as 15-25 (cf. Chapter 12). This very high content of humus in A horizons is associated with other distinctive properties such as low bulk density, high water holding capacity and very high CEC (Oba, 1976).

The micromorphology of these dark A horizons from Japan was documented by Kawai (1969) who inferred that they were commonly associated with a blocky loose micromorphological fabric or a fine grained porous fabric.

Ortho, macro-sized vugh voids, with numerous channel voids in their vicinity, and many ortho, micro-sized vugh voids in plasma are special characteristics of the blocky, loose fabric, along with loose aggregation of primary structure.

In the fine grained porous fabric, micropeds are dispersed and there is very high porosity. Associated organic carbon contents ranged from 13-21% and soil colours are 7.5YR or 10YR hue with a chroma of 1.

In New Zealand, in a predominantly mesic temperature regime, Andisol topsoils are deep, dark and humic when compared with associated soils, but do not reach the high values for these properties reported from Japan and Chile. For instance, the thickness of black coloured A horizons rarely exceeds 20 cm and organic carbon contents range between 8 and 12% (N.Z. Soil Bureau, 1968, Part 3; Gibbs, 1968).

Marked correlation between native vegetation and colour of the upper horizons has been recorded in soil survey reports. This is particularly so in the pumice soils of the central North Island where, for instance, the change from native podocarp forest to scrub dominated by bracken (*Pteridium aquilinum var. esculentum*) is marked by an abrupt increase in blackness of the topsoil (Vucetich & Wells, 1978).

Properties of A horizons in volcanic ash soils, and particularly the stage of humification and C/N ratio, have been linked to the methoxyl-carbon content by Japanese workers (Kosaka, 1963). A comparative study of New Zealand and Japanese volcanic ash topsoils using methoxyl-carbon contents as a guide (Birrell, 1966) suggested that Japanese soils generally are at a later stage of humification than their New Zealand counterparts.

B. Field Texture

A striking feature of Andisols high in allophane, is that despite apparently high measured clay contents, the soil material is not sticky. Field textures are distinctive and readily identified by experienced pedologists. They are variously described as slippery, greasy, soapy, smeary, or unctuous. This is very different from the clayey feeling typical of soils containing crystalline clays such as kaolinite, montmorillonite, or halloysite.

Although apparently well drained, the soil may have a high water content which can be easily expressed between the fingers. The soil is plastic but it does not adhere to the fingers, as do soils containing well crystallised clays. It is this which imparts the greasy feel in the moist state and the sensation of a silty texture. When dry the soil loses its greasiness and becomes friable and powdery.

Experienced pedologists are able to estimate reasonably accurately the moisture content at about pF 3 on the basis of the combination of field texture and consistence, bearing in mind that this is a function of the amount of allophane present and the degree of moisture held by the allophane, which, in turn, is related to the climatic history of the soil. When moisture content at pF 3 is about 20-50%, the soil does not feel very unctuous and the cohesion, although evident, is weak. When moisture content is about 50-100%, the unctuous feel is usually obvious. When the soil contains more than 100% moisture, it is soapy with strong cohesion. Moisture is expressed on crushing between the fingers. With more than 150 to 200% moisture, it is harder to break down the blocks with the fingers.

This distinctive field texture is correlated with allophane content and with positive reaction to the Fieldes & Perrott (1966) allophane field test. Andisols dominated by vitric volcanic material do not have these properties.

C. Consistence

As with field texture, description of the consistence of Andisols high in allophane has defied the formal terms. It is most commonly described as fluffy, and although this property is probably a reflection of low bulk density and high porosity resulting from high allophane content, it is a striking and detectable morphological characteristic.

The presence of imogolite in Andisols, identified particularly in Japan (Yoshinaga & Aomini, 1962) and Chile (Besoain, 1969), also seems to have an effect on consistence. For instance, in the temperate regions of Chile with annual temperature variations > 5°C, the presence of imogolite is associated with extremely friable soils, in spite of the very high percentages (100%) of water in the freely drained soil. The yellow B horizon is composed of tiny round aggregates and the soil is puffy, loose and very soft. Furthermore, water appears to be absorbed or lost in the same way as in young halloysitic soils. Water retention is high – 100% or more – but after air-drying the soil is able to re-absorb most of the water, whereas where allophane is dominant the water is irreversibly lost.

D. Density

A low bulk density is a required characteristic for all Andisols, except those dominated by vitric volcanic ash. Although the actual value is not measurable in the field, the relative lightness of soil clods is readily identifiable by experienced pedologists. These low bulk densities and associated high porosity seem to be related to the high specific surface area characteristic of allophane.

E. Associated Characteristics

Andisols dominated by allophane have a number of particular characteristics which have no specific morphological expression, but which can be inferred from a combination of properties identifiable in the field. These include:

(a) a critical limit of stability under pressure. Waxy, sensitive clays rich in allophane and common in Andisols on sites with high rainfall exhibit a sudden and large change in strength with deformation under increasing load (N.Z. Soil Bureau, 1968, Part 2). The moisture content is usually too high for satisfactory compaction for foundations.

(b) a high capacity for water retention associated with very high specific surface area. The "field capacity" (measured at pF 3) on a soil kept in its initial moist state is generally greater than 100% of the weight of dry soil (at 105°C). It can reach 300%. Colmet-Daage *et al.* (1967) have studied this property in detail and have stated that beyond a certain threshold of dehydration (about pF 4.2) there is an irreversible dehydration of the soil.

(c) structural stability. Because of the natural stability of allophane, most Andisols have a very stable structure towards water. This explains their high porosity and their very low susceptibility to erosion (Sieffermann, 1969).

(d) a strong affinity for O.M. which tends to be protected from decomposition (Wada & Higashi, 1976).

Some of these characteristics are important and dominant enough to be expressed in the Andisol proposal at the great group level.

Andisols with unusually specific properties have been identified at high altitude in the Andes (Wright, 1965). The very wet, cold regions of the Andes have low evapotranspiration and are often cloud covered. The soils are black, extremely spongy with high water content (up to 200% at pF 2.5), and react strongly and instantaneously to the Fieldes & Perrott (1966) allophane test. They are very high in O.M. and have a very high CEC which varies with the pH. They have all the characteristics of allophanic soils but with very high percentages of O.M. and they occupy vast areas. French pedologists working in the region have called them organo-Hydrudands. They vary in depth from 60 cm to several metres and were formed partially from very fine volcanic ash erupted from the volcanoes and carried far distances by wind. The fine ash sticks together because of the permanent dampness and is held in place by the vegetation to produce a combination of Histosol and Andisol.

F. Soil Forming Ash Showers

The intermittent accumulation of volcanic ash has considerable impact on both the genesis and morphology of Andisols. In active volcanic regions it is uncommon to find soils which do not have layered ash deposits and buried soils within the control section. Interpretation of the morphology of such profiles is a prime element in unravelling the history of volcanic activity and has given rise to extensive pedological investigations in the fields of tephrachronology and tephrastratigraphy particularly in Japan (e.g., Sasaki, 1974) and New Zealand (Vucetich & Pullar, 1964, 1969, 1973; Pullar & Birrell, 1973).

III. SELECTED EXAMPLES OF PROFILE MORPHOLOGY

Three profile descriptions have been selected to demonstrate part of the range of morphological properties displayed by Andisols (Appendix I and Table I). The pedons described are well-known and comprehensively documented soils from the Pacific Basin and are central examples of the great groups they represent.

The Taupo soil from New Zealand is classified in the N.Z. Genetic Soil Classification as a yellow-brown pumice soil (N.Z. Soil Bureau, 1968). It is pumiceous with high proportions of volcanic glass throughout and the fine earth has a pH in NaF which ranges from 10.2 in the (B) horizon to 8.8 in the C13 horizon. It has a udic moisture regime and 15 bar water values on air dry samples ranging from 12.2% to 2.0%, and on field moist samples ranging from 23.4% to 3.3% (Cotching & Rijkse,1978). In the Andisol proposal it is a Vitrudand.

Table 1. Morphological comparison of selected pedons.

	Taupo (New Zealand)	Imaichi (Japan)	Hilo (Hawaii, USA)
A horizon thickness	12 cm	82 cm	40 cm
A horizon colour	10YR 3/1 very dark grey	7.5YR 1/1-2/1 black	10YR 3/3 dark brown
Dominant subsoil colour	10YR 5/6 and 2.5Y 6/4 yellow brown	10YR 6.5/7 brownish yellow	2.5YR 3/4 and 5YR 3/4 dark reddish brown
Dominant field texture	sandy loam & loamy sand	silt loam	silty clay loam
Dominant consistence	friable	compact	friable
Range of structure	moderate fine blocky & crumb to single grain	weak fine granular to massive	weak fine granular to strong fine blocky
Tephra layers	Three identified	Two identified	
Buried soils	One identified	One identified	
Ped coatings			thick, translucent gelatinous in subsoil
Other properties	high proportion of vesicular pumice		all horizons dehydrate irreversibly

Salient morphological features of the Taupo soil are the coarse texture throughout; friable consistence becoming loose in some horizons; weakly developed structures; a weakly developed yellowish brown cambic horizon; and the presence of tephra layers and a buried soil within the control section. Bulk density figures range from 0.66 – 0.73 g/cm^3.

The Imaichi soil from Japan is an example of a "Kuroboku" soil (Ministry of Agriculture and Forestry Japanese Government 1964 Chapter VIII). Bulk density figures range from 0.44-0.71 g/cm^3 and figures for phosphate adsorption coefficient are high. It occurs in a udic moisture regime and has an epipedon more than 80 cm thick with moist colour values and chromas 2 or less throughout. Figures for organic carbon range from 20.19% in the A11 horizon to 13.24% in the A13. In the Andisol proposal it is a Melanudand.

The most striking morphological characteristic is the thick, dark epipedon which is described as slightly compact to compact, and apart from the surface horizon, massive throughout. The field texture is dominantly silt loam and one other tephra layer is identified at the base of the profile.

The Hilo soil from Hawaii has been classified as a Hydrol Humic Latosol (Swindale & Sherman, 1965), and as a Typic Hydrandept (Soil Conservation Service, 1976). Dry bulk density figures range from 0.61 to 0.80 g/cm^3. No data were available for pH in NaF or phosphate retention. It occurs in an isohyperthermic temperature regime, and figures for 15 bar water of the field moist samples range from 69.8% in the Ap horizon to 149.5% in the B28 horizon. In the Andisol proposal it is a Hydrotropand.

The most distinctive morphological feature of the Hilo soil is the irreversible drying which occurs in all horizons. Thick, translucent, gelatinous coatings of amorphous colloidal oxides are a prominent feature of lower horizons. Uniform dark reddish brown colours and silty clay loam textures prevail throughout the subsoil. It is probable that most profiles comprise numerous ash bands but the deep, strong weathering tends to obscure them.

Table 1 compares the main morphological features of the Taupo, Imaichi and Hilo profiles.

IV. MORPHOLOGICAL PARAMETERS USED IN THE ANDISOL PROPOSAL

Apart from aquic properties which are employed at the suborder level, salient morphological characteristics are used as differentiae at the great group level. *Aquic* suborders are defined on the presence of an histic epipedon or on the occurrence of low chromas, or mottles or both. A suggested addition to this definition is a placic horizon that rests on a duripan. In Japan some Andisols developing under an aquic regime have very thick, surface horizons with high O.M. contents which are dark enough to obscure low chroma colours or mottles. A great group of Melanaquands has been proposed and an additional aquic criterion based on the identification of active ferrous iron will be required (ICOMAND Circular 1, pp. 10-11, 1979; Circular 2, pp. 14-15, 1980).

Melanic great groups are proposed in the Aquands, Borands and Udands. The definition requires a thick epipedon with low colour value and chroma and high content of organic carbon. Such great groups accommodate the thick, black soils which are well known from Japan (Egawa, 1977) and from the high Andean regions of South America (Wright, 1965). The Imaichi series (Appendix 1) displays melanic properties.

Vitric great groups are provided in all suborders and are defined on the content of 15 bar water. They accommodate coarse textured, commonly weakly developed and in most cases vitreous or pumiceous soils. Vitrudands are extensive in the central North Island of New Zealand on pumice deposits (Taupo soil, Appendix 1).

Placic great groups are provided in three suborders, Borands, Udands and Tropands. Placoborands have not yet been identified (ICOMAND Circular 2, p.9, 1980) and may not exist. Placotropands and Placudands are known to one of the authors (GDS), but descriptive data have not yet been documented. As in other orders placic great groups are defined by the presence of a placic horizon within a specific depth in half or more of each pedon.

Duric great groups are identified in Xerands and Ustands, and tentatively in Aquands. They are defined on the presence of a duripan. Hardpan layers have been recorded in Andosols in South America (Wright, 1965) and in Japan where they are known as "masa" or "kora" cemented horizons and may occur in a udic moisture regime (ICOMAND Circular 2, p. 15; Appendix 1). It is not clear from the available evidence whether these are pedogenic or geologic horizons.

Hydric great groups are provided for the freely drained soils that rarely or never become drier than field capacity in the Tropands and Udands. They are defined on the basis of their undried 15 bar water content. It is not certain that Hydrudands exist, but some data suggest that they might occur in Chile (ICOMAND Circular 1 1979, Appendix 1). Hydrotropands are well known from Hawaii (Swindale & Sherman, 1965) where their most distinctive morphological feature is the irreversible drying they undergo when exposed (Hilo soil, Appendix 1).

Subgroups defined on morphological criteria include hydric, vitric, placic and aquic which have definitions similar to the great group with the same formative element; entic, thapto-histic, lithic, pachic, ruptic and ustollic already used and defined in Soil Taxonomy (Soil Survey Staff, 1975); and psammic which is defined on the basis of particle size and is provided for Andisols that are particularly subject to wind erosion.

V. CONCLUSIONS

This review has not encompassed the total spectrum of Andisols, because data on many important members, particularly those in intertropical regions, very cold climates, and dry areas, are still being generated through the activities of ICOMAND.

However, it is clear that many of the very distinctive and specific properties of these soils are reflected in their morphology. A feature of this brief review has been the discovery that comprehensive and relevant morphological descriptions of Andisols are well documented from only a few countries. This is not altogether surprising in view of the relatively short history of global interest in such soils. Current momentum in the classification field should improve this situation.

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APPENDIX 1

Profile description data for three examples of Andisols.

TAUPO SANDY LOAM (Reference: Cotching & Rijkse, 1978)

LOCATION: 8 km south of Waiotapu, Wharepaina, west of State Highway (Rotorua-Taupo) back of Mr Bell's property, northern side of silage pit at the end of main race
Central North Island, New Zealand.

MAP SHEET: NZMS 1 N85 Grid reference: 781747

TOPOGRAPHY: Slope: Flat to easy rolling
Landform: Terrace
Altitude: 335 m a.s.1.

SOIL DRAINAGE: Well drained

VEGETATION: Present: Improved pasture (ryegrass clover)
Native: Manuka scrub, and bracken fern
The area had light podocarp forest and scrub prior to Polynesian fires

PARENT MATERIAL: Taupo Pumice, on Whakatane Ash, Mamaku Ash, Rotoma Ash, Waiohau Ash, Rotorua Ash and Rerewhakaaitu Ash

CLIMATE: Mean annual rainfall 1500-1550 mm
Mean annual temperature 12°C

LAND USE: Dairying, semi-intensive sheep farming, beef and exotic forestry

DESCRIPTION:

A	0-12 cm	very dark grey (10YR 3/1) sandy loam; friable; weakly developed coarse subangular blocky structure breaking to moderately developed fine subangular blocky and crumb structure; abundant roots; few fine lapilli; distinct smooth boundary.
(B)	12-18 cm	yellowish brown (10YR 5/6) gritty sandy loam; friable; moderately developed medium and fine subangular blocky structure breaking to moderately developed fine crumb structure; abundant roots; few coarse and many fine lapilli; distinct smooth boundary.
C_{11}	18-36 cm	light yellowish brown (2.5Y 6/4) loamy sand; friable; massive breaking to weakly developed medium and fine angular blocky structure crushing to fine crumb structure; many fine strong brown (7.5YR 4/6) iron stained root channels; very few black (N2) charcoal concentrations; very few dark greyish brown (2.5Y 4/2) inclusions; horizon becomes greyer with depth; few roots; distinct smooth boundary.
C_{12}	36-44 cm	dark greyish brown (10YR 4/2) and light brownish grey (2.5Y 6/2) coarse sand; friable; single grain; few roots; few fine strong brown (7.5YR 4/6) iron stained root channels; (Rhyolite Block Member); distinct smooth boundary.
C_{13}	44-65 cm	light grey (2.5Y 7/2) pumice gravel; loose; single grain; many roots; distinct strong brown and yellowish brown iron staining in upper 7cm of horizon; sharp smooth boundary.
D_r	65-70 cm.	grey (5Y 5/1) loamy sand; friable; massive; few roots; (Rotongaio Ash); distinct wavy boundary.
II uA	70-86 cm	brown (10YR 4/3) greasy sandy loam; friable; weakly developed medium subangular blocky structure crushing to weakly developed crumb structure; few roots; few medium very dark brown (10YR 2/2) organic matter concentrations; many fine lapilli; indistinct irregular boundary.
II C	86-100+ cm	yellowish brown (near 10YR 5/8) greasy loamy sand; very friable; very weakly developed medium angular blocky structure breaking to moderately developed medium crumb structure; very few roots.

IMAICHI (Reference: Ministry of Agriculture & Forestry, Japanese Government, 1964)

LOCATION: Dozawa, Imaichi-shi, Tochigi Prefecture (Longitude, 139°44', East; Latitude, 36°41', North)
TOPOGRAPHY: Upland; slope, west 2°; Elevation, 310 m (1030 feet)
CLIMATE: Mean annual temperature, 12.5°C (55°F); Annual precipitation, 1522 mm (59.9 inches). (Utsunomiya Local Meteorological Observatory)
PARENT MATERIAL: Wind blown volcanic ash
VEGETATION: Deciduous forest, Nara (*Quercus serrata*), Kunugi (*Quercus accutissima*) and others.
DESCRIPTION:

A11 0-12 cm (0 to 5 inches) Black (7.5YR 2/1), very dark brown (10YR 3/1.5) when dry, silt loam; weak, fine granular structure, few fine pores; slightly compact (16mm), slightly sticky, slightly plastic; semi-moist; many roots; smooth, clear boundary.

A11 12-28 cm (5 to 11 inches) Black (7.5YR 1/1), very dark gray (1.25Y 2.5/1) when dry, silt loam; massive, few fine pores; compact (20mm), slightly sticky, slightly plastic; semi-moist; common roots; smooth, gra dual boundary.

A13 28-62 cm (11 to 24 inches) Black (7.5YR 1/1), very dark gray (2.5Y 3/1) when dry, silt loam few weathered yellow pumice gravel; massive, few fine pores; compact (20mm), slightly sticky, slightly plastic; semi-moist; common roots; smooth, gradual boundary.

AIIB 62-82 cm (24 to 32 inches) Black (7.5YR 2/1), dark grayish brown (1.25Y 4/2) when dry, silt loam; many weathered yellow pumice gravel and few half weathered gravel; massive, few fine pores; compact (23mm), slightly sticky, slightly plastic; semi-moist; smooth, gradual boundary.

IIB 82-110 cm (32 to 43 inches) Brownish yellow (10YR 6.5/7), very pale brown to yellow (10YR 7.5/4.5) when dry, weathered pumice gravel layer (Hichihonzakura); very compact (26mm), non sticky, non plastic; semi-moist to moist.

HILO SILTY CLAY LOAM (Reference: Soil Conservation Service, 1976)

LOCATION: Island of Hawaii, Hawaii County, Hawaii. Approximately 2.8 km (1.8 miles) north of Hilo Post Office. Sample site is located 30 m (100 feet) south of road at a point 0.5 km (0.3 mile) west of Haaheo School which is at the north end of Wainaku Village.
VEGETATION: Originally ohia-tree fern vegetation, now cleared and in sugarcane.
CLIMATE: Average annual precipitatinn is 438 cm (175 inches). The mean annual temperature is 22.2°C (72°F), the mean January temperature 20.0°C (68°F), and the mean July temperature 23.9°C (75°F).
PARENT MATERIAL: Volcanic ash.
TOPOGRAPHY: Undulating to rolling low windward slopes of Mauna Kea, 3 percent slope to east
ELEVATION: 105 m (350 feet)
DRAINAGE: Well drained; rapid permeability; slow runoff
SOIL MOISTURE: Moist
REMARKS: Textures are apparent field textures. Colours are for moist soil. All horizons dehydrate irreversibly to sand and gravel size aggregates
DESCRIPTION:

Ap 0-40 cm (0-16 inches) Dark brown (10YR 3/) silty clay loam mixed with dark reddish brown (5YR 3/4) by cultivation; weak very fine and fine granular structure; friable, sticky, plastic, moderately smeary; many roots; many very fine and fine interstitial pores; few to common firm ash nodules; abrupt smooth lower boundary.

B21 40-53 cm (16-21 inches) Dark reddish brown (5YR 3/3) silty clay loam; weak medium subangular blocky structure; friable, sticky, plastic, moderately smeary; many roots; many very fine and fine and common medium and few coarse tubular pores; thick gelatinous coating on ped surfaces, some surfaces appear like clay flow; few firm ash nodules; abrupt smooth boundary.

B22	53-58 cm (21-23 inches)	Dark reddish brown (2.5YR 3/4) silty clay loam, weak fine and very fine subangular blocky structure; friable, sticky, plastic, moderately smeary; common roots; many very fine and fine and common medium and few coarse tubular pores; common firm ash nodules of 13 to 25mm (½ to 1 inch) in diameter; ped surfaces have gelatinous appearance; abrupt smooth boundary.
B23	58-65 cm (23-26 inches)	Dark brown (7.5YR 3/2) silty clay loam; moderate very fine subangular blocky structure; friable, sticky, plastic, moderately smeary; common fine roots; many very fine, fine and medium and few coarse tubular pores; ped surfaces have gelatinous appearance, some surfaces look like clay flows; few firm ash nodules; abrupt smooth boundary.
B24	65-75 cm (26-30 inches)	Dark reddish brown (5YR 3/4) silty clay loam; moderate very fine subangular blocky structure; friable, sticky, plastic, moderately smeary; common fine roots; many very fine, fine and medium and few coarse tubular pores; ped surfaces have translucent gelatinous appearance, some coatings appear like clay flows; few firm ash nodules; abrupt smooth boundary.
B25	75-80 cm (30-32 inches)	Dark reddish brown (2.5YR 3/4) silty clay loam; moderate subangular blocky structure; friable, sticky, plastic, moderately smeary; few fine roots; many very fine, fine and common medium and few coarse tubular pores; ped surfaces have translucent gelatinous appearance; abrupt smooth boundary.
B26	80-83 cm (32-33 inches)	Dark brown (7.5YR 3/2) silty clay loam; moderate very fine subangular blocky structure; friable, sticky, plastic, moderately smeary; few fine roots; many very fine, fine and common medium and few coarse tubular pores; thick translucent gelatinous coatings on ped surfaces that appear like clay flows; few firm ash nodules; abrupt smooth boundary.
B27	83-93 cm (33-37 inches)	Dark reddish brown (5YR 3/4) silty clay loam, moderate very fine subangular blocky structure; friable, sticky, plastic, moderately smeary; few roots; many very fine, fine and medium and few coarse tubular pores; thick gelatinous coating on ped surfaces; few firm ash nodules of dark reddish brown (2.5YR 3/4); clear smooth boundary.
B28	93-123 cm (37-49 inches)	Dark reddish brown (5YR 3/4) silty clay loam; moderate fine and medium subangular blocky structure; friable, sticky, plastic, moderately smeary; few roots; many very fine, fine and medium and few coarse tubular pores; thick gelatinous coating on ped surfaces; clear smooth boundary.
B29	123-128 cm (49-51 inches)	Dark brown (7.5YR 3/3) silty clay loam; strong very fine subangular blocky structure; friable, sticky, plastic, moderately smeary; no roots; many very fine, fine and common medium tubular pores; thick translucent gelatinous coating on ped surface; few firm ash nodules: abrupt smooth boundary.
B210	128-133 cm (51-53 inches)	Dark reddish brown (2.5YR 3/4) silty clay loam; weak very fine and fine subangular blocky structure; friable, sticky, plastic, strongly smeary; no roots; many very fine, fine and medium and few coarse tubular pores; thick gelatinous coating on ped surfaces; common firm ash nodules of 6 to 18mm (¼-¾ inch) in diameter; abrupt smooth boundary.
B211	133-140 cm (53-56 inches)	Dark reddish brown (5YR 3/4) silty clay loam; moderate very fine subangular blocky structure; firm, sticky, plastic, strongly smeary; no roots; many very fine, fine and medium and few coarse tubular pores; translucent gelatinous coating on ped surfaces; few firm ash nodules; abrupt smooth boundary.
B212	140-145 cm (56-58 inches)	Dark reddish brown (2.5YR 3/4) silty clay loam; moderate very fine subangular blocky structure; friable, sticky, plastic, strongly smeary; no roots; many very fine, fine and common medium and few coarse tubular pores; ped surfaces have translucent gelatinous appearance; many firm ash nodules of 6 to 25mm (¼-1 inch) in diameter; abrupt smooth boundary.

B213	145-168 cm (58-67 inches)	Dark reddish brown (5YR 3/4) silty clay loam; strong very fine subangular blocky structure; friable, sticky, plastic, strongly smeary; no roots; many very fine, fine and common medium and few coarse tubular pores; ped surfaces have gelatinous appearance; few firm ash nodules.

ANDOSOLS

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