Taxonomy and
Management of Andisols

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PREFACE

Since 1975 the Soil Conservation Service of the U.S. Department of Agriculture has established six international committees to critically evaluate and re-define the taxa and definitions of the U.S. system of soil classification, Soil Taxonomy, for soils of the lower latitudes.

In order to provide fora for discussion of the issues studied by the various committees and to allow the examination of key examples of the soils under consideration in the field, the University of Puerto Rico initiated and helped organize a series of international soil classification workshops. In close collaboration with host country institutions, previous workshops were held in Brazil in 1977, Malaysia and Thailand in 1978, Syria and Lebanon in 1980, in Rwanda in 1981, and in the Sudan in 1982. These workshops dealt with the classification of Alfisols and Ultisols with low activity clays, Oxisols, Aridisols, high-altitude soils of the tropics, and Vertisols and Aridisols, respectively.

The first three workshops were largely funded by the U.S. Agency for International Development (AID) through grants to the University of Puerto Rico. Beginning with the Rwanda workshop, a new AID-sponsored program of the U.S. Department of Agriculture Soil Conservation Service, the Soil Management Support Services (SMSS), provided most of the funds, in part through grants to the University of Puerto Rico.

The Sixth International Soil Classification Workshop held in Chile and Ecuador from 9 to 20 January 1984 thus formed part of a comprehensive transnational effort to better adapt Soil Taxonomy to the edaphic conditions of the tropics and subtropics. It addressed the taxonomy and management of soils derived from volcanic ash in general and the mandate of the International Committee on the Classification of Andisols (ICOMAND) in particular.

The Chile/Ecuador workshop was a joint endeavor that involved many institutions. The national societies of soil science assumed the responsibility of orchestrating the local efforts. In Chile, the Universidad Austral de Chile, the Universidad de Chile, the Universidad de Concepción, the Pontifica Universidad Católica de Chile, and the Universidad de Santiago, the Consejo de Rectores de las Universidades Chilenas, the Instituto Nacional de Capacitación Professional, and the Corporación Nacional Forestal collaborated with the Sociedad

Chilena de la Ciencia del Suelo. In Ecuador, the Ministerio de Agricultura y Ganadería, the Instituto Nacional de Investigaciones Agropecuarias, and the Consejo Nacional de Ciencia y Tecnologiá assisted the Sociedad Ecuatoriana de la Ciencia del Suelo. The workshop was co-sponsored by the two national societies, the Soil Management Support Services, the University of Puerto Rico, and the U.S. Agency for International Development. Major funding was provided by AID through the SMSS project.

The chairmen of the Host Organizing Committees, Dr. Walter Luzio L. in Chile and Dr. Fausto Maldonado in Ecuador, and their committee members deserve high commendations for the excellent logistic and technical preparation of the workshop. Without their inputs and contributions the promise of a scientifically successful and socially enjoyable workshop could not have been realized. Special credit in this regard must be accorded to Dr. Renato Grez of the Universidad Austral de Chile.

The compilation of the proceedings was a joint effort of the University of Puerto Rico and SMSS. Ms. Sheila A. Oltz, the managing editor, performed the complex task of editing the technical papers with diligence and competence.

Part I of the proceedings includes the technical papers presented at the workshop, both in Chile and Ecuador. Part II provides reference background on the field excursions in Chile and includes complete descriptive and analytical data for the study pedons supplied by the National Soil Survey Laboratory of the USDA Soil Conservation Service. Part III contains the same information for Ecuador.

We consider the proceedings an up-to-date reference publication on the classification and characteristics of some important Andisols of Latin America, and on the management of Andisols for various uses.

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FOREWORD

El Taller sobre Clasificación y Manejo de Andisols realizado en Chile y Ecuador constituyó el sexto de una serie cuya finalidad ha sido mejorar y afinar "Soil Taxonomy" en aquellos suelos de regiones tropicales y subtropicales de limitada representatividad en USA.

Para ambos países latinoamericanos significó un considerable esfuerzo organizativo y de movilización de recursos humanos y materiales. Estos últimos particularmente escasos en países de limitado desarrollo. Sin embargo hemos estimado que el balance es positivo si se considera lo que se invirtió y los resultados que se obtuvieron. Baste solamente con mencionar los cuarenta participantes extranjeros, en representación de veinte países, considerados de entre los mejores científicos y técnicos en sus respectivas especialidades, con los que técnicos chilenos y ecuatorianos tuvimos la oportunidad de intercambiar experiencias e información.

Mirado el Taller ya con cierta perspectiva nos queda la satisfacción de haber contribuído al progreso de una rama importante de la Ciencia del Suelo, cuya materialización será una realidad a través del Comite Internacional para la Clasificación de Andisols (ICOMAND) en un futuro cercano. Así, la idea y proposición del Dr. Guy D. Smith (Q.E.P.D.) de crear el nuevo orden de los Andisols dentro de "Soil Taxonomy" significará una profundización y una ampliación de los conocimientos sobre los suelos derivados de materiales volcánicos, tan importantes para extensas regiones en desarrollo.

La presente obra ha sido dividida en tres tomos. Uno agrupa los trabajos presentados por los especialistas, otro la Guía de Terreno para Chile y otro la Guía de Terreno para Ecuador, incluyendo las descripciones de los suelos y sus análisis. De esta manera será más fácil manejar la información de campo.

Estamos ciertos que la publicación de estos Proceedings constituye la mejor retribución para todos aquellos que se entregaron desinteresadamente a la preparación y organización del Taller.

Walter Luzio Leighton

PERSPECTIVES AND BACKGROUND

RATIONALE FOR AN ORDER OF ANDISOLS IN SOIL TAXONOMY

Richard W. Arnold

In Soil Taxonomy, soils derived from volcanic ash are classified as Andepts, a suborder of the order Inceptisols. Many soil scientists now consider this classification inadequate and have proposed the order of Andisols for soils with volcaniclastic materials. This paper examines the taxonomic concepts of order and suborder, and the rationale for including Andisols in Soil Taxonomy.

Soil Taxonomy is a hierarchal classification system whose categories are defined with abstract concepts, but whose classes are identified and recognized by observable and measurable soil features. The system design has been guided by opinions and consensus judgments about soil formation.

TAXONOMIC CONCEPTS

Order

The order category is defined as soils whose properties are the result of, and reflect, major soil-forming processes (Arnold, 1983). Soils record their history in large measure by their features which are the relatively stable and relic properties produced by the interplay of processes that occurred at a specific site. Although we cannot prove or disprove the details of when or why these processes occurred, we can determine conceptually what changes have occurred and where they have taken place. The realization that important changes have occurred, or can occur, and that observable and measurable soil features are the result of such events is the morphogenetic basis of the highest category in Soil Taxonomy.

For example, the dispersion, translocation, and deposition of crystalline clays and the solution and recrystallization of carbonates are thought to result in clay skins on ped faces and secondary lime filaments, in the matrix of an argillic horizon respectively, of a Haplustalf.

Each class within this category is distinguished by a unique combination of properties and features. For example, an ochric epipedon, an argillic horizon, and a high base saturation in the substratum are features that identify a soil as belonging to a specific order, in this case the Alfisols. Diagnostic features are thought to be marks of major processes; they are also abstractions that bridge the gap between the reality of soils and the mechanics of this system of classification.

Soils are commonly characterized by the variability of nature, whereas a classification system is necessarily characterized by a rigidity and systematic manipulation of information imposed by man.

Suborder

The suborder category of Soil Taxonomy may be abstractly defined as soils whose properties are the result of, and reflect, the dominant control of the current soil-forming processes.

The suborders are classes of soils whose properties include both a historical record and the current status. Usually the more stable properties are closely related to prior events and processes, whereas the temporal variations are more closely related to events and processes of the recent past and of current conditions. The interactions of the existing ecosystems are thought to be related in a significant way to the soil properties and features used to identify the classes in this category. For example, organic matter contents and nutrient cycling are controlled by seasonal moisture and temperature patterns.

The kind of parent material is a major control of the kinds of modifications that are possible in some soils. In others, geomorphic processes such as flooding or internal mass movement appear to be major determinants affecting the development of soil horizons.

Although such features or processes may be useful in recognizing classes in the suborder category, the properties selected must be those that represent or reflect a major control of the current soil-forming processes. The number of properties and the number of classes are up to the designers and users of Soil Taxonomy. We group together those soils we want to keep together, or separate those soils we want to keep apart, and then find the criteria that support the classes and also satisfy the category definition.

Order vs. suborder

The main difference between the orders and the suborders in Soil Taxonomy is whether the soil properties selected are thought to reflect a major process of soil formation or to reflect a major control of the current process. It is clearly a matter of genetic concepts: the expected cause-and-effect relationships between measurable properties and hypothetical processes and events. There are no absolutes or truth to be revealed. Instead there is only a reasoned logic and internal consistency within a taxonomy to be realized.

INCEPTISOLS

The Inceptisols are soils whose properties are marks of modest modifications of parent materials. They generally are not strongly weathered, have horizons that may be transformed into other kinds merely by continuation of the current processses, and genetically represent early to intermediate stages in the differentiation of horizons (Allen and Fanning, 1983). These soils have the capacity to be changed further, and as such, they represent points of departure. The processes appear to reflect relatively short time spans, at least pedologically, even though the individual processes may be of different kinds and are those we associate with other orders. In summary, the Inceptisols are soils whose properties are thought to reflect pedologically young soils--altered from their parent materials but with numerous possibilities for further development.

Andepts

The Andepts, a suborder class of the Inceptisols, are soils whose properties reflect a major control of the current processes in addition to seeming to be pedologically young. Properties associated with volcaniclastic material, including low bulk density and chemical activity common to amorphous components, are thought to largely determine the processes that can take place (Foss, et al., 1983). The volcaniclastic material is significantly different from other mineral materials and provides a unique internal environment in which changes must occur. It is considered to be more important as a control than soil moisture, soil temperature, or other types of process control. Several other suborders, Psamments and Rendolls, are also controlled by their materials. Because of the limited number and kind of soils derived from volcanic ash in the United States and lack of available data, scientists have grouped these soils together in the Inceptisols, and have attempted to separate them from Spodosols having similar properties.

ANDISOLS

The decision to classify soils with volcaniclastic materials as a suborder of inceptisols worked only for a while.

Dissatisfaction with the Andepts spread as conferences on volcanic ash soils were held, more soil surveys were completed, and information on soil use and management of volcanic soils became more available. Dr. Guy Smith, who studied volcanic soils and their data in Central and South America and in New Zealand, noted that families of Andepts did not convey sufficient information about climatic conditions to make relevant statements about their expected behavior. This was in contrast with families in other subgroups. Smith believed that Soil Taxonomy would be improved by having another order--that of Andisols. One obvious way to gain information is to elevate a group of soils to a higher categorical level, thereby adding another set of characteristics used to satisfy the definition of that higher category.

Worldwide recognition of the ecological significance of soils derived from volcaniclastic material and a desire to convey more information in the taxa would seem to be adequate justification for proposing and establishing another order in Soil Taxonomy. A consensus of soil scientists in favor of the suggestion implies that such a modification can and will work. A taxonomy is a creation and tool of its designers and modifications are made to serve their purposes.

Soil Taxonomy is intended for practical purposes of soil survey programs. Statements about soil properties and their expected behavior test the usefulness of the system (Smith, 1983). But in addition to having a practical application, the new proposals for an order of Andisols must stand up scientifically in the hierarchal system of Soil Taxonomy.

Diagnostic features of the Andisols

The proposed order of Andisols is tentatively defined as those mineral soils that have at least 35 cm of soil materials with vitric or andic soil properties in the upper 60 cm of the profile. If an argillic, natric, spodic, or oxic horizon is present, it must be buried at a depth of more than 50 cm (Leamy, 1983).

Vitric soil properties exist where (a) more than 60% by volume of the whole soil consists of cinders, pumice, or pumice-like material or more than 40% by weight of the sand fraction consists of volcanic glass, and (b) extractable aluminum content exceeds 0.4% if extracted with acid-oxalate or 0.3% if extracted with 4M potassium hydroxide.

Andic soil properties exist where there is (a) a bulk density of less than 0.9 g/cm^3 of the fine earth fraction at 1/3 bar, (b) a phosphate retention value of more than 85, and (c) extractable aluminum of more than 2.0% if extracted with acid-oxalate or more than 1.5% if extracted with 4M KOH.

Recently deposited volcaniclastic materials do not have the chemical characteristics specified for vitric and andic soil properties. The active aluminum in allophane, imogolite, and Al-humus complexes has to be developed; it is not inherited (Allen and Fanning, 1983). Thus, a transformation must occur with sufficient intensity or duration to be measurable in more than half of the upper 60 cm of soil.

The emphasis is on the properties that result from changes in the parent materials. In Andisols, weathering has reached a state such that aluminum is very active in the chemical behavior of the soil. These soils have properties commonly associated with pedologically young soils; that is, they exhibit modest horizon differentiation. Eventually, an Andisol may acquire the features diagnostic of another soil order.

In my opinion, the set of features used to recognize vitric and andic soil properties are the result of, and do reflect, a major soil process. There must be a significant accumulation of volcaniclastic materials in the upper one meter of soil, either as surficial sediments or as shallowly buried deposits, and the materials must have been altered measurably. The modifications mainly involve interactions of aluminum and humus in a diversity of environments. These properties represent an abstract genetic process andd satisfy the definition and concept of the order category of Soil Taxonomy.

Suborders of the Andisols

Raising the Andepts to the order category implies that the properties selected for the suborder level should result from, or reflect, a dominant or major control of the current processes that operate in differentiating the soil.

Seven suborders of Andisols are proposed in Circular Letter Number 5 of ICOMAND (M. Leamy, 1983. Mimeographed report. Soils Bureau, Department of Scientific and Industrial Research, New Zealand). These are: Aquands, Allands, Borands, Torrands, Xerands, Ustands, and Udands. The implied controls of the current processes are:

- an aquic moisture regime (Aqu)
- high aluminum saturation (All)
- cold soil temperatures (Bor)
- an aridic moisture regime (Torr)
- a xeric moisture regime (Xer)
- an ustic moisture regime (Ust)
- other, mainly an udic moisture regime (Ud).

Soil water content and distribution are obvious controls of weathering transformation in the current environment. Cold soil temperatures inhibit most chemical processes and restrict biological activity. High aluminum saturation, high extractable acidity, and low pH in the upper part of the solum affect growth of vegetation, other biological activity, and weathering processes. The combination of these conditions is considered to be a dominant influence on the processes acting in these soils. Although other features could be selected as major controls of processes, many soil scientists favor the testing of the few selected ones listed above.

High temperatures, mainly isotemperature regimes, are not considered a major control of events. They are important but are recognized at the great group level, where the soil properties represent additional controls of processes. This is a priority decision based on the consensus of soil scientists. Thus, where high isotemperatures combine with enough moisture to cause important changes in soils, or in their use and behavior, a great group modifier would be used. The proposed Tropaquands and Tropudands are examples.

Although the physical characteristics and behavior of vitric and andic soil properties are important, they are not considered to be major controls of soil-forming processes. Consequently, they are not used to separate suborders of Andisols. These unique properties are thought to be additional controls on processes and are used to define and separate great groups in all suborders except the Allands, in which no vitric properties have yet been recognized.

SUMMARY

The rationale for the order of Andisols and its assocciated suborders, great groups, subgroups, and families is two-fold. First, the proposed classification provides groupings of soils about which scientists can make many meaningful statements in their soil survey work; and second, the proposal maintains scientific integrity within a taxonomic system that provides common threads of genesis. The Andisols conceptually represent an important stage of development for some soils, and the properties selected for use in the suborders are thought to represent ideas about major controls of the current soil processes.

The definitions and utility of all classes in Soil Taxonomy require continuous scrutiny, careful testing, and seasoned judgment if they are to contribute to improved knowledge and the service of mankind. To do otherwise is to limit ourselves and the future.

LITERATURE CITED

Allen, B.L., and D.S. Fanning. 1983. Composition and soil genesis. p. 169-171. *In* L.P. Wilding, N.E. Smeck, and G.F. Hall (eds.) Pedogenesis and Soil Taxonomy I: Concepts and interactions. Elsevier, Amsterdam.

Arnold, R.W. 1983. Concepts of soils and pedology. p. 1-21. *In* L.P. Wilding, N.E. Smeck, and G.F. Hall (eds.) Pedogenesis and Soil Taxonomy I: Concepts and interactions. Elsevier, Amsterdam.

Foss, J.E., F.R. Moormann, and S. Rieger. 1983. Inceptisols. p. 355-381. *In* L.P.. Wilding, N.E. Smeck, and G.F. Hall (eds.) Pedogenesis and Soil Taxonomy II: The soil orders. Elsevier, Amsterdam.

Smith, G.D. 1983. Historical ddevelopment of Soil Taxonomy-Background. p. 23-49. *In* L.P. Wilding, N.E. Smeck, and G.F. Hall (eds.) Pedogenesis and Soil Taxonomy I: Concepts and interactions. Elsevier, Amsterdam.

PARENT MATERIALS OF ANDISOLS

V. E. Neall

ABSTRACT

Parent materials of Andisols show a complete range of chemical composition and mineralogy with the exception of ultrabasic volcanics. They may originate by widely different mechanisms. Volcanic parent materials of major importance to Andisol classification discussed in this paper are lava flows, tephras, pyroclastic flows, lahar deposits, volcanic alluvium, and volcanic loess.

INTRODUCTION

Andisols are only one of two soil orders restricted to a specific parent material, in this case volcanic rock or its comminuted equivalent. Not all soils of volcanic parent materials are Andisols. Rather, Andisols represent part of a continuum principally dependent on time, climate, and vegetation existing between Entisols at one extreme and Alfisols, Spodosols and Oxisols at the other. With such a dominant influence of parent material on the genesis of this soil order, one may ask, "How have the parent materials of Andisols come about?"

To answer this, one may begin by viewing the distribution of Andisols. They occur on every continent except Antarctica, closely paralleling the global distribution of active and dormant volcanoes. Volcanic activity has occurred at all latitudes and altitudes, so volcanic deposits occur in any climate.

Two-thirds of the world's volcanoes are in the northern hemisphere and only 18% are between 10° S and the South Pole. This reflects the larger land area north of the equator. Of all the volcanoes currently recognized, nearly 900 (or 66% of those listed) lie around the Pacific Ocean where subduction of the Pacific, Nazca, Juan de Fuca, Cocos, and Philippine plates is generating a high incidence of volcanism, termed the "Pacific ring of fire." Roughly 60% of all volcanoes are within 2,000 m of sea level with 64 (or 5%) above 5,000 m, of which four-fifths are in the South American Andes (Simkin, et al., 1981). The highest is Llullaillaco here in Chile.

Andisols are derived from a wide range of volcanic lithologies ranging from rhyolitic and dacitic to andesitic and basaltic composition, but none are known from the rare ultrabasic volcanics (Komatiites). In general, Andisols with andic properties form from volcaniclastics of andesitic and basaltic composition; those with vitric properties from rhyolitic and dacitic composition. However, where rhyolitic and dacitic beds are distal and thin, andic properties may result. Also, soils on young andesitic and basaltic lava flows and breccias may show vitric properties.

The genesis of Andisol parent materials is varied. These are considered in turn.

LAVA FLOWS

Lava flows are the type of volcanicc product that comes to mind when people think of volcanic activity. Yet they are not nearly as common a parent material of Andisols as other volcanic products. This is probably due to many soils derived solely from lava flows being young and insufficiently weathered, thus belonging to the Entisol order.

Andisols derived directly from lava are most common in basaltic terrain, probably because of the fluidity of basaltic lava and its tendency to flow over wide areas. This is in marked contrast to the rare occurrence of Andisols from rhyolitic lava flows. Andisols from basalt lava flows are reported from sites of crustal tension that exist in restricted parts of most continents and numerous oceanic islands where sea-floor spreading is taking place. Andisols of this type are reported from Hawaii (Uehara, et al., 1971), Fiji (Twyford and Wright, 1965; Shepherd and Heall, 1983) and Samoa (Wright, 1963) in the Pacific and from the Western Sudan (White, 1967), Ethiopia and Kenya (Frei, 1978) in Africa. In many cases, the soils may have a mantle of volcanic ash overlying the lava flows.

TEPHRA

It is the aerial distribution of tephra mantling widespread areas with volcanic ash that has created a large proportion of the world's Andisols. A term coined by Thorarinsson (1954), tephra was defined as "all the clastic volcanic material which during an eruption is transported from the crater through the air, corresponding to the term 'lava' to signify all the molten material flowing from the crater." Although not specifically excluding all flow deposits, some authors have taken this definition to refer strictly to airfall volcaniclastic materials (Crandell, 1980; Miller, 1980; Neall, 1972). Since then a second school of thought considers tephra to encompass pyroclastic flows (Cole and Kohn, 1972) and Thorarinsson (1974) adjusted his original definition to "define tephra as a collective term for all airborn pyroclastics, including both airfall and flow pyroclastic material." The International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks has now recommended that tephra be a collective term for all pyroclastic deposits that are predominantly unconsolidated (Schmid, 1981). The two-fold usage continues.

Dispersal

Tephra dispersal will depend on wind speed, height of the eruption column and magma type, but increasingly the role of water in the explosivity and dispersal of tephras is being recognized. For example, one traditionally associates rhyolitic magmas, rather than basaltic magmas, with highly explosive eruptions. Yet the 1886 A.D. basaltic eruption of Mt. Tarawera in New Zealand generated 1.3 km^3 of scoria that covered 4,500 km^2 to more than 5 cm thickness (Pullar and Birrell, 1973) in one of the most explosive basaltic eruptions in historic times. Thus groundwater, geothermal steam, and even the sea may cause a phreato-magmatic eruption, greatly increasing the explosivity of any magma type to create more widely dispersed tephras.

Size

Tephras range in size from molten bombs or solid blocks greater than 64 mm diameter through lapilli size to less than 2 mm diameter ash particles. They may be dense lithic fragments (often accessories to the eruption) or vesiculated and either felsic (pumice) or mafic (scoria) in lithology. In Hawaii, one sees the finest of all tephras in the form of Pelees hair, thin strands of fibrous basaltic glass that are produced by explosions of gas-rich, extremely fluid basaltic lava fountains. Liquid droplets are drawn into threads up to 2 m or more in length that may drift in the wind for distances up to 15 km (Williams and McBirney, 1979).

Stratigraphy

The work of numerous volcanic stratigraphers and soil scientists has helped to define, map, and date the principal soil-forming tephra parent materials of Andisols. The world bibliography and index of Quaternary tephochronology gathered these numerous publications on this subject together for the first time (Westgate and Gold, 1974). It is not possible to even attempt to review all this work, but certain articles deserve special mention. In the U.S.A., Mullineaux (1974) described in detail 11 layers of tephra of post-glacial age erupted from Mt. Rainier. Later work by Mullineaux and Crandell (1981) described nine eruptive periods of tephra emission from Mt. St. Helens. These tephras have spread across large tracts of Washington and Oregon states as well as southern Canada. Of great interest is that this work showed former eruptions from Mt. St. Helens to be cyclical in composition, and over the last 40,000 years tephras ranged from dacite to basalt. Another example is Mt. Tarawera which prior to the 1886 A.D. basaltic scoria eruption had erupted 5.2 km^3 of rhyolitic pumice about 650 years ago. These instances are important to us because when examining Andisols, one must not overlook compositional changes within tephras from one volcano which may be identifiable in the soil, and grossly affect nutrient availability. These changes may not be visible to the geologist studying the volcanic cone which may represent only the latest phase(s) of lava extrusion.

The complex tephra stratigraphy of Japan has been described by numerous workers and its relevance to Andisols summarized (Ministry of Agriculture and Forestry, 1964). The largely andesitic tephras of Japanese Andisols are subdivided on their dominant mafic mineralogy into four classes, some of which are found only in specific regions. Of special mention is the map of the distribution of all late Quaternary tephras in Hokkaido (Sasaki, 1974) at 1:600,000 scale. In New Zealand, the major Holocene tephras of the Central North Island were first defined and mapped by Vucetich and Pullar (1964); to be followed by maps of the late Pleistocene tephras in 1969. Revised isopach maps are presented by Pullar and Birrell (1973). References to numerous other occurrences of volcanic ash soils are presented in Leamy, et al. (1980).

PYROCLASTIC FLOWS

Pyroclastic flows may be either pumiceous or lithic in composition, the former being a more widespread Andisol parent material because of its more explosive, voluminous nature. Large areas of Andisols with vitric properties have developed from pyroclastic flow deposits. Of interest to Andisol classification is the welding that can take place at the very high temperatures of pyroclastic flow emplacement. Originally defined as ignimbrite in New Zealand, such welded pyroclastic flows may form very dense rock. However, because many flows show a degree of welding in only some part of their distribution, the meaning of the term "ignimbrite" has now changed and is used for pyroclastic flows irrespective of their welding characteristics. Of importance to forestry and agriculture in New Zealand has been the recognition of unsuspected partial welding in otherwise unwelded Taupo Pumice deposits in New Zealand. It has not been possible to predict where weak welding has occurred in these deposits, and Pullar (1980) was first to try and map the areas of "compaction." The economic significance of the partial welding is to totally exclude deep-rooting lucerne or *Pinus radiata* from penetrating the subsoil.

The cangagua of Ecuador and the talpetate of Mexico and Nicaragua, which can be more than 100 m thick, may have a similar origin. As Colmet-Daage (1975a) has commented, "It is very difficult to know if the silica cement came from present pedological processes or from old geological processes." G.D. Smith considered the material to be sufficiently widespread and important to establish two Duric great groups in his original Andisol proposal, signifying that he considered cangagua to be a duripan.

LAHARS AND VOLCANIC ALLUVIUM

Lahars

Adjoining the andesite stratovolcanoes of the world are often extensive circular aprons of detrital volcaniclastics termed "ring plains" (Morgan and Gibson, 1927). These volcaniclastics have originated from the multiple collapses of former and existing volcanic cones, creating extensive lahars--volcanic mudflows, debris flows, and debris avalanches--that spread radially outwards to inundate the former topography.

Lahars are particularly common in the circum-Pacific countries and originate by a variety of triggering mechanisms (Neall, 1976a, 1976b). Some originate by collapse of the margins of or eruptions through crater lakes. These are the true lahars which are very common in Indonesia (van Bemmelen, 1949) and which have also occurred historically in Japan, Guatemala, St. Vincent, Chile, and New Zealand. Other lahars have been triggered by pyroclastic flows being admixed with lakes and rivers, and have been particularly common in the eastern Pacific and central America.

Heavy rains mobilizing thick and often recently deposited volcanic ash deposits create the rain lahars common throughout the world. Subglacial volcanic activity may lead to storage of water beneath ice caps that infrequently overflow to generate jokulhlaups or glacier runs observed most frequently in Iceland. On one occasion 7 km^3 of water plunged out from beneath the glaciers of southern Iceland to briefly carry as much water as the Amazon River (Thorarinsson, 1957). These flows have formed the parent materials of the sandur plain of southern Iceland. Eruptions may melt snow and ice to generate lahars as has occurred in Japan, Kamchatka, at Cotopaxi in Ecuador, and here in Chile at Villarica and Colbuco.

Finally, phreatic explosions and directed blasts have generated many debris avalances of widespread nature, the more famous ones being the 1888 A.D. collapse of Bandai-san in Japan, the prehistoric Osceola Mudflow in Washington, U.S.A., and the most recent example at Mt. St. Helens in May, 1980.

Andisols may be formed directly from young lahars, or may be composed of varying thicknesses of weathering tephra overlying laharic breccias, conglomerates, or sandstones (e.g. Tan, 1965; Palmer, et al., 1979). One of the unique features of some lahar deposits is the formation of numerous mounds on their upper surface, as seen in Chile (Macphail, 1973), Indonesia, Japan, and New Zealand. This morphology leads to distinctive toposequences of Andisols from the well-drained sites on mounds to the poorly drained sites with Aquands in between. These have been documented for the most extensive lahar field in New Zealand by Palmer, et al. (1979) in Egmont County.

Here in Chile there are morainic deposits mantled with volcanic ash that form similar landscapes and Andisols to those from lahars. The tephra mantle is thin (<1m) and water runoff is very slow so the soils are swampy and waterlogged. These are the Niadi soils, which are not cultivated due to the difficulty of drainage (Colmet-Daage, 1975b). In just the same way that some lahar deposits may form lithic or paralithic contacts in Andisol subsoils, obstructing free drainage, so too do the fluvio-glacial deposits, some of which are silica, cement to form duripans.

Volcanic alluvium

Rivers draining volcanic regions deposit volcanic alluvium alongside their channels, which gives rise to Andisols. In Taranaki, New Zealand, the soils adjoining the rivers draining Mt. Egmont are all Andisols derived from alluvium. However, once the alluvium reaches the sea, the sand-size grains are worn by the waves to remove glass selvedges and are then concentrated on the beaches to provide sand dunes of volcanic mineralogical assemblages that do not form Andisols. Andisols also develop from mixed alluviums at Mt. Rainier in Washington, U.S.A., where the volcanic component to some alluviums is only 50%, but sufficient short-range order clay minerals are present to create Andisols.

VOLCANIC LOESS

In regions peripheral to volcanoes, tephras will become interbedded within other actively sedimenting materials from lake sediments and peats to colluvium and loess. By far the most common relationship of major importancce to Andisol classification is tephra interbedded with loess and tephra resorted by the wind as volcanic loess. Numerous localities exist all around the Pacific where classic volcanic ash soils are now being reinterpreted as having nonvolcanic components.

Volcanic loess was first recognized of widespread significance here in South America when Teruggi (19 7) described loessoid deposits formed of volcanic origin across much of Argentina. Besoain (1964) also recognized a blanket of volcanic loess here in Chile due to the prevailing southwest winds redistributing volcanic materials along the lower foothills of the Andes. Besoain noted how this volcanic loess obscured the boundary between the Holocene "trumao" Andisols and the red-brown volcanic clays of older age.

In New Zealand the significance of tephric loess was recognized in the 1970s. Now even the lower subsoil of the Egmont soil is interpreted to be a tephric loess of late Pleistocene age overlain by Holocene volcanic ash. This evidence is based on nonvolcanic mineralogical assemblage (such as quartz, garnet, and epidote) and size particle parameters (Stewart, et al., 1977). Tephric loess appears to be strongly climatically controlled and was most widespread during the late Pleistocene (Benny, et al., 1983).

In Mexico, aeolian redeposited tephra is called "toba-sediment" and is widespread about the lower slopes of the Sierra Nevada (Miehlich, 1980). As the volcanic component of loess decreases, one observes a gradation from Andisols to Inceptisols or Alfisols.

Of significance in the high Andes today and probably in many other countries in late Pleistocene times is the active wind erosion of tephras to form saltating dunes. Such dunes are found mostly fossil in New Zealand (Vucetich and Pullar, 1969; Neall, 1975) and rarely form today above 1,000 m altitude. However, formation of coppice dunes from wind-eroded tephra is common in the high Andes and the susceptibility of some Andisols to wind erosion in South America led G.D. Smith to erect a Psammic subgroup. The realization of drier climatic conditions during the late Pleistocene triggering wind erosion of tephras must be a warning to soil conservators working in ustic moisture regimes today.

CONCLUSION

While Andisols occupy only about 1% of the world's land surface, they support a disproportionate number of the world's population that derives its food from agriculture and horticulture on these soils. The more we learn about how these soils originated, beginning with their many types of volcanic parent materials to the numerous climatic and vegetative influences that have molded them, the more we will learn of the genesis of their unique physical and chemical properties.

LITERATURE CITED

Benny, L.A., R.B. Stewart, J.H. Kirkman, and N.M. Kennedy. 1983. Tephric loess formation as related to climate during late Quaternary time in the Central North Island, New Zealand. *In* Abstracts Pacific Science Association 15th Congress. Dunedin, N.Z.

Besoain, E.M. 1964. Clay formation in some Chilean soils derived from volcanic materials. N.Z.J. of Sci. 7:79-86.

Cole, J.W., and B.P. Kohn. 1972. Pyroclastic Nomenclature in New Zealand. Comment, N.Z.J. of Geol. and Geophys. 15:686-687.

Colmet-Daage, F. 1975a. The volcanic ash soils of Ecuador. p. 1-19. *In* Conferences. Cornell University. Centre des Antilles. Bureau des Sols. Office de la Recherche Scientifique at Technique Outre-Mer.

Colmet-Daage, F. 1975b. Some aspects of Chilean ash volcanic soils. p. 20-42. *In* Conferences. Cornell University. Centre des Antilles. Bureau des Sols. Office de la Recherche Scientifique et Technique Outre-Mer.

Crandell, D.R. 1980. Recent eruptive history of Mount Hood, Oregon, and potential hazards from future eruptions. U.S. Geol. Surv. Bull. 1492.

Frei, E. 1978. Andepts in some high mountains of East Africa. Geoderma 21:119-131.

Leamy, M.L., G.D. Smith, F. Colmet-Daage, and M. Otowa. 1980. The morphological characteristics of Andisols. p. 17-34. *In* B.K.G. Theng (ed.) Soils with variable charge. N.Z. Soc. of Soil Sci., Lower Hutt, N.Z.

Macphail, D.D. 1973. The geomorphology of the Rio Teno Lahar, Central Chile. The Geographical Review: 517-532.

Miehlich, G. 1980. Los suelos de la Sierra Nevada de Mexico. Fundacion Alemana para la investigacion cientifica. Puebla, Mexico.

Miller, C.D. 1980. Potential hazards from future eruptions in the vicinity of Mount Shasta Volcano, northern California. U.S. Geol. Surv. Bull. 1503.

Ministry of Agriculture and Forestry, 1964. Volcanic ash soils in Japan. Japanese Government, Tokyo.

Morgan, P.G., and W. Gibson. 1927. The geology of the Egmont Subdivision, Taranaki, New Zealand. N.Z. Geol. Surv. Bull. 29.

Mullineaux, D.R. 1974. Pumice and other pyroclastic deposits in Mount Rainier National Park, Washington. U.S. Geol. Surv. Bull. 1326.

Mullineaux, D.R., and D.R. Crandell. 1981. The eruptive history of Mount St. Helens. p. 3-15. *In* P.W. Lipman and D.R. Mullineaux (eds.) The 1980 eruptions of Mount St. Helens, Washington. U.S. Geol. Surv. Prof. Paper 1250.

Neall, V.E. 1972. Tephrochronology and tephrostratigraphy of western Taranaki (N108-109), New Zealand. N.Z.J. of Geol. and Geophys. 15:507-557.

Neall, V.E. 1975. Climate-controlled tephra redeposition on Ponakai ring plain, Taranaki, New Zealand. N.Z.J. of Geol. and Geophys. 18:317-326.

Neall, V.E. 1976a. Lahars - global occurrence, and annotated bibliography. Pub. of Geol. Dep., Victoria University of Wellington, N.Z. No. 5.

Neall, V.E. 1976b. Lahars as major geological hazards. Bull. of the Int. Assoc. of Engineering Geol. 14:233-240.

Palmer, R.W.P., V.E. Neall, and J.A. Pollok. 1981. Soils of Egmont and part Taranaki Counties, North Island, New Zealand. N.Z. Soil Survey Report 64.

Pullar, W.A. 1980. Tephra and loess cover deposits on Kaingaroa Plateau including detailed lithology of upper Taupo Pumice. N.Z. Soil Bureau Scientific Report 44.

Pullar, W.A., and K.S. Birrell. 1973. Age and distribution of late Quaternary pyroclastic and associated cover deposits of the Rotorua and Taupo area, North Island, New Zealand. N.Z. Soil Survey Report 1.

Sasaki, T. (ed.) 1974. Distribution of the late Quaternary pyroclastic deposit in Hokkaido, Japan. Misc. Pub. Hokkaido Natl. Agric. Exp. Stn., No. 4.

Schmid, R. 1981. Descriptive nomenclature and classification of pyroclastic deposits and fragments. Recommendations of the I.U.G.S. Subcommission on the Systematics of Igneous Rocks. Geology 9:41-43.

Shepherd, T.G., and V.E. Neall. 1983. Volcanic soils of Tutu Estate, Taveuni, Fiji Islands *In* Abstracts. Pacific Science Association 15th Congress. Dunedin, N.Z.

Simkin, T., L. Siebert, L. McClelland, D. Bridge, C. Newhall, and J.H. Latter. 1981. Volcanoes of the World. Smithsonian Institution, Washington.

Stewart, R.B., V.E. Neall, J.A. Pollock, and J.K. Syers. 1977. Parent material stratigraphy of an Egmont Loam profile. Taranaki, New Zealand. Aust. J. Soil. Res. 15:177-190.

Tan, K.H. 1965. The Andisols in Indonesia. Soil Sci. 99: 375-378.

Teruggi, M.E. 1957. The nature and origin of Argentine loess. Journ. Sed. Petrol. 27:322-332.

Thorarinsson, S. 1954. The tephra fall from Hekla on March 29, 1947. *In* J. Einarsson, G. Kjartansson, and S. Thorarinsson (eds.) The Eruption of Hekla, 1947-48, II (3). Societas Scientiarum Islandica and the Museum of Natural History, Reykjavik.

Thorarinsson, S. 1957. The jokulhlaup from the Katla area in 1955 compared with other jokulhlaups in Iceland. Museum of Natural History, Dept. of Geol. and Geog., Reykjavik. Miscellaneous Papers No. 16.

Thorarinsson, S. 1974. The terms tephra and tephrochronology. p. xvii-xviii. *In* J.A. Westgate and C.M. Gold (eds.) World Bibliography and Index of Quaternary Tephrochronology. The University of Alberta, Edmonton.

Twyford, I.T., and A.C.S. Wright. 1965. The soil resources of the Fiji Islands. Government of Fiji, Suva.

Uehara, G., H. Ikawa, and H.H. Sato. 1971. Guide to Hawaii Soils. College of Tropical Agric. Hawaii Agric. Exp. Stn. Misc. Pub. 83.

Van Bemmelen, R.W. 1949. Geology of Indonesia. Vol. 1. Government Printing Office, The Hague.

Vucetich, C.G. and W.A. Pullar. 1964. Stratigraphy and chronology of late Quaternary volcanic ash in Taupo, Rotorua, and Gisborne districts. N.Z. Geol. Surv. Bull. 73:43-88.

Vucetich, C.G., and W.A. Pullar. 1969. Stratigraphy and chronology of late Pleistocene volcanic ash beds in Central North Island, New Zealand. N.Z.J. of Geol. and Geophys. 12:784-837.

Westgate, J.A., and C.M. Gold. (eds.) 1974. World Bibliography and Index of Quaternary Tephrochronology. The University of Alberta, Edmonton.

White, L.P. 1967. Ash soils in Western Sudan. J. of Soil Sci. 18:309-317.

Williams. H., and A.R. McBirney. 1979. Volcanology. Freeman, Cooper and Co., San Francisco.

Wright, U.A.C.S. 1963. Soils and land use of Western Samoa. N.Z. Soil Bur. Bull. 22.

THE NATURE OF ANDIC AND VITRIC MATERIALS

Roger L. Parfitt

ABSTRACT

Andisols, which have low bulk density and an exchange complex dominated by "amorphous" material (ECDAM), are said to have andic properties. The amorphous material is better described as short-range order material. It is usually a mixture of allophane, imogolite, and Al-humus complexes, but it may also contain ferrihydrite, volcanic glass, opaline silica, and Fe-humus complexes.

Allophane, imogolite, and Al-humus complexes all contain active Al. Active Al is best measured by a chemical extraction of Al with a dissolution reagent such as acid-oxalate. It can also be measured by a secondary process, such as phosphate adsorption or fluoride adsorption.

Andisols, which contain significant amounts of glass, pumice, or cinders and which have weathered to give a little active Al, are said to have vitric properties.

INTRODUCTION

Soil Taxonomy (Soil Survey Staff, 1975) defined the Andepts as:

1. Inceptisols
2. which are more or less freely drained
3. having low bulk density
4. andeither allophane with high CEC or mostly pyroclastic materials.

This was an attempt to define the group of volcanic ash soils which had previously been called andosols. Andosol comes from the Japanese words "an" meaning black and "do" meaning soil. These soils are, however, called Kuroboku soils, in Japan, meaning dark friable soils, which is a much better general description of these soils.

The Andepts in Soil Taxonomy were further defined in terms of what we now see as Andic or vitric properties. The Andic properties were:

1. Bulk density < 0.85 g/cc
2. Exchange Complex Dominated by Amorphous Material (ECDAM).

and ECDAM was defined as:

1. CEC (pH 8.2) > 150 meq/100 g
2. 15 bar water > 20% by weight
3. pH (NaF) > 9.4
4. 15 bar water/clay > 1.0
5. % C > 0.6
6. DTA endotherm near 100°C
7. BD > 0.85 g/cc.

The vitric properties were:

>60% by weight vitric volcanic ash, cinders or other vitric pyroclastic material.

In the Andisol proposal these definitions, particularly ECDAM, were considered to be inadequate and in the proposal the central concept of an Andisol was given as having:

1. soil developing in "volcaniclastic" material
2. exchange complex dominated by "amorphous compounds" of Al, Si, and humus
3. low bulk density
4. low permanent charge
5. high variable charge
6. P fixation
7. high water retention
8. high % C
9. Al toxicity not usual
10. high liquid limits, high plastic limits

It is important to note the emphasis placed on "amorphous compounds" in this central concept because it implies that soils which have a predominance of crystalline minerals are to be excluded, even though they may have formed from volcanic ash. Therefore, soils which have halloysite, kaolinite, or crystalline iron oxides as the major part of the clay fraction are to be excluded from Andisols. These soils usually occur in the lowland tropical or subtropical regions and may be classified as Oxisols, Ultisols, or Mollisols.

Also soils formed in very recent tephra may not have weathered to give sufficient "amorphous compounds" and these are to be excluded from andisols. It is suggested that they can be classified as Andents.

ANDIC MATERIAL

It has been known for some 30 years that andosols contain a high content of X-ray amorphous substances (Quantin, 1972) but during the last ten years the nature of these substances has been better defined (Wada, 1980; Parfitt, 1980). We can now analyze soils for these substances and a variety of tests are available to help define Andisols.

The "X-ray amorphous substances" which are present in these soils are thought to be allophane, imogolite, Al-humus complexes, glass, opaline silica, Fe-humus complexes, and ferrihydrite. The term "X-ray amorphous," however, can no longer be used since some of these substances do have X-ray lines. The term "short range order material" (SROM) is now preferred.

Imogolite

Imogolite is a tubular mineral about 22 Å in diameter with a wall about 7 Å thick. The formula is $(OH)_3Al_2O_3SiOH$ and the external surface contains AlOH groups which are similar to those in gibbsite (Wada, 1977). Imogolite also occurs in spodosols and soils developed on basalt flows (Tait, et al., 1978; Mizota, 1981).

Allophane

Allophanes are members of a series of naturally occurring minerals which are hydrous alumino silicates with short-range order and a predominance of Si-O-Al bonds (van Olphen, 1971). It appears that there are two reference points in the allophane series which occur in volcanic ash soils: they are allophane with Al/Si = 2/1 and with Al/Si = 1/1 (Wada, 1977; Parfitt, et al., 1980). The structure of these allophanes is related to that of imogolite in that silicate is bonded to a curled gibbsite-like sheet. More or less silicate may be present so that Al/Si ratios can range from 0.8 to 3. The particles of allophane appear to be hollow spherules about 40 Å in diameter.

Allophane also occurs in Spodosols, Dystrochrepts, some basalt soils and some stony recent soils remote from volcanoes (Mizota, 1981; Childs, et al., 1983; Anderson, et al., 1982; Parfitt and Webb, 1983).

Al-humus complexes and Fe-humus complexes

These complexes have long been known to occur in Spodosols, and they can be extracted with 0.1 M $Na_4P_2O_7$ (McKeague, et al., 1971). Routine pyrophosphate extraction indicates that these complexes are present in nearly all soils, particularly A horizons. Al-humus complexes are present in significant amounts in surface horizons of many Japanese Kuroboku soils (Wada and Higashi, 1976; Shoji and Fujiwara, 1984).

Opaline silica and volcanic glass

These materials are often present in Andisols (Wada, 1980) and are short range order materials with a similar infrared spectra. They are much less reactive than the other SROM and are of marginal interest in defining Andic properties.

Ferrihydrite

Ferrihydrite is a recognized mineral and has short range order (Schwertmann and Taylor, 1977). A structural formula, Fe_2O_3 2FeOOH $2.6H_2O$, has been suggested (Russell, 1979). It was previously called amorphous iron oxide or iron gel (Wada, 1980) and it also occurs in hydromorphic soils and in Inceptisols, Alfisols, and Ultisols in New Zealand.

Identification of Andic material

In the Andisol proposal we are looking for methods which allow us to identify the SROM which help to give Andisols their unique properties. We need methods which separate Andisols from Oxisols, which also have P fixation properties, and from Spodosols, which also have Al-humus complexes and may contain allophane.

It is now clear that the materials which give most Andisols their P fixation properties, their high water retention and a part of their variable charge are the large amounts of allophane, imogolite, and Al-humus complexes (Wada, 1980; Shoji and Fujiwara, 1984). In some Andisols, ferrihydrite and Fe-humus may be important, but further data is required to confirm this. Organic C is usually high in Andisols and is probably important in that it complexes Al and contributes to the variable charge, but high organic C values are not unique to Andisols.

The key to separating Andisols from other orders then lies in methods of identifying allophane, imogolite, and Al-humus complexes.

Fluoride reaction. All these compounds have AlOH groups which will react with fluoride or phosphate and Wada (1980) suggested Andic materials should be defined in terms of active Al rather than amorphous material. The reactions of this Al with fluoride or phosphate can be used to identify Andic material. The P retention method is a measure of the phosphate adsorption capacity of a soil and soils with significant amounts of Andic material have P retention values of > 85%.

The fluoride reaction releases OH groups which are measured with a pH meter (Kawaguchi and Matsuo, 1955; Fieldes and Perrott, 1966). Soils with significant amounts of Andic material give pH values between 10 and 12. However, soils with small amounts of Andic material can also give reactions pH > 10. There are a number of problems associated with this reaction, namely:

1. NaF reagent often contains acid or alkali impurities.
2. Stirring needs to be controlled.
3. Dried soils give low results.
4. Spodosols and some Oxisols also react.
5. There are problems dissolving the NaF.

Pyrophosphate extraction. The pyrophosphate extraction method can be used to extract Al from Al-humus complexes (Higashi and Shinagawa, 1981), but with allophane very little Al is extracted (Table 1).

Table 1. Dissolution of allophane and imogolite in oxalate (o), pyrophosphate (p), and dithionite (d) reagents.

	Al/Si	Al_o (%)	Si_o (%)	Al_p (%)	Al_d
Allophane 963	2.0	25.6	13.3	1.7	4.5
Imogolite	2.0	25.0	13.0	-	0.5
Allophane KnP	1.1	16.4	15.8	-	-

Acid-oxalate extraction. Acid-oxalate extraction (Tamm, 1934; Schwertmann, 1964) is particularly effective in dissolving allophane, imogolite, and Al-humus complexes (Higashi and Ideda, 1974; Wada, 1977; Parfitt and Henmi, 1982).

The data in Table 1 indicate that large amounts of Al and Si are extracted from aluminum-rich allophane and imogolite using acid-oxalate, and published data suggest that dissolution is complete (Parfitt and Henmi, 1982). Data for allophane with Al/Si close to 1 (Table 1) shows that large amounts are also extracted from silica-rich allophanes.

Other methods. Al-humus complexes are soluble in several reagents and data in Table 2 indicates that pyrophosphate, acid-oxalate, and dithionite-citrate-bicarbonate are all effective in dissolving the Al from these complexes (see also Shoji and Fujiwara, 1984). Both Al-humus complexes and allophane are largely dissolved in acid-oxalate (Wada, 1977), therefore, the Al released by this reagent may be used to identify Andic material.

Table 2. Dissolution of Al, Fe-humus in a Haplohumod Bh horizon formed in rhyolitic ash and Senbata Andisol A.

	Pyrophosphate			Acid-oxalate			Dithionite	
	Cp (%)	Alp (%)	Fep (%)	Al_o (%)	Fe_o (%)	Si_o (%)	Al_d (%)	Fe_d (%)
Spodosol Bh	5.8	0.88	0.23	0.96	0.26	0.01	1.01	0.37
Andisol Ap	-	1.25	0.87	1.66	1.61	0.13	1.32	1.53

A field office method which extracts 75% of the Al extracted by acid-oxalate has been developed (Kimble and Holmgren, 1981; Blakemore, 1983). This uses 4 M KOH and should be tested as an alternative method.

Dissolution analysis. When dissolution analysis is applied to soil clays and soils, data such as in Table 3 is obtained. Pyrophosphate dissolves Al-humus complexes, whereas acid-oxalate dissolves allophane together with Al-humus. The oxalate Al values are all greater than pyrophosphate indicating that allophane and Al-humus complexes are both present. The Al/Si ratio of the allophane has been calculated by the method of Parfitt and Henmi (1982) and show reasonable agreement between the clay fraction and the soil. Other work (Parfitt, et al., 1983) also suggests that the acid-oxalate method can be applied to soils and it is probably the best method for estimating allophane in soils at present (Farmer, et al., 1983).

Table 3. Dissolution analysis of Egmont loam (a) clay, (b) soil

	Oxalate		Pyrophosphate		Allophane
	Al_o (%)	Si_o (%)	Al_p (%)	$\frac{Al_o-Al_p}{Si_o}$	(%)
			CLAY FRACTION <2μm		
A	8.2	3.0	2.2	2.1	30
Bw1	12.7	4.5	1.7	2.5	50
Bw2	13.3	7.2	1.3	1.7	50
			SOIL < 2 mm		
A	3.0	1.0	1.0	2.1	8
Bw1	3.5	1.4	0.7	2.1	11
Bw2	3.4	1.4	0.6	2.1	11

Acid-oxalate Al values then, represent the Al that is held in allophane, imogolite, and Al-humus complexes.

Variation of other properties with acid-oxalate Al

There is a good relationship between acid-oxalate Al and P retention for New Zealand pedons containing volcanic ash (Fig. 1) indicating that the phosphate adsorption by these soils is largely controlled by the amount of Al in allophane and Al-humus complexes. Japanese soils containing Al-humus have high P retention values suggesting they contain more active AlOH groups.

There is also a general relationship between acid oxalate Al and bulk density and 15-bar (Figs. 2 and 3) for New Zealand pedons. This indicates allophane and Al-humus influence these properties.

The relationship between pH (NaF) and acid-oxalate Al is not particularly good (Fig. 4). In this data set, there are several points to note:

1. The soils were air-dried.
2. It appears that Al-humus complexes are more reactive than allophane (Wada, 1980).
3. Soils, including Oxisols, with oxalate Al values <1% can have pH (NaF) values which are quite high.
4. Podsolized horizons also may have values >9.4.

For these reasons, acid-oxalate Al is considered to be a better measure of active Al than pH (NaF) and a value of 2% (equivalent to about 8% allophane) allows the separation of Andisols from Oxisols and Spodosols. Soils with 0.4-2.0% oxalate Al may be included in Andisols if they have vitric properties. Soils with 1.5-2.0% oxalate Al may be included as Andic subgroups of other orders, e.g. Andic Dystrochrept, Andic Hapludolls. Is is recognized that allophane and imogolite have little if any measurable permanent charge. They do, however, have a considerable variable charge (Wada, 1980). Organic matter also has a high variable charge, and it has not been possible to find a satisfactory routine method for measuring the variable charge for Andic materials. It also appears that it may not be necessary to use variable charge ratios because the P retention and the acid-oxalate Al methods may be adequate to separate Andisols from other orders.

Central concepts of soil with Andic properties

The Andisol, developed on andesitic ash in New Zealand, illustrates the central concept of a soil with Andic properties (Table 4). These soils have low bulk densities, high P retention, high oxalate Al, high pH (NaF), high organic C and low Al (KCl) values.

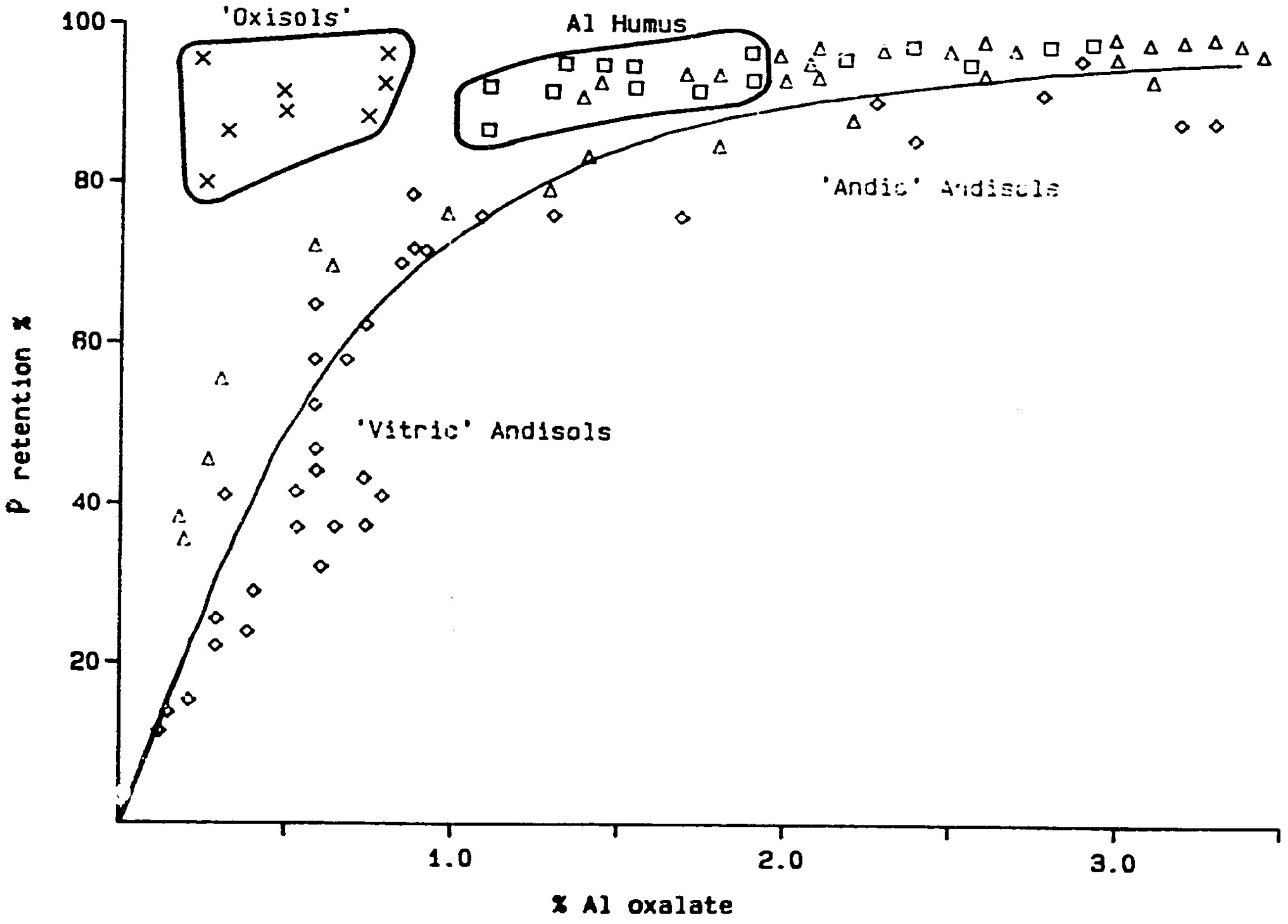


Fig. 1 Relationship between acid-oxalate Al and Phosphate retention for soils containing volcanic ash.

Table 4. Some data for an Egmont soil, New Zealand (Hapludand).

	cm	BD (g/cc)	P retn (%)	Al_o (%)	Al_p (%)	pH(NaF)	15-bar wet (%)	water dry (%)	C (%)	Al(KCl) (meq/100 g)
Ap	0-21	0.75	88	3.2	0.6	10.7	30	23	10	0.3
Bw1	21-38	0.73	98	4.7	0.4	11.0	36	18	4	0.1
Bw1	38-55	0.66	99	4.9	0.3	10.8	39	16	2	0.1
Bw2	55-89	0.75	99	5.0	0.3	10.9	42	16	2	0.1

Table 5 shows data for an intergrade between an Andisol and Oxisol formed on volcanic ash in Cameroon (A. Herbillon, personal communication). The bulk densities are low and the recent ash in the A horizons contains some Andic material. The B horizons, however, are oxic horizons which have formed from older ash. They have high P retention which is due to iron oxides; the oxalate Al values are fairly low (0.8%) but pH (NaF) values are >9.4.

Table 5. Some data for a Pamfuetle oxisol, Cameroon (Andic Acrorthox).

cm		Al_o (%)	pH(NaF)	P retn. (%)	BD (g/cc)
0-10	A11	1.7	10.4	97	0.7
10-26	A12	2.2	10.5	96	0.7
26-40	2B1	0.8	9.8	91	0.8
40-81	2B2	0.8	9.6	91	0.8

Table 6 shows data for a podzolised glacial till which contains allophane and demonstrates that there are other soils which have Andic properties in some horizons although they do not usually meet the thickness requirements for Andisols.

Fig. 2 Relationship between acid-oxalate Al and bulk density for New Zealand soils containing volcanic ash.

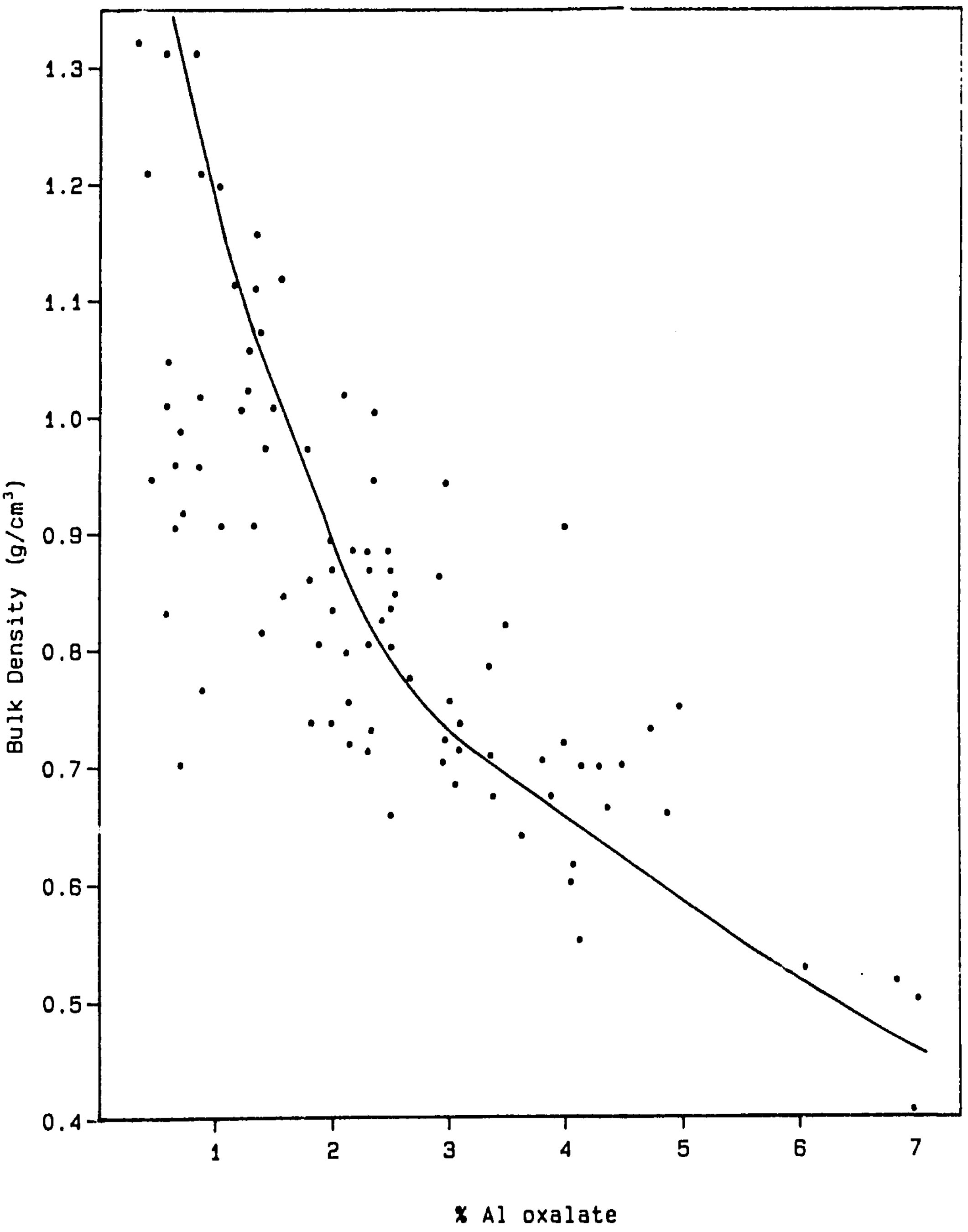


Table 6. Some data for a Te Anau Inceptisol on glacial till, New Zealand (Andic Haplumbrept).

cm		Al_o (%)	Al_p (%)	pH (NaF)	P retn. (%)	BD (g/cc)
0- 9	A	1.0	0.7	9.8	71	<0.9
9-18	BA	1.4	1.1	10.9	90	<0.9
18-30	Bh	2.7	1.3	11.4	98	<0.9
30-41	Bhs	2.9	1.1	11.5	98	<0.9
41-52	Cm	1.0	0.3	11.1	95	

VITRIC MATERIAL

Vitric material is defined on page 228 of Soil Taxonomy (Soil Survey Staff, 1975) as "glass and crystalline particles that are coated with glass and partially devitrified glass." Soils with vitric properties, however, may also contain pumice or pumice-like material or cinders, in addition to glass.

Vitric material can be measured in a field office with a polarizing microscope, whereas pumice, pumice-like material, and cinders can be estimated in the field. In order to simplify the process of identifying vitric properties it is suggested that the soil should be examined, on one hand, for cinders, pumice and pumice-like material or, on the other hand, the sand fraction (0.05-2 mm) should be examined for glass or vitric material.

Volcanic ashes can have compositions which are rhyolitic, dacitic, andesitic, or basaltic, and the glass also varies with ash composition (Kobayashi, et al., 1976).

Rhyolitic ash contains both glass shards and glass selvedges which occur on pyroxenes, amphiboles, and feldspars. The glass in rhyolitic ash does not hydrate readily and can persist for many thousands of years (Kirkman and McHardy, 1980). The glass can be easily identified and grain counts can be obtained using a polarizing microscope.

Andesitic ash contains glass which appears as a matrix which usually contains microlites of feldspars. Glass is also present as selvedges on pyroxenes, amphiboles, and feldspars. When the glass selvedges appear to cover most of the surface of a grain, the grain can be counted as glass.

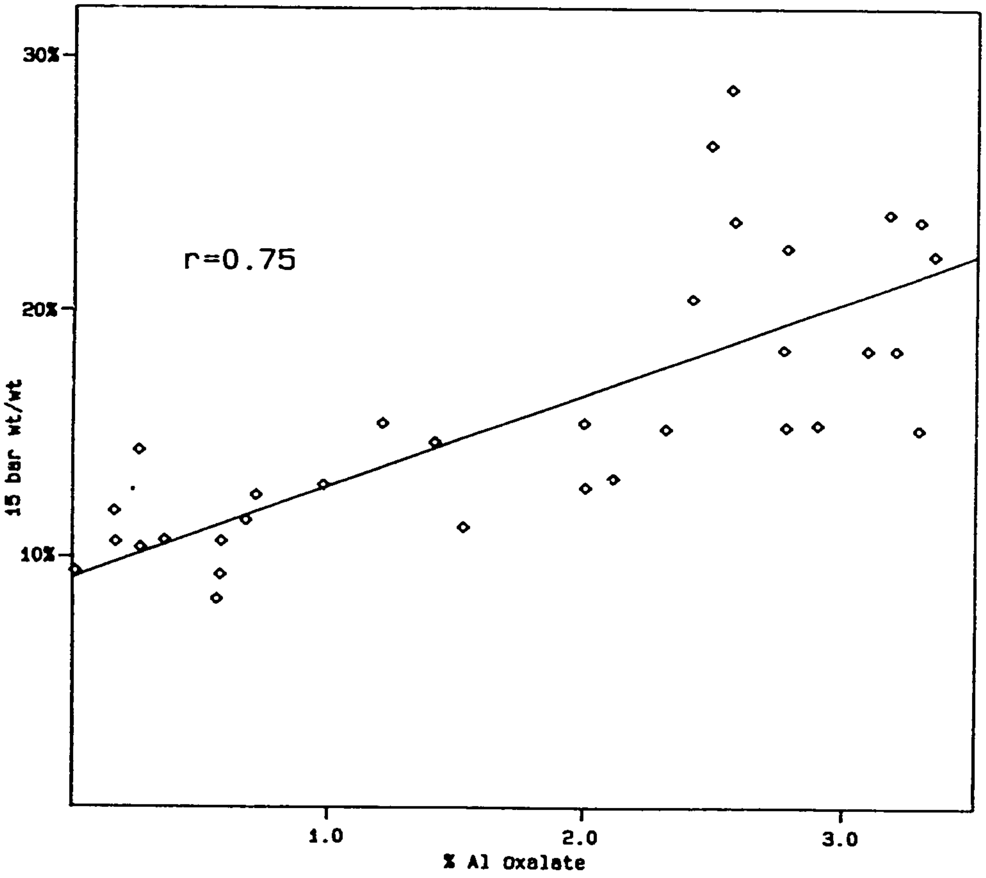


Fig. 3 Relationship between acid-oxalate Al and 15-bar water (gravimetric) for New Zealand volcanic ash soils.

Basaltic ashes may or may not contain glass depending on the type of eruption. Individual grains of basaltic glass are dense and very dark and can be difficult to identify. The glass can also form a matrix in which feldspars are imbedded or it can form as straw-like threads.

Soils with vitric properties show some degree of weathering and in the Andisol proposal the weathering was indicated by reaction with NaF (pH > 9.2). This reaction indicates the presence of Al-humus complexes, allophane, imogolite, and possibly ferrihydrite. For the reasons discussed above, the acid-oxalate reaction is preferred to the NaF reaction and the value of 0.4% acid-oxalate Al is used as a boundary between Andisols and Entisols. This value represents 1-2% allophane (or equivalent Al-humus) in the <2 mm soil.

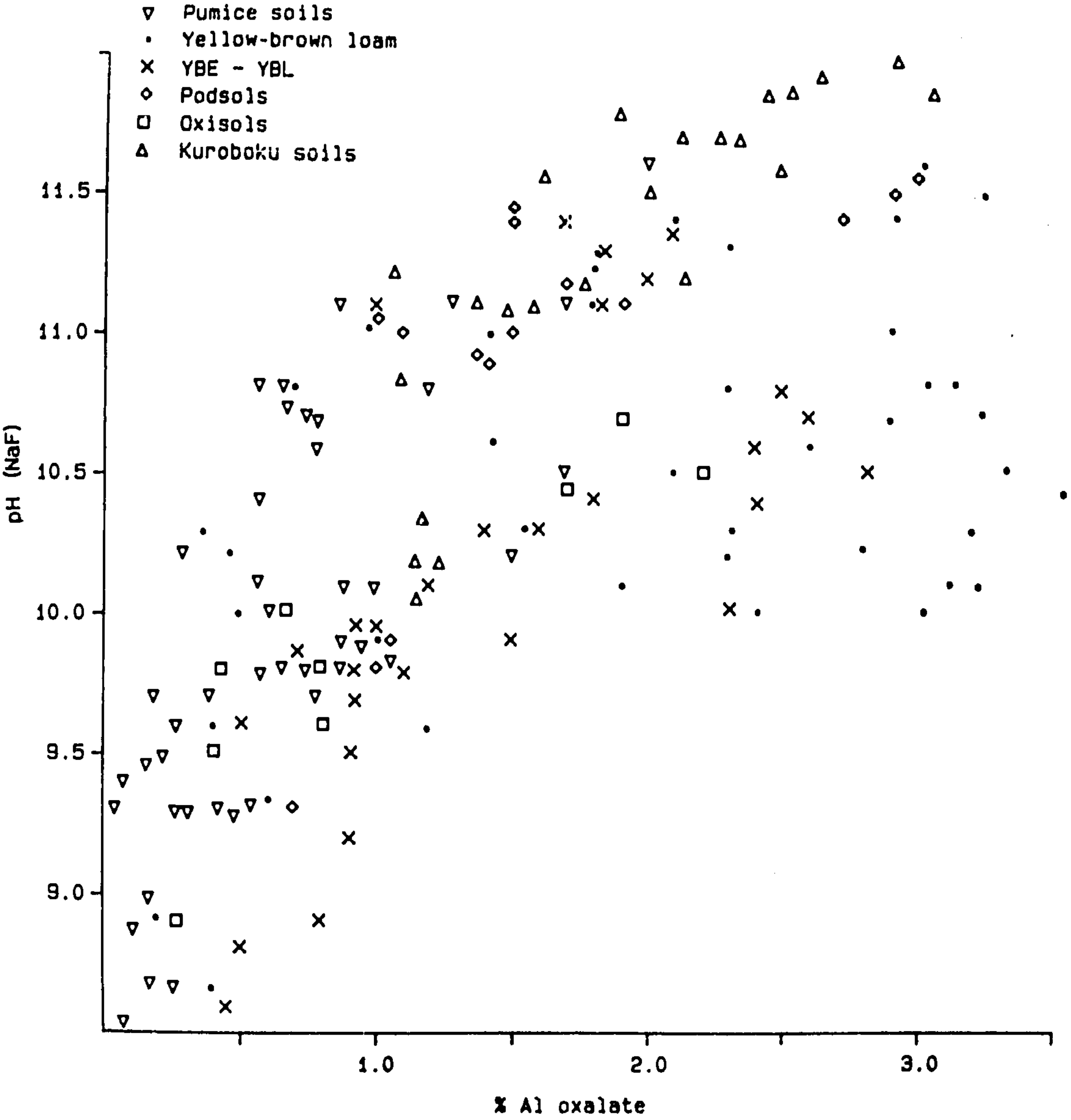
Central concept of soil with vitric properties

The analysis of an Andisol developed on rhyolitic tephra (2,000 y B.P.) in New Zealand is used to illustrate the central concept of a soil with vitric properties (Table 7). These soils have a glassy matrix and have weathered to give about 3% allophane and Al-humus complexes. P retention values are medium to low and pH (NaF) values are usually > 9.5.

Table 7. Some data for a Taupo soil, New Zealand (Vitrudand).

	cm	Al_o (%)	Al_p (%)	pH(NaF)	P retn. (%)	Glass (%)	C (%)
Ap	0- 12	0.6	0.5	10.6	58	>70	4.2
BW	12- 25	1.3	0.4	11.1	76	>70	1.8
C1	25- 70	0.6	0.1	10.4	37	>70	0.4
C2	70-130	0.2	0.02	9.4	15	>90	0.2

Fig. 4 Relationship between acid-oxalate Al and pH(NaF) for Andisols and intergrades to Spodosols, Oxisols and Entisols



LITERATURE CITED

Anderson, H. A., M. L. Berrow, V. C Farmer, A. Hepburn, J. D. Russell, and A. D. Walker. 1982. A reassessment of podzol formation processes. J. Soil Sci. 33:125-136.

Blakemore, L. C. 1983. An evaluation of KOH-Al extraction for New Zealand soils and comparison with acid oxalate extractable Al. Soil Taxonomy News. 6:12-13.

Childs, C. W., R. L. Parfitt, and R. Lee. 1983. Movement of aluminium as an inorganic complex in some podzolised soils, New Zealand. Geoderma 29:139-155.

Farmer, V. C., J. D. Russell, and B. F. L. Smith. 1983. Extraction of inorganic forms of translocated Al, Fe, and Si from a podzol Bs horizon. J. Soil Sci. 34(3):571-576.

Fieldes, M., and K. W. Perrott. 1966. The nature of allophane in soils. 3. Rapid field and laboratory test for allophane. N. Z. J. Sci. 9:623-629.

Higashi, T., and H. Ikeda. 1974. Dissolution of allophane by acid oxalate solution. Clay Sci. 4:205-211.

Higashi, T., and A. Shinagawa. 1981. Comparison of sodium hydroxide-tetraborate and sodium pyrophosphate as extractants of Al/Fe-humus "complexes" in Dystrandepts, Japan. Geoderma 25:285-292.

Kawaguchi, K., and Y. Matsuo. 1955. Semi-quantitative test for active alumina in soils by KF reaction: KF-treatment-phenophthalein test paper. Bull. Res. Inst. Food Sci. Kyoto Univ. 16:8-13.

Kimble, J., and G. Holmgren. 1981. New field procedure. Soil Taxonomy News 1:11-12.

Kirkman, J. H., and W. J. McHardy. 1980. A comparative study of the morphology, chemical composition and weathering of rhyolitic and andesitic glass. Clay Min. 15:165-173.

Kobayashi, S., S. Shoji, I. Yamada, and J. Masui. 1976. Chemical and mineralogical studies on volcanic ashes. Soil Sci. Pl. Nutr. 22:7-13.

McKeague, J. A., J. E. Brydon, and N. M. Miles. 1971. Differentiation of forms of extractable iron and aluminium in soils. Soil Sci. Soc. Am. Proc. 35:33-38.

Mizota, C. 1981. Clay mineralogy of seven Dystrandepts developed from basalts in Northland, the French Massif Central and Western Oregon. Soil Sci. Pl. Nutr. 27:511-522.

Parfitt, R. L. 1980. Chemical properties of variable charge soils. p. 167-194 *In* B. K. G. Theng (ed.) Soils with Variable Charge. Soil Sci. Soc. N. Z., Lower Hutt.

Parfitt, R. L., R. J. Furkert, and T. Henmi. 1980. Identification and structure of two types of allophane from volcanic ash soils and tephra. Clays and Clay Min. 28:328-334.

Parfitt, R. L., and T. Henmi. 1982. Comparison of an oxalate-extraction method and an infrared spectroscopic method for determining allophane in soil clays. Soil Sci. Pl. Nutr. 28:183-190.

Parfitt, R. L., M. Russell, and G. E. Orbell. 1983. Weathering sequence of soils from volcanic ash involving allophane and halloysite, New Zealand. Geoderma 29:41-57.

Parfitt, R. L., and T. Webb. 1983. Allophane in some South Island yellow-brown shallow and stony soils and in high country and upland yellow-brown earths. N. Z. J. Sci. 27(1):37-40.

Quantin, P. 1972. Andosols. Cahiers ORSTOM, séries pedologie, 10:273-301.

Russell, J. D. 1979. Infrared spectroscopy of ferrihydrite: evidence for the presence of structural hydroxyl groups. Clay Min. 14:109-113.

Schwertmann, U. 1964. The differentiation of iron oxides in soil by extraction with ammonium oxalate solution. Z. Pflanzenernähr. Düng. Bodenk 105:194-202.

Schwertmann, U., and R. M. Taylor. 1977. Iron oxides. p. 145-180. *In* J. B. Dixon and S. B. Weed (eds.) Minerals in Soil Environments. Soil Sci. Soc. Am., Madison.

Shoji, S., and Y. Fujiwara. 1984. Active Al and Fe in the humus horizons of Andosols from Northeastern Japan : Their forms, properties, and significance in clay weathering. Soil Sci. (In press)

Soil Survey Staff. 1975. Soil Taxonomy. Agric. Handbook No. 436. Soil Conservation Service, U. S. Dept. Agric. U. S. Govt. Printing Office, Washington, D. C.

Tait, J. M., N. Yoshinaga, and B. D. Mitchell. 1978. The occurrence of imogolite in some Scottish soils. Soil Sci. Pl. Nutr. 24:145-151.

Tamm, D. 1934. Uber die Oxalat methode in der Chemischen Bodenanalyse. Medoln St., Skogsförs Anst. 27:1-20.

Van Olphen, H. 1971. Amorphous clay materials. Science 171:91-92.

Wada, K. 1977. Allophane and imogolite. p. 603-638 *In* J. B. Dixon and S. B. Weed (eds.) Minerals in Soil Environments. Soil Sci. Soc. Am., Madison.

Wada, K. 1980. Mineralogical characteristics of Andisols. p. 87-107 *In* B. K. G. Theng (ed.) Soils with Variable Charge. N. Z. Soc. Soil Sci., Lower Hutt.

Wada, K., and T. Higashi. 1976. The categories of aluminum- and iron-humus complexes in Ando soils determined by selective dissolution. J. Soil Sci. 27:357-368.

PHYSICO-CHEMICAL CHARACTERISTICS OF ANDISOLS

Goro Uehara

Andisols occupy a key taxonomic position in soil classification. Their taxonomic importance arises from their unique physico-chemical properties which in turn are related to their unique mineral composition. The unusual physico-chemical properties of Andisols are a consequence of the high specific surface and variable surface charge of the solid phase. The solid phase consists primarily of glass and its weathering products: allophane, imogolite, and proto-imogolite. Because of the porosity and high permeability of glassy volcanic ejecta, organic matter is distributed and accumulated to greater depths in Andisols than in other soils. A combination of organic matter and high specific charge allophane, imogolite, and proto-imogolite impart most of the physico-chemical characteristics to Andisols.

The purpose of this paper is to illustrate the use of double layer theory to explain the physico-chemical behavior of Andisols.

MINERALOGY OF ANDISOLS

It would not be possible to adequately describe the physico-chemical characteristics of Andisols without first giving a brief account of the mineralogy. The two most frequently cited minerals of Andisols are allophane and imogolite. Allophane is a hollow sphere about 35-55 A° in diameter (Wada, 1979). Imogolite is tubular alumino-silicate with a wall thickness of only five atoms. Both minerals have a specific surface of about 1000 M^2/gm. A third constituent of Andisols which is receiving increasing attention (Farmer; 1982, 1983) is proto-imogolite, a precursor of imogolite with even shorter range order than allophane or imogolite.

Layered silicates are also common in Andisols, particularly in Andisols that occur in arid to semi-arid environments. The most common layered silicate is halloysite. Smectite and chorites are also not uncommon. The post-erosional tephra deposits on the Island of Oahu, Hawaii, have been largely transformed to zeolites. The oxides and hydrous oxide of iron and aluminum are also common in the highly weathered Andisols. However, the name Andisol brings to mind a soil dominated by minerals with short-range order sucn as allophane, imogolite, and proto-imogolite. I will refer to soil materials dominated by short-range order allophane, imogolite or proto-imogolite as andic and those dominated by pumice, cinder, or ash as vitric. This paper is primarily designed to describe the physico-chemical features of andic materials.

SURFACE CHEMISTRY OF ANDIC MATERIALS

Andic materials are amphoteric and possess high specific surface. They are net positively charged under acid conditions but become net negatively charged at higher ph's. The pH at which the charge on the surface is net zero is referred to as the isoelectric point or the zero point of charge. The zero point of charge shifts to higher pH as the silica-alumina or silica sesquioxide ratio of the material decreases.

Under conditions of intense leaching, the soil pH tends to migrate to the zero point of charge. Mattson (1932) referred to the tendency of soil pH to follow the isoelectric point as isoelectric weathering.

Since intense leaching and weathering results in (a) loss of silica and accumulation of sesquioxide, (b) shift in the zero point of charge to higher pH, and (c) tendency of soil pH to follow and stay near the zero point of charge, the most highly weathered and leached Andisols tend to have relatively high soil pH.

When reviewed in the context of general experience, the chemical properties of andic soil materials are full of contradictions. Table 1 illustrates an Andisol that shows data which are related in ways familiar to soil scientists: (1) increases in soil pH with increases in base saturation and (2) increases in CEC with increases in soil pH.

These commonly observed relationships are, however, shattered when data from another Andisol is examined. The data presented in Table 2 show trends that differ markedly from those in Table 1. In Table 1, base saturation decreases with increasing pH, and CEC also tends to decrease with increasing pH.

The most peculiar feature of the data in Tables 1 and 2 is that soil pH is about the same in both cases, but the base saturation is about an order of magnitude lower in Table 2. A theory that accounts for this apparent discrepancy must also explain how it is possible for a soil to have a base saturation of 3% at a soil pH of 6.4.

Table 1. Chemical properties of a Haplustand (Eutrandept). Source (SCS staff, 1976)

Depth (cm)	Organic Carbon (%)	Sum of Bases	NH_4OAc CEC	Base Saturation (%)	pH		SiO_2/Al_2O_3 mole ratio	15 Bar water content (%)	Bulk Density gm/cm^3
		----- meq/100 gm -----			H_2O (1:5)	1N KCl (1:5)			
0-50	3.29	27.7	45.8	60	5.4	4.5	6.25	34.9	0.87
50-78	1.97	36.2	50.2	72	5.8	4.8	4.70	39.5	0.85
78-90	0.90	55.2	63.1	87	6.6	5.6	3.18	73.2	0.79
90-133	0.60	62.0	67.6	97	6.7	5.6	2.74	98.9	0.46

Table 2. Chemical properties of a Hydrotropand (Hydrandept). Source (SCS staff, 1976)

Depth (cm)	Organic Carbon (%)	Sum of Bases	Extr. acidity	NH_4OAc CEC	Base Saturation (%)	pH		SiO_2/Al_2O_3 mole ratio	15 bar water content (%)
		------- meq/100 gm --------				H_2O (1:1)	1N KCl (1:1)		
0-40	5.3	4.0	63.6	67.7	6	5.8	5.6	0.90	68.9
40-53	3.06	2.9	65.5	68.4	4	6.1	6.2	0.43	105.6
58-65	3.23	2.8	63.8	66.6	4	6.3	6.4	0.49	123.1
75-80	2.26	1.5	57.6	59.2	3	6.4	6.5	0.38	105.5

THEORY

The electrochemistry of the double layer can be applied to explain the apparent contradictions in trends illustrated in Tables 1 and 2. To apply double layer theory, it is necessary to make two assumptions about andic materials: first that they possess variable surface charge, and second, that H^+ and OH^- are the potential determining ions.

An equation that describes the electrochemistry of such a system can be derived by combining the Gouy-Chapman equation

$$\sigma_o = \frac{(2n\varepsilon kT)^{1/2}}{\pi} \sinh \frac{ze}{kT} \Phi_o \qquad (1)$$

with a Nernst-type equation

$$\Phi_o = \frac{kT}{e} \ln \frac{H^+}{H_o^+} \qquad (2)$$

to obtain

$$\sigma_o = \frac{(2n\varepsilon kT)}{\Pi}^{1/2} \sinh z(1.15)(pHo-pH) \qquad (3)$$

In equations 1, 2, and 3, the symbols represent the following:

σ_o = surface charge density (esu/cm^2)
n = electrolyte concentration (ions/cm^3)
k = Boltzmann constant
T = absolute temperature
z = counter ion valence
e = electron charge (esu)
Φ_o = surface potential (statvolt)
H^+ = Hydrogen ion activity
H_0^+ = Hydrogen ion activity at the zero point of charge
pHo = pH corresponding to the zero point of charge

In order to apply equations 3 to the data in Tables 1 and 2, it is necessary to convert units of esu/cm^2 to the more familiar units of meq/cm^2. This is done by simply multiplying $_o$ by an appropriate constant (K).

$$s_o \text{ (meq/cm}^2) = K \frac{\text{meq/cm}^3}{\text{esu/cm}^2} \text{ (esu/cm}^2)$$

With the above conversion, the cation exchange capacity (CEC) of Tables 1 and 2 relate to equation 3 through the expression

$$CEC = S(K\sigma_0) = Ss_0 \qquad (4)$$

where S is the specific surface of the andic material in cm^2/gm and CEC is in units off meq/gm.

We now have a physico-chemical model to describe the variable charge behavior of andic materials.

THEORY APPLICATION

Equation 3 predicts that surface charge density and therefore CEC, increases with salt concentration, temperature, counter ion valence, and pH. Unfortunately, in Table 2 the CEC was determined by the $BaCl_2$- Triethyleneamine method at pH 8.2 and in Table 1 by the ammonium acetate, pH 7 method. On the other hand, the CEC values are high in both cases by any standard. These high CEC values are possible because both materials possess high specific surface. The high specific surface can be surmised from the high 15 bar water contents.

The CEC values obtained by the $BaCl_2$ and NH_4OA_C methods are laboratory artifacts. They not only reflect the high specific surface of the samples, but the high pH and electrolyte concentration employed in the measurement of CEC as well. A more appropriate and better estimate of the true CEC is the value of the sum of bases. In both cases, the sum of bases correspond to the effective CEC. Although effective CEC is defined as the sum of bases plus KCl-extractable aluminum, the aluminum level in both soils can be considered to be negligible in view of the relatively high pH values.

In order to examine the CEC in the field, equation 4 needs to be rewritten as

$$ECEC = Ss_O \qquad (5)$$

where ECEC is the effective CEC or the sum of bases. The ECEC is at least 10 times higher in Table 1 than Table 2 even though the specific surface as indicated by the 15 bar water content appears to be much higher in Table 2. The andic material in Table 2, therefore, possesses a high specific surface and a low ECEC. This enables us to conclude that the surface charge density s_O or σ_O of the soil in Table 2 is low.

The data that signals the low ECEC in Table 2 is the difference in pH measured in 1NKCl and water or ΔpH defined as

$$\Delta pH = pH_{KCl} - pH_{H2O} \qquad (6)$$

Note that with the exception of the surface horizon, all pH's in 1NKCl are higher than the pH measured in water. It is now well known that when pH increases with increasing salt concentration ($pH_{KCl} > pH_{H_2O}$), one can under most situations assume that one is dealing with a net positively charged surface (Mekaru and Uehara, 1972). Fig. 1 graphically illustrates the difference between the soils represented in Table 1 and 2.

The curves in Fig. 1 have been drawn to qualitatively show the effects of pH and electrolyte concentration on surface charge density of the two Andisols. For illustrative purposes, the curves have been drawn so that the set of curves for each soil differ only in the position of the zero point of charge (ZPC). The vertical line drawn at about pH 6 marks the general vicinity of pH values recorded in Tables 1 and 2. Fig. 1, therefore, is a graphical representation of equation 3 for two electrolyte concentrations (1NKCl and natural soil solution) over a range of pH for the two Andisols.

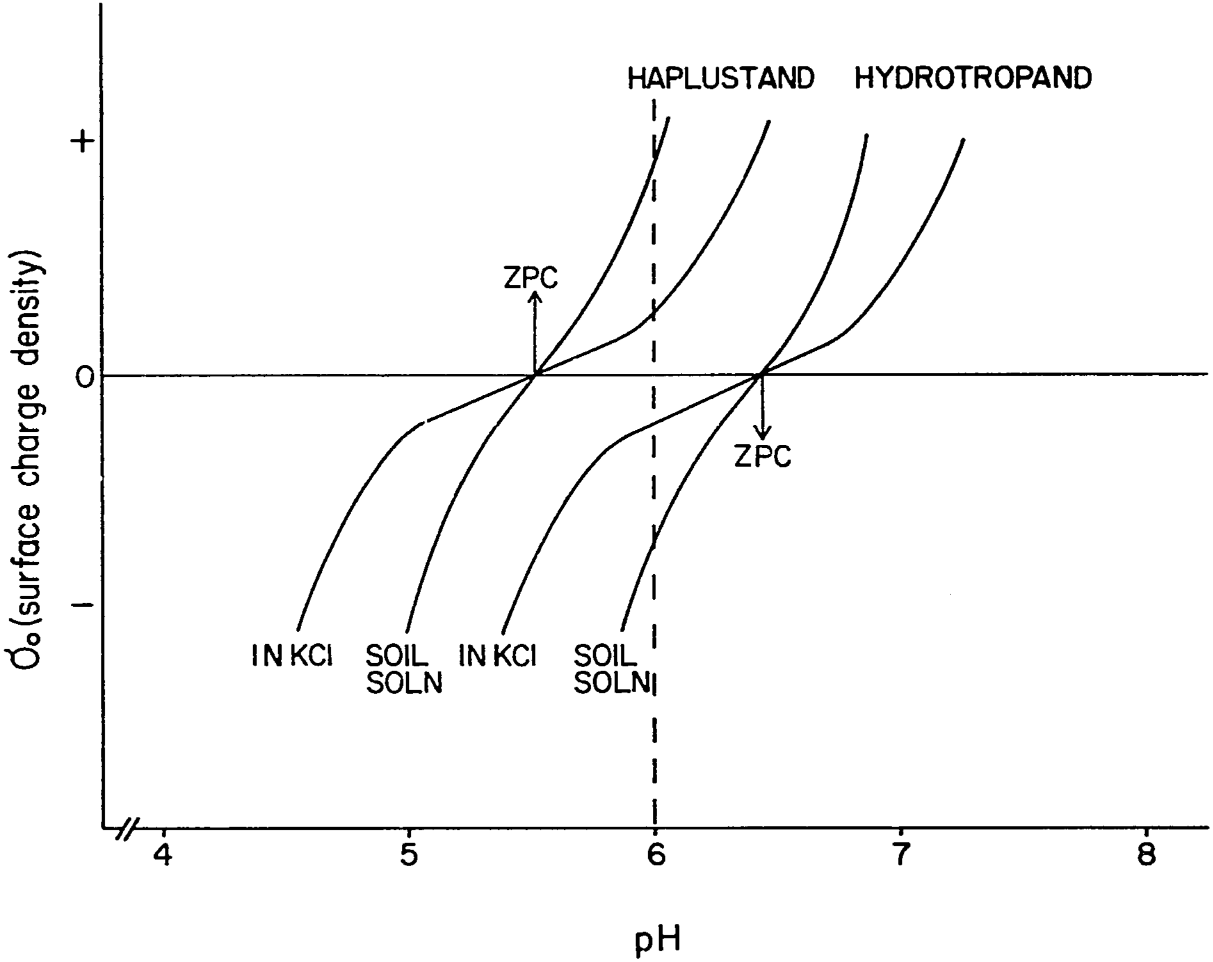
If we now examine equation 3 or its graphical representation in Fig. 1, it becomes clear that at pH values near 6, the Haplustand (Table 1) is net negatively charged, whereas the Hydrotropand (Table 2) is, with the exception of the surface horizon, net positively charged. This means that while the pH in water does not differ greatly between soils, the net charge is negative in one case and positive in the other. Equation 3 and Fig. 1 clearly illustrate how two soils with identical pH's can have different signs and magnitude of surface charge.

When the zero point of charge (pHo) is lower than soil pH, pH is negative, soil pH is depressed by addition of electrolyte, and the surface charge is net negative. This is the case for the Haplustand (Table 1). In the Hydrotropand, the zero point of charge is above the prevailing soil pH, pH is positive, soil pH is raised by addition of electrolyte, and the surface charge is net positive. The physico-chemical properties of the Haplustand and Hydrotropand are determined by the position of the zero point of charge.

The position of the zero point of charge is most likely 4 or less in the Haplustand and greater than 6 in the Hydrotropand. The zero points of charge are in turn inversely related to the SiO_2/Al_2O_3 mole ratio, i.e. the lower the ratio, the higher the zero point of charge. Pure silica has a low zero point of charge (~2.0), whereas pure alumina or corundum has a high (~9.0) zero point of charge.

In equation 3, pHo or the zero point of charge increases as organic matter and SiO_2 content of the clay fraction decreases. Organic matter is another soil constituent that has a low zero point of charge and therefore tends to keep soils in the acid range.

Fig. 1. Effect of pH and electrolyte concentration on surface charge density of two Andisols



Under conditions of strong leaching, the equilibrium soil pH tends to migrate to the zero point of charge. In equation 2, this means that $H^+ = H_o^+$ and therefore the surface potential ϕ_0 is zero. In equation 3, this means that σ_0 is zero.

The Haplustand (Table 1) is a base-rich soil. It has a high pH which is at least 2 pH units higher than the zero point of charge. Leaching such a soil will remove bases and lower pH. Because the zero point of charge is on the acid side of prevailing soil pH, leaching with water will shift the equilibrium pH to lower values.

If, on the other hand, the Hydrotropand (Table 2) is similarly leached, soil pH will tend to rise because the zero point of charge is on the alkaline side of prevailing soil pH. The tendency of soil pH to migrate to the zero point charge is synonymous with Mattson's (1932) isoelectric weathering.

It is useful to note that in equation 3 $pH_o < pH$ in the Haplustand and $pH_o > pH$ in the Hydrotropand. When $pH_o < pH$, the surface charge is negative and σ_0 is negative, making the soil a cation exchanger. However, when $pH_o > pH$, σ_0 and the surface charge is positive and the soil is an anion exchanger. The Haplustand is a cation exchanger at pH 6 and the Hydrotropand is an anion exchanger at the same pH.

Note also that even though the Hydrotropand is an anion exchanger, a measurable quantity of bases (~3 meq/100 g) can still be detected. This simply means that negative charges exist and therefore bases can be adsorbed on net positively charged surfaces.

This immediately raises the question of the validity of equation 4, which assumes that CEC is the product of specific surface and net surface charge density. Equation 4 is largely correct when the CEC of a soil is large and the magnitude of the positive charge is negligible. This is the case with the Haplustand.

In the Hydrotropand the net charge is very close to zero. In this situation, the net charge may be near zero but the magnitude of the negative and positive charge can comparatively be large. In fact, the magnitude of the positive and negative charges increases with electrolyte concentration. At the zero point of charge, for example, net charge remains zero but the absolute magnitude of the negative and positive charge increases with increasing salt concentration. This means that even when a soil material is net positively charged, the ECEC can be greatly increased by simply increasing electrolyte concentration. It is therefore not proper to define the ECEC as a product of specific surface and net negative surface charge density. ECEC should be defined as the product of the specific surface and the absolute negative surface charge density.

NaF TEST

One of the simplest diagnostic tests for andic materials is the NaF test. The test calls for a measure of pH in 1NNaF (SCS Staff, 1972). Andic materials generally produce higher pH in NaF than other soils and a critical NaF pH of 9.4 has been tentatively recommended to separate andic from non-andic materials. In general, andic materials with high base saturation and high SiO_2/Al_2O_3 mole ratios tend to have lower NaF pH. For this reason, the NaF pH tends to be higher in the Hydrotropands than in Haplustands as shown in Tables 3 and 4.

PHOSPHATE RETENTION

As a rule, andic materials adsorb large amounts of phosphorus from solution. Ligand exchange between fluoride and phosphate ions with surface hydroxyls increases with decreasing SiO_2/Al_2O_3 mole ratios. For this reason Hydrotropands with low SiO_2/Al_2O_3 mole ratios tend to have higher phosphate retention values and give higher NaF pH than Haplustands with high base saturation, low zero points of charge and high SiO_2/Al_2O_3 mole ratios. In fact, andic materials with very high SiO_2/Al_2O_3 mole ratio, high water pH and high base saturation frequently do not adsorb phosphorus in large amounts as shown in Table 3. The phosphate retention test for andic material excludes many of those materials with high SiO_2/Al_2O_3, and high base saturation.

VARIABLE CHARGE FRACTION

Since the surface charge on andic materials is predominantly variable and pH dependent, Blakemore (1978) recommended that andic materials by definition must possess a variable charge fraction greater than 0.7. This requirement is defined as

$$\frac{CEC_{pH=8.2} - \Sigma Base + KCl \text{ extractable } Al}{CEC_{pH=8.2}} > 0.7 \qquad (7)$$

In the above expression, the CCEC measured at pH 8.2 by the $BaCl_2$ - triethanolamine method represents total charge and the sum of bases plus KCl-extractable aluminum is supposed to represent permanent charge. The numerator by definition is intended to give the magnitude of the variable charge. Unfortunately, the sum of bases and extractable aluminum is not

Table 3. pH, phosphate retention and bulk density of a Haplustand (Recel, 1980).

Depth (cm)	pH			Phosphate Retention (%)	Bulk Density gm/cm^3	15 Bar water content (%)
	H_2O	1NKCl	NaF			
	5.4	4.7	9.3	58	--	37.7
	6.1	5.2	9.6	75	0.66	52.4
	6.2	5.3	9.7	62	0.84	48.9
	6.2	5.3	9.8	60	0.77	40.2

Table 4. pH, phosphate retention and bulk density of a Hydrotropand (Recel, 1980).

Depth (cm)	pH			Phosphate Retention (%)	Bulk Density gm/cm^3	15 Bar water content (%)
	H_2O	1NKCl	NaF			
0-17	4.9	4.7	9.7	90	0.85	51.8
17-39	5.4	4.9	8.7	97	0.49	126.7
39-65	6.0	5.6	10.5	99	0.37	189.0
65-70	6.2	5.8	10.8	99	0.35	176.0
70-85	6.3	5.7	10.7	99	0.34	190.9
85-110	6.1	5.8	10.7	99	0.32	194.5
110-125	6.3	6.0	10.2	99	0.33	183.0

a measure of permanent charge and therefore equation 7 does not achieve the intended purpose of assessing the variable charge fraction of andic materials. It is recommended that this requirement be dropped from the definition of andic materials.

BULK DENSITY

Low bulk density is a reflection of the high specific surface of andic materials. A high specific surface is a necessary but not sufficient condition for low bulk density. The bulk density of a high specific surface material can be increased by imposing high pressures at the optimum moisture content for compaction. As a rule, however, bulk density generally is inversely related to specific surface. In andic materials specific surface is roughly correlated to the water content retained at the 15 bar water tension as shown in Tables 3 and 4.

CONCLUSION

The physico-chemical properties of Andisols are primarily determined by their high content of materials with short-range order. These materials consist of volcanic glass and the weathering products of glass. Materials dominated by glass are called vitric and those dominated by the weathering products of glass are called andic.

Andic materials can be distinguished from non-andic weathering products by their high pH in NaF solution, high phosphate retention and low bulk density. These characteristics are accessory features of a material with short-range order, high specific surface, and high surface density of hydroxyls associated with aluminum.

In andic materials with high S_1O_2/Al_2O_3 mole ratios, the surface density of hydroxyls associated with aluminum decreases and the NaF and phosphate retention tests fail. The test also fails when andic materials are diluted with large quantities of vitric materials.

LITERATURE CITED

Blakemore, L. C. 1978. Exchange complex dominated by amorphous material (ECDAM). Attachment to "A preliminary proposal for reclassification of Andepts and some andic subgroups" submitted by Guy D. Smith. Soils Bureau, Department of Scientific and Industrial Research, Private Bag, Lower Hutt, New Zealand.

Farmer, V. C. 1983. Proto-imogolite around the world: Part I. New Zealand Soil News. 31:66-69.

Farmer, V. C. 1983. Proto-imogolite around the world: Part II. New Zealand Soil News. 31:98-104.

Mattson, S. 1932. The laws of soil colloidal behavior: IX. Amphoteric reactions and isoelectric weathering. Soil Sci. 34:209-240.

Mekaru, T., and G. Uehara. 1972. Anion adsorption in ferruginous tropical soils. Soil Sci. Soc. Am. Proc. 36:296-300.

Wada, K. 1979. Structural formulas of allophane. pp. 537-545. *In* M. M. Mortland and V. C. Farmer (eds.) International Clay Conference. Elsevier, Amsterdam.

PROPERTIES OF ANDISOLS CRITICAL TO VARIOUS LAND USES

PROPERTIES OF ANDISOLS IMPORTANT TO FORESTRY

R. T. Meurisse

ABSTRACT

Properties of Andisols affecting forest site productivity, species composition, regeneration, response to fertilizers, nutrient leaching and erosion are described. Important properties vary, depending on the ecosystem. Physical properties such as high plant available water, low bulk density, and low thermal conductivity affect distribution of plant associations and site productivity. These are particularly important on medial to cindery, frigid and cryic Andisols. When compared with non-Andisols in similar environments, Andisols nearly always have higher productivity potential and it ranges from about 1.8 to more than 15 m^3/ha/yr in North America.

Generally, forest productivity potential increases with increasing organic matter, total nitrogen and available phosphorus contents. Nitrogen levels as high as 38,000 kg/ha occur in a coastal Andisol ecosystem, but are very low on some cindery Andisols. Andisols generally have a high ability to retain nutrients, even when vegetation is removed by wildfire or management.

Surface erosion potential generally is low, but can be increased by increasing water repellency with fire.

INTRODUCTION

In this discussion, the term "Andisols" includes soils developed from a variety of volcanic materials, including recent pyroclastics with little soil development. The term is inclusive with properties in the range described by Ohmassa (1965), Wright (1965), and Flach, et al., (1980).

Although extensive land area is managed for forestry and related resources, little attention has been focused on properties of Andisols important to forest management. Specific data are lacking in some forest ecosystems and are scarce and fragmented in others. In much of the literature, it is difficult to determine whether the soils are truly Andisols or only closely related.

Environments in which forested Andisols are developing are diverse and result in diverse forest ecosystems. Similarly, the nature and properties of the soils vary among the ecosystems. For these reasons, properties important to the practice of forestry vary depending upon the ecosystem. In the temperate regions of North America, four distinct forested ecosystems, dominated by Andisols, are easily recognized. Three of these ecosystems have relatively homogeneous soils, but are distinctly different from each other. The fourth, the Cascades region, is heterogeneous and includes soils with properties encompassing the other three but is lacking specific data. They are all in the Pacific Northwest of the U.S.A. and southeastern British Columbia, Canada. Three North American Andisol ecosystems are described in terms of their geography, dominant climax tree cover, and dominant family mineralogical and temperature classes (Table 1). They are: (1) Coastal, western hemlock (*Tsuga heterophylla)* [Raf] Sarg.) / Sitka spruce (*Picea sitchensis* [Bong] Carr.), medial, iso-mesic ecosystem; (2) interior, grand fir (*Abies grandis* [Dougl.] Lindl.)/lodgepole pine (*Pinus contorta* Dougl.), medial and ashy, frigid ecosystem; and (3) interior, lodgepole pine/ponderosa pine (*Pinus ponderosa* Laws.), cryic, cindery ecosystem.

PROPERTIES IMPORTANT TO SITE PRODUCTIVITY, REGENERATION, AND SPECIES COMPOSITION

Evaluation of forest site productivity or forest site quality has been the subject of many studies (Carmean, 1975). Generally, attributes of soil profiles that reflect the status of soil moisture, nutrients and aeration have been given the most attention. Properties that describe quantity and quality of tree root growing space are useful for determining differences in site quality. Quantity of growing space is best reflected by soil depth or effective soil depth above root-restricting layers. Quality of soil media for tree growth frequently has been estimated from such properties as texture, internal drainage or organic matter content.

Physical properties and characteristics

Of the soil physical properties and characteristics, plant available water, bulk density and, for pumiceous soils, thermal properties appear to be most important.

Plant available water. Plant available water generally is considered to be the most limiting factor affecting forest growth. Several authors have reported on the water storage

Table 1. Some generalized, representative characteristics of three Andisol ecosystems in the Pacific Northwest, U.S.A. [from: Meurisse, (1972), Geist and Strickler (1978), Dyrness, (1960), and Carlson, (1979)]

Ecosystem	Mean annual precipitation (mm)	Depth (cm)	Organic matter	Total Nitrogen	Available P (ppm)	Exch. Bases me/100g	Texture	Moisture Stress (KPa) (% by weight)	
			%					10	1500
Coastal, western hemlock/Sitka spruce medial, iso-mesic	2030-3050	0-18	17	.5	5	2.7	Sil	45	28
		18-51	15	.4	3	2.8	Cl	45	29
Interior, lodgepole pine/grand fir medial, frigid	500-1250	0-15	4	.10	63	4.5	Sil	65	21
		15-30	2	.06	36	3.0	Sil	—	—
		30-60	1	.04	22	2.7	Sil	65	22
Interior, lodgepole pine/ponderosa pine cindery, cryic	380-1525	0-15	6	.13	14	3.3	CoSl	57	9
		15-30	1	.03	6	4.2	LCoS	—	—
		30-60	0.2	.01	4	2.4	CoS	70	4

potential of Andisols (Dyrness, 1960; Geist and Strickler, 1978; and Gradwell, 1976). Geist and Strickler (1978) compared forested soils from ash and basalt in northeastern Oregon, U.S.A. (Table 2). At 10 KPa tension, ash soils averaged 10% more water by volume than basalt soils. At 1500 KPa, basalt soils held about 4% more water by volume than ash soils.

Table 2. Mean moisture content by volume at 3 moisture stress levels for ash and basalt derived soils in northeastern Oregon, U.S.A. (from Geist and Strickler, 1978).

Sampling Interval (cm)	No. Samples	Moisture Stress Level		
		10 KPa	100 KPa	1500 KPa
		- - - - - - -% by volume- - - - - - -		
Ash soils				
0-15	35	44.7	18.6	14.2
15-30	35	44.5	17.5	12.7
30-60	33	43.8	19.0	13.4
60-90	21	39.2	26.4	20.2
Basalt soils				
0-15	22	35.6	23.6	18.5
15-30	17	33.6	22.2	16.9
30-60	7	40.3	30.3	25.1

Dyrness (1960) reported similar values for gravelly sandy loam and loamy sand pumice soils under ponderosa pine in central Oregon, U.S.A. Values averaged about 30-45% by volume at 10 KPa and 2 to 12% at 1500 KPa tension (Table 3). Water content in the field on May 11 was slightly higher than at 10 KPa for most horizons. Dyrness (1960) concluded that the range in available moisture is much greater than that in the surface layer of a loam soil. Furthermore, large proportions of the total soil moisture are in a readily available form between 10 and 100 KPa tension.

Geist and Strickler (1978) evaluated the potential water storage of soil profiles to a depth of 90 cm by grouping data according to timber type. Ponderosa pine averaged a little more than 6 cm. It was the lowest potential storage of four groups. Soils in this group are from basalt. The other three groups (mixed conifer, lodgepole pine, and spruce-fir) are from volcanic ash of varying depths and average about 15 to 23 cm potential water storage in the 10 to 1500 KPa range. This compared with 58 cm of water, by volume, in a ponderosa pine, cindery ecosystem site (Dyrness, 1960).

Table 3. Soil moisture constants by field sampling on May 11 and pressure membrane extraction at two different tensions in a cindery Andisol (from Dyrness, 1960).

Plant Association	Horizon	Approximate Field Capacity (May 11)	Extraction Tension 10 KPa	1500 KPa
		------------ % by volume	-----------	
Pinus/Purshia	A_1	37	32	12
Plot A	AC	34	40	6
	C_1	43	36	3
Pinus/Purshia	A_1	47	43	7
Plot B	AC	42	46	6
	C_1	39	35	2

Bulk density. Soil bulk density has been found to be an important variable for tree growth and regeneration (Steinbrenner and Gessel, 1955; Youngberg, 1959; Van der Weert, 1974; Brown and Loewenstein, 1978; and Wert and Thomas, 1981). Soils having lower bulk densities in either A or B horizons usually provide higher tree growth than those with high bulk densities. The study by Wert and Thomas (1981) in the southern Oregon Coast Range was on Typic Haplumbrepts. Undisturbed bulk densities were .91 g/cc at 5 cm and 1.06 g/cc at 10 cm depths. They found that Douglas-fir (*Pseudotsuga menziessi* [Mirb.] Franco) productivity was decreased by 11.8% when compacted, and that a bulk density of 1.20 g/cc is heavily compacted.

Minore, et al. (1969) studied the effects of soil density on seedling root growth of seven northwestern U.S.A. tree species. Roots of all species were able to penetrate soils with density of 1.32 g/cc. Roots of western red cedar (*Thuja plicata* Donn), western hemlock and sitka spruce did not penetrate soils with density of 1.45 g/cc. No roots penetrated the 1.59 density cores. These three species grow mostly on soils with surface bulk densities of 1.0 g/cc, or less.

Thermal properties. Pumice soils in central Oregon, U.S.A., have been found to exhibit thermal properties important to the distribution of lodgepole and ponderosa pine (Cochran, et al., 1967; Cochran, 1975). Table 4 illustrates some of these properties. Thermal conductivity and heat capacity are similar to peat, and considerably lower than for sand or clay. These properties are attributed to low bulk density and arrangement of the pore space. Because of the low thermal conductivity of pumice material, there is wide temperature variation at the surface, but variation in temperature decreases rapidly with depth. This results in shallow damping depth which causes the pumice soils to remain cold, causing these soils to be very susceptible to frost heaving (Cochran, 1975).

Table 4. Thermal properties of a sand, peat, clay and Lapine AC horizon at a water content of 40 cm^{3}/cm^{3} (from Cochran, et al., 1967).

Material	Thermal Conductivity (mcal sec^{-}cm^{-}O$_{C}$$^{-}$)	Heat Capacity (cal m^{3}-O$_{C}$-)	Diurnal Damping Depth (cm)
AC horizon	1.25	0.55	8.0
Peat	0.70	0.52	6.1
Clay	3.80	0.70	12.2
Sand	5.40	0.70	14.6

The effect of these properties on regeneration and species composition is significant. Some areas are poorly stocked or treeless. These are mostly in basins or flat topography where cold air accumulates. Lodgepole pine is able to compete better than ponderosa pine under these conditions (Cochran, et al., 1967; Cochran, 1975). The result is that abrupt boundaries between lodgepole pine and ponderosa pine are common. Some special management practices can help to ameliorate some of the problems of regenerating these forests.

Plant associations in relation to some physical properties and soil type

Plant associations are a kind of "plant community of definite composition, presenting a uniform physiognomy and growing in uniform habitat conditions" (Daubenmire, 1968). In the two interior ecosystems, soil physical properties discussed above, including effective soil depth, are strongly related to specific plant associations.

Hall (1973) described the plant associations in the Blue Mountains of eastern Oregon and southeastern Washington. Soil parent materials were one of the differentiating criteria. Eight of 17 commercial forest plant associations were on soils with thin or no volcanic ash on the surface and nine were on dominantly ash-derived soils (Vitrandepts). The non-ash soils are mostly ponderosa pine or ponderosa pine mixed with Douglas fir and grand fir.

Associations on the ash soils are dominantly grand fir, Douglas fir and grand fir with western larch (*Larix occidentalis* Nutt.) or lodgepole pine. Productivity averages 2.2m^3/ha/yr for the non-ash associations and 4 m^3/ha/yr for the ash associations (Table 5). This difference probably is due largely to differences in plant-available water as described by Geist and Strickler (1978).

Volland (1982) classified the plant associations in the central Oregon pumice region. Forty-five commercial forest associations, (capable of producing greater than 1.4 m^3/ha/yr) were defined. Eighteen associations were dominated by lodgepole pine, 14 by ponderosa pine and 13 mixed conifer or mountain hemlock (*Tsuga mertensiana* [Bong.] Carr.). Mean productivity values are shown in Table 5. Within each association group, those with pumice thickness, at least 18 cm thick, (Andisols) are the highest in productivity. The least mean difference is in the ponderosa pine group. The lodgepole pine group has the largest number of associations. The number of lodgepole associations reflects the thermal properties described by Cochran, et al. (1967) and Cochran (1975). The lower productivities may reflect lower levels of available moisture in non-pumice soils.

Table 5. Mean and range of productivity potentials of three plant association groups on cindery and medial Andisols and non-Andisols in two different ecosystems.

Association Group	(from Volland, 1982) interior, cindery, cryic			Ecosystems	(from Hall, 1973) interior, medial, frigid		
	x	Range	Assocs.	m^3/ha/yr	x	range	Assocs.
Lodgepole Pine							
Andisols	4	2.4-5.7	9		2.7	2.3-3.2	2
Non-Andisols	2.5	1.4-4.6	9		2.4	-	1
Ponderosa Pine							
Andisols	3.4	1.8-6.4	5		3.4	-	1
Non-Andisols	3	1.6-3.8	9		2.2	1.3-4.1	5
Mixed Conifer							
Andisols	6.6	3.1-11.5	5		4.6	2.0-8.0	6
Non-Andisols	5.2	3.8-7.4	8		3.0	-	1

Chemical and mineralogical properties

Forest site productivity estimates based on chemical and mineralogical properties have been fewer than for physical properties and less conclusive (Carmean, 1975). Nevertheless, some studies have reported definitive relationships for some chemical and mineralogical properties.

Chemical properties. Studies in the Coastal, hemlock/spruce Andisol ecosystem have demonstrated significant relationships between site index of western hemlock and several chemical properties (Meurisse, 1972; Meurisse, 1976). These are among the most productive forest soils in North America. Productivity potentials of western hemlock and Sitka spruce range from about 10 to more than 15 m^3/ha/yr.

Statistically significant linear relationships were found for organic matter content (P=.05), phosphorus content (P=.01) and cation exchange capacity (P=.05). Organic matter and phosphorus were positively correlated (r=.68 and .78) and cation exchange capacity showed a negative relationship (r=-.66). Organic matter contents were high in these soils (Table 1). A horizon values ranged from about 15 to 38% and B horizon values ranged from about 2 to 15%. Average site index values for western hemlock were relatively high for all the soils in this area. They ranged from about 37 to 65 meters at 100 years age. The highest site index values were associated with the highest organic matter contents.

Nitrogen content was not significantly correlated with site index (r=.50) in the Oregon Coast Range soils (Meurisse, 1972, 1976). Total nitrogen within the rooting zone ranged from 2,180 kg/ha to 38,000 kg/ha. However, sites having low site index values contained 7,840 kg/ha and high sites 26,880 kg/ha. It may be that measures of available nitrogen would be more strongly related than total N in these soils.

In contrast to the humid, coastal Andisols, the interior ash and pumice soils have considerably lower organic matter and nitrogen levels, but slightly higher phosphorus contents and extractable bases (Youngberg and Dyrness, 1964; Geist and Strickler, 1978; Brown and Loewenstein, 1978; Carlson, 1979). These lower values may be contributing factors to the generally lower productivity potentials on these soils compared with the Andisols in the Western Cascades and Coastal regions of the U.S.A. Within the ash and pumice soil regions, definitive relationships between nutrient supply and site index, or other measures of productivity have not been clearly established. Perhaps this is because factors affecting moisture availability, including effective soil depth, are more limiting to tree growth than nutrients in those areas.

This does not mean that nutrient supply is unimportant on these soils. Geist (1977) and Youngberg (1975) have shown that these soils respond to fertilization. Also, Ballard (1978), in New Zealand, found that removal of 2.5 to 26 cm of pumice soil resulted in a 2 m reduction in site index of Monterey pine (*Pinus radiata* D. Don) at 20 years. This was attributed to the reduced ability to meet increased nitrogen demands. Similarly, Ballard and Will (1981) found a 12 % reduction in productivity of Monterey pine at 16 years on a pumice soil on which logging waste, thinning debris and litter was removed. Nitrogen may be sufficient to meet increased demands on the raked area after thinning.

Mineralogical properties. Few studies of clay mineralogy have been conducted to evaluate the effects on forest productivity. However, some studies have shown direct relationships between clay content and site index (Carmean, 1975). Chichester, et al. (1969) studies the clay mineralogy of soils from Mazama pumice in central Oregon. They found that the exchange complex of those soils was dominated by amorphous clays with dissolution weight loss greater than 70%. The amount of amorphous material increased with depth and at drier sites. The clay content in those soils was less than 8%. Even though minimally developed, these soils were more productive than non-Andisols (Volland, 1982).

In contrast, medial Andisols of western Oregon, with KOH dissolution weight loss of 41 to 61% in A horizons and 60 to 72% in B horizons, showed a relationship between degree of weathering and site quality of western hemlock (Meurisse, 1972). Site quality was found to increase with decreasing amounts of amorphous minerals and increasing amounts of phyllosilicates. However, productivity of these soils is considerably higher than for the cindery and ashy pumice soils of the interior ecosystems.

PROPERTIES IMPORTANT TO FERTILIZER RESPONSE AND NUTRIENT LEACHING

Fertilizer retention and response

Fertilizers are becoming increasingly important as a silvicultural technique to increase forest productivity, produce seed from seed orchards and establish other vegetation for erosion control on forest lands (Bengston, 1979). Because costs of application are high, properties affecting potential response and ability of soils to retain added fertilizers are important and need to be understood.

Application of nitrogen fertilizer to thinned and unthinned stands of ponderosa pine on pumice soils in Oregon resulted in significant responses (Youngberg, 1975). Combination of thinning and fertilization resulted in a greater response than either one alone. Similar results were obtained for 13 to 14 year old Monterey pine stands in New Zealand (Woolons and Will, 1975). Only applications of nitrogen fertilizer were effective.

Orchardgrass (*Dactylis glomerata* L.), used as an indicator crop on forested ash soils in the greenhouse, responded significantly to applications of nitrogen and sulfur, and nitrogen, phosphorus and sulfur, but not to nitrogen alone (Geist, 1971). Response on the ash soils was considerably greater than for the other soils studied.

Will and Youngberg (1978) found that pumice soils in central Oregon are marginally deficient in sulfur. Sulfur added to a 45 year old ponderosa pine stand, at the rate of 112 kg/ha, gave a small increase in tree growth. When sulfur was added with 224 kg/ha nitrogen, the response was greater. Over a ten-year period, basal area growth was 50% greater than in untreated plots.

Studies of some medial Andisols in the Oregon Coast range have shown some evidence of response to phosphorus (Meurisse, 1972, 1976). A greenhouse bioassay with Monterey pine resulted in significant P or NxP interaction with yield (g/pot). Hielman and Ekuan (1980 a,b) obtained increases in foliar P content and yield of Douglas fir and western hemlock seedlings in the greenhouse with applications of P at 300 kg/ha.

In contrast to results obtained with nitrogen fertilizer in other Pacific Northwest soils, little or no response to urea fertilizer has been found in coastal soils in western hemlock stands (University of Washington, 1979). It is thought one explanation may be that phosphorus is deficient. Since these soils contain high levels of amorphous clays, there is high probability that P would be fixed under field application. Thus, properties affecting P fixation may be very important in these soils.

Nutrient leaching

Leaching of nutrients from forest sites can be important because of the effects on productivity, loss of applied fertilizer, or water quality. Some Andisols may be more susceptible to nutrient losses than others.

Stark and Spitzner (1982) studied the effects of adding selected nutrients to some excessively drained, droughty Andisols in western Montana. These soils are deficient in Ca, Cu, K, Mg, Zn, and total N. Addition of Ca released considerable Mg. Addition of Mg released Ca. More Cu was released than was added.

Ballard (1979) found that when seven fertilizers were applied to a pumice soil in New Zealand at 200 kg/ha (N equiv.) and leached with 5 cm of water per week for 16 weeks, over 90% of the ammonium sulfate, ammonium nitrate and calcium ammonium nitrate applied was lost in ten weeks. All fertilizers also increased the leaching rates of Ca, Mg, and K. In another study, urea N was applied at 220 kg/ha N to a pumice soil, in a 13 year old, thinned stand of Monterey pine (Worsnop and Will, 1980. After three years, no N was lost by leaching and no change occurred in the leaching rate of other nutrients.

Dyck, et al (1981), measured leaching rates following clearfelling and burning in the central volcanic highland of New Zealand. Although monthly mean NO_3-N concentrations for the burning and logged area were increased over the control, the authors concluded that it was not sufficient to threaten soil fertility of those soils.

Grier (1975) studied the effects of wildfire on nutrient distribution and leaching on ashy soils in Washington, U.S.A. Results showed that large nutrient losses occurred during the fire and that mineralized cations then leached rapidly into the soil, where large amounts were maintained.

The results of these studies indicate that coarse textured pumice and ash soils are capable of retaining most added fertilizers or nutrients released from normal management activities and even wildfire. This could be attributed to the vesicular nature of the pores which cause retention of soil solution (Borchardt, et al., 1968; Chichester, et al., 1969).

PROPERTIES IMPORTANT TO EROSION

Erosion from forest lands can affect site productivity and water quality. Warkentin and Maeda (1980) reported that surface erosion from moving water is not a major problem. Helvey and Fowler (1979) found no measurable difference in erosion of ash soils between seeded and unseeded areas in northeastern Oregon on slopes averaging 30% following clearcut logging and tractor piling of slash. However, only 3.2 cm of precipitation was recorded during the measurement period.

John (1978) found that heating to 150-500°C induced water repellency beneath Monterey pine and scrub to extreme levels. In contrast, sand from beneath pasture did not exhibit water repellency. Such increases in repellency could lead to accelerated soil loss if extensive and if slopes are steep.

Andisols are often subject to land slumps or shallow landslides (Warkentin and Maeda, 1980). However, thes authors state that this may be due to the steep slopes on which Andisols commonly occur. Taskey, et al., (1979) studied landscape stability in relationship to clay mineralogy in the Cascades of western Oregon, U.S.A. Behavior and form of amorphous material and halloysite were controlled by availability of water. Soil instability appears to be promoted when these materials remain wet throughout the year. These authors also found a relationship between contrasting materials which resulted in perched water tables. Smectite-rich materials below caused high water content above in the amorphous materials which had less sheer strength.

LITERATURE CITED

Ballard, R. 1978. Effect of slash and soil removal on the productivity of second rotation radiata pine on a pumice soil. New Zealand J. of Forest Sci. 8(2):248-258.

Ballard, R. 1979. Transformation of nitrogen fertilizers and movement of nutrients from the surface of a rhyolitic pumice forest soil. New Zealand J. of Forest Sci. 9(1): 53-67.

Ballard, R., and G. M. Will. 1981. Removal of logging waste, thinning debris, and litter from a *Pinus radiata* pumice soil site. New Zealand J. of Forest Sci. 11(2):152-163.

Bengston, G. W. 1979. Forest fertilization in the United States: Progress and Outlook. J. of Forestry. 78:222-229.

Borchardt, G. A., A. A. Theisen, and M. E. Harward. 1968. Vesicular pores of pumice by mercury intrusion. Soil Sci. Soc. Amer. Proc. 32:735-737.

Brown, H. G., and H. Loewenstein. 1978. Predicting site productivity of mixed conifer stands in northern Idaho from soil and topographic variables. Soil Sci. Soc. Amer. J. 42:962-971.

Carlson, G. 1979. Soil Resource Inventory - Winema National Forest. USDA Forest Service, PNW Region, Portland, Oregon.

Carmean, W. H. 1975. Forest site quality evaluation in the United States. Advances in Agron. 27:209-269.

Chichester, F. W., C. T. Youngberg, and M. E. Harward. 1969. Clay mineralogy of soils formed on Mazama pumice. Soil Sci. Soc. Amer. Proc. 33(1):115-120.

Cochran, P. H. 1975. Soil temperature and natural forest regeneration in south-central Oregon. p. 37-52. *In:* C. T. Youngberg (ed.) Forest Soils and Forest Land Management. 5th North Amer. For. Soils Conf. Colo. State Univ. Ft. Collins, Colo.

Cochran, P. H., L. Boersma, and C. T. Youngberg. 1967. Thermal properties of pumice soil. Soil Sci. Soc. Amer. Proc. 31:454-459.

Daubenmire, R. 1968. Plant communities. A textbook of plant synecology. Harper and Row, New York.

Dyck, W. J., B. D. Webber, and P. G. Barton. 1981. Soil-water nutrient concentrations after clearfelling and burning of *Pinus radiata*. New Zealand J. of Forest Sci. 11(2):128-144.

Dyrness, C. T. 1960. Soil-vegetation relationships within the ponderosa pine type in the central Oregon pumice region. Ph.D. thesis, Corvallis, Oregon State Univ.

Flach, K. W., C. S. Holzhey, F. DeConinck, and R. J. Bartlett. 1980. Genesis and classification of Andepts and Spodosols. pp. 441-426. *In* B. K. G. Theng (ed.) Soils with Variable Charge. New Zealand Soc. of Soil Sci., Dept. Sci. Ind. Res., Lower Hutt.

Geist, J. M. 1971. Orchardgrass responses to fertilization of seven surface soils from the central Blue Mountains of Oregon. USDA For. Serv. Res. Paper, PNW-122.

Geist, J. M. 1977. Nitrogen response relationships of some volcanic ash soils. Soil Sci. Soc. Amer. J. 41(5): 996-1000.

Geist, J. M. and G. S. Strickler. 1978. Physical and chemical properties of some Blue Mountain soils in northeast Oregon. USDA For. Serv. Res. Paper, PNW-236.

Gradwell, M. W. 1976. Available water capacities of some intrazonal soils of New Zealand. New Zealand J. of Agric. Res. 19:69-79.

Grier, C. C. 1975. Wildfire effects on nutrient distribution and leaching in a coniferous ecosystem. Canadian J. of For. Res. 5(4):599-607.

Hall, F. C. 1973. Plant communities of the Blue Mountains in eastern Oregon and southeastern Washington. USDA For. Serv., PNW Region.

Heilman, P. E., and G. Ekuan. 1980a. Effects of phosphorus on growth and mycorrhizal development of Douglas fir in greenhouse pots. Soil Sci. Soc. Amer. J. 44:115-119.

Heilman, P. E., and G. Ekuan. 1980b. Phosphorus response of western hemlock seedlings on Pacific coastal soils from Washington. Soil Sci. Soc. Amer. J. 44:392-395.

Helvey, J. D. and W. B. Fowler. 1979. Grass seeding and soil erosion in a steep, logged area in northeastern Oregon. PNW For. Range Exp. Stn. Res. Note 343.

John, P. H. 1978. Heat-induced water repellency in some New Zealand pumice soils. New Zealand J. of Sci. 21(3): 401-407.

Meurisse, R. T. 1972. Site quality of western hemlock and chemical characteristics of some western Oregon Andic soils. Ph.D. Thesis, Corvallis, Oregon State University.

Meurisse, R. T. 1976. Some chemical and other properties of western hemlock soils in Oregon - their relationship to productivity. *In* W. A. Atkinson and R. J. Zasoski (eds.) Western Hemlock Management. Univ. of Washington.

Minore, D., C. E. Smith, and R. F. Woolard. 1969. Effects of high soil density on seedling root growth of seven northwestern tree species. PNW For. and Range Exp. Stn. Res. Note PNW-112.

Ohmasa, M. 1965. Scope of volcanic ash soils, their extent and distribution. *In* World Soil Resources Report 14. FAO/UNESCO Project.

Stark, N., and C. Spitzner. 1982. Nutrient storage by Andic soils. Soil Sci. 133(1):33-41.

Steinbrenner, E. C., and S. P. Gessel. 1955. Effect of tractor logging on soils and regeneration in the Douglas fir region of southwestern Washington. Soc. of Amer. For. Proc. 1955:77-80.

Taskey, R. D., M. E. Harward, and C. T. Youngberg. 1979. Relationship of clay mineralogy to landscape stability. *In* C. T. Youngberg (ed.) Forest Soils and Forest Land Management, 5th North Amer. For. Soils Conf. Colo. State Univ., Ft. Collins, Colo.

University of Washington. 1979. Regional forest nutrition research project. Biennial Report 1976-78. Inst. of Forest Resources.

Volland, L. A. 1962. Plant associations of the central Oregon pumice zone. USDA For. Serv., PNW Region.

Warkentin, B. P., and T. Maeda. 1980. Physical and mechanical characteristics of Andisols. p. 281-301. *In*: B. K. G. Theng (ed.) Soils with Variable Charge. New Zealand Soc. of Soil Sci. Dept. Sci. Ind. Res., Lower Hutt.

Weert, R. Van der. 1974. Influence of mechanical forest clearing on soil conditions and resulting effects on root growth. Tropical Agriculture 51(2):325-331.

Wert, S., and B. R. Thomas. 1981. Effects of skid roads on diameter, height, and volume growth in Douglas fir. Soil Sci. Soc. Amer. J. 45(3):629-632.

Will, G. M., and C. T. Youngberg, 1978. Sulfur status of some central Oregon pumice soils. Soil Sci. Soc. Amer. J. 42(1):132-134.

Woolon, R. C., and G. M. Will. 1975. Decreasing growth in high production radiata pine stands by nitrogen fertilizers. New Zealand J. of For. 20(2):243-253.

Worsnop, G., and G. M. Will. 1980. Fate of 15N urea fertilizer applied to a recently thinned radiata pine stand on a pumice soil. New Zealand J. of For. Sci. 10(2): 381-394.

Wright, A. C. S. 1965. The "Andisols" or "Humic Alophane" Soils of South America. *In:* World Soil Resources Report 14. FAO/UNESCO Project.

Youngberg, C. T. 1959. The influence of soil conditions following tractor logging on the growth of planted Douglas fir seedlings. Soil Sci. Soc. Amer. Proc. 23:76-78.

Youngberg, C. T. 1975. Effects of fertilization and thinning on the growth of ponderosa pine. Soil Sci. Soc. Amer. Proc. 39(1):137-139.

Youngberg, C. T., and C. T. Dyrness. 1964. Some physical and chemical properties of pumice soils in Oregon. Soil Sci. 97(6):391-399.

MANAGEMENT AND CLASSIFICATION OF ANDISOLS OF COSTA RICA

A. Alvarado and E. Bornemisza

INTRODUCTION

Andepts cover 13.3% of Costa Rica, presenting unique properties. This paper summarizes most of the Costa Rican literature on the genesis, classification, management, fertility, mineralogy, and physics of these soils. Fourteen tables are presented to show the fertility, mineralogical and physical properties; ten more tables include the analyses required for classification of the main shallow and deep Andepts as well as some Andeptic subgroups. The reported properties indicate similarities with other allophanic soils derived from basic ashes in other Latin American countries.

According to estimates made from FAO-UNESCO map for Mexico and Central America (FAO-UNESCO, 1976), Andepts in Costa Rica cover about 719,000 hectares. However, this area is densely populated as it contains many of the capital cities of the provinces.

The most notable physiographic features in Central America are the 100 large and 150 minor alineated volcanoes that range in height from 846 to 4210 m above sea level on the Pacific Coast. The volcanoes' ejecta is mainly distributed on the Pacific side of the mountains by the prevailing trade winds (Martini, 1969).

Holocene volcanism is mainly of andesitic-basaltic nature, especially in Meridional Central America. The Septentrional side, which is believed to be a continuation of the North American Continent, presents a Quaternary to Terciary volcanic activity of rhyolitic nature.

The environmental conditions where Andisols are formed in Costa Rica are summarized in Fig. 1. Important features that affect soil genesis and management are: a) the sorting by size and density of the ash particles by the wind, b) the temperature and moisture gradients on the mountain slope, and c) the changes in vegetation cover. Due to the mentioned features, the lower part of the mountains are Andeptic subgroups of Alfisols, Ultisols and Inceptisols; the middle of the slope

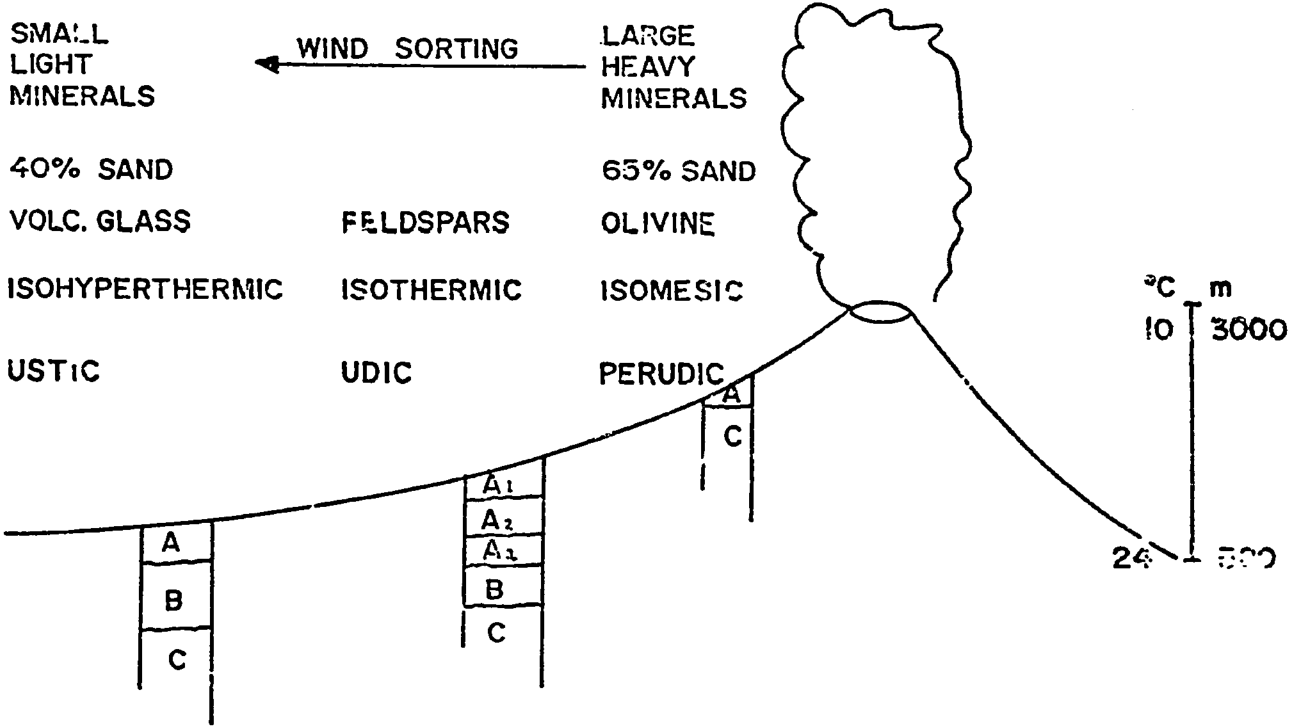


Figure I: Environmental conditions where andisols are formed in Costa Rica.

is mainly covered by Ustands and Udands and the upper portion of the slope by Andents (former Vitrandepts).

MINERALOGICAL PROPERTIES

The mineralogical composition of two volcanic areas of Costa Rica is presented in Table 1; the total analyses of ashes from the same areas is included in Table 2. Even though there are differences in the minerals' distribution, the total chemical composition of the ash is similar as is the initial release of elements (Table 3), exceptions made for Ca, Na, and SiO_4^{-2}. However, in a lapse of 15 years of weathering, Ca and Mg contents decreased to one-half of the original values, but K and Na decreased to one-fourth. These changes also affected the organic matter content which underwent a threefold increase with a net increase in CEC of 23.44 meq/100 g soil (Table 4) as found by Guerrero and Bornemisza (1975) and Chaverri and Alvarado (1979).

The chemical changes mentioned depend on weathering conditions and lead to different types of clays. Colmet-Daage, et al., (1973) described clay mineralogical suites in Costa Rica which have been also investigated by Gonzales, et al., (1972) and Andriesse and Muller (1973). A generalized weathering sequence is primary minerals ----> amorphous gels of Si and Al ----> allophanes ----> metaholloysite ----> halloysite with a last step to gibbsite, kaolinite or montmorillonite, depending on the weathering condition. In general (Fig. 1), the toeslope will be dominated by 2:1 clays, the foot slope by halloysite and (gibbsite-kaolinite), the backslope by allophane-halloysite, and the summit by crystalline primary minerals (Besoain, 1976).

FERTILITY PROPERTIES

Soil fertility analyses for 11 A and B horizons of Andepts from Costa Rica done by Palencia and Martini (1970) are included in Table 5. From this data, it can be observed that the main differences between the topsoil and the subsoil are the decrease with depth of the organic matter content and the nitrogen content, other parameters being almost the same.

Looking for differences between volcanic suites, Alvarado (1975) samples 124 A horizons from the Poás and the Irazú Volcanoes, the former suite being at least 40 years older than the latter (10 years old). Data (Table 6) showed that recent volcanic ash-derived soils contain considerably more

Table 1. Mineralogical composition of recent ashes from the Irazú and Arenal Volcanoes.

Mineral (%)	Irazú Ash	Arenal Ash
Feldespar	70.0	30.0
Pyroxene	16.4	7.0
Olivine	4.9	2.0
Fe-Ti Oxides	4.9	1.0
Vitreous masses	3.2	60.0
Apatite	0.7	0.0

Source: Chaves (1969).

Table 2. Total chemical analyses of recent ashes from the Irazú and Arenal Volcanoes.

Element (%)	Irazú Ash[a]	Arenal Ash[b]
SiO_2	54.9	53.0
Al_2O_3	17.0	17.0
Fe_2O_3	2.7	9.5
FeO	4.6	9.5
MgO	5.5	4.7
CaO	7.8	8.3
Na_2O	3.4	3.8
K_2O	2.1	2.3
H_2O^-	0.14	-
H_2O^+	0.20	-
TiO_2	0.99	1.05
P_2O_5	0.43	0.30
MnO	0.14	0.10

[a] Source: Murata, et al. (1966)

[b] Source: Chaves (1969)

Table 3. Water extractable cations and anions in selected recent ash (time of extraction of 18 hours).

Element (ppm)	Irazú Ash	Arenal Ash
Ca	4.75	10.35
Mg	3.30	3.20
K	3.50	4.00
Na	8.80	5.00
Mn	0.08	0.28
PO_4^{-3}	Tr	Tr
SO_4^{-2}	18.00	24.80
SiO_4^{-4}	1.20	0.80

Source: Bornemisza (1971).

Table 4. Changes with time of the chemical properties of the Irazú ashes.[a]

Property[b]	Years after erupted	
	0	15
pH H_2O	6.10	5.50
pH KCl	5.60	4.60
Ca meq/100 g	2.50	1.40
Mg meq/100 g	0.80	0.40
K meq/100 g	1.60	0.40
Na meq/100 g	0.29	0.10
CEC meq/100 g	5.26	28.70
O.M. %	0.91	2.96
P ppm	6.00	18.00

[a] Source: Chaverri and Alvarado (1979).

[b] Ca, Mg, K, Na and CEC by NH_4OAc pH7; P by modified Olsen.

Na and P, but less organic matter content and Ca content than the older soils.

Table 5. Differences in fertility of A (0-50 cm) and B (50+ cm) horizons of Andepts from Costa Rica.[a]

Variable[b]	A Horizons		B Horizons	
	Range	Average	Range	Average
Clay and Silt %	35.0-98.5	74.2	38.0-96.8	64.8
O.M. %	5.6-35.6	15.7	1.9-10.2	5.4
N %	0.23-1.78	0.6	0.06-0.44	0.2
P ppm	0.2-4.9	1.6	0.1-6.3	1.3
pH H_2O (1:1)	4.6-6.7	5.7	4.7-6.8	6.0
CEC meq/100 g	26.4-88.1	44.4	28.2-58.2	40.7
Ca meq/100 g	0.7-18.0	6.4	0.3-9.7	4.0
Mg meq/100 g	0.2-3.1	1.6	0.1-3.4	1.2
K meq/100 g	0.8-3.6	2.3	0.4-3.0	1.6
Al meq/100 g	0.2-14.0	6.9	0.4-13.1	6.9
B.S.	4-59	25.7	2-49	18.4

[a]Source: Adapted from Palencia and Martini (1970).

[b]CEC, Ca, Mg, and K by NH_4OAc pH7; Al by NH_4OAc pH 4.8; P by Bray 1.

Table 6. Fertility parameters in recent (Irazú) and older (Poás) A horizons of 124 Andepts from Costa Rica.[a]

Variable[b]	Poás Ashes		Irazú Ashes	
	Range	Average	Range	Average
Clay %	4.0-24.6	11.5	3.6-57.0	18.4
Silt %	6.0-44.2	27.3	5.6-49.4	23.7
Sand %	43.0-85.6	61.3	23.0-79.8	57.9
O.C. %	2.4-11.0	6.6	0.0-7.3	3.4
P ppm	6-180	26	6-477	152
pH H_2O (1:2.5)	4.4-5.8	5.1	4.0-5.5	5.0
Ca meq/100 g	1.0-4.8	3.9	0.2-5.1	2.9
Mg meq/100 g	0.7-7.3	2.5	0.3-6.3	2.7
K meq/100 g	0.1-2.9	0.8	1.0-2.1	0.6
Na meq/100 g	0.1-1.4	0.4	0.6-2.1	1.2

[a]Source: Alvarado (1975).

[b]Ca, Mg, K, and Na by NH_4OAc pH7; P by 0.5.M H_2SO_4.

From both studies, it can observed that the range of the properties studied is large, the tendency of the soils being to have a pH of 5.0 to 6.0, high in organic matter and enough bases content, particularly K.

In a greenhouse experiment with 15 soil samples and using the missing element technique, Martini (1970) studied the effect of N, P, K, Ca, Mg, S, minor elements (M.E.) and a complete treatment using tomatoes as an indicator plant. In general for the topsoil the more limiting elements were P>N >Ca>M.E.>S>K>Mg and for the subsoils P>N>M.E.>Ca>Mg>S>K.

Bertsch (1982) studied nine A horizons of Dystrandepts from different areas of Costa Rica in a greenhouse experiment using sorghum as the indicator plant. In this case N, P, K, Mg, Zn, Cu, S, and B were studied and P was by far the more limiting element; K limited yields only in 40% of the cases and in spite of the high retention capacity of S and B (70-91% and 85-96%, respectively) the addition of these elements did not increase the yields.

It was also found (Bertsch, 1982) that KCl-exchangeable Al did not play any role in the fertility of these soils, the amounts of exchangeable Al being very low in these soils (Igue and Fuentes, 1972). In a field experiment, Fassbender and Molina (1972) added up to 11.2 tons Ca O/ha to sugar cane with significant economic effect with the addition of up to 2.8 tn of lime (Table 7). The application of 0-8-16 tons/ha of calcium carbonate on Dystrandepts caused an increase in P leaching (from 0.1 to 3.0%), and increased P availability at the expense of P retained which was reduced by 7 to 8% (Urrutia and Igue, 1972).

Table 7. Effect of liming on sugar cane yield in the Birrisito soil series.[a]

Treatment (ton/ha)		Yield (ton/ha)	
$CaCO_3$	CaO	Cane	Sugar
0.0	0.0	199.2	22.3
3.8	1.4	224.7	24.2
7.6	2.8	243.1	27.1
15.2	5.6	235.4	25.2
30.4	11.2	231.7	25.6

[a] Source: Fassbender and Molina (1965).

Even though Martini (1970) found a response to minor elements in the greenhouse, Bertsch (1982) did not find a response to the application of Fe, Zn, Mn, Cu, or Mo. Field experiments with coffee (Oficina del Café, 1982) have shown the need of B, Mg, and Zn for the crop growing on Andepts; actual coffee fertilizer formulas include N-P-K-B-Mg (20-5-10-5-1.5) but P and K responses are questionable.

Total Zn contents in Andepts from Costa Rica are low, while extractable-Zn contents show a wide variation (Peralta, et al., 1981). The application of Zn to corn affected its growth and foliar content in a greenhouse study (Marihno and Igue, 1972). Field additions of 0 and 43.5 kg Zn/ha to potato did not increase the yield (Chaverri and Bornemisza, 1977).

Table 8. Extractable SO_4-S in profiles of volcanic ash derived soils of Costa Rica.

1963-65 Ash		Umbric Vitrandept		Typic Dystrandept		Oxic Dystrandept	
Depth (cm)	SO_4-S (ppm)	Depth (cm)	SO_4-S (ppm)	Depth (cm)	SO_4-S (ppm)	Depth (cm)	SO_4-S (ppm)
0-13	10	13-35	18	0-30	48	0-38	112
		35-50	0	45-75	20	38-60	258
		50-90	0	80-90	92	90-110	412
		105-120	18	160-180	42	165-180	508

Source: Fox (1974).

Available sulfur content increases with the age of the soil (Table 8) as found by Fox (1974), the organic and inorganic contents remaining almost the same (Table 9), according to Blasco (1972). In spite of soil age, the addition of 60 kg S/ha to sorghum under greenhouse conditions did not increase yields (Pérez and Oelsligle, 1975), other parameters being more limiting to plant growth (Table 10).

Table 10. Response of sorghum to the application of 60 kg S/ha under greenhouse conditions.

Soil No.	Dry Matter (g/pot)		Poliar S (ppm)		Assimilated S (mg/pot)	
	+S	-S	+S	-S	+S	-S
1	19.8	22.3	804	800	15.9	18.4
2	20.2	18.2	608	658	12.3	12.0
3	4.1	4.7	787	512	3.3	2.4
4	8.6	7.0	750	675	6.6	5.2
5	6.7	7.2	825	833	5.6	6.1
6	5.1	4.0	858	904	4.4	3.4
7	19.8	19.7	1366	1241	26.6	26.9

Source: Pérez and Oelsligle (1975).

Table 9. Total -S, organic -S, and inorganic -S in profiles of volcanic ash-derived soils of Costa Rica.

Volcanic Ash-Derived Soils	Depth (cm	Total -S (ppm)	Org -S (%)	Inorg -S (%)
1963-65 Ash	0-10	1452	36.2	63.8
	30-40	1827	21.2	78.8
Typic Dystrandept	0-30	2000	27.9	72.1
	30-60	2012	23.9	76.1
	60-110	2132	22.3	77.7
	110-155	1815	25.3	74.7
	155-190	1768	22.3	77.7
	190-210	1913	27.0	73.0
Oxic Dystrandept	0-25	1617	33.1	66.9
	25-65	1799	37.8	62.2
	65-110	1365	30.1	69.9
	110-135	821	28.0	72.0
	135-170	476	43.5	56.5
	170-210	1443	13.7	86.3

Source: Blasco (1976)

In a study with soils of Costa Rica, Fassbender (1968) found that on the average, Andosols retained 86.4% of the P added, and Latosols and Alluvial soils retained 58.2% and 42.0% respectively. In another study with Costa Rican Andepts 82.4% of the P added was retained, 82.5% as Al-P, 14.4% as Fe-P, 1.6% as Ca-P and 2.9% as NH_4Cl-soluble P (Igue and Fuentes, 1971).

The amounts of P retained by Andepts vary with elevation and moisture regime (Table 11). The lower values are found in the upper parts of the landscape mainly due to the coarser texture (low ECEC) of the soils. The higher P retention values are found at middle elevation where more amorphous materials develop (high O.M). There is also a good correlation of P retention with the NaF-pH, reflecting the influence of amorphous aluminum on both properties (Fig. 2) as found by Alvarado and Buol (1984).

Table 11. Phosphorus retention in Andepts of Costa Rica as a function of moisture regime and elevation.

Moisture Regime and Elevation (masl)	P retained (%)	NaF (pH)	O.M. (%)	ECEC (meq/100g)
Ustic; 1000-1500	69.6	10.1	8.5	8.7
Udic; 1500-2500	80.8	11.2	16.5	3.9
Udic; 2500-3500	51.2	9.1	6.1	2.2

Phosphorus recovery from Andepts is very low. In a greenhouse study Bornemisza and Fassbender (1970) applied 200 ppm of P_2O_5 to a Typic Dystrandept and found that corn plants absorbed only 1.11% of the P from the fertilizer. The use of monocalcium phosphate monohydrate (MCPM), ordinary superphosphate (MCP-S), and dicalcium phosphate anhydrous (DCPA) gave different results in Dystrandepts from Costa Rica. MCPM and MCP-S dissolved more completely than DCPA (Urrutia and Igue, 1972). The size of the fertilizer P granules affect its efficiency; Suárez and Igue (1974) found that the largest granules produced the greatest residual effect on Andepts lasting for two corn crops under greenhouse conditions.

Potato yields are increased by the application of phosphorus (Table 12). The amount of P needed for maximum yields varied from 480 kg P_2O_5/ha in a Typic Dystrandept (Chaverri and Bornemisza, 1977) to 858.5 kg P_2O_5/ha in a Hydric Dystrandept (Palmeri, 1983). The effect of P application on broccoli yield is shown in Table 13.

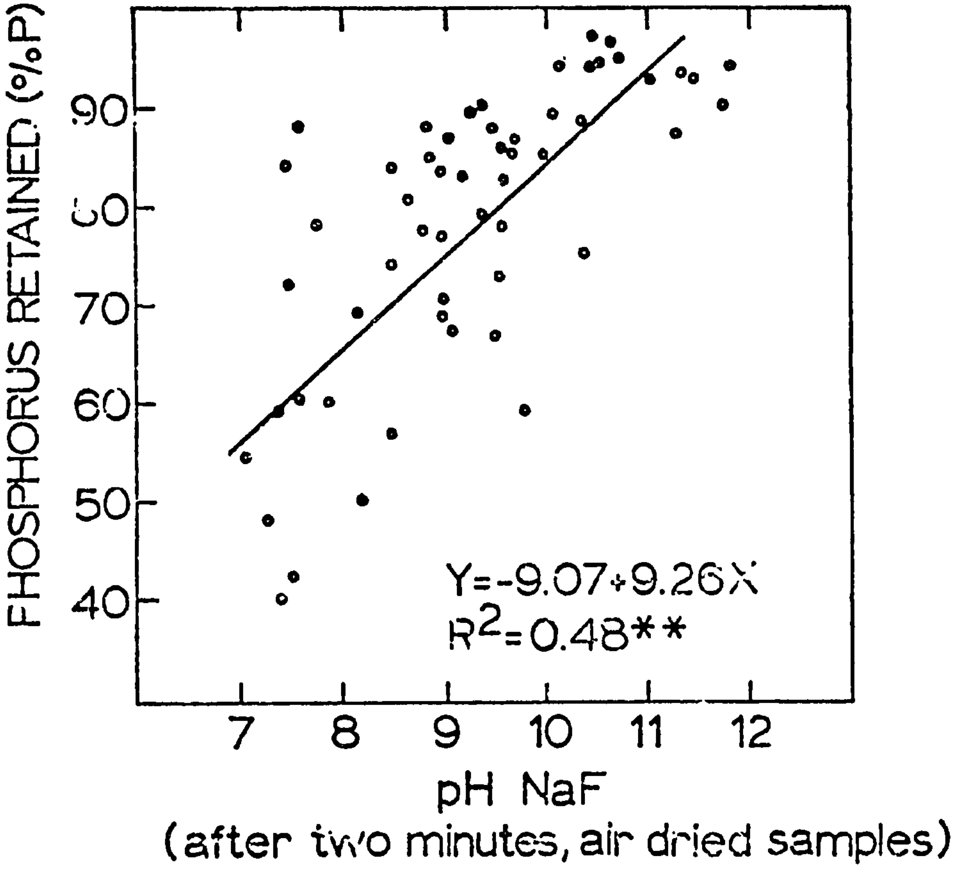


Figure:2: Relationship between P retention and pH in NaF in 59 soil samples from Costa Rica and Guatemala.

Table 12. Effect P application on the yield of potato growing on a Hydric Dystrandept.

Dosis of N (kg/ha)	Dosis of P_2O_5 (kg/ha)					
	0	250	500	750	1000	X
0	17.3	23.1	26.6	27.3	28.6	24.6
150	16.4	23.4	27.5	31.4	34.5	26.2
300	18.1	27.9	32.1	38.5	38.8	31.1
450	17.6	30.5	32.8	37.2	37.6	31.1
X	17.4	26.2	29.8	33.6	34.9	28.4

Source: Palmieri (1983).

Table 13. Effect of N and P application on the yield (ton/ha) of broccoli growing on an Oxic Dystrandept.

Dosis of N (kg/ha)	Dosis of P_2O_5 (kg/ha)				
	0	200	300	400	X
0	12.5	17.8	16.5	20.6	16.8
200	19.7	17.4	20.4	15.8	18.3
300	19.2	27.4	21.5	21.3	22.4
X	17.1	20.9	19.5	19.2	19.2

Source: Perera (1976).

PHYSICAL PROPERTIES

Physical properties of Andepts from Costa Rica are presented in Tables 15 to 24. There are differences in the determination of the bulk density when using the clod technique (dry weight/dry volume) instead of the core technique (dry weight/wet volume); bulk density increases due to dryness of the sample as reported by Forsythe (1972).

Particle density is relatively low (2.1-2.4 g/ml) and soil porosity is normally greater than 50% (Gavande, 1968 and González and Gavande, 1969); potential volume changes are critical (values between 4.0 to 6.0) according to Alvarado and Buol (1975). Workability of Andepts is easier than for other soils of Costa Rica as observed in Table 14.

Table 14. Calculated mechanical power needed for farm operations in some Costa Rican soils.

Mechanical power (HP) needed for:	Andept	Tropept	Ustert
Plowing	30-40	40-45	80-90
Tillage	30-40	50-60	100-110
Seeding	20-30	20-30	50-60
Subsoiling	30-40	45-50	70-80

Source: Molina (1977).

Dispersion of Andepts, particularly of Hydrandepts, is difficult (Forsythe, 1972). The morphology of irreversibly formed aggregates has been described by Andriesse and Muller (1973).

GENESIS AND CLASSIFICATION

There is no summary of the literature on the genesis and classification of Andepts of Costa Rica. The resume of Sáenz (1966) on Andepts from the Central Valley is the last attempt, however more of the literature on these soils has been published afterwards.

For simplicity, the soils developed from or influenced by volcanic ash will be separated in three groups: shallow volcanic ash-derived soils, deep volcanic ash-derived soils, and soils covered by relatively thin layers of volcanic ash.

Shallow volcanic ash-derived soils

Three types of phenomena may reduce the rate of soil development: lava flows (Table 15), high elevation with consequent low temperature values (Table 16), and presence of compacted alluvial beds underlying the recent ash (Table 17).

Soils in the upper positions of the landscape may be Umbric or Typic Vitrandepts, depending on the amount and frequency of the ash being deposited. If the amount of ash is not enough to kill the trees (*Quercus* spp.) usually a Typic Placandept may form. The third group of shallow Andepts is found in the lowlands, where thin layers of volcanic ash may cover colluvial and alluvial materials.

Table 15. Shallow volcanic ash-derived soil over lava flows.

Classification: Umbric Vitrandept (Knox and Maldonado, 1969)

Horizon	A1	B2	II B3	II C
Depth cm	0-30	30-80	80-130	130-140
pH H_2O	5.5	6.1	6.4	
O.M. %	35.2	0.0	0.5	
Exch. Ca meq/100 g	1.0	0.0	0.0	
Exch. Mg meq/100 g	0.7	0.0	0.0	
Exch. K meq/100 g	0.2	0.1	0.1	
CEC	53.8	36.1	22.6	
B.S %	4	0	0	
Sand %	32	Poor	Dispersion	
Clay %	32	Poor	Dispersion	
Silt %	36	Poor	Dispersion	
H_2O at 15 bars %	100	87	43	
Bulk density g/cc	0.6	0.8	n.d.	
Fragments %	30	40	50	70

Table 16. Shallow volcanic ash-derived soil at high elevation.

Classification: Typic Placandept, thixotropic, isomesic (Otárola and Alvarado, 1977).

Horizon	Oi	A2	B2h	2hii	BC	C
Depth cm	-7-0	0-3	3-6	6-8	8-25	25-40
pH H_2O	4.0	4.2	4.3	4.8	5.2	5.2
pH NaF, 2 min.	7.3	8.0	9.3	10.4	11.8	11.7
O.M. %	42.9	16.1	18.8	19.3	9.0	12.7
Exch. Ca meq/100 g	9.2	4.7	2.1	0.8	0.4	0.5
Exch. Ma meq/100 g	1.3	0.8	0.8	1.2	0.5	0.7
Exch. K meq/100 g	0.9	0.4	0.4	0.2	0.1	0.1
CEC meq/100 g	nd	nd	nd	nd	nd	nd
B.S. %	nd	nd	nd	nd	nd	nd
Sand %	7	3	6	13	24	42
Clay %	47	30	31	25	24	20
Silt %	46	67	63	62	52	38
H_2O at 1/3 bar %	193	64	88	107	74	59
Particle density g/cc	1.6	2.0	1.6	2.1	2.1	2.1

Table 17. Shallow volcanic ash-derived soil in the lowlands.

Classification: Lithic Dystrandept, thixotropic, isohyperthermic (Mas, 1980).

Horizon	A11	A12	IIB/R
Depth cm	0-20	20-30	30-52
pH H_2O	5.7	6.0	6.0
O.M. %	9.4	8.6	3.8
Exch. Ca meq/100 g	2.1	2.1	2.2
Exch. Mg meq/100 g	0.5	0.9	1.9
Exch. K meq/100 g	0.1	0.2	0.1
CEC meq/100 g	54.9	41.0	29.2
B.S. %	5	8	14
Sand %	44	55	52
Clay %	10	6	6
Silt %	46	39	42
H_2O at 1/3 bars %	55	56	54
H_2O at 15 bars %	33	40	33

In general, shallow volcanic ash-derived soils are considered as classes VI to VII but some may classify as class IV and are intensively used for vegetable production.

Deep volcanic ash-derived soils

Most of these soils presently classify as Dystrandepts and Hydrandepts. As shown in Fig. 1, some belts can broadly be defined, these soils occupying the lower and medium portions of the landscape. Dystrandepts are by far more abundant than Hydrandepts, since most of the area where these soils occur have a ustic moisture regime.

Tables 18 to 21 show the main characteristics of Typic, Entic, Oxic, and Hydric Dystrandepts, respectively. Out of these subgroups, the Typic and Hydric Dystrandepts are more common, the latter being a transition soil integrading toward the Hydrandepts belt. Table 22 shows properties of a Typic Hydrandept, the main characteristic being the thixotropy through the whole profile.

In general, these soils can be considered as the model concept of Andepts since they are the deep, dark, low bulk density, etc., soils described elsewhere. These soils are grouped in classes III, IV, V, and VI, and are mainly used for coffee, vegetables, and dairy production in Costa Rica.

Intergrades to other soil orders

In many instances, older soils are covered by recent volcanic ash, infringing Andic properties to the previous soil. In Tables 23 and 24 the properties of two very common intergrades to Tropepts and Ustults are included. Similar situations occur with Ustalfs and Humults.

LITERATURE CITED

Alvarado, A. 1975. Fertilidad de algunos Andepts dedicados a potreros en Costa Rica. Turrialba 25(3):265-270.

Alvarado, A. and S. W. Buol. 1975. Toposequence relationships of Dystrandepts in Costa Rica. Soil Sci. Soc. Am. Proc. 39(5):932-937.

Alvarado, A., and S. W. Buol. 1984. Field e imation of phosphorus retention by Andepts. Soil Sci. Soc. Am. J. (In press).

Alvarado, A., N. Glover, and O. Obando. 1982. Reconocimiento de suelos de Puriscal-Salitrales y Tabarcia-San Ignacio de Acosta. pp. 102-118. *In* J. Heuveldop and L. Espinoza. (eds.) El Componente arbóreo en Acosta y Puriscal, Costa Rica. ASCONA/CATIE/GTZ/MAG.

Andriesse, J. P., and A. Muller. 1973. Mineralogical properties of two profiles of volcanic ash soil from Costa Rica. Turrialba. 23:307-317.

Bertsch, F. 1982. Fertilidad de nueve suelos clasificados como Typic Dystrandepts en Costa Rica. Thesis Mg. Sci., Turrialba, Costa Rica, CATIE-UCR.

Besoain, E. 1976. Mineralogía de arcillas de algunos suelos volcánicos de Costa Rica. pp. 249-278. *In* M. Blasco and R. Guerrero. (eds.) II Panel sobre suelos volcánicos de América. Univ. de Nariño-IICA-OEA. Pasto, Colombia.

Blasco, M. 1972. Contenido y metabolism del azufre en suelos volcánicos de Centro América. pp. 107-123. *In* II Panel sobre suelos volcánicos de América. Univ. de Nariño-IICA-OEA, Pasto, Colombia.

Bornemisza, E. 1971. Extraction of anions and cations from recent volcanic ash. Soil Sci. Soc. Am. Proc. 35(3):506-507.

Bornemisza, E. and H. W. Fassbender. 1970. Uptake of fertilizer phosphate from nine soils from the humid tropics. Agrochimica 14 (2-3):260-268.

Chaverri, B. A., and E. Bornemisza. 1977. Interacción fósforo-zinc en el cultivo de la papa (*Solanum tuberosum* L.) en la zona de Pacayas. Agronomía Costarricense. 1:83-92.

Chaverri, D., and A. Alvarado. 1979. Cambios químicos de importancia agrícola sufridos por las cenizas del Volcán Irazú en 15 años. Agronomía Costarricense 3(2):181-182.

Chaves, R. 1969. Características físicas, químicas y mineralógicas de los materiales eruptados por el volcán Arenal (Costa Rica). Inst. Geogr. C. R. Informe Semestral enero-junio. pp. 49-67.

Colmet-Daage, F., F. Maldonado, C. de Kimpe, M. Trichet and G. Fusil. 1973. Caracteristiques de quelques sols derives de cendres volcaniques de la Cordillera Centrale du Costa Rica. Ed. Prov. Office de la Recherche Scientifique et Technique Outre-Mer, Centre des Antilles, Bureau des Sols. Guadalupe.

FAO-UNESCO. 1976. Mapa mundial de suelos; vol. III, México y América Central. París.

Fassbender, H. W., L. Muller, and F. Balerdi. 1963. Estudio del fósforo en suelos de América Central. II Formas y su relación con las plantas. Turrialba 18(4):333-347.

Forsythe, W. M. 1972. Proposed techniques to avoid the effect of air-drying on the water retention of soils derived from volcanic ash. pp. 481-496. *In* II Panel sobre Suelos Volcánicos de América, Univ. de Nariño-IICa-OEA, Pasto, Colombia.

Fox, R. I. 1974. Examples of anion and cation adsorption by soils of tropical America. Tropical Agriculture (Trinidad) 51:200-210.

Gavande, S. A. 1968. Water retention characteristics of some Costa Rican soils. Turrialba 18(1):34-38.

Gonzalez, M. A., and S. A. Gavande. 1969. Propiedades físicas de algunos suelos dedicados al cultivo de la caña de azúcar en Costa Rica. Turrialba 19(2):234-245.

Gonzalez, S. P., K. Igue, and G. Besoain. 1972. Secuencia de meteorización y su relación con las propiedades de carga y superficie de la fracción arcilla de algunos andosoles de Costa Rica. Turrialba 22(4):439-448.

Guerrero, J. I., and E. Bornemisza. 1975. Capacidad de intercambio catiónico en suelos de cenizas volcánicas recientes. Turrialba 25(4):385-391.

Igue, K., and R. Fuentes. 1971. Retención y solubilización de ^{32}P en suelos ácidos de regiones tropicales. Turrialba 21(4):429-434.

Jimenez, J. R. 1979. Particularidades pedogenéticas en cuatro Andepts de Costa Rica. Thesis Ing. Agr., Esc. Fitot., Fac. Agr., Univ. Costa Rica.

Knox, E. G., and F. A. Maldonado. 1969. Suelos de cenizas volcánicas, excursión al volcán Irazú. A-8, pp. 1-12. *In* Panel sobre suelos derivados de cenizas volcánicas de America Latina, Turrialba. FAO/IICA.

Marinho, M. L., and K. Igue. 1972. Factors affecting Zn absorption by corn from volcanic ash soils. Agron. J. 64(1):2-8.

Martini, J. A. 1969. Distribución geográfica y características de los suelos derivados de cenizas volcánicas de Centroamerica. *In* Panel sobre suelos derivados de cenizas volcánicas de América Latina, Turrialba, FAO/IICA.

Martini, J. A. 1970. Caracterización del estado nutricional de los principales Andosoles de Costa Rica, mediante la técnica del elemento faltante en el invernadero. Turrialba 20(1):72-84.

Mas, F. 1980. Proyecto fronterizo Costa Rica-Panamá, Zona de Coto Sur. Clasificación de suelos y evaluación de tierras. San José, Costa Rica.

Molina, R. 1977. Relación entre la mecanización agrícola y algunas propiedades físicas de los suelos de Itiquís y de la Cuenca Baja del Río Tempisque. Thesis Ing. Agr., Esc. Fitot., Fac. Agron., Univ. of Costa Rica.

Murata, K. J., et al. 1966. The 1963-65 eruption of Irazu volcano, Costa Rica. Bull. Volcanologique 29:766-796.

Oficina del Cafe. 1982. Informe anual de labores 1981. Programa Cooperative Oficina del Café-MAG. San José, Costa Rica.

Otarola, C., and A. Alvarado. 1977. Caracterización y clasificación de algunos suelos del Cerro de la Muerte, Talamanca, Costa Rica. Suelos Ecuatoriales 8(1):397-400.

Palencia, J. A., and J. A. Martini. 1970. Características morfológicas, físicas y químicas de algunos suelos derivados de cenizas volcánicas en Centroamerica. Turrialba 29(3):325-332.

Palmieri, V. 1983. Respuesta de la papa (*Solanum tuberosum* L.) a la fertilización nitrógene y fósforo en la zona de Fraijanes, Alajuela. Thesis Ing. Agr., Esc. Fitotec., Fac. Agr., Univ. of Costa Rica.

Peralta, F., E. Bornemisza, and A. Alvarado. 1981. Zinc adsorption by andepts from the Central Plateau of Costa Rica. Commun. in Soil Sci. Plant Anal. 12(7):669-682.

Perera, G. E. 1976. Efecto del nitrógeno y fósforo en la producción de brocoli (*Brassica oleraceae* var. *italica*) en la zona de Juan Viñas, Costa Rica. Thesis Ing. Agr., Esc. Fitot., Fac. Agron., Univ. of Costa Rica.

Perez, A., and D. D. Oelsligle. 1975. Comparación de diferentes extractantes para azufre en suelos de Costa Rica. Turrialba 25(3):232-238.

Rojas, V. M. 1973. Estudio de algunos suelos del Cantón de Naranjo. Thesis Ing. Agr., Esc. Fitot., Fac. Agr., Univ. Costa Rica.

Saenz, A. 1966. Suelos volcánicos cafeteros de Costa Rica. Publ. UCR ., Serie Agron. No. 6. San José, Costa Rica.

Suarez, D., and K. Igue. 1974. The effect of granule size and phosphorus uptake from volcanic ash soil. Turrialba 24(2):180-186.

Urrutia, J., and k. Igue. 1972. Reacciones de los fosfatos monocálcico y dicálcico anhidro en suelos volcánicos. Turrialba 22(2):144-149.

Vasquez, A. 1982. Estudio detallado de suelos de la Subestación Experimental Agrícola Fraijanes. Fac. Agr., Univ. Costa Rica.

Table 18. Properties of Andepts of the lower positions of the landscape in a ustic-isothermic environment.

Classification: Typic Dystrandept (Alvarado and Buol, 1975).

Horizon	A11	A12	A13	IIA14	IIB1	IIIC	IVC
Depth cm	0-24	24-37	37-60	60-90	90-115	115-125	125-200
pH H_2O	5.5	5.7	5.9	6.0	6.1	6.6	6.1
pH NaF, 2 min	10.3	10.4	10.9	10.7	10.7	10.1	10.7
O.M. %	17.4	10.8	7.4	9.2	5.5	0.2	1.6
Exch. Ca meq/100 g	2.8	2.5	3.6	6.1	3.2	1.1	3.1
Exch. Mg meq/100 g	2.5	0.9	1.0	1.7	0.9	0.3	0.7
Exch. K meq/100 g	0.5	0.2	0.1	0.1	0.1	0.1	0.1
CEC meq/100 g	43.1	39.8	31.3	32.8	35.4	10.1	18.1
B.S. %	15.8	10.2	16.0	24.9	12.6	17.5	23.6
Sand %	39	36	36	38	54	66	32
Clay %	14	10	9	10	6	6	15
Silt %	47	54	55	52	40	28	5
H_2O at 15 bars %	44	36	32	33	32	26	43
Bulk Dens. g/cc	1.02	0.99	0.59	0.84	0.79	1.11	0.80
Particle Dens. g/cc	2.00	2.12	2.11	2.13	2.13	2.40	2.22
Porosity %	49	53	72	61	63	5	64
P.V.C. Swell Index	6.9	5.2	39	5.2	4.5	1.4	1.6

Table 19. Properties of Andepts at high elevation in a udic-isomesic environment.

Classification: Entic Dystrandept (Otárola and Alvarado, 1977).

Horizon	A1	A2	B1	B2b	BC
Depth cm					
pH H_2O	5.2	5.3	5.1	5.0	5.3
pH NaF, 2 min	11.2	11.2	11.6	10.4	11.3
O.M. %	7.9	13.5	8.7	25.6	7.1
Exch. Ca meq/100 g	0.6	0.4	0.1	7.4	0.6
Exch. Mg meq/100 g	0.5	0.5	0.5	2.0	0.6
Exch. K meq/100 g	0.2	0.3	0.1	0.8	0.2
CEC meq/100 g	nd	nd	nd	nd	nd
Sand %	62	18	40	8	32
Clay %	13	22	14	16	32
Silt %	25	60	46	76	36
H_2O at 1/3 bar %	102	123	102	95	99
Bulk Dens. g/cc	0.52	0.44	0.58	0.55	0.72
Particle Dens. g/cc	2.31	1.95	2.07	1.53	1.89
Porosity %	78	78	72	64	62

Table 20. Properties of Andepts at low elevation in a udic isohyperthermic environment.

Classification: Oxic Dystrandept (Knox and Maldonado, 1969).

Horizon	Ap	A12	IIB21	IIB22	IIB23	IIB24
Depth cm	0-38	38-72	72-100	100-141	141-170	170-185
pH H_2O	4.6	5.0	5.8	5.9	5.9	5.7
O.M. %	24.7	22.5	7.2	0.0	3.6	4.9
Exch. Ca meq/100 g	0.0	0.0	0.0	0.0	0.0	0.0
Exch. Mg meq/100 g	0.1	0.0	0.0	0.0	0.0	0.0
Exch. K meq/100 g	0.2	0.1	0.1	0.2	0.1	0.1
CEC meq/100 g	48.9	55.0	28.7	28.9	35.0	29.2
B.S. %	1	0	0	1	0	0
Sand %	19	17	3	4	3	3
Clay %	44	42	40	33	35	29
Silt %	37	41	57	63	62	68
H_2o at 15 bars %	100	120	100	87	110	110
Bulk density g/cc	0.5	nd	0.5	0.6	0.5	0.6

Table 21. Properties of Andepts in a transition zone from ustic/udic-isomesic environment.

Classification: Hydric Dystrandept (Vásquez, 1982).

Horizon	A11	A12	B21	B22	B23	IIB
Depth cm	0-22	22-34	34-64	64-86	86-108	108-140
pH H_2O	4.7	5.0	5.3	5.3	5.4	5.4
O.M. %	19.5	20.1	7.3	12.8	6.8	7.8
Exch. Ca meq/100 g	3.3	3.2	2.3	1.3	1.6	1.8
Exch. Mg meq/100 g	1.2	1.0	0.7	0.4	0.6	0.6
Exch. K meq/100 g	0.7	0.3	0.1	0.3	0.2	0.1
CEC meq/100 g	56.7	59.2	51.2	47.3	50.1	49.3
B.S. %	9	8	6	4	5	5
Sand %	24	8	28	28	8	18
Clay %	25	30	31	24	35	35
Silt %	51	62	41	47	57	47
H_2O at 1/3 bars %	66	52	63	53	47	51
H_2O at 15 bars %	39	39	40	34	32	36
Bulk density g/cc	0.69	0.75	0.89	0.87	0.83	0.84
Particle density g/cc	1.84	2.10	2.15	2.16	2.12	2.09
Porosity %	63	64	59	60	61	60

Table 22. Properties of Andepts in a udic-isomesic environment.

Classification: medial, thixotropic, isomesic, typic Hydrandept (Jiménez, 1979).

Horizon	A11	A12	AB	IIB2	IIC
Depth cm	0-40	40-80	80-90	90-130	130-150
pH H_2O	5.3	5.5	5.6	5.8	5.7
pH NaF, 2 min	11.0	11.2	11.0	10.7	10.8
O.M. %	15.4	12.9	11.7	6.4	4.1
Exch. Ca meq/100 g	0.6	0.8	0.6	0.2	0.5
Exch. Mg meq/100 g	1.2	1.3	1.2	1.1	1.2
Exch. K meq/100 g	0.2	0.2	0.1	0.1	0.3
CEC meq/100 g	30.3	43.9	38.2	42.0	37.1
KCl-Al meq/100 g	0.5	0.2	0.2	0.1	0.1
B.S. %	7	5	5	4	5
Sand %	52	46	50	66	62
Clay %	9	11	14	15	17
Silt %	39	43	36	19	21
H_2O at 1/3 bars %	58	62	58	40	58
H_2O at 15 bars %	44	43	41	28	42
Bulk Dens. g/cc	0.76	0.69	0.71	0.70	nd
Particle Dens. g/cc	1.90	1.93	1.94	2.02	1.91
Porosity %	60	64	63	66	nd

Table 23. Properties of an Inceptisol covered by recent volcanic ash.

Classification: Andic Dystropept (Rojas, 1973).

Horizon	Ap	B1	B2	B3
Depth cm	0-24	24-50	50-100	100-140
pH H_2O	5.1	5.1	5.2	5.3
pH NaF, 2 min	10.0	10.0	10.0	10.0
O.M. %	5.7	0.8	0.1	nd
Exch. Ca meq/100 g	0.4	0.7	0.8	2.4
Exch. Mg meq/100 g	0.9	0.9	1.0	1.8
Exch. K meq/100 g	0.2	0.1	0.1	0.1
CEC meq/100 g	28.3	39.4	40.4	29.9
B.S. %	5	4	5	14
Sand %	48	34	36	38
Clay %	21	43	37	35
Silt %	31	23	27	27
H_2O at 1/3 bars %	57	49	47	51
H_2O at 15 bars %	27	32	34	34
Bulk density g/cc	0.60	0.86	0.91	0.95
Particle density g/cc	1.91	2.21	2.15	2.81
Porosity %	69	61	58	66

Table 24. Properties of an Ultisol covered by recent volcanic ash.

Classification: Andic Rhodustult (Alvarado, et al., 1982)

Horizon	A1	B21t	IIB22t	IIB23t	IIBC
Depth cm	0-12	12-62	62-90	90-122	122-155
pH H_2O	5.7	5.6	5.6	5.4	5.3
pH NaF, 2 min	10.0	9.9	10.0	10.2	10.1
O.M. %	9.8	0.2	tr.	tr.	tr.
Exch. Ca meq/100 g	9.9	8.4	9.4	7.5	4.0
Exch. Mg meq/100 g	3.5	2.8	3.9	2.7	1.1
Exch. K meq/100 g	0.2	0.1	0.1	0.1	0.1
CEC meq/100 g	38.0	29.2	34.4	30.5	30.1
KCl-Al meq/100 g	1.4	0.5	1.6	3.3	4.3
B.S. %	36.1	39.1	39.1	33.9	17.3
Sand %	26	26	16	18	30
Clay %	31	41	55	53	39
Silt %	43	33	29	29	31
Bulk Dens. g/cc	0.99	nd	1.05	1.13	1.00
Particle Dens. g/cc	2.37	2.60	2.63	2.63	2.69
Porosity %	58	nd	60	57	63

PROPERTIES OF ANDISOLS IMPORTANT TO PADDY RICE

K. Wada

ABSTRACT

Studies on changes in morphology, clay mineralogy, organic matter fraction and chemical properties of Andisols by the use for paddy rice, mostly in Japan, were reviewed. Andisols undergo morphological, physical, and chemical changes, but clay minerals and/or a substantial amount of humus remain largely unaltered at least for 50 to 100 years. The properties of Andisols important to upland crops, such as phosphate fixation and weak retention of base, remain important to paddy rice too. In addition, excess percolation of water, weak retention of NH_4-N and sometimes iodine toxicity can be problems specific to Andisols, particularly at the start of paddy cultivation. Some of these problems are solved by continuing paddy cultivation and some by appropriate water and fertilizer managements.

INTRODUCTION

Almost all kinds of soil can be used to grow paddy rice if water conditions are favorable, and Andisols are no exception. From a global viewpoint, Andisols have only a minor importance as the paddy soil, as its distribution is limited. A substantial portion of Andisols are, however, used as paddy in a region like Japan (Table 1), where among the three types of Andisols, Aquic Dystrandepts, which constitute 70% of paddy Andisols, exhibit a higher production capability for paddy rice than for upland crops. The differences in the crop performance between the three Andosols indicate that drainage is an important factor determining their production capability.

The object of this paper is to examine the effects of paddy cultivation on the nature and properties of Andisols, to assess the properties of Andisols important to paddy rice and to review management practices suggested to solve the problems related to some of these properties. Examples are drawn mostly from studies on Andisols in Japan.

Table 1. Areas of Arable Andisols in Japan Classified Acccording to the Use and Production Capability[a]

Soil Group[b]	Land Use									
	Paddy Rice					Upland Crops and Orchard				
	Area (10^3ha)	P.C.C.[c]				Area (10^3ha)	P.C.C.[c]			
		I	II	III	IV		I	II	III	IV
		(%)					(%)			
Dystrandepts	17	0	21	78	1	851	0	30	68	2
Aquic Dystrandepts	274	0	61	37	1	72	0	13	86	1
Andaquepts	51	0	43	57	0	2	0	0	76	24
Whole arable soils	2887	0	61	39	0	1832	0	31	63	6

[a] Prepared according to the statistics given in the Report of Basic Soil Survey published by Ministry of Agriculture, Forestry and Fishery in 1980.

[b] Soil correlation: Dystrandepts=Kuroboku soils; Aquic Dystrandepts=Tashitsu (very moist) Kuroboku soils; Andaquepts= Kuroboku glei soils.

[c] P.C.C.=Production capability class.

Class	Limiting factors of hazards for crop production	Requirement of amelio-rative practices
I	no or only few	no
II	some	some
III	many	fairly intensive
IV	more than III	very intensive

SOIL MORPHOLOGY

Table 2 shows a comparison of Andisol profiles observed by Mitsuchi (1970) in 50 to 60 year-old paddy fields and adjacent upland crop fields. The pair of the upland and paddy soils is derived from the same tephras deposited on a foot slope or on a terrace. The paddy soils still maintain important features of Andisols, but there are changes imposed by the specific use for paddy rice: 1) a slight decrease in the tone of red in the surface horizon, 2) the formation of separate iron-oxide (Bcg$_1$ir or Bc$_1$ir) and manganese-oxide (B$_3$mn or B$_2$mn) accumulation horizons, 3) compaction of the lower portion of A (Ag$_2$) and the formation of the so-called plow pan (Bcg$_1$ir), and 4) breakdown of crumb structure characteristic to the surface horizon of Andisols and development of blocky structure in Bcg$_1$ir or Bc$_1$ir.

Migration of iron and manganese in the mobile divalent state from the reduced surface horizon and precipitation as sparingly soluble respective oxides in the subsurface horizon is an important feature of paddy soils. A visual notion of this feature, red, yellow, brown to black mottlings and spots are, however, generally inconspicuous in paddy Andisols. This has been attributed to a weak eluviation and illuviation of iron and manganese or a masking of the mottling and spot colors with black humus. Mitsuchi (1970) found, however, in the paddy soils shown in Table 2 that 25% (Profile I) and 13% (Profile II) of Fe migrated from Apg and Ag$_2$ to Bcg$_1$ir or Bc$_1$ir, respectively, and 50 to 60% of Mn similarly migrated further down to B$_2$mn or B$_3$mn. These figures are comparable with those found for typical paddy soils on alluvium in Japan. The poor mottlings and spots in the paddy Andisols were, therefore, attributed to the rapidness of oxidation and precipitation that occurs throughout the subsoil on draining and drying due to the porous nature of Andisols.

Moorman and van Breemen (1978) wrote that the plow pan formation was poor in soils with a stable structure, like Andepts and Oxisols, and in soils with high organic matter. A considerable area of paddy fields with Andepts often exhibits water percolation exceeding 50 to 60 mm per day, particularly where sand and/or gravel layers are present in the subsoil. This excess percolation enhances the lowering of soil temperature in a cool climate causing a cold injury of rice plants. Application of bentonite at a rate of 10 ton/ha to such Andisols and mixing it with the surface soil was found effective in reducing the percolation rate and increasing the yield of rice (Honya, 1961). Continued paddy cultivation, however, results in the formation of a plow pan in most Andisols, as illustrated in Table 2. The formation of even an indurated iron oxide pan in the subsurface horizons was reported in coarse-textured, very permeable paddy Andisols (Kato and Matsui, 1960).

Table 2. Comparison of Andisol Profiles (I; Mizoguchi, Tottori and II; Hata, Nagano) Used for Upland Crops and Paddy Rice[1]

Profile			
I		II	
Land use			
Upland	Paddy	Upland	Paddy
Horizon thickness (cm); humus and texture			
Ap 14; +++; L A_{12} 11; +++; L A_3 10; ++ ; L BC >40; + ; CL	Apg 12; +++; L Ag_2 6; +++; L Bcg_1ir 13; +++; L B_2 16; +++; C B_3mn >30; + ; LiC	Ap 17; +++; L A_3 36; ++ ; L B_1 17; + ; CL B_2 >25; - ; CL	Apg 14; ++; L Ag_2 4; ++; L Bc_1ir 3; ++; L B_2mn 7; ++; L B_1' 12; + ; Cl B_2' >30; - ; CL
Color and mottling[2]			
Ap 7.5YR 1.5/1; - A_{12} 7.5YR 1/1; - A_3 10YR 2/2; - BC 7.5YR 5/6; -	Apg 10YR 2.5/1; - Ag_2 10YR 2.5/1; Fe(+) Bcg_1ir 7.5YR 1.5/1; Fe++ B_2 7.5-10YR 3/2; Fe(+) B_3mn 7.5YR 5/6; Mn+	Ap 7.5YR 2/2; - A_3 10YR 3/3; - B_1 7.5YR 4/4; - B_2 7.5YR 5/6; -	Apg 10YR 2/2; - Ag_2 10YR 2/2; Fe(++) Bc_1ir 10YR 3/2; Fe++ B_2mn 10YR 3/3; Mn++ B_1' 10YR 4/4; - B_2' 7.5YR 5/6; -
Structure[3] and compactness[4]			
Ap Cr ; 14 A_{12} wBl→Cr; 15 A_3 wBl ; 18 BC wBl ; 16	Apg wBl; 13 Ag_2 wBl; 21 Bcg_1ir mBl; 25 B_2 wBl; 21 B_3mn wBl; 17	Ap Cr ; 12 A_3 Ms→Cr; 17 B_1 Ms→Cr; 20 B_2 Ms→Cr; 18	Apg Ms ; 16 Ag_2 wBl ; 20 Bc_1ir mBl ; 26 B_2mn wBl ; 23 B_1' Ms→Cr; 20 B_2' Ms→Cr; 19

[1] Prepared according to the descriptions given by Mitsuchi (1970).

[2] ( ) indicates that mottlings are inconspicuous.

[3] Cr=crumb; Bl=blocky; Ms=massive; m=moderately developed; w=weakly developed; Ms→Cr; massive but disintegrates into crumb.

[4] Yamanaka's penetrometer reading.

SOIL MINERALOGY

Soil mineralogy is one of the most important determinants of the inherent capability of paddy soils. Moorman and van Breemen (1978) quoted data showing higher yields on Vertic Tropaquepts and Aquolls derived from volcanic pyroclastic materials than on Tropaquepts derived from recent and semi-recent river sediments originating from Ultisols with farmer's and high levels of management in Philippines. The former soils are high in weatherable minerals and have a dominance of 2:1 lattice clay minerals and allophane.

A favorable effect of montmorillonite is also seen in Japan even at high levels of water and fertilizer managements, e.g. Onikura, 1967. The role of weatherable minerals brought in the surface soil from active volcanoes is well illustrated in the rice lands in areas such as parts of Java and of Luzon, which are among the world's most productive (Moorman and van Breemen, 1978). On the other hand, the effect of allophane is disputable. Onikura (1967) measured regional differences in rice yield in Kyushu at comparable levels of management and related them to soil clay mineralogy. The lowest yield was found in regions where paddy soils were derived from volcanic ash and had a dominance of allophane, sometimes with 1:1 lattice clay minerals.

Earlier, changes in clay mineralogy of Andisols under rice cultivation, such as a transformation of allophane into 1:1 lattice clay minerals, was suggested, (e.g. Kobayashi and Shinagawa, 1958). On the other hand, only a slight increase of SiO_2/Al_2O_3 molar ratio (0.32 to 0.34, and 0.41 to 0.46) in "free oxides," which were extracted by a Mg-reduction method, was found for the paddy soils in Table 2 and virtually no change in the kind and contents of associated layer silicates (Mitsuchi, 1970).

Mizota, et al., (1982) compared the clay mineralogy of the Ap horizons of Andisols used for paddy rice and upland crops collected from agricultural experiment stations in different parts of Japan. Six of 13 paddy soil samples contained allophane and imogolite and none contained gibbsite, whereas parallel figures were 15 and 7 for 22 upland soil samples. Substantial numbers of diatoms were found in five paddy and one paddy converted upland soil samples. Allophane in both the paddy and upland soil samples has a SiO_2/Al_2O_3 ratio in the range of 1.0 to 1.4. Various layer silicates were present in different combinations and amounts, but there was no particular difference between the paddy and upland soil samples. One unique mineral, possibly an "embryonic halloysite" (Wada and Gondo, unpublished) was, however, found in two paddy soil samples. A predominance of allophane and no particular difference in clay mineralogy was found between two paddy and one upland Andisols (40 to 80 year cultivation) derived from nearly the same ash deposits (Kuroboku-Soken, 1983), though the contents of halloysite and diatoms were higher in the surface horizons of the paddy soils.

SOIL ORGANIC MATTER

Typical Andisols are noted to contain a large amount of well-humified organic matter. The organic matter content of Andisols was found to decrease with continuing paddy cultivation (Tokudome and Kanno, 1976). The C/N ratio also decreased from 25 to an uncultivated soil to 14 to 15 after 35 to 55 years of cultivation. On the other hand, no particular difference was found in the carbon content and/or the C/N ratio between comparable forest and paddy (2 to 20 year) Andisols (Adachi, 1973) and between upland crop and paddy (40 to 80 year) Andisols (Kuroboku-Soken, 1983), where the C/N ratios were 14 to 15.

Mitsuchi (1974) compared the content and nature of organic matter in paddy soils and adjacent unflooded arable soils. An increase of organic matter content attributable to paddy cultivation was found in two Brown Lowland Soils, two Gray Lowland Soils, and one Yellow Soil, but not in two Andisols. The humic acids accumulated in the former three soils were low in the degree of humification, whereas there were very slight changes in the composition of organic matter and in the nature of humic acids accumulated in the Andisols.

CHEMICAL PROPERTIES

As described in the preceding sections, the changes in the clay minerals and organic matter imposed by the specific use for paddy rice are generally small in Andisols. It is expected, therefore, that the chemical properties of Andisols that affect the growth of upland crops and are not changed by seasonal flooding would affect the rice growth too.

Base and silica status

The base saturation and soluble silica content of Andisols are either increased or decreased by irrigation and flooding. A remarkable enrichment of bases and silica occurred in cultivated Andisols for upland crops when irrigated with river water flowing from the area of a recent volcanic activity (Kobayashi, 1956). In Japan, some enrichment of bases was usually noted in paddy Andisols as compared with upland Andisols in regions surrounding active volcanoes (Honya and Ishikawa, 1956; Kobayashi and Shinagawa, 1958; Tokudome and Kanno, 1976; Kuroboku-Soken, 1983).

Favorable effects of silica adsorption on reducing phosphate fixation (or increasing available phosphate) and reducing active aluminum was inferred by Kobayashi (1956) and Onikura (1960). Whether silica is adsorbed or desorbed on Andisols by irrigation depends, however, on the content of organic matter in the soil, the clay mineral composition and the concentration of silica in irrigation water, which was found to require more than 10 to 25 ppm for the adsorption to occur (Wada and Inoue, 1974; Sadzawka and Aomine, 1977).

NH_4^+ and K^+ retention

Harada and Kutsuna (1955) and others reported that the soils derived from volcanic ash retain much less strongly NH_4^+ and K^+ than Ca^{2+}. It has been shown that the weak retention of NH_4^+ is a characteristic of ion-exchange sites in variable charge components, allophane, imogolite, and Al-humus complexes (Okamura and Wada, 1984). Honya (1961) pointed out that this feature could influence unfavorably the retention of NH_4^+ in paddy Andisols, where the surface horizon is reduced by flooding. Rice plants growing on an allophanic soil showed a higher nitrogen absorption/dry matter production ratio at early stages of growth, which was related to a high NH_4^+ concentration in soil solution (Seino, et al., 1976).

The use of bentonite mentioned earlier was also recommended to alleviate the NH_4-N loss in paddy Andisols (Honya, 1961). Ono and Uchida (1981) recommended to apply NH_4-N in the form of $(NH_4)_2HPO_4$ to lower the NH_4^+ concentration in the soil solution. The increase of CEC with phosphate application was marked for Andisols that adsorb large amounts of phosphate, e.g. Schalscha, et al., 1972).

Phosphate fixation

Strong phosphate fixation and low available phosphate content is a feature characteristic to Andisols and is one of the main causes for their low production capability. Phosphorus availability is usually higher in flooded soils than in upland soils. Ten to 20% decrease of phosphate adsorption measured by a conventional Japanese method was found in the Ap horizons of Andisols used for paddy rice cultivation (Honya and Ishikawa, 1956; Mitsuchi, 1970; Kuroboku-Soken, 1983). On the other hand, Fig. 1 shows that phosphate adsorption increases with increasing amounts of humus that complexes with Al and Fe, and is higher in samples with allophane and imogolite than in those without these minerals, irrespective of cultivation for paddy rice and upland crops (Mizota, et al., 1982). Honya (1961) showed that high doses of phosphorus

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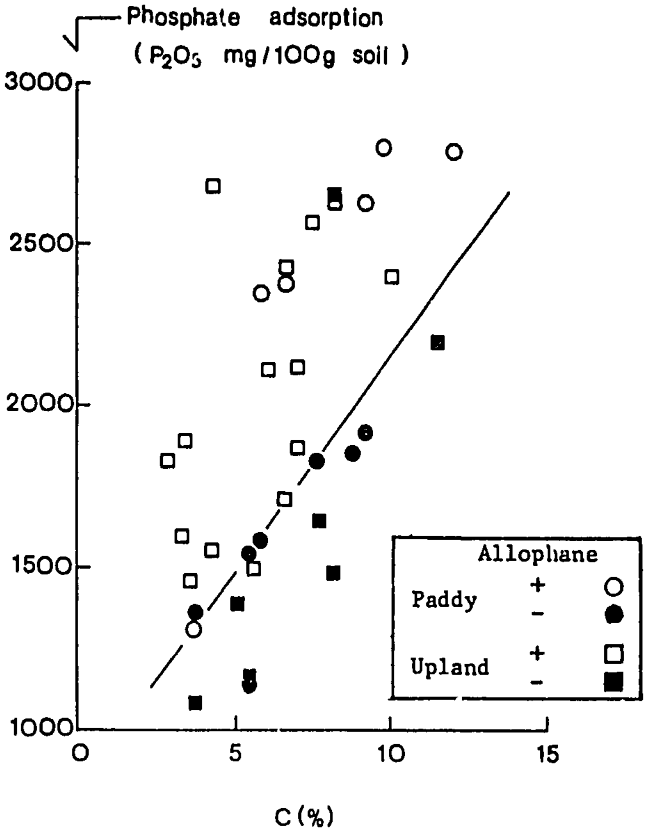

Fig. 1 Relationships between the carbon content and phosphate adsorption of Andisols used for paddy rice (circle) and upland crops (square) that differ in containing (open) and not containing (closed) allophane (Mizota et al., 1982)

fertilizer (200 kg P_2O_5/ha) for several years are effective to stimulate early growth and ripening for paddy rice newly cultivated on Andisols, particularly in a cool climate.

Iodine toxicity

In Japan, a nutritional disorder of paddy rice called "Kaiden Akogare" (reclamation red withering) caused by toxicity of iodine occurred in newly constructed paddy fields of Andisols on terraces in northern to central Honshu. This would occur when the content of water soluble iodine in the soil and that of alkali- soluble iodine in the plant exceeds 1 and 30 ppm respectively (Watanabe and Tensho, 1970). Under upland conditions, iodine is adsorbed as I_2 on humus, and no toxicity of iodine appears. When the soil is submerged, I_2 is reduced to I^-, which appears in the soil solution (Tensho and Yen, 1970). I^- is, however, removed by leaching, and the disorder disappears after two to three years' cultivation. Any means that accelerates the leaching of I^- is effective to alleviate its toxicity.

SUMMARY AND CONCLUSION

In parts of Java and of Luzon, the paddy fields in the area of recent volcanic activity are productive, where volcanic ash deposits cause enrichment of weatherable minerals. In Japan, paddy fields on Andisols have often been less productive than those on other soils at high levels of management. Those Andisols undergo physical and chemical changes by paddy rice cultivation, but clay minerals and/or a substantial amount of humus featuring Andisols can remain largely unaltered at least for 50 to 100 years. Only halloysite in association with diatoms can form where silica enrichment takes place. The properties of Andisols important to upland crops, such as phosphate fixation and weak retention of base, remain important to paddy rice too. In addition, excess percolation of water, weak retention of NH_4-N and sometimes iodine toxicity can be problems specific to Andisols, particularly at the start of paddy cultivation. Some of these problems are solved by continuing paddy cultivation and some by appropriate water and fertilizer managements.

LITERATURE CITED

Adachi, T. 1973. Studies on the humus of volcanic ash soils. Bull. Nat. Inst. Agr. Sci. (Japan) B24:127-264.

Harada, T., and K. Kutsuna. 1955. Cation exchange in soils. (1) Bull. Nat. Inst. Agr. Sci. (Japan) B5:1-26.

Honya, K. 1961. Studies on the improvement of rice plant cultivation in volcanic ash paddy fields in Tohoku district. Bull. Tohoku Agr. Exp. Sta. 21:1-143.

Honya, K., and M. Ishikawa. 1956. Studies on physical and chemical properties of volcanic ash paddy soils. Bull. Tohoku Agr. Exp. Sta. 8:94-102.

Kato, Y., and T. Matsui. 1960. The classification of paddy soils at the western foot of Mt. Fuji, with special reference to the surface geology. J. Sci. Soil Manure, Japan 31:387-390.

Kobayashi, T. 1956. Studies on the improvement of upland soil by means of irrigation practice. Memoirs Fac. Agr. Kagoshima Univ. 2:121-127.

Kobayashi, T., and A. Shinagawa. 1958. Studies on the paddy soils in upland of volcanic ash soil (I). Bull. Fac. Agr. Kagoshima Univ. 7:163-171.

Kuroboku-Soken. 1983. International correlation of Kuroboku soils (volcanic ash soils) and related soils. Faculty of Agriculture, Kyushu University, Fukuoka.

Mitsuchi, M. 1970. Some characteristics of paddy soils developed on volcanogenous Kuroboku soils (Andosols) J. Sci. Soil Manure, Japan 43:307-313.

Mitsuchi, M. 1974. Characters of humus formed under rice cultivation. Soil Sci. Plant Nutr. 20:249-259.

Mizota, C., M. A. Carrasco, and K. Wada. 1982. Clay mineralogy and some chemical properties of Ap horizons of Ando soils used for paddy rice in Japan. Geoderma 27:225-237.

Moorman, F. R., and N. van Breemen. 1978. Rice: Soil, water, land. International Rice Research Institute, Los Baños.

Okamura, Y., and K. Wada. 1984. Ammonium-calcium exchange equilibria in soils and weathered pumices that differ in cation-exchange material. Submitted to publication in J. Soil Sci.

Onikura, Y. 1960. Resilication to volcanic ash soils. Part 4. J. Sci. Soil Manure, Japan 31:360-364.

Onikura, Y. 1967. Some soil factors relating to regional differences in rice productivity in Kyushu, Japan. Bull. Kyushu Agr. Exp. Sta. 12:225-233.

Ono, S., and Y. Uchida. 1981. Behavior of NH_4-N in ammonium phosphate applied to paddy field of volcanic ash soil in cool region of Japan. Bull. Tohoku Agr. Exp. Sta. 63:137-150.

Sadzawka, R. M. A., and S. Aomine. 1977. Adsorption of silica in river waters by soils in Central Chile. Soil Sci. Plant. Nutr. 23:297-309.

Schalscha, E. B., P. F. Pratt, T. Kinjo, and J. Amart A. 1972. Effect of phosphate salts as saturating solutions in cation-exchange capacity determinations. Soil Sci. Soc. Amer. Proc. 36:912-914.

Seino, K., K. Yamashita, T. Motomatsu, and M. Motooka. 1976. The growth pattern of rice plant in several main paddy soils in the southern district of Japan. Bull. Kyushu Agr. Exp. Sta. 18:133-156.

Tensho, K., and K. Yen. 1970. Radio-iodine uptake by plant from soil with special reference to lowland rice. Soil Sci. Plant Nutr. 16:30-37.

Tokudome, S., and I. Kanno. 1976. Effects of rice cultivation on the nature of humus of Humic Allophane soils. Pedologist 20:24-30.

Wada, K., and A. Inoue. 1974. Adsorption of monomeric silica by volcanic ash soils. Soil Sci. Plant Nutr. 20:5-15.

Watanabe, I., and K. Tensho. 1970. Further study on iodine toxicity in relation to "Reclamation Akagare" disease of lowland rice. Soil Sci. Plant. Nutr. 16:192-194.

PROPERTIES OF ANDISOLS IMPORTANT TO PASTURE AND HORTICULTURE

V. E. Neall

INTRODUCTION

Andisols (Smith, 1978) offer unique physical and chemical properties for pasture farming and horticulture due largely to their volcanic parent materials and the short range order clay minerals weathered from them. As nearly all the Andisols in New Zealand with Andic properties are used for pasture, horticulture and cropping, this review is based to a large extent on the New Zealand experience. Andisols in New Zealand with vitric properties are principally used for forestry and pasture, so are less intensively utilized. This information has been supplemented with overseas examples where appropriate (Ugolini and Zasoki, 1979), concentrating on the practical implications of these properties. The unique properties of Andisols important to pasture and horticulture are considered in turn.

PHYSICAL PROPERTIES

Bulk density and porosity

A high content of short range order clay minerals (more specifically allophane and imogolite) is responsible for the low bulk density observed in Andisols. This property is sufficiently diagnostic to be included in the definition of the soil order, where Andisols with Andic properties are required to have a bulk density of less than 0.9 Mg/m^3. In fact, many Andisols with vitric properties would also satisfy this criterion but other requirements provide a more suitable definition. The importance of bulk density to pasture and horticultural plants is that this property is associated with a high porosity which provides aeration for plant roots (except in poorly drained sites where Aquands are recognized and also excluding low bulk density but often water-saturated Histosols). Most plant roots actively respire and there is a need for these roots to have adjacent gas-filled pores in continuity with the surface for respiration to take place. In saturated soils oxygen diffuses too slowly to supply the needs of most plants.

In low bulk density Andisols there is usually an associated high content of macropores which favor the proliferation of roots. If the subsoil horizons are thick, then there is usually an abundance of macropores to considerable depth so deep and widespread root growth can take place. Macropores also conduct water faster than micropores. Many Andisols often contain up to 20% by volume of macropores (larger than 60 μm in B horizons) which promote rapid drainage (Gradwell, 1978).

Drainage and structure

After rains Andisols show special advantages for pasture and horticulture. Rapid drainage at low tensions promotes a soil free from excessive wetness. This property is doubly valuable when combined with the short range order clay minerals present which are of a non-swelling type and are free from stickiness when wet. From a pasture management standpoint this prevents "pugging" or puddling of the soil under the feet of grazing animals or from the wheels of farm machinery. Gradwell (1974) has reported experiments on this resistance to deformation. Applying a loaded piston into a well wetted Andisol led to initial deep penetration but continual applications of the piston produced less deep penetrations. After many overlapping applications, the underlying soil still contained appreciable air-filled pores following a simulated drainage. The persistence of macropores, which drain readily, appears to be critical as it leads to compaction and increase of strength under traffic. In addition the water content of the Andisol in its original structural condition and at a tension similar to that at field capacity was well below the lower plastic limit for the soil. Thus for many Andisols deformation of the soil at field capacity would not produce the plastic flow which appears to be most damaging to soil structure.

In some Andisols with vitric properties compaction of pasture topsoils has been noted leading to a massive or platy structure with low vertical hydraulic conductivity. However, in most Andisols well structured topsoils offer ideal conditions for pasture management which is maintained with a healthy grass sward. For horticultural purposes, more weakly structured subsoils (even single grained in some Andisols with vitric properties) are limiting to intensive cultivation. While market gardening for potatoes, onions, carrots, and turnips is practiced on many Andisols, good crop rotation ensures maintenance of the topsoil structure.

Where structure is poor or absent, there is a high susceptibility to erosion by water or wind. Underground tunneling and streambank erosion are particularly problematical in pumice country, where soil conservation practices are required.

Markedly increased erosion of New Zealand's pumice country under pasture has been the subject of intensive investigation. The main conclusions drawn are that surface water runoff is greater from pasture areas than those in scrub or native forest (Jackson, 1973). The major cause of pasture runoff is very intense precipitation falling on pasture soils which appear to have much lower infiltration rates than forested soils. The answer lies in a marked decrease under pasture of the soil volume occupied by macropores which reduces the storage capacity of the soil. Soils on stock tracks have even lower contents of macropores than the average for pasture and may be important sources of runoff and sediment. Successful conservation practices aimed at reducing runoff have concentrated on afforestation and fencing off highly sensitive areas to prevent animal damage. Andisols with andic properties are less of an erosion problem largely due to their stability in an undisturbed state attributed to their high permeability and high cohesion (Warkentin and Maeda, 1980).

Water retention

The water content at field capacity of Andisols varies considerably but many of them are quite high. In Andisols with a hydrous character gravimetric water contents range to well over 100%, more particularly in tropical perhumid regions. Much of this water, however, is strongly retained as evidenced by the high 15-bar water retention values, so is thus unavailable to plants. These high water contents derive from the large content of short range order clay minerals present with high specific surface areas. Andisols with a very high water content on disturbance have a markedly lower strength than in their undisturbed state. These soils soften readily, particularly buried soils high in organic matter (Maeda, et al., 1977), and may not support continual passage of machinery.

After air drying, the power of Andisols to retain water is irreversibly reduced. This phenomenon is explained by the increased aggregation of allophane particles on drying which results in a decrease in both the volume of micropore space and the surface area.

In many Andisols, the 15-bar water retention of subsoils considerably exceeds those of the topsoils above them (Gradwell, 1968, 1976), despite the contribution of organic matter to the retention of water. It would appear that in these situations the topsoils have at some stage in their history experienced severe drying that has not occurred in the underlying subsoils. The irreversible change in 15-bar water content on air drying depends on the climate as well as the short range order clay minerals present.

Of the Andisols, it is those with vitric properties that seem to have high plant-available water contents. The capacity to store water available to plants remains high to considerable depths, so that the amount of water that a particular crop can use will depend on its rooting characteristics. Pumice often has vesicles occupying up to 60% of the volume of fragments, so a large soil volume is available for water storage. Even coarse pumice subsoils have up to 30% available water-holding capacity per unit volume as a result of the primary pumice particles. This means that for any horticultural or pasture crop extending its root system to a depth of 1.5 m, the available water capacity is equivalent to 500 mm of rainfall (Will and Stone, 1967).

In contrast, the Andisols with andic properties rank only a little better than most other soil orders (Gradwell, 1976), in plant-available water contents. It is in fact andic soils which contain pumice that show available water capacities transitional to vitric soils. In a recent study of a Typic Hapludand near Mt. Egmont, a soil from deep allophanic volcanic ash under pasture, some water extraction during summer occurred to a depth of 1.8 m. Pasture growth was limited by soil water when the soil water deficit was about 60 mm and nonirrigated yields were reduced to half of the irrigated yields when the deficit was 125 mm (R.L. Parfitt, pers. com.).

Consistence

The friable to slightly firm consistence of many Andisols is another property encouraging easy root penetration. It may, however, also offer disadvantages because it provides an ideal environment for insect pests. In New Zealand pastures, the preference of grass grubs (*Costelytra zealandica*) and manuka beetle (*Pyronota* spp.) for the upper friable subsoil horizons leads to parting of the grass roots and topsoil which die and are easily removed by animals or the wind. Combating infestations by converting to deeper rooting pastures such as lucerne is one alternative, or applying heavy stocking rates to cause heavy treading of topsoils is another method to reduce the pest populations (Thomson, et al., 1978).

Profile discontinuities

The general lack of barriers to deep root penetration is one of the distinctive features of most Andisols. Only where there is high water (Aquands) or a hard pan is root penetration limited. Deeper rooting plants such as asparagus and lucerne can often reach depths of 2 to 4 m. This enables such crops to take advantage of the high moisture-holding capacity and to exploit reserves of nutrients at depth, especially if paleosoils are present.

The suggestion of being able to name the two dominant particle size classes at the family level or where there are more than two to prefix them to dominant classes by the word "aniso", deserves special mention (see Icomand Circular Letter No. 5, 26 August, 1983). Strongly contrasting particle size or mineralogy classes are particularly common in the Andisols and such inhomogeneities in the soil are becoming increasingly recognized by plant physiologists as of vital importance to root growth. While not specific to Andisols, the recognition of mottling in fine-textured soils just above an underlying coarse-textured layer may not represent a normal drainage impedance. It appears that these profile discontinuities may be unimportant when the soil is saturated, but form key features in unsaturated conditions when coarser-textured horizons rapidly lose their ability to conduct water. This strongly influences root growth (Clothier, et al., 1978).

Man's influence

In New Zealand the demand for Andisols in thermic or warmer regions for intensive horticultural development is one of the significant trends in Andisol utilization in the latter half of the 20th century. High profitability of export quality fruit has led landowners to utilize all available land to grow subtropical and citrus crops. Andisols on landscapes where the slope is greater than 15° are limiting to the types of horticultural enterprises possible. Thus landowners have begun extensive soil recontouring where the top 20 cm of topsoil is stripped and stockpiled, the underlying horizons molded to a desirable gradient and the topsoil replaced. Unfortunately this anthropic mixing on a macroscale takes little acount of the highly desirable physical properties of the subsoil. Extreme mixing of the subsoil materials brings less desirable halloysitic parent materials to the new subsoil and unexpected changes in the water table and water flow have resulted, including greatly increased erosion immediately following such practices. Little of this activity is currently documented.

CHEMICAL PROPERTIES

Phosphate and sulphur retention

Of the chemical properties important to pasture and horticulture on Andisols, P retention undoubtedly ranks first. It is so diagnostic that it is used in defining Andisols with andic properties. In New Zealand, Andisols with vitric properties are the only soils with comparably high but less extreme values for P retention. While traditional techniques for P retention determination are laborious, the NaF field test has traditionally been used to identify high P retaining soils in non-podzolising environments in field situations.

The **significance** of P retention to agriculturalists and horticulturalists has tended to be threefold:

1. In a grass/clover pasture, grasses respond to nitrogen produced from nodulated clovers. Most New Zealand pastures have a clover component and it is the clovers that respond to P fertilizers. Thus a high soil P retention has led in the past to the recommendation for heavy applications of P fertilizers at least until a steady state situation has been reached when only maintenance rates are required. To give an example of the effect of P retention on P fertilizer usage one can model P requirements at maintenance levels for an Andisol (with high P retention) versus an Inceptisol (with low P retention) using the New Zealand Ministry of Agriculture and Fisheries fertilizer recommendation scheme (Cornforth and Sinclair, 1982).

This model is based on the level of added P that maintains near constant annual production and soil nutrient status by replacing nutrients lost from the cycling pool of plant-available nutrients. For a dairy farm carrying 25 stock units/ha = 10 stock units/ac (a dairy cow of 390 Kg weight and producing 185 Kg of milkfat = 7.6 stock units) on an Andisol with andic properties, near Mt. Egmont (P retention >90%) operating at its potential with about 90% pasture utilization, the P requirement is 69 Kg P/ha/yr (approximately 700 Kg/ha of superphosphate at 10% total P). If this situation is compared with an Inceptisol from alluvium near Massey University at the same carrying capacity but with a P retention less than 40%, then the P requirement would be 39 Kg P (approximately 400 Kg/ha of superphosphate). This simple example using the M.A.F. model illustrates the effect of high P retention on fertilizer requirements in a practical way, the Andisol requiring 30 Kg P/ha/yr more due to greater loss of P (P.E.H. Gregg, pers. comm.).

High-producing dairy farmers on some New Zealand Andisols have been applying up to 1,125 Kg of 30% potassic superphosphate (80 Kg P, 169 Kg K, 90 Kg S) per ha per annum, usually in two dressings in autumn and spring. While the average use is nearer to 900 Kg per ha on high-producing farms and only 250-375 Kg per ha on sheep farms, the question is being asked of New Zealand soil scientists, especially with the increasing costs of P fertilizers, "How much phosphate do we really need?" The subject is somewhat controversial at present, some workers suggesting that irrespective of the P retention it is the high-producing farms that require the high fertilizer applications (Karlovsky, 1975).

There is now field evidence that P fertilizers may have been well above the maintenance requirements for many soils for two reasons. First, trials show that stopping fertilizer applications for one year can provide monetary savings to farmers, but it should be pointed out that beyond this period there is likely to be a reduced pasture production so this is not recommended. Also stopping P applications should not be practiced where soil tests indicate low fertility. Reducing superphosphate fertilizer input to 500 Kg per ha annually will have minimal effect on pasture production or composition, at least over the first two years (O'Connor and Feyter, 1980). Second, the high rates of 50% potassic superphosphate applications has led to high K and N concentrations in herbage which are considered conducive to hypomagnesaemia or grass tetany in dairy cows (Turner, et al., 1978).

Soils with high P retention can also be advantageous for particular purposes. For example in the disposal of dairy shed or dairy factory effluent, spray irrigation on to Andisols may reduce eutrophication or pollution of waterways. However, under the heavy applications from dairy factory wastes even a high P retentive Andisol may become saturated with P and begin releasing it. New disposal sites may then need to be chosen (McAuliffe, et al., 1979). Also highly P retentive soils are ideal for growing plants with low P requirements. Andisols with andic properties are ideal for growing cut flowers of the Proteaceae family which are very sensitive to high levels of available phosphate.

2. A high P retention has usually been taken as an indicator of a high organic matter content in a steady state situation (Jackman, 1964a). This would suggest either a high potential for mineralization and an adequate supply of nitrogen, or a slow decomposition process in these soils. High carbon-nitrogen ratios may be responsible for a slow decomposition rate but because organic matter combines with allophane or aluminium to stabilize humus, it is the short-range order minerals of Andisols that limit decomposition (Kanno, 1962). However, it should be pointed out that on a volume weight basis organic matter is not unusually high in many Andisols (Broadbent, et al., 1964).

Annual rates of immobilization of nitrogen, sulphur, and phosphorus in organic forms are quantitatively important when compared with the amounts needed to maintain good pasture growth. Jackman (1964b) suggests that Andisols under pasture should be ploughed infrequently and shallowly in order to reduce the subsequent immobilization of available nutrients. Minimum tillage (or direct drilling) is likely to offer potential for reducing P requirements of an Andisol.

3. Together with a high P retention, Andisols with andic properties usually show a high capacity to adsorb sulphate, although this may be considerably less than the P retention. The sulphate adsorption is very much controlled by soil pH with maximum sorption at low pH (Marsh, et al., 1983). Thus in these situations non-sulphur containing fertilizers would be effective, providing adequate accessions of S have occurred in the past or are continuing.

However, Andisols with vitric properties commonly show a S deficiency due to the weakly weathered and thus low colloid content of these soils. Sulphur responses have been shown on pumice soils in Oregon (Youngberg and Dyrness, 1965) and New Zealand (During, 1972).

Other elements

The porous nature of Andisols readily contributes to their leaching and loss of cations. It will be noted in the P model discussed before that potassic superphosphate is a widely used fertilizer on New Zealand pastures correcting for not only high P retention but also a widespread K (and S) deficiency. On rhyolitic and andesitic Andisols Mg deficiency may be widespread (Metson, 1968). On New Zealand Andisols with vitric properties, grass tetany has been observed not only with dairy cows but also in sheep. High incidences of grass tetany occur on strongly leached Andisols with andic properties; other metabolic disorders corrected by administration of Mg and Ca are recognized in dairy cows (Turner, et al., 1978). Magnesium has also been found limiting in some horticultural crops. At the more strongly leached sites above about 2,000 mm rainfall per annum lime responses in pasture growth and milk yield are obtained.

On the rhyolitic pumice soils (Andisols with vitric properties) of the Central North Island of New Zealand there is a severe inherited Co deficiency from magmatic differentiation that causes "bush sickness" in sheep and cattle (Andrews, 1970a; 1970b; 1971). Control has depended almost entirely on the use of cobaltised superphosphate. Topdressings that supply 350 g $Co\ SO_4.7H_2O$ per ha per annum have been effective in preventing outbreaks of the disease.

These soils also tend to be low in cooper (Wells, 1957; Cunningham, 1960). Copper deficiency in cattle is associated with pumice soils that grow pastures high in molybdenum. In contrast, some pumice soils show Mo deficiency (During, 1972). Copper availability in Japanese Andisols seems to be related to the parent materials, the mafic ashes containing much higher Cu levels than felsic ashes. However, available and total Zn levels were not related to parent material but appear to be more related to weathering conditions (Saigusa, et al., 1976).

Selenium-responsive diseases in New Zealand Andisols probably result from a soil-inherited selenium deficiency due to the weakly weathered state of the primary soil minerals and glass (Hodder and Watkinson, 1976).

Lucerne appears to be an effective excluder of Na on pumice soils, to the extent of providing insufficient Na to grazing animals; large responses to Na supplementation have been found with both sheep and cattle (Schultz, et al., 1979). Widespread

B deficiency is also observed in lucerne and brassica root crops on pumice soils (During, 1972), just as it occurs in lucerne, barley, orchard grass, and lettuce growing in Japanese Andisols (Masui, et al., 1973). Also deficiencies of Si, Mn, Fe, and Mo are a common problem in one of the vegetable-growing districts on Andisols in Japan (Ministry of Agriculture and Forestry, 1964).

Other animal health problems in younger tephras are iodine deficiency and fluorosis. Fluorine-contaminated tephra creates dental lesions and damages membranes of joints. It has constantly troubled sheep farmers in Iceland since at least 1693 A.D. To combat the growth of prominences on the molars of sheep and horses, Icelandic farmers invented a special type of pliers to break off these outgrowths (Thorarinsson, 1979).

CONCLUSION

In conclusion, Andisols are ideal for the growing of a wide range of horticultural crops; some soils may show element deficiencies but these are readily overcome. The increased monetary value obtainable for horticultural produce compared with pastoral products has resulted in horticulture beginning to displace traditional Andisol grasslands.

LITERATURE CITED

Andrews, E.D. 1970a. Cobalt and animal health in New Zealand. Part I. N.Z. Agric. Sci. 5(1):5-8.

Andrews, E.D. 1970b. Cobalt and animal health in New Zealand. Part II. N.Z. Agric. Sci. 5(2):11-15.

Andrews, E.D. 1971. Cobalt deficiency in sheep and cattle. N.Z. Dept. of Agric. Bull. 180.

Broadbent, F.E., R.H. Jackman, and J. McNicoll. 1964. Mineralization of carbon and nitrogen in some New Zealand Allophane soils. Soil Sci. 98:118-128.

Clothier, B.E., J.A. Pollock, and D.R. Scotter. 1978. Mottling in soil profiles containing a coarse-textured horizon. Soil Sci. Soc. Am. J. 42:761-763.

Cornforth, I.S., and A.G. Sinclair. 1982. Model for calculating maintenance phosphate requirements for grazing pastures. N.Z.J. of Exp. Agric. 10:53-61.

Cunningham, I.J. 1960. Molybdate topdressing and animal health. N.Z.J. of Agric. 100:419-428.

During, C. 1972. Fertilizers and soils in New Zealand farming. A.R. Shearer, Government Printer, Wellington.

Gradwell, M.W. 1964. Laboratory test methods for the structural stabilities of soils under grazing. Int. Congr. Soil Sci., Trans. 10th (Moscow) 1974, 1:341-350.

Gradwell, M.W. 1968. The moisture-holding properties of Waikato soils and methods of their determination. N.Z.J. of Agric. Res. 11:631-654.

Gradwell, M.W. 1976. Available-water capacities of some intrazonal soils of New Zealand. N.Z.J. of Agric. Res. 19:69-78.

Gradwell, M.W. 1978. Pore-size distributions of some New Zealand soil groups. N.Z.J. of Agric. Res. 21:603-614.

Gradwell, M.W. 1979. Subsoil hydraulic conductivities of major New Zealand soil groups of water contents near field capacity. N.Z.J. of Agric. Res. 22:603-614.

Hodder, A.P.W., and J.H. Watkinson. 1976. Low selenium levels in tephra-derived soil - inherent or pedogenetic? N.Z.J. of Sci. 19:397-400.

Jackman, R.H. 1964a. Accumulation of organic matter in some New Zealand soils under permanent pasture. I. Patterns of change of organic carbon, nitrogen, sulphur, and phosphorous. N.Z.J. of Agric. Res. 7:445-471.

Jackman, R.H. 1964b. Accumulation of organic matter in some New Zealand soils under permanent pasture. II. Rates of mineralization of organic matter and the supply of available nutrients. N.Z.J. of Agric. Res. 7:472-479.

Jackson, R.J. 1973. Catchment hydrology and some of its problems. p. 73-80. *In* Information Service, D.S.I.R. (ed.) Proc. of Soil and Plant Water Symposium. N.Z. Dept. of Sci. and Ind. Res. Inf. Series No. 96. A.R. Shearer, Government Printer, Wellington.

Kanno, I. 1962. Genesis and classification of humic allophane soil in Japan. p. 422-427. *In* G.N. Neale. Int. Soc. Soil Sci., Trans. Comm. IV, V Palmerston North, N.Z.

Karlovsky, J. 1975. How much phosphate do we really need? N.Z. Agric. Sci. 9:149-153.

Maeda, T., H. Takenaka, and B.P. Warkentin. 1977. Physical properties of allophane soils. Adv. Agron. 29:229-264.

Marsh, K.B., J.K. Syers, and R.W. Tillman, 1983. Retention and leaching of sulphur in soils. p. 9-17. *In* P.E.H. Gregg and J.K. Syers (eds.) Proceedings of the Technical Workshop on Sulphur in New Zealand Agriculture, Massey University, Palmerston North.

Masui, J., S. Shoji, M. Saigusa, H. Ando, S. Kobayashi, I. Yamada, and K. Saito. 1973. Mineralogical and agrochemical properties of Kawatabi Volcanic Ash soil. Tohuku J. of Agric. Res. 24:166-174.

McAuliffe, K.W., K.D. Earl, and A.N. Macgregor. 1979. Spray irrigation of dairy factory wastewater onto pasture - a case study. Prog. Wat. Tech. 179:33-43.

Metson, A.J. 1968. Magnesium. p. 76-82. *In* Soils of New Zealand Part 2. N.Z. Soil Bureau Bull. 26.

Ministry of Agriculture and Forestry. 1964. Volcanic ash soils in Japan. Japanese Government, Tokyo.

O'Connor, M.B., and C. Feyter. 1980. Eliminating or reducing fertilizer on dairy farms. Ruakura Farmers' Conference Proceedings, Hamilton, N.Z.

Saigusa, M., K. Saito, and S. Shoji. 1976. Occurrence of Cu and Zn within the profiles of soils formed from different parent ashes and corn response to these elements. Tohuku J. of Agric. Res. 27:12-19.

Schultz, I., M.A. Turner, and J.G. Cooke. 1979. Effects of fertilizer potassium: sodium ratio on yield and concentration of sodium, potassium, and magnesium in lucerne and white clover. N.Z.J. of Agric. Res. 22:303-308.

Smith, G.D. 1978. The Andisol Proposal.

Thomson, N.A., G. Rhys, and A. Carpenter. 1978. Control of manuka beetle. Proceedings N.Z. Weed and Pest Control Conference 31:164-166.

Thorarinsson, S. 1979. On the damage caused by volcanic eruptions with special reference to tephra and gases. p. 125-159. *In* P.D. Sheets and D.K. Grayson (eds.) Volcanic activity and human ecology. Academic Press, New York.

Turner, M.A., V.E. Neall, and G.F. Wilson. 1978. Survey of magnesium content of soils and pastures and incidence of grass tetany in three selected areas of Taranaki. N.Z.J. of Agric. Res. 21:583-592.

Ugolini, F.C., and R.J. Zasoski. 1979. Soils derived from tephra p. 83-124. *In* P.D. Sheets and D.K. Grayson (eds.) Volcanic activity and human ecology. Academic Press, New York.

Warkentin, B.P., and T. Maeda. 1980. Physical and mechanical characteristics of Andisols. p. 281-301. *In* B.K.G. Theng. Soils with Variable Change. N.Z. Soc. of Soil Sci. Lower Hutt.

Wells, N. 1957. Soil studies using sweet vernal to assess element availability. Part 3. Copper in New Zealand soil sequences. N.Z.J. of Sci. and Technology 38B:884-902.

Will, G.M., and E.L. Stone. 1967. Pumice soils as a medium for tree growth. 1. Moisture storage capacity. N.Z.J. of Forestry 12:189-199.

Youngberg, C.T., and C.T. Dyrness. 1965. Biological assay of pumice soil fertility. 2. Soil Sci. Soc. Am. Proc. 19:182-187.

PROPERTIES OF ANDISOLS IMPORTANT TO ENGINEERING

B. P. Warkentin

ABSTRACT

Andisols have particular characteristics which influence engineering uses. This is true for both fine-grained soils and for soils dominated by pumice. Low bulk density, poor compactability, large changes in cohesion and friction angle on drying, and high permeability are among the Andisol characteristics which require engineering designs which differ from those for soils in other orders. Therefore, classification of Andisols in a separate order has value for engineering uses.

Grain-size distribution is not a useful index property for Andisols because of difficulty in dispersion and large changes in apparent grain size on drying. The other index property used in soil engineering, plasticity, may be useful. These soils have plasticity characteristics of high liquid limit and low range of plasticity which are not shared by other soils. Fine-grained Andisols can be identified by their position on the plasticity chart. The engineering classification systems now in use can be readily extended to provide categories for Andisols based upon plasticity and nature of pumice particles.

Water retention is dominantly by capillary forces, so water movement can be described by concepts based upon pore size and continuity. Soil strength attenuation by compaction is difficult to achieve for wet or for dry soils. Organic matter content is often high, which increases the changes associated with amorphous materials, e.g. low bulk density and irreversible changes on drying. Organic contents in the range of 3-15% organic carbon need to be considered in engineering uses. Andisols are only slightly erosive in the natural state, but become highly erosive when dried and disturbed.

INTRODUCTION

The modification of Soil Taxonomy to include an Andisol order implies that a group of soils exists with properties, soil-forming processes, and management problems that distinguish it from soils in other orders. This paper will examine properties important to engineering uses of soils, to see how Andisols differ from other orders. Both coarse-grained (pumice or vitric soil properties) and fine-grained (andic soil properties) Andisols will be considered, since both have particular properties of concern in soil engineering.

A list of soil characteristics and properties that are important to engineering uses, and which distinguish Andisols, includes: high natural water content, low bulk density, high plastic limit and low range of plasticity, high permeability, marked change in physical properties on drying, large shrinkage of moist samples on drying but little swelling on rewetting, and little effect of exchangeable cation on water retention and other physical properties.

Because many soil engineering investigations are site-specific rather than extended across a landscape, it is often difficult, from the engineering literature, to get enough information on a sample to be able to place it into any but the highest levels of Soil Taxonomy. Information for classification must often be inferred from geologic data, size description, and measurement of plasticity. General terms such as "volcanic ash soils" will, therefore, be used more frequently than is desirable in this paper.

In some of the earlier soil engineering literature, soils containing halloysite were grouped with those containing allophane. Halloysite imparts some of the same properties of plasticity, low bulk density, and irreversible changes on drying, but the effects are much less pronounced than with allophane. These two groups can be distinguished on the basis of their engineering behavior.

This review and interpretation is written to explore the usefulness of the Andisol order in engineering uses of soils. It complements the reviews by Maeda, et al. (1977) and Warkentin and Maeda (1980), where measured physical and engineering characteristics of these soils are discussed. Northey (1966) has discussed many aspects of the correlation of engineering and pedological soil classification.

PHYSICAL PROPERTIES

Bulk density

Maeda, et al. (1983) summarized bulk density values from Japan (Fig. 1), from New Zealand and from the soil mechanics

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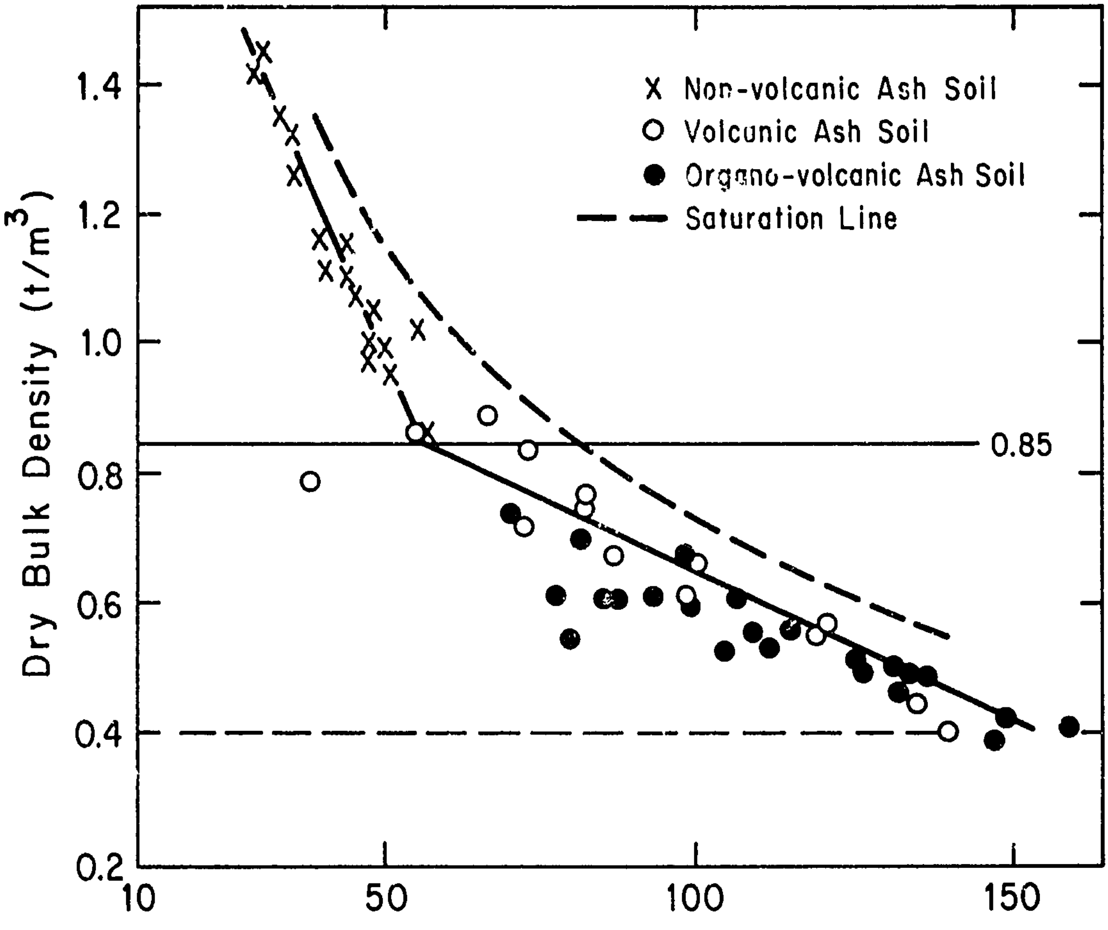

Figure 1. Position of Japanese Andisols on the chart of bulk density vs. water content (Maeda et al., 1983).

literature. A value of 0.85 t m^{-3} satisfactorily separated volcanic ash soils from those of non-volcanic origin. They found no volume change between natural field water content and 0.3 bar (-0.0 MPa) water content, and only a few percent increase in bulk density between 0.3 and 15 bar (-1.5 MPa) water contents. They suggested, therefore, that bulk density could be measured at field water content.

The increase in bulk density on air-drying gives added information on shrinkage behavior of the soil.

Grain size distribution

Grain size distribution is widely used as an index property for other soil characteristics that are harder to measure. Permeability, plant-available water, and tillage requirements can all be estimated from grain size. These estimates are usually empirical, and are developed for a particular soil region. A number of multiple regression equations have been published relating various physical characteristics to grain size distribution. These relationships are generally reliable; the exceptions are soils with short range order minerals in the clay fraction, soils weathered in place, and soils with more than 30% clay.

The difficulties in using grain size to characterize Andisols fall into three categories: (a) visualizing component clay grains in the amorphous material, (b) incomplete and unpredictable dispersion of samples into ultimate grains, and (c) the large change in measured grain size on drying.

Most Andisols probably have units that can be considered as clay grains (Maeda, et al., 1977). Even if the clay fraction is truly an amorphous gel, which may be true for some hydric Andisols, the measurement of clay size material would still be useful. "Clay content" is related to the number of sites for physical and chemical interaction.

Dispersion is usually achieved by adjusting the pH and applying some energy. There may be a relationship between chemical composition and pH for maximum dispersion, but this has not been systematically investigated. Many Andisols disperse best around pH 3, and ultrasonic dispersion is often used. With some care, dispersion can be achieved for most samples. A more difficult question involves the degree of dispersion, how much dispersion achieves the "ultimate grains" or the best correlation (index) with other soil characteristics.

Probably the most difficult matter is the change in grain size on drying. This means that grain size analyses must be measured on samples that have not been dried below the field (natural) water content if the results are to be useful for predictions about behavior of that soil. A number of measurements have been made illustrating the changes on drying. Two examples from the detailed studies by Kubota (1972) are shown in Fig. 2. The irreversible changes start at about -1 MPa (pF 4), and become more complete as the soil dries further. In other soil samples, the irreversible drying starts at -10 MPa (pF 5). Irreversible changes in grain size occur at higher soil water potential (higher water content) for soils with higher allophane content. This effect has been studied extensively for plasticity (Soma, 1978). Some Hydrandepts change irreversibly from a smeary gel at field water content to an apparently sandy soil with no cohesion when they are air dry.

When good dispersion is achieved on undried samples, clay contents of Andisols measured in the laboratory are considerably higher than estimated from hand texturing in the field. New correlations need to be established if grain size is to be used.

These difficulties, taken together, indicate that grain size distribution (texture) is an imperfect index for predicting engineering behavior of Andisols. Some information can be obtained from grain size determined at field water contents, but little from dried samples. This makes routine analyses difficult.

Plasticity

The second index property commonly used by soil engineers to predict soil behavior is plasticity. The plastic limit is the water content at which the stress-strain behavior of soil changes from that of a semi-solid to that of a plastic body. Below the plastic limit-water content, the soil sample cannot be rolled into a thread, but breaks into pieces. Liquid limit is the water content at which behavior changes from plastic to liquid. The difference in water content, on a weight basis, between the liquid and plastic limits, is the plasticity index. This is the range in water content over which a soil will exhibit plastic behavior. Plasticity is a property of the clay-size fraction with a small effect from silt.

The general relationships which soil engineers predict from measured plasticity "constants" can be summarized as follows: comparing soils with equal liquid limit, an increasing plasticity index would indicate decreasing permeability, increasing volume change, and increasing strength. At the same plasticity index, increasing liquid limit is associated with increasing permeability and decreasing strength.

The two characteristics of plasticity which separate Andisols from soils of other orders are the large decrease in plasticity on drying, and the high liquid limit compared with the plasticity index. Fig. 3 shows the plasticity constants for various samples of Andisols from Japan. The liquid limit is generally above 70%. The lines of wet and dry samples

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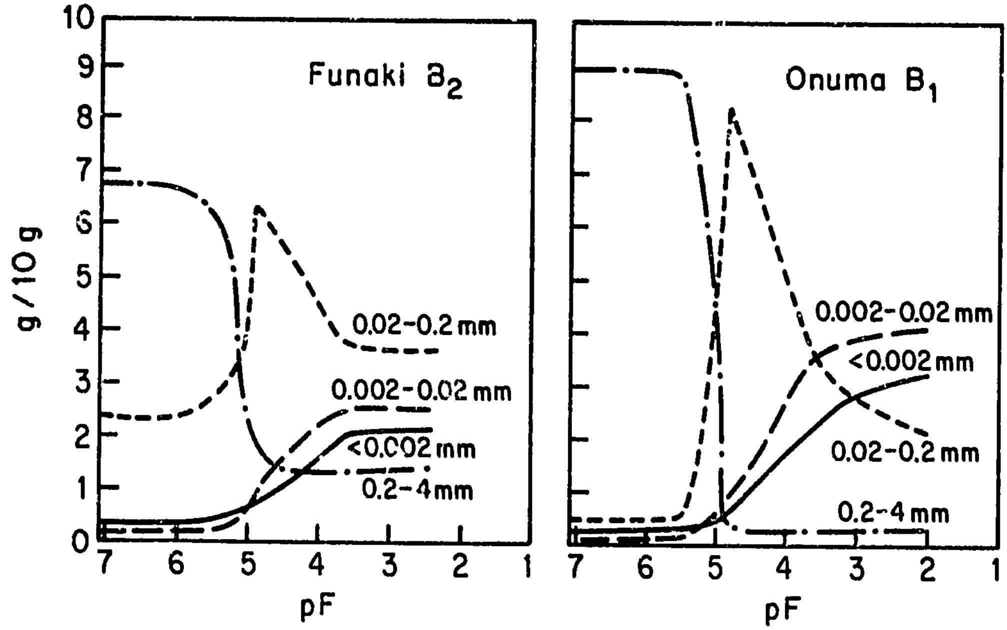

Figure 2. Particle size distribution of two Andisols after drying to different suction values (Kubota, 1972).

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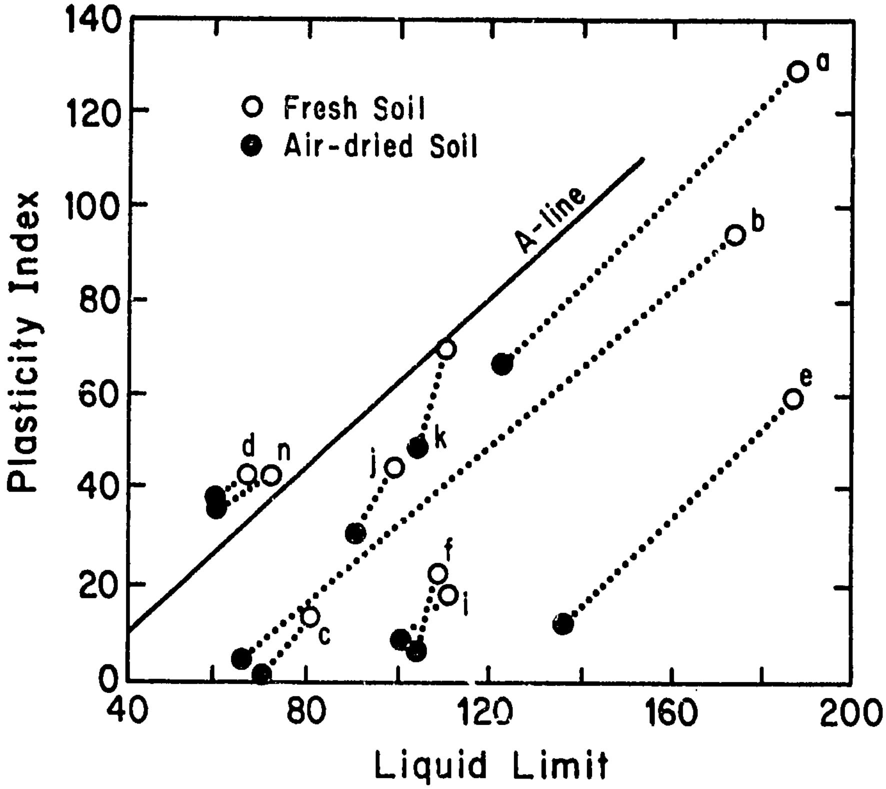

Figure 3. Plasticity of wet and air-dry allophane soils (from Yamazaki and Takenaka, 1965).

are approximately parallel to the "A" line for many samples. Higher liquid limit values are related to higher allophane content and to larger decreases in plasticity on drying. Many samples become nonplastic on drying, i.e. the liquid and plastic limits are at the same water content, and hence the plasticity index is zero.

In principle then, it should be possible to use plasticity to identify Andisols and to separate different groups of Andisols. Warkentin and Maeda (1974) and McNabb (1979) have shown that plasticity is related to the "intensity of allophanic character." A criterion for Andisols could be based on position of a sample on the plasticity chart. An example of such a grouping of Andisols, from Warkentin and Maeda (1974), is shown in Fig. 4 for a limited number of samples.

Several difficulties, however, stand in the way of using plasticity as a criterion for Andisols. The first is the requirement that the sample be maintained at least as wet as the minimum field water content. This is, however, also a requirement for measurements of other physical and engineering characteristics. The more serious concern is the different result that would be obtained for the same soil dried in the field to different water contents. We do not have sufficient measurements yet to know whether these differences are related to behavior of the soil body in the field. Maeda, et al. (1983) showed that the effect of drying varied over a wide range (10-200%).

A second difficulty is the uncertainty in measurement of plasticity of Andisols, especially those that show low plasticity. Different laboratory personnel would get different results, using the present methods. A method less dependent upon the operator would have to be devised.

Interaction with water

The interaction of soil particle surfaces with water causes changing engineering behavior of soils with changing water content. Interaction leading to water retention can range from capillary effects to swelling. In capillarity, water fills voids due to the pressure difference across a curved air-water interface. One or more layers of water molecules must be adsorbed on the soil surface to anchor the capillary film. Water retention in sands can be explained in this way. In the extended swelling exhibited by Vertisols with high sodium, the surface interacts with exchangeable cations to form a diffuse swarm of cations which are osmotically active and result in repulsion between clay particles. This explains the high water retention. Water retention of soils falls between the pure capillary and pure osmotic swelling extremes.

Andisols fall close to the capillary water retention model

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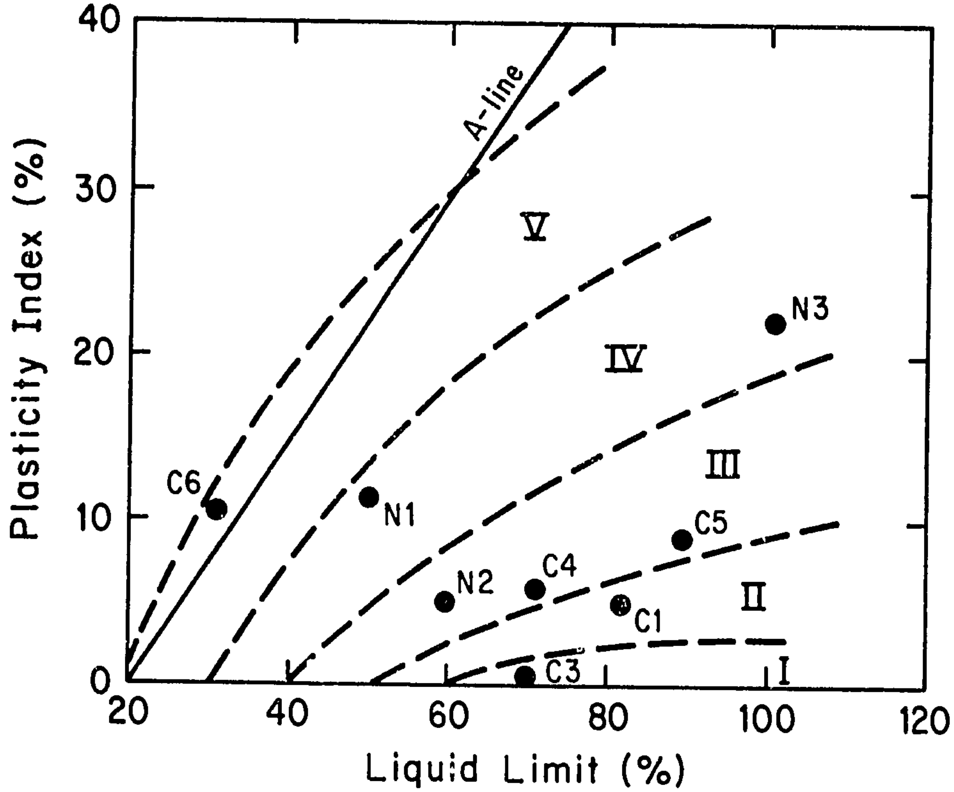

Figure 4. Grouping of Andisols with different plastic properties (Warkentin and Maeda, 1974).

(Maeda and Warkentin, 1975). Water retention and plasticity are almost independent of exchangeable cations or anions. When these soils dry, the volume decreases, but on rewetting there is little volume increase. As the gel structure is replaced by a porous matrix, water retention remains high due to small voids. Rousseaux and Warkentin (1976) have measured the size distribution of small voids for several Andisols, and related this to chemical composition. Measurements of surface area of allophane by water vapor adsorption probably measures filling of small voids rather than a surface with monomolecular layers of water.

Since interaction of Andisols with water can be described with capillary models, engineering characteristics such as permeability can be predicted from these models.

The "smeariness" of Andisols, a distinctive feature, results from their water retention properties. The matrix of the soil is weak, and can be broken by crushing the soil between thumb and fingers. This crushing destroys the voids and releases free water, causing the sensation of "smeariness." This is often referred to as "thixotropy." That word should be retained in its original meaning as a reversible sol-gel transformation. For some but not all Andisols, the effect is reversible. A new term, not thixotropy, should be used for this behavior.

Some Andisols with high organic matter contents become hydrophobic when dried (Ellies, 1977). This behavior must be considered in predicting water relations. It will lead to greater erosion and slower recharge of water in the soil profile.

Variability of physical properties

Authors of papers in the soil engineering literature often state that the variability of measured properties of Andisols is greater than that of other soils with which they deal. A larger variability makes it more difficult to choose "representative" samples, and to predict engineering behavior. Further, water content and bulk density, which are usually normally distributed, may follow non-Gaussian distributions in Andisols. Warkentin and Maeda (1980) have evaluated variability of physical properties and conclude that the statement appears to be true. The spatial distribution of the variability, and hence the best sampling strategies, have not been determined. The variability could result from nonuniform weathering, different degrees of drying in different microclimates, or more mixing due to movement of soil material on steep slopes.

Even without soil movement, samples could contain both Andisols and other soils. Andisols are defined on the basis of shallow depths, e.g. the top 50 cm of soil, or a layer of

35 cm thickness. Other layers may have contrasting properties. For agricultural uses, the top 50 cm layer would have a dominant influence on use of the land; for engineering investigations, samples are taken to greater depth and may include other soil material.

SOIL ENGINEERING USES

Engineering classification systems

The purpose of engineering soil classification systems is to group soils having similar behavior, i.e. response to loading, compactability, permeability, etc. The system most commonly used for categorizing soils for engineering uses is the Unified Soil Classification System, ASTM D-2487 (Table 1). The American Association of State Highway and Transportation Officials (AASHTO) system is similar. Grain size and plasticity are the two characteristics used to place a soil sample in one of 15 Unified System groups. Soils with predominantly coarse grains, more than 50% sand and gravel, are divided on the basis of how well graded they are, and on the basis of amounts of silt or clay present. Silts and clays are separated on their plastic properties, specifically their position on the plasticity chart (Fig. 5). Organic soils are in a separate category; organic matter makes silts more plastic and increases the liquid limit of clays.

Table 1. Simplified unified soil classification system for engineering uses. (See engineering texts for more detail.)

Coarse grained (>50% retained on 200 mesh sieve)	Fine grained (<50% retained on 200 mesh sieve)
GW well graded gravels	ML silts and fine sands
GP poorly graded gravels	CL clays of low plasticity
GC clayey gravels	OL organic silts and clays
SW well graded sands	MH silts of medium plasticity
SP poorly graded sands	CH clays of high plasticity
SM silty sands	OH organic clays
SC clayey sands	

Andisols could fall into a number of soil engineering groups. Vitrandepts or soils with pumice grains could be in the sand or gravel groups. This would not draw attention to those properties which distinguish pumice, e.g. low crushing strength and high internal porosity.

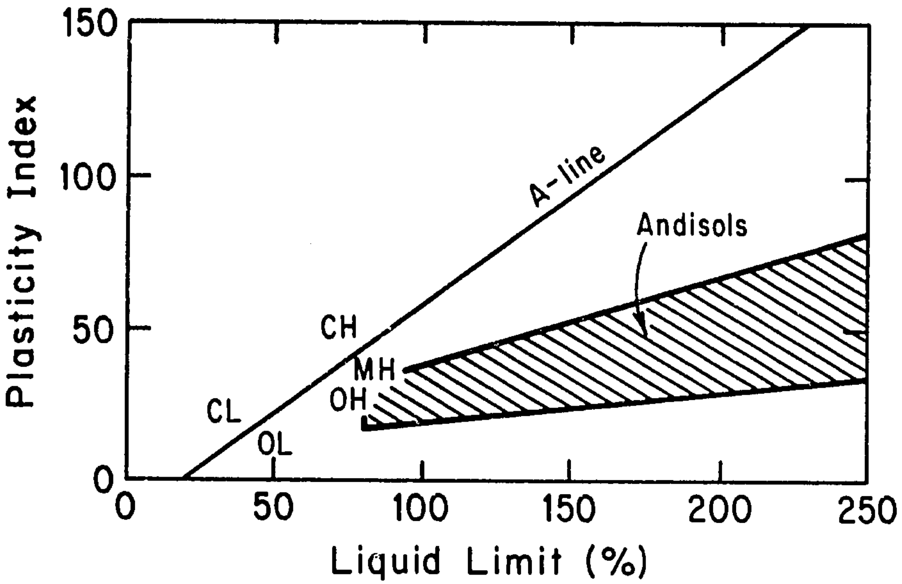

Figure 5. The plasticity chart for use in engineering classification of soils. The position of Andisols is from Wesley (1973).

Andisol samples with silt and clay would go into Unified groups OH (organic clays), OL (organic silts), MH (inorganic clays), or ML (inorganic silts) on the basis of position on the plasticity chart. Usually these Andisols fall outside the OH or OL range on the plasticity chart (Fig. 5). A separate grouping could easily be established for these soils, e.g. soils with liquid limit above 70% and plasticity index below PI = 0.3 L.L. When these samples are dried, they would be classified as OL, ML, or SM (silty sands). The Andepts mapped in Oregon are listed on the SCS-5 sheets as falling dominantly into ML, MH, or SM groups. These interpretations are based upon measurements on dried samples.

The Japanese Society of Soil Mechanics and Foundation Engineering has added three additional groups to the Unified System: OV (organic volcanic ash soils), VH_1, and VH_2 (volcanic ash soils).

The AASHTO and Unified groupings give approximately the same information except that the SM group would be expected to be A1 or A2 in the AASHTO system, not A4; and MH should be A5, not A7.

Since Andisol samples can be recognized from appearance of the sand and gravel-size grains or from the plasticity, it would be preferable to create separate categories or to make a special notation to alert users to the properties of Andisols.

Engineering uses and the Andisol order

Does the proposed Andisol order contain soils that have similar properties within the order, but are distinct in their engineering behavior from soils in other orders? The answer is apparently yes.

The coarse-grained Vitrandepts should be separated from other coarse-grained soils because of the low crushing strength, the low unit weight (bulk density) and the difficulty in compacting the soils to increase bearing capacity.

The fine-grained Andisols have low plasticity, high permeability, and unique compaction characteristics. Wooltorten (1954) and Hirashima (1948) were the first to discuss problems in road bed construction on these soils, and to relate them to the nature of amorphous clays. Medium-grained soils with vitric properties are the most difficult to recognize from soil engineering tests.

Soil engineers can recognize Andisols first from the geologic and climatic setting, the known or suspected presence of volcanic ash or pumice, the high (above 40%) natural water content, the position of a sample on the plasticity chart, and specific tests such as pH in NaF or plasticity and grain size changes on drying (Thrall, 1981).

We are now, however, able to predict engineering behavior, with the precision required, from properties such as allophane content. The Andisol group indicates a range of properties; empirical tests are still required to obtain, for example, the strength parameters for a specific site (Thrall, 1981; Warkentin, 1982).

Erosion

Several factors contribute to an apparent high erosivity of Andisols: the steep slopes on which these soils are often found, the loss of cohesion on drying, and the modest shear strength at the high void ratios found in situ. The high permeability argues against a high erosion potential.

Based on measurements of size of water-stable aggregates and amount of material left in suspension in water for some Hawaiian soils, Yamamoto and Anderson (1967) stated that ". . . soils from volcanic ash are more erodible than soils of basaltic flow or of colluvial origin." All the soils they investigated would, under full vegetative cover, be rated as only slightly to moderately erodible.

From a summary of soil detachability and soil erodibility in the tropics, Lal (1980) concluded that Andisols and Vertisols were less easily detached than Alfisols by raindrop impact.

Field experience in Japan indicates that Andisols are only moderately erosive. When they become dried, and lose cohesion, they are subject to severe wind erosion (Okajima, 1977).

Ellies and Funés (1980) found that aggregate stability of Andepts was higher than for Ustalfs in Chile. Under similar conditions they found breakdown of aggregates was 48, 50, and 65% for a Typic Dystrandept, a Hydric Dystrandept, and a Udic Rhodustalf (kaolinitic). The Andepts had a liquid limit of about 80% and a plasticity index of 2% (see Figs. 4 and 5). The Ustalf plasticity fell on the "A" line.

Shallow soil failures (slumping) in the Cascade Mountain region of the western U.S.A. result when strata of lower permeability underly andic horizons. Water content of the upper horizons increases, and the small strength loss combined with the steep slopes leads to slumping (Taskey, et al., 1979). When this occurs along a stream bank, sediment will be carried away. However, there is little movement of sediment by overland flow into a stream.

Andisols in the undisturbed and undried condition are stable in roadcuts 30 m high in regions of high rainfall. Free standing slopes of 70° are common (e.g. Wesley, 1973).

El-Swaify and Cooley (1980) found soil losses in Hawaii to be below recommended annual tolerance limits. Larger amounts of erosion occurred when a high proportion (> 20%) of the watershed was in field roads. This is consistent with the prediction that Andisols are stable in situ, but when compacted and dried, they become highly erodible.

El-Swaify and Dangler (1977) used simulated rainfall to measure the erodibility factor, K (tons/acre/EI) in Hawaii (Table 2). The values for the Hydrandept and the Dystrandept would be rated low (Dangler and El-Swaify, 1976), while the Entic Eutrandept would be rated highly erodible. They commented on the large variability in measured K values for these soils.

Table 2. Erodibility of Andepts in Hawaii (from El-Swaify and Dangler, 1977).

		Erodibility, K
Hilo Sicl	Typic Hydrandept	0.07
Kukaiau sicl	Hydric Dystrandept	0.17
Naalehu stony sicl	Typic Eutrandept	0.21
Pakini vfsl	Entic Eutrandept	0.55
4 series	Oxisols	0.17 (ave)
2 series	Ultisols	0.05 (ave)

El-Swaify and Dangler (1977) calculated correlation coefficients for the relationship between measured K values and various properties measured on the soil samples. The correlation was higher for volcanic ash soils than for residual soils, and the most important parameters were different. Mean weight diameter of aggregates, clay percent, and difference in pH between water and KCl had the highest correlation coefficients for the Andepts, while hydrologic parameters of infiltration rate or permeability were most important for residual soils. These differences indicate that the erosion process is different in Andisols, and erosion control could be different.

Erosion is, therefore, not a major limitation in use of Andisols in an unaltered environment. Intensive use of these soils, especially where drying would occur, and on steep slopes, would lead to erosion. Management systems should protect the surface from overland flow; the high permeability of the soil would then assure minimum erosion.

ENGINEERING PROPERTIES

Compaction

It is usually desirable, in engineering applications, to increase soil strength and/or decrease permeability by compacting soil. Optimum root development and crop growth usually require avoiding or reversing the effects of compaction. An understanding of the process of compaction is, therefore, important for a range of soil uses.

The effects of compaction are measured as an increase in bulk density, a decrease in porosity, a change in pore size distribution to smaller average pore size, or a change in fabric of the soil. The term "fabric" is used here in Brewer's (1964) definition as the arrangement of grains and voids. Fabric is one part of soil structure. The changes in fabric on compaction are most often studied in soil mechanics; however, the success of overcoming compaction in agriculture by deep "ripping" depends in part upon whether fabric changes have been induced. Ripping can alter the fabric only at the "mm" level of structure. Changes at smaller levels of structure cannot be reversed by tillage.

It might appear that some compaction would not be a serious concern for agricultural use of a soil with initial bulk density below 0.8 tm $^{-3}$ (porosity of 70%). Experience, however, indicates that root growth is restricted when Andisols are compacted, even when the final bulk density is below 1 tm^{-3} (62% porosity).

The amount of compaction depends upon the applied load (stress), the properties of the soil such as grain size distribution (texture) and nature of minerals, the soil structure, and the water content. Of these, applied load and water content are the controllable variables.

Andisol behavior differs from "textbook" compaction in that there is no sharp maximum and hence a poorly defined optimum water content for maximum density of moist samples (Figs. 6 and 7). The compressibility index (decrease in porosity per unit stress) is low, which means less compaction for a given load. The bulk density (applied load relationship) changes with water content, but this appears to be due to changes in soil characteristics on drying, rather than to the expected effect of water content on grain rearrangement during compaction.

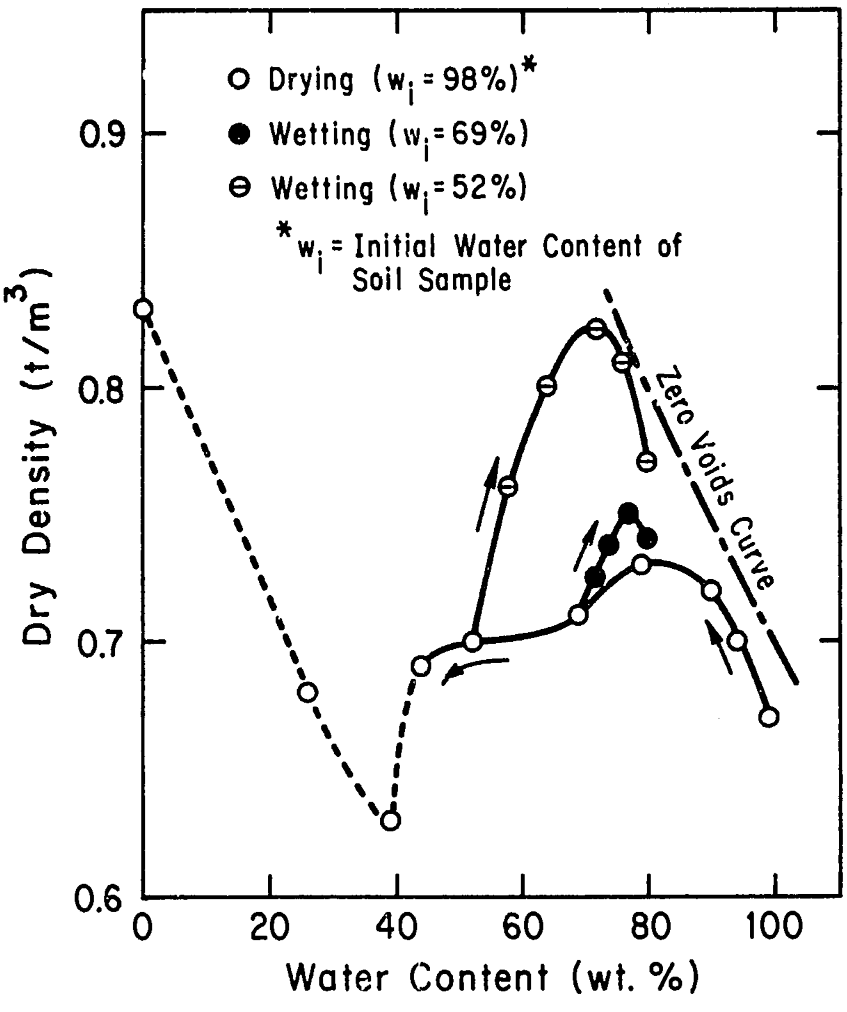

Figure 6. Compaction curves of an Andisol from Japan. Organic matter content = 25% (Maeda et al., 1983).

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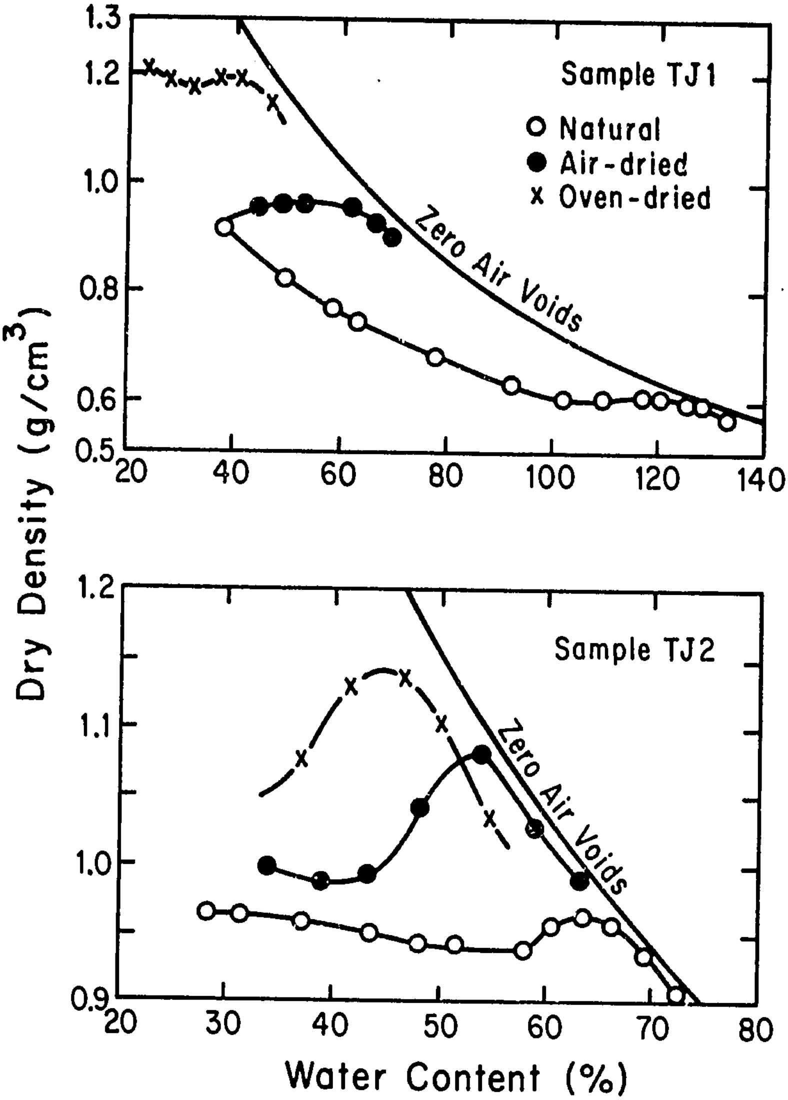

Figure 7. Compaction curves for Andisols from Indonesia (Wesley, 1973).

The maximum dry density that can be achieved decreases as optimum water content for compaction increases (Fig. 8). In the wet condition, Andepts cannot be effectively compacted by vibration (Fig. 9).

Dried samples of Andisols are closer to the expected compaction curves (Figs. 6 and 7). In soil engineering then, it is often desirable to dry these soils in thin layers before compaction. For crop growth, management systems which prevent drying may be desirable.

A different problem arises with Vitrandepts, where grains are crushed during compaction. Again, they do not show standard compaction behavior, and increases in density are difficult to achieve. Vibration - compaction is usually more successful than application of static loads, consistent with a structure that depends upon friction and interlocking at intergrain contacts. This also has implications for choice of tillage implements for these soils; vibrating tools could be undesirable.

Effect of organic matter on engineering properties

The presence of organic matter causes special concerns for engineering uses of Andisols. Organic matter usually results in undesirable engineering behavior of soils. Organic matter imparts to soils some of the characteristics associated with allophane materials, e.g. irreversible changes on drying. Organic matter contents of 5-15% organic carbon are common in Andisols, and many engineering characteristics appear to be linearly related to organic matter content. This may be a secondary effect, because bulk density decreases with increasing organic matter (Fig. 10). Takenaka, et al. (1977) found a linear change in measured engineering characteristics to about 15% organic matter, and less influence at higher levels. The break in Fig. 10 is at about 10%. This is in contrast to the mineral soil orders, especially under agricultural uses, where organic carbon contents are usually less than 5%. In these mineral soils, increases in organic carbon content in the range from 1 to 3% carbon are very significant, but beyond about 3%, soil characteristics such as structure do not increase with increasing organic matter.

Some effects of organic matter on engineering characteristics were discussed by Warkentin and Maeda (1980). In general, increasing organic matter results in: decrease in unconfined compressive strength (Fig. 11), increase in compression index, decrease in coefficient of consolidation, increase in amount of secondary compression, and increase in apparent angle of shearing resistance (Yasuhara and Takenaka, 1977).

Maeda, et al. (1976) have shown the effect of organic matter on the liquid limit of an Andisol on drying (Fig. 12).

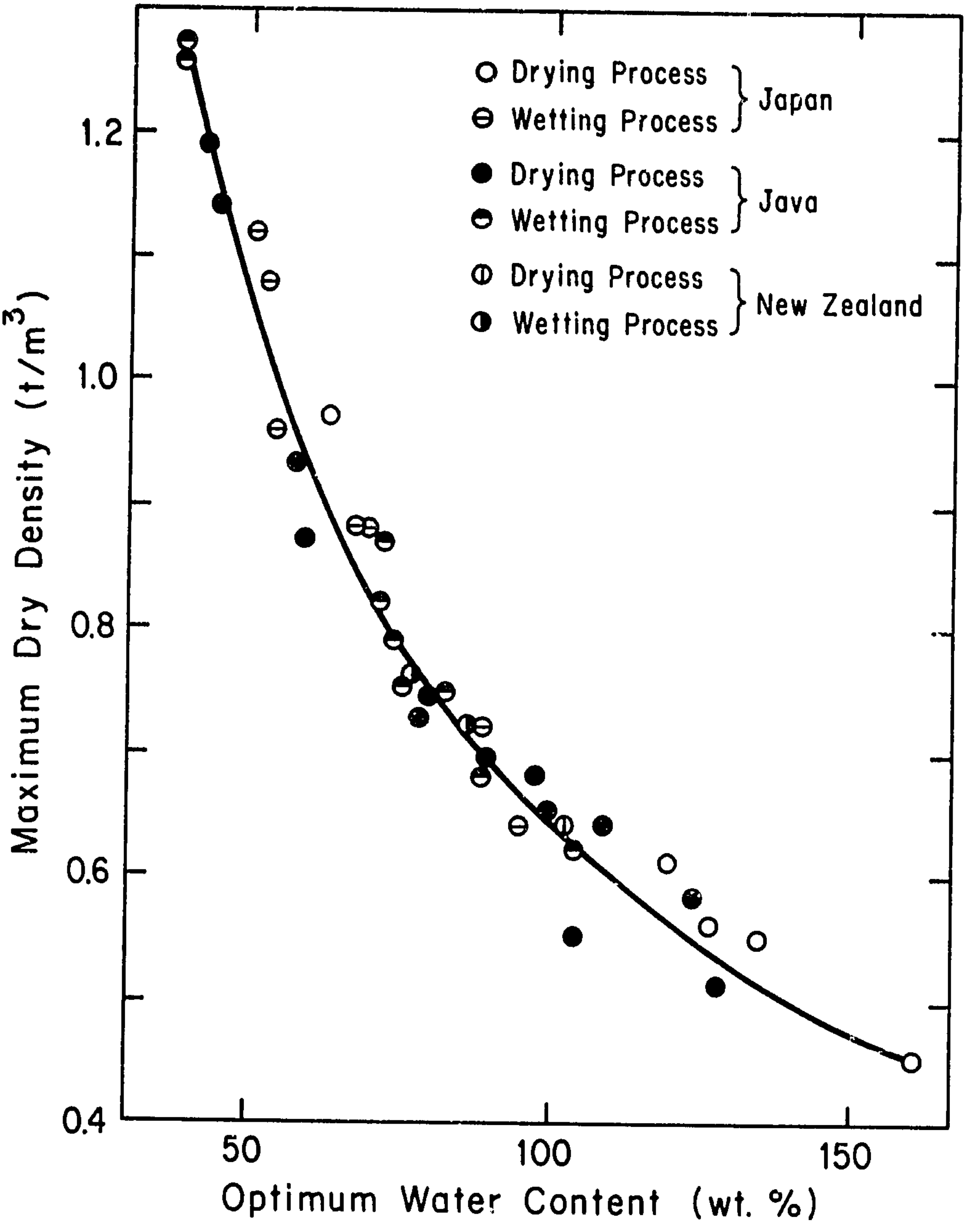

Figure 8. Relationship between maximum dry density and optimum water content of compacted Andisols (Maeda et al., 1983).

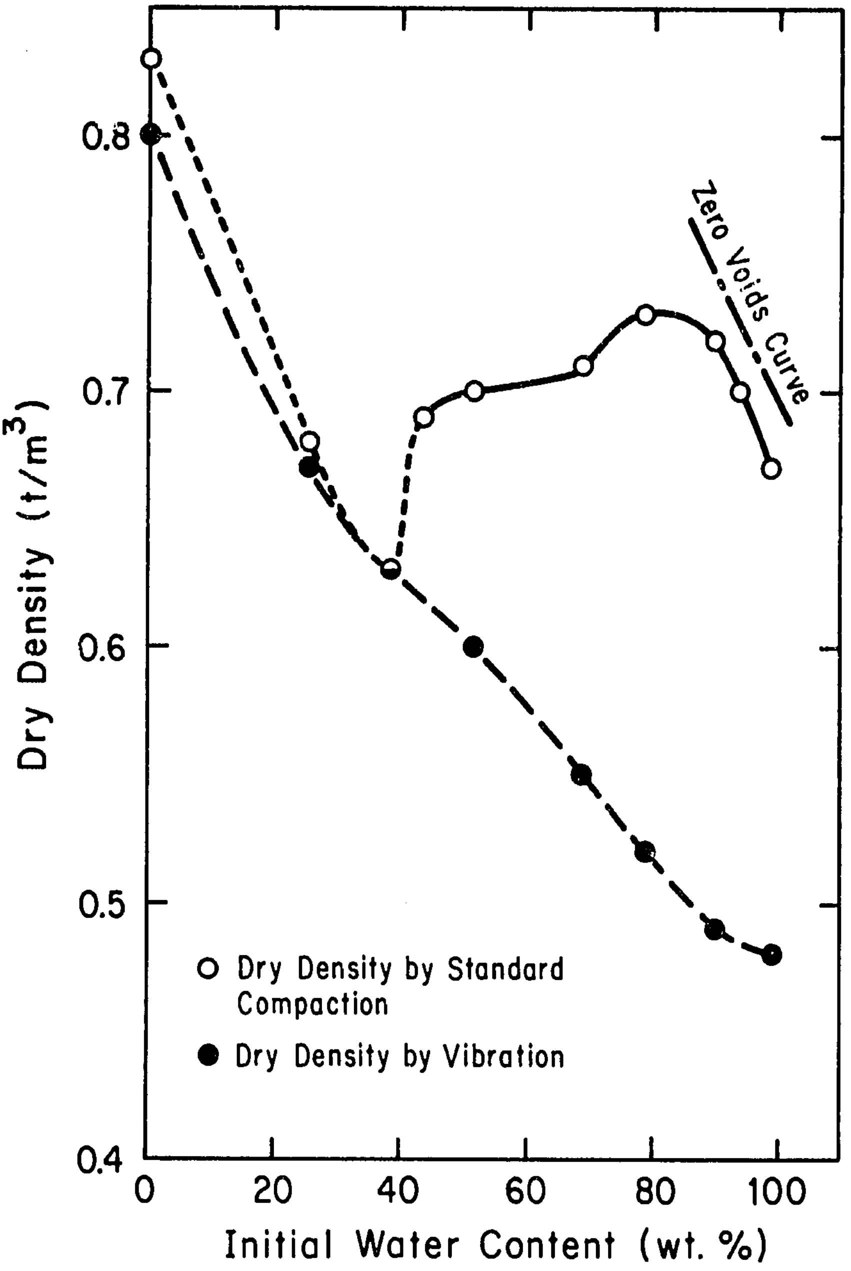

Figure 9. Compaction curves during drying, with different compaction methods, for an Andisol from Japan (Maeda et al., 1983).

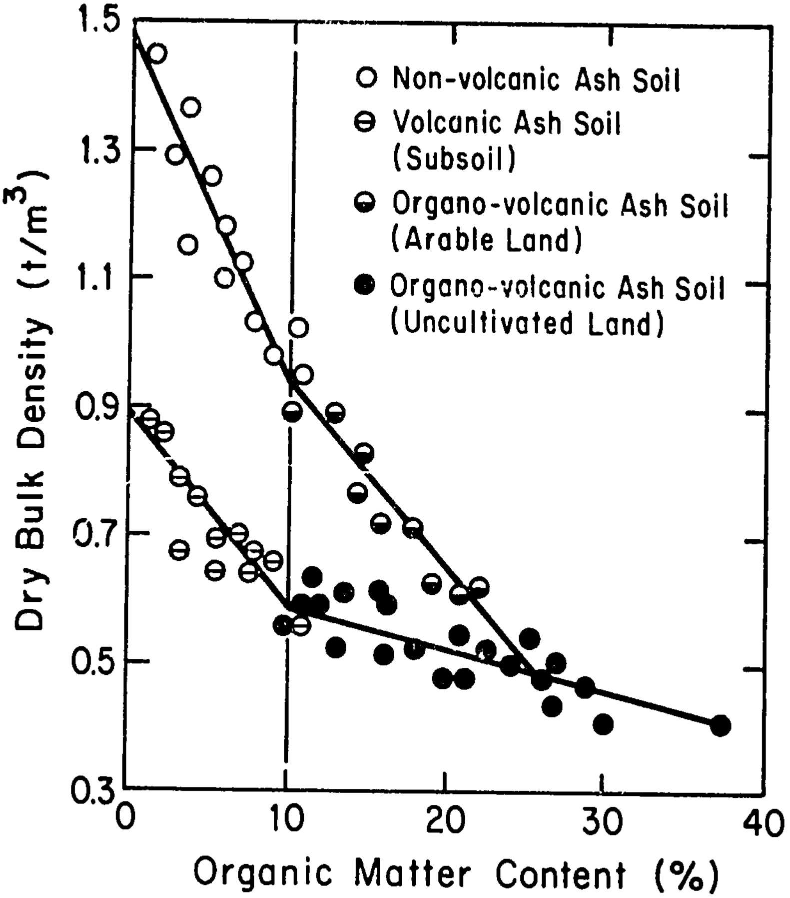

Figure 10. Relationship between dry bulk density and organic matter content of Andisols (Maeda et al., 1983).

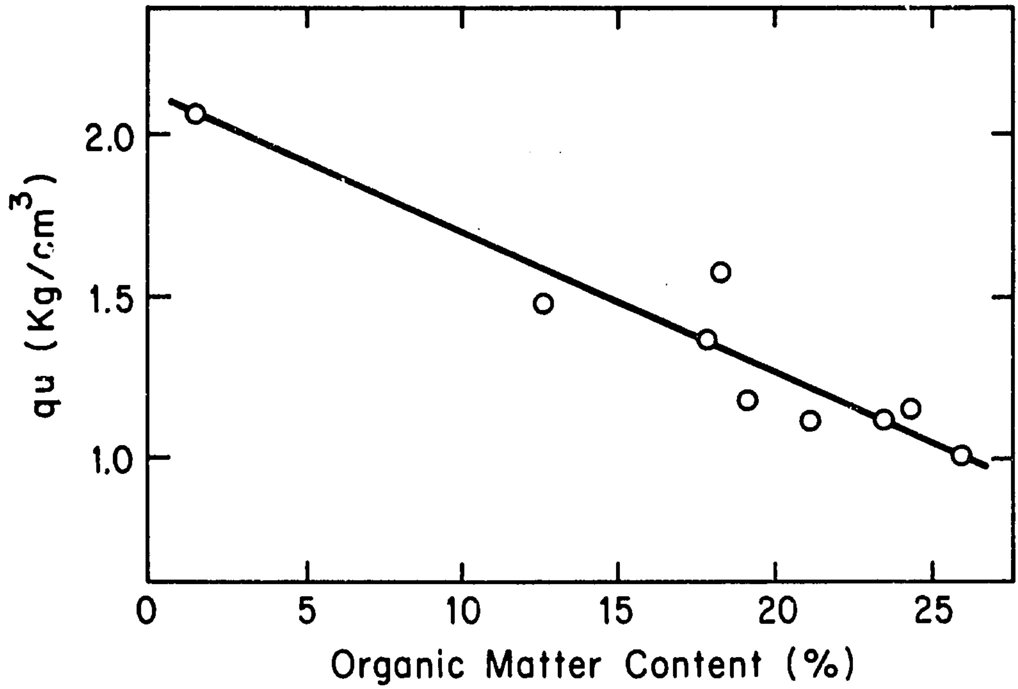

Figure 11. Relationship between organic matter content and maximum unconfined compression strength (Adachi et al., 1977).

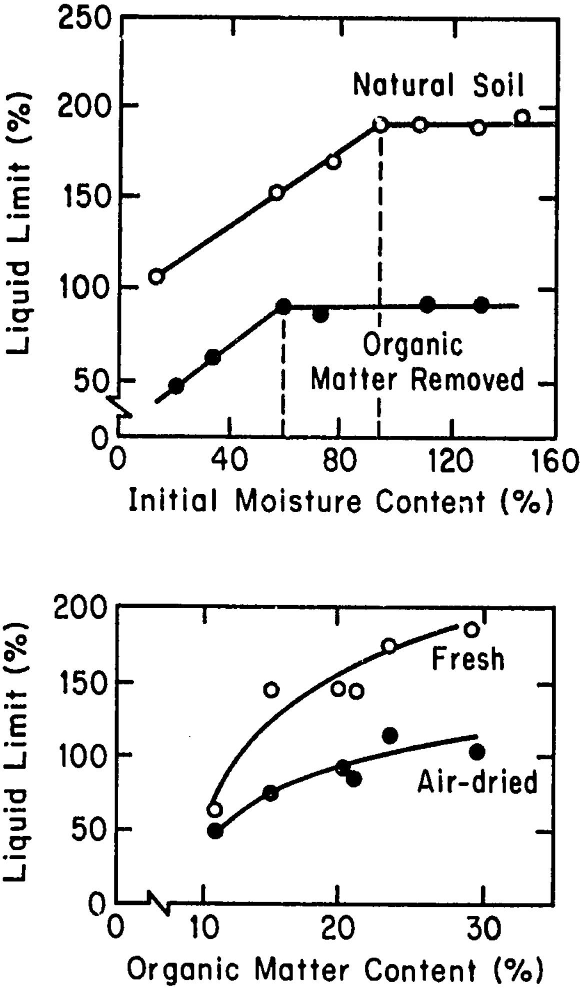

Figure 12. Effect of organic matter content on liquid limit of Andisols (Maeda et al., 1976).

The liquid limit increases with organic matter content. The water content below which irreversible changes occur is higher when organic matter is present.

These are qualitative relationships, established experimentally. It is now known how much of these effects can be explained as properties of mixtures of organic matter and inorganic materials and how much is due to the organic-inorganic bond or to modification of the inorganic surface due to adsorbed organic molecules. For example, Chassin and Le Berre (1978) have shown that hydration properties of an Andisol depend upon configuration of adsorbed organic macro-molecules.

Characterization of the organic-mineral particles is required, followed by a study of engineering behavior.

THE "VITRIC" ANDISOLS

Vitrandepts containing volcanic glass are similar in engineering behavior to sandy soils with the same grain-size distribution. Basic mechanics and experience with sandy soils will be adequate guides for engineering uses. Smoothness of surfaces of the glass grains will affect friction parameters and compressibility. Pumice grains, however, are different because of high internal porosity and low crushing strength. This section will concentrate on soils dominated by pumice.

There is considerable literature, especially in Japanese journals, describing engineering and physical characteristics of pumice soils. Warkentin and Maeda (1980) give a brief review. The most important physical property is the porosity of pumice grains--the nature, size, and volume of pores. This in turn is determined by nature of the eruption and stage of weathering.

Intra-particle or internal pores in unweathered pumice may have few connections to the particle surface, and hence are "dead-end" pores. Weathering will expose these pores and allow them to adsorb and release water. Different sources of pumice and different stages of weathering, therefore, result in a range of effectiveness of intra-particle pores. Sasaki, et al. (1969) describes three kinds of "active" intra-particle pores, depending upon the ease of movement of water into and out of the pores.

Water retention is lowest in unweathered, coarse-particle pumice. As weathering proceeds, more intra-particle pores become active, and water retention increases. Values up to 100% water at pF 4 have been measured (Maeda, et al., 1970). Soils containing weathered pumice often have plant-available water capacities which are much larger than those for other soils of the same grain-size distribution.

The amount of water available to plants cannot be calculated from water retention curves. First, the layering of typical pumice soils, with many ash falls, influences the amount of water retained at field capacity. Usually the water content is higher than predicted from water retention curves. Secondly, the structure of pumice soils, with interlocking grains to give discontinuous pores often restricts root growth. So while water is available at normal rooting depth, it cannot be used by the plant.

Heat conductivity of soil is important in frost penetration and in dissipating heat from buried power lines. The heat capacity of pumice particles is about one-half that of crystalline sand grains. The thermal conductivity and thermal diffusivity (which relates temperature changes to the temperature gradient) are also low. This results in slow warming of the soil and slow dissipation of heat.

SUMMARY

Implications for classification of Andisols

1. A bulk density of 0.85 tm^{-3} appears to be a good dividing line to identify soils developed on volcanic ash.

2. The bulk density change from field (natural) water content to 0.3 bar (-0.03 MPa) may be sufficiently small that it will be unnecessary to specify bulk density at a particular soil water potential. Bulk density should be measured at field water content.

3. Grain-size distribution measured on undried samples will probably be a useful index when the relationships with engineering behavior have been determined.

4. The correlation of clay content measured in the laboratory with hand "texturing" in the field is not the same for Andisols as for soils with crystalline clay minerals. New relationships should be established if grain size is to be used as an index for soil behavior.

5. For any analyses, the sample treatment should always be specified--dried or field water content, sieved or undisturbed, etc. Irreversible changes in physical properties begin at different water contents for different Andisols. The water content at time of sampling (field water content or natural water content) should also be recorded.

6. The "smeariness" of Andisols is a feature recognizable in the field. Since it is not necessarily reversible, i.e. thixotropic, a new term is needed to describe this behavior.

7. Since the irreversible changes on drying are important for engineering uses, a measurement of this change would be useful. Ease of measurement and potential for other uses indicates that wet and dry 15 bar (-1.5 MPa) water contents should be measured for characterization of Andisols.

8. Predictions of erodibility of Andisols based upon empirical relationships with grain-size distribution and infiltration rate established for other soil orders are likely not valid. New relationships are needed based upon the mechanisms of erosion of Andisols.

9. Organic matter content has a large influence on engineering behavior of Andisols. It is not yet possible to use this in classification, because the specific effects of organic matter are not understood.

LITERATURE CITED

Adachi, T., S. Tsutsumi, and H. Takenaka. 1977. Studies on the strength characteristics of organo-volcanic ash soils. Trans. Japan. Soc. Irrig. Drain. Reclam. Engin. 71:39-43.

Brewer, R. 1964. Fabric and Mineral Analysis of Soil. Wiley, New York.

Chassin, P., and B. Le Berre. 1978. Influence des substances humiques sur les propriétés des argiles. IV. Interprétation des propriétés d'hydratation des andosols et des sols sablo-humiféres. Bulletin de L'AFES 3.

Cochran, P. H., L. Boersma, and C. T. Youngberg. 1967. Thermal properties of a pumice soil. Soil Sci. Soc. Amer. Proc. 31:454-459.

Dangler, E. W., and S. A. El-Swaify. 1976. Erosion of selected Hawaii soils by simulated rainfall. Soil Sci. Soc. Amer. J. 40:769-773.

Ellies, A. 1977. Effecto de tenso-activos y oxido de calcio sobre la humectacion y tension superficial del agua en el suelo. Agro-Sur. (Chile) 5:104-108.

Ellies, A., and J. Funés. 1980. Morphologie und Stabilität von Aggregaten aus chilenischen Vulkanasche-Böden. Z. Pflanzen ernaehr. Bodenkd. 143:530-536.

El-Swaify, S. A., and K. R. Cooley. 1980. Sediment losses from small agricultural watersheds in Hawaii (1972-1977). USDA-SEA. ARM-W-17.

El-Swaify, S. A., and E. W. Dangler. 1977. Erodibility of selected tropical soil in relation to structural and hydrologic parameters. p. 105-114. *In* Soil Erosion: Prediction and Control. Soil Cons. Soc. Amer. Spec. Publ. 21.

Hirashima, K. B. 1948. Highway experience with thixotropic volcanic clay. Proc. Hwy. Res. Board 28:481-496.

Kubota, T. 1972. Aggregate formation of allophanic soils: Effect of drying on the dispersion of the soils. Soil Sci. Plant Nutr. (Tokyo) 18:79-87.

Lal, R. 1980. Physical and mechanical characteristics of Alfisols and Ultisols with particular reference to soils in the tropics. p. 253-279. *In* B. K. G. Theng (ed.) Soils With Variable Charge. New Zealand Soc. Soil Sci., Lower Hutt.

Maeda, T., S. Sasaki, and T. Sasaki. 1970. Studies on the physical properties of volcanic soils in Hokkaido. 2. Properties of pumice with respect to water. Trans. Jap. Soc. Irrig. Drain. and Reclam. Engin. 31:25-28.

Maeda, T., K. Soma, and S. Sasaki. 1976. Studies on the relationship between physical properties and organic matter content of soil. Jap. Soc. Irrig. Drain. and Reclam. Engin. 61:9-17.

Maeda, T., K. Soma, and B. P. Warkentin. 1983. Physical and engineering characteristics of volcanic ash soils in Japan compared with those in other countries. Irrig. Eng. and Rural Planning 3:16-31.

Maeda, T., H. Takenaka, and B. P. Warkentin. 1977. Physical Properties of Allophane Soils. Adv. Agron. 29:229-264.

Maeda, T., and B. P. Warkentin. 1975. Void changes in allophane soils determining water retention and transmission. Soil Sci. Soc. Amer. J. 39:398-403.

McNabb, D. H. 1979. Correlation of soil plasticity with amorphous clay constituents. Soil Sci. Soc. Amer. J. 43:613-616.

Northey, R. D. 1966. Correlation of engineering and pedological soil classification in New Zealand. N.Z. J. Sci. 9:809-32.

Okajima, H. 1977. Reclamation and improvement of soils derived from volcanic ash. p. 64-84. *In* Y. Ishizuka and C. A. Black (eds.) Soils Derived from Volcanic Ash in Japan. International Maize and Wheat Improvement Center (CIMMYT), Mexico.

Rousseaux, J. M., and B. P. Warkentin. 1976. Surface properties and forces holding water in allophane soils. Soil Sci. Soc. Amer. J. 40:446-451.

Sasaki, T., T. Maeda, and S. Sasaki. 1969. Studies on physical properties of volcanic soils in Hokkaido, Japan. 1. Pores of pumices. Trans. Jap. Soc. Irrig. Drain. and Reclam. Engin. 27:57-60.

Soma, K. 1978. Studies on the relationship between Atterberg limits and initial water content of soil. Soil Phys. Cond. and Plant Growth (Japan) 38:16-25.

Takenaka, H., T. Adachi, S. Tsutsumi, N. Nagata, H. Kouno, Y. Kodani, and K. Miwa. 1977. Physical properties of volcanic and nonvolcanic ash soils in Japan. Trans. Jap. Soc. Irrig. Drain. and Reclam. Eng. 71:1-7.

Taskey, R. D., M. E. Harward, and C. T. Youngberg. 1979. Relationship of clay mineralogy to landscape stability. p. 140-154. *In* C. T. Youngberg (ed.) Proc. 5th North Am. Forest Soils Conf., Colorado State University, Fort Collins, CO.

Thrall, F. G. 1981. Geotechnical significance of poorly crystalline soils derived from volcanic ash. Ph.D. Thesis, Oregon State University.

Warkentin, B. P. 1982. Importance of soil clay minerals to physical properties of soils. 12th Int. Cong. Soil Sci. 5:394-403.

Warkentin, B. P., and T. Maeda. 1974. Physical properties of allophane soils from the West Indies and Japan. Soil Sci. Soc. Am. Proc. 38:372-377.

Warkentin, B. P., and T. Maeda. 1980. Physical and Mechanical Characteristics of Andisols. p. 281-301. *In* B. K. G. Theng (ed.) Soils with Variable Charge. New Zealand Soc. Soil Sci., Lower Hutt, New Zealand.

Wesley, L. D. 1973. Some basic engineering properties of halloysite and allophane clays in Java, Indonesia. Geotechnique 23:471-494.

Wooltorten, F. L. D. 1954. The Scientific Basis of Road Design. Edward Arnold, London.

Yamamoto, T., and H. W. Anderson. 1967. Erodibility indices for wildland soils of Oahu, Hawaii, as related to soil-forming factors. Water Resources Res. 3:785-798.

Yamazaki, F., and H. Takenaka. 1965. On the influence of air-drying on Atterberg's limit. Trans. Agric. Eng. Soc. Japan 14:46-48.

Yasuhara, K., and H. Takenaka. 1977. Physical and mechanical properties. p. 49-67. *In* T. Yamanouchi (ed.) Engineering Problems of Organic Soils in Japan. J. Soil Mech. Found. Eng., Tokyo.

RATIONALES FOR TAXONOMIC CRITERIA FOR ANDISOLS

USE OF SOIL TEMPERATURE REGIMES IN SOIL TAXONOMY

S. W. Buol

ABSTRACT

Soil temperature is presently used at practically every category in Soil Taxonomy. The impact of soil temperature is essentially the same in all soils and relates most dramatically to agricultural management. Few other soil properties are associated with soil temperature. Therefore, it is proposed that soil temperature in all soils be uniformly recognized at only the soil family category.

INTRODUCTION

Soil temperature regimes are used in nearly every category of Soil Taxonomy. In fact, one may say that a soil temperature regime supersedes all of Soil Taxonomy in that one of the non-soil materials sharing the surface of the earth is permanent ice. However, in this discussion an attempt will be made to present a brief history of how soil temperature criteria were developed, discuss where temperature criteria are presently used in Soil Taxonomy, and consider the unification of temperature criteria at the family category. No attempt will be made to discuss the methods used in measuring soil temperature.

BRIEF HISTORY OF SOIL TEMPERATURE REGIMES

Soil temperature regimes as we know them today were not part of the 7th Approximation in 1960. "Cryudents," "Cryaquepts," and "Cryochrepts" were tentatively defined as having mean temperature less than 8.2°C with a summer temperature less than 15.5°C if cultivated or less than 10°C if an O horizon was present. Family names were not developed in 1960 but it was suggested that they be named for predominant series or as a series of titles that would indicate criteria most appropriate to that subgroup. The example of texture, mineralogy, and consistence was given but no mention was made of temperature.

In the June 1964 draft, temperature was clearly considered a criteria to be used in all families (Table 1). Two items in Table 1 are of specific concern to the discussions of the present International Committees, ICOMAND, etc. First, it was recognized that using the same criteria at two levels in the system was redundant and should be avoided. Second, there were different temperature limits proposed in the iso families than in the non-iso families. No "Trop" great groups were in the system in the 1964 draft so the question of redundancy with "iso" families was not raised. A concern that the temperature limits in the "iso" families should be different from those in the "non-iso" families apparently was never followed and even though the hyperthermic and iso-hyperthermic families were added, the temperature limits became the same in both the intertropical and the temperate latitudes of the world.

The acceptance of soil temperature as a soil property was not unanimous among U. S. soil scientists. Soil temperature was a climatic property in the opinion of many. This position was countered by the argument that sandy texture was the property of sandstone parent material and clay texture was the property of old lake beds, etc. There was also the concern among many soil scientists that no good way existed of measuring or predicting soil temperature. A direct approach finally prevailed in which it was reasoned that if you could put your hand on the soil and feel a sensation of temperature and then insert a thermometer in the soil and measure a temperature, temperature was a soil property. The challenge was to standardize a method of soil temperature measurement that could be repeated by different individuals in different places. The Smith, et al., 1964 publication is strongly recommended for review.

By 1966, in the second Supplement, Tropepts, Tropaquepts, Tropaquods, etc., were in the system. Tropustults were also identified but dropped by 1970.

In the selected chapters circulated in 1970 Pergelic, Cryic, Frigid, Boreal, Mesic, Thermic, and Hyperthermic families were defined essentially as they are used in Soil Taxonomy, albeit Boreal, used for anything colder than Frigid, was later dropped. Isotemperature families, with the same temperature limits as the "non-iso" families, were also listed with no explanation of why the isothermic limit was lowered from 24°C to 22°C.

In the higher categories "Trop" great groups were presented in several suborders of Alfisols, Spodosols, Inceptisols, Entisols, Ultisols and Histosols as well as the Tropepts. Some definitions were limited to isomesic or warmer "iso" soil temperature regimes but in all cases the criteria "mean summer and mean winter soil temperatures differing no more than 5°C at 50 cm or a lithic or paralithic contact, whichever is shallower," was the only criteria to key the suborder or great group.

Table 1. Quoted from the June 1964 "Draft, Subject to Change" material transmitted to Soil Survey Staff and Collaborators via C. E. Kellogg memo June 22, 1964.

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4. Soil temperature: Soil temperature classes, as named and defined in a and b below, are used as family differentiae in all orders. The names below are tentative and are used in the family descriptive name unless the name of the higher taxon carries the same limitation. Thus, frigid is implied in all Cryic great groups, and becomes redundant if used in the family name. However, frigid is not an absolute requirement for all Boralfs, and the names of families of Glossoborals, for example, should indicate whether they are frigid or mesic.

Soil Temperature Classes (at 50 cm [20 in.] depth)

a. Soil with 9° F. or more difference between mean summer (June, July, and August) and mean winter (December, January, and February) temperatures, and with mean annual temperatures as follows:

(1)	less than 47 degrees (8.3°C)	Frigid
(2)	47 to 59 degrees	Mesic
(3)	more than 59 degrees (15° C)	Thermic

b. Soil with less than 9° F. difference between summer and winter temperature and mean annual temperature as follows:

(1)	less than 47 degrees (8.3°C)	Isofrigid
(2)	47 to 75.2 degrees	Isomesic
(3)	more than 75.2 degrees (24°C)	Isothermic

In discussing soil families, it is again pointed out that family names used as family modifiers "unless the name of a higher taxon carries the same limitation. Thus, frigid is implied in all cryic great groups, and becomes redundant if used in the family name." Closely following that statement the heading of a list of all "iso" soil temperature regimes states "(b) Soils with less than 5°C (9°F) difference between mean summer and winter soil temperatures at 50 cm depth, or at a lithic or paralithic contact, whichever is shallower,..." Redundancy between using "iso" families in "Tropo" subgroups and suborders was ignored.

The definitions and procedures outlined above were incorporated in Soil Taxonomy.

Present use of "iso" or "Trop" criteria

Table 2 lists all the suborders where "Trop" is presently used. The "Trop" great groups have been underlined to draw your attention to their location in the sequence of keying. All of the great groups above the "Trop" are allowed to be recognized both in "iso" and "non-iso" soil temperature regimes (except Paleudalf, which is specifically excluded from "iso" soil temperature regimes). Of course, the families of the "Trop" great groups and suborder Tropept are all "iso" soil temperature regimes and those great groups falling below the "Trop" great group are excluded from "iso" or tropical soil temperature regimes.

Table 2. Key sequence highlighting effect of "Trop."

Entisols

Aquents	Psamments	Fluvents	Orthents
Sulfaquents	Cryopsamments	Cryofluvents	Cryorthents
Hydraquents	Torrispsamments	Xerofluvents	Torriuthents
Cryaquents	Quartzipsamments	Ustifluvents	Xerorthents
Tropaquents	Udipsamments	Torrifluvents	Troporthents
Psammaquents	Troposamments	Tropofluvents	Udorthents
Haplaquents	Xeropsamments	Udifluvents	Ustorthents
	Ustipsamments		

Inceptisols

Aquepts	Andepts	Tropepts	Ochrepts
Sulfaquepts	No "Trop" GG	all "iso"	No "iso"
Placaquepts			
Halaquepts			
Fragiaquepts			
Cryaquepts			
Plinthaquepts			
Andaquepts			
Tropaquepts			
Humaquepts			
Haplaquepts			

Spodosols

Aquods	Humods	Orthods
Fragiaquods	Placohumods	Placorthords
Cryaquods	Tropohumods	Fragiorthods
Duraquods	Fragihumods	Cryorthods
Placaquods	Cryohumods	Troporthods
Tropaquods	Haplohumods	Haplorthods
Haplaquods		
Sideraquods		

Table 2. (Continued)

Alfisols

Aqualfs	Ustalfs	Udalfs
Plinthaqualfs	No "Tropo"	Agrudalfs
Natraqualfs		Natrudalfs
Duraqualfs		Ferrudalfs
Tropaqualfs		Glossudalfs
Fragiaqualfs		Fraglossudalfs
Glossaqualfs		Fragiudalfs
Albaqualfs		Paleudalfs (cannot be iso)
Ochraqualfs		Rhodudalfs
		Tropudalfs
		Hapludalfs

Ultisols

Aquults	Humults	Udults	Ustults
Plinthaquults	Sombrihumults	Fragiudults	No "Trop"
Fragiaquults	Palehumults	Plinthudults	
Albaquults	Plinthohumults	Paleudults	
Paleaquults	Tropohumults	Rhodudults	
Tropaquults	Haplohumults	Tropudults	
Ochraquults		Hapludults	
Umbraquults			

Histosols

Folists	Fibrists	Hemist	Saprists
Cryofolists	Sphagnofibrists	Sulfohemists	Cryosaprists
Tropofolists[1]	Cryofibrist	Sulfihemists	Borosaprists
Borofolists[1]	Borofibrist	Luvihemists	Troposaprists
	Tropofibrist	Cryohemists	Medisaprists
	Medifibrist	Borohemists	
	Luvifibrist	Tropohemists	
		Medihemists	

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[1] Wording is such that isofrigid Folists, not cryic, are not provided for if they exist.

Present use of "bor" and "cry" criteria

"Bor," defined simply as colder than 8°C mean annual soil temperature is used as suborder criteria in the Alfisol and Mollisol orders. Cryic criteria, although a bit complicated, attempt to define those boric or frigid soils that have a growing season too short for most common cultivated crops. Isofrigid (less than 8°C) is considered as cryic in *Soil Taxonomy*. Mercifully, when you explain that a Cryoboralf is "cry," i.e. cold in the summer, and "bor," i.e. cold the entire year (what else would you expect if it were cold in the summer?), by convention frigid is not used at the family category. However, this raises the question: Why is temperature more important in the well-drained Boralf soil than in a catenally related Ochraqualf 50 meters away, equally as cold, and where temperature is recognized by a frigid family name?

Table 3 is an incomplete listing of how soil family use of temperature is affected by higher category use of "bor," "cry," and "trop."

Table 3. Examples of the using temperature in higher categories on families (Listed in key sequence).

Alfisols		**Great Groups**	
Aqualfs:	→	Plinthaqualfs	All families
Boralfs:	No temp. families[1]	Natraqualfs	All families
Ustalfs:	No frigid families	Duraqualfs	All families
Xeralfs:	Frigid families	Tropaqualfs	Only iso families
Udalfs:	No frigid families	Fragiaqualfs	Only non-iso families
		Glossaqualfs	Only non-iso families
		Albaqualfs	Only non-iso families
		Umbraqualfs	Only non-iso families
		Ochraqualfs	Only non-iso families

Aridisols: All families are used except some "Bor" great groups which do not use frigid. Both iso and non-iso families.

Entisols:			
	Cryaquents:	No temp. family	Frigid families in most other great groups
	Cryofluvents:	No temp. family	
	Cryorthents:	No temp. family	
	Cryopsamments:	No temp. family	

Histosols:

Saprists: (much the same in Hemist, Folist, and Fibrist)

Cryosaprists:	No temp. families
Borosaprists:	No temp. families
Troposaprists:	Only iso families
Medisaprists:	Only non-iso families

Inceptisols:

Aquepts:	All families
Andepts:	All families
Plaggepts:	All families
Tropepts:	Only iso families (redundant)
Ochrepts:	Only non-iso families
Umbrepts:	Only non-iso families

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[1] Boralfs cannot have Xeric soil moisture regimes.

Table 3. (Continued)

Aquepts:	
Sulfaquepts:	none
Placaquepts:	iso and non-iso families
Halaquepts:	frigid, iso, and non-iso families
Fragiaquepts:	frigid and other non-iso families (potential iso)
Cryaquepts:	use no temperature families (acid-non-acid)
Plinthaquepts:	none
Andaquepts:	frigid, iso, and non-iso families
Tropaquepts:	all redundant iso families
Humaquepts:	frigid and other non-iso families
Haplaquepts:	frigid and other non-iso families
Andepts:	
Cryandepts:	no temperature families
Durandepts:	none
Hydrandepts:	all iso to date (thrixotropic seems redundant)
Placandepts:	all iso but not redundant
Vitrandepts:	frigid, iso, and non-iso families
Eutrandepts:	frigid, iso, and non-iso families
Dystrandepts:	frigid, iso, and non-iso families
Mollisols:	like Alfisols
Oxisols:	no high cateogry temperature use: all temp. families possible
Spodosols:	Cry and Tropo use: no use of "Bor"
Ultisols:	order excludes frigid Tropo used with redundant "iso"
Vertisols:	no high category use of temp. frigid, iso, and non-iso families used

DISCUSSION

There is no doubt the system works the way it is and perhaps we should adhere to the country adage "if it's not broken, don't fix it." But, the inconsistent use of identical criteria is difficult to explain. Certainly, a desire to simplify the systematics of Soil Taxonomy motivates the following proposal. The genetic implications of using temperature criteria at a high level are also of concern. In this respect, note that the central concepts of several suborders, i.e. the Hapludults, Ochraqualfs, Ochraquults, etc., become separated from their tropical (iso) counterparts with the present use of "Tropo." This permits the perpetuation of the myth that soils in the tropics are uniquely different just because they are in the tropics. We now recognize that the "iso" criteria defines that unique "tropical" difference better than any other criteria we can measure in the soil. While "iso" criteria is of paramount importance in the interpretations we make about soils, it does not appear to have had any marked effect on any of the other soil properties.

The properties defined by "iso" do greatly influence the agronomic use of a soil. Some of these are photoperiod, planting dates, sequence or rotation of crops, disease and insect control as well as obvious crop selection. The most significant point, however, is that where present, the "iso" criteria defines a soil condition that affects the use of every soil, regardless of its other characteristics, in very nearly the same way. For example, if a Tropudult is recommended for sugar cane because of its "iso" properties so are the Paleudults, Udipsamments, and Plinthaquepts occurring in the same field. The soil property that qualifies them for sugar cane is the "iso" thermic soil temperature regime. With the present system, this is identified for both the great group and family categories in the Tropudult, but only at the family level in the Udipsamments, Plinthaquepts, and Paleudults.

One of the advantages of a hierarchical system of taxonomy is that it allows a scientific discipline the opportunity to structure what it considers its most important knowledge to peer scientists in other disciplines. Higher categories of a taxonomic system should be useful in providing names for use in small scale maps. Are we really communicating information of substance when we map Cryoboralfs, in the high latitudes, Hapludalfs in the temperate zone and Tropudalfs in the tropics? And, by omission at the same level, we are saying the properties of Paleudults or any of the "Ustalfs," Ustults," Mollisols and Vertisols are so important that "iso" criteria should not be recognized at a high category? The tendency to convey importance of a property by the category in which it is used in a hierarchical system is one adverse effect of such a system in soils where one has to know the intended use to evaluate the important of the property.

In the section on "Forming and Defining Taxa" (p. 10 of Soil Taxonomy) it is written:

> "Because we want to be able to make the most important statements possible about taxa, those properties that are important to plant growth and that result from or influence soil genesis should be considered in the higher categories. Those that are important to plant growth but are unrelated to genesis should be considered only for the lowest categories. For example, in soils that are only slightly weathered, the nature and

> amount of clay may be the result of geologic accidents."
>
> . . .
>
> "Although the difference between illite and montmorillonite is important to plant growth, it should be used as a differentiating characteristic only in a low category."

Few, if any, pedologists would argue that temperature is not a factor in soil genesis. However, the morphology imprinted on a soil by temperature (excluding permafrost) may be realized only after long periods of pedogenesis. The impact of soil temperature on plant growth is direct, obvious, and most importantly independent of other soil properties. It is best expressed uniformly at the family category.

Potential alternatives

In view of the fact that: 1) soil temperature regimes most clearly manifest themselves in the agronomic interpretations made of a soil, and 2) soil temperature regimes are similar in their influence on the agronomic interpretations of all soils almost regardless of other soil properties, a uniform recognition of the soil temperature properties in all taxa is proposed.

The following proposal would not lose any soils in Soil Taxonomy but simply restructure those that are identified by temperature at a high category.

1. Eliminate all "Trop" criteria that are identified as "iso soil temperature regime." Any "Trop" defined by criteria other than soil temperature would not be affected. This creates uniform recognition in all soils at the iso family level.

2. In the iso soil families, recognize temperature ranges considered important to tropical crops instead of the present ranges borrowed from the temperate zone.
   (a) One limit proposed is isofrigid or perfrigid (see below) as mean annual soil temperature of less than 10°C rather than the present 8° C limit.

3. Use perfrigid families for present Cryic criteria (leaving Pergelic for permafrost), thereby unifying this interpretative feature in all soil orders.

4. Replace all higher categories defined as "bor," but not "cryic" with frigid families. (Note, if it is an isofrigid Boralf, it would be a perfrigid family with a 10°C MAST warmer limit.)

It is also suggested that ICOMMORT explore additional soil family groupings that consider major crop or cropping system requirements. One suggestion is to define a limit to citrus and/or sugarcane production by perhaps combining hyperthermic with an iso-soil family. It seems artificial to separate iso from non-iso when the non-iso gets warm enough that crop production is not limited by seasonal temperature.

SUMMARY

Temperature regime had a difficult time being accepted as a soil property. Once accepted, it often became the tool to geographically separate certain soils while other soils were allowed to range over the same limit, often because they were less well understood. Most of the soil temperature criteria used in higher categories started before the family criteria were established. The resulting nonsystematic use of identical criteria creates unnecessary complication in Soil Taxonomy. Most of you may recall Guy Smith's statement at a meeting such as this in Bangkok. As we contemplated a complicated definition he said simply, "Have compassion for the students who have to learn the system." Uniform and consistent recognition of soil temperature criteria at the soil family category simplifies the system not only for those that will learn it but also for those that attempt to use and interpret it.

LITERATURE CITED

Smith, G.D., F. Newhall, L.H. Robinson, and D. Swanson. 1964. (Reprinted in 1970). Soil Temperature regimes--their characteristics and predictability. USDA-SCS-TP-144.

SOIL CLIMATIC REGIMES AS CRITERIA FOR ESTABLISHING SUBORDERS OF ANDISOLS

A. Van Wambeke

Soil Taxonomy (Soil Survey Staff, 1975) considers each taxon to be a separate kingdom which can be subdivided and structured independently without concern for other taxa.

Andisols are being proposed at the order level. They can therefore be classified in a way which seems most appropriate to the classifiers. In spite of this freedom, the developers of the Andisol classification have closely adhered to the classical framework of Soil Taxonomy which uses soil climatic criteria at the suborder level. The first proposal (Smith, 1978) and subsequent ICOMAND circular letters (1979-1983) distinguish suborders on the basis of soil moisture and temperature regimes. There have been no attempts to use the marks which soil climates imprint on the soils to recognize the suborders instead of the soil climatic regimes themselves.

The purpose of this paper is to explain the use of climatic regimes in Soil Taxonomy, with special reference to Andisols, and to introduce a discussion among the participants to the ICOMAND workshop.

WHY CLIMATIC PROPERTIES IN SOIL TAXONOMY?

It is a controversial issue whether soil climate as such (soil temperature, soil moisture regime, etc.) is a property that can be used as a valid criterion to classify soils. The controversy arises each time soils of one climatic region are compared with soils of another region. Some classifiers contend that climatic differences are not significant, or that soil temperature and soil moisture which continuously change over time are not soil properties. Others, on the contrary, are not satisfied when a class indiscriminately contains soils from contrasting climatic environments.

Soil Taxonomy is a system which considers soil temperature and moisture to be soil properties. For Soil Taxonomy, a soil is a thing out of doors with climatic attributes that strongly influence soil genesis as well as root growth. Taken out of its environment, a pedon is not a soil anymore but an incomplete sample which has lost a considerable part of the differentiating characteristics that are important for the objectives of the classification.

THE MOISTURE CONTROL SECTION IN ANDISOLS

The intent of the soil moisture control section is to facilitate the estimation of soil moisture regimes from climatic data.

The upper boundary is the depth to which a dry (tension >1500 kPa, but not air dry) soil will be moistened by 2.5 cm of water within 24 hours. The lower boundary is the depth to which a dry soil will be moistened by 7.5 cm of water within 48 hours. Soil Taxonomy does not state how water is applied to the soil during moistening.

The moisture control section of a Taupo soil, a Typic Vitrudand (ICOMAND Circular letter No. 2) with approximately 30% by volume available water capacity would be located between 8.3 and 25 cm depth. For pedon 6 of Soil Taxonomy (1975), an Hydric Dystrandept, the boundaries would be 11 and 30 cm depths respectively. For pedon 71, a Typic Cryandept, the moisture control section would extend from 7 and 19 cm. All these values are obtained by calculations which use laboratory data; they are considerably less than the moisture control section boundaries obtained for other soils having comparable textures.

Although considerable care should be exercised when calculating these boundaries from analytical data obtained on allophanic soil samples (which may or may not have been air-dried), appropriate methods should be developed. The shallow diagnostic control sections, the open structure of surface layers, and higher hydraulic conductivities may distort estimates of moisture regimes in Andisols.

It should be noted that the methods for determining soil moisture regimes for classification purposes at the suborder level should not necessarily be the same in all orders. In Vertisols, other criteria are used, e.g. the time that cracks stay open during one year. For Andisols a fixed size moisture control section may perhaps better serve this purpose.

THE PLACE OF SOIL MOISTURE REGIMES IN SOIL TAXONOMY

The suborder is the level at which soil climate as such is most commonly used to differentiate taxa. This property is considered to be important enough to influence soil genesis significantly; the definitions of the classes, however, are very broad (see Table 1) and generally cannot serve direct land-use interpretations for detailed soil surveys.

One of the major objectives of placing soil moisture regimes at a high level in the classification is to facilitate small-scale mapping for which series and family delineations are too small to be legibly represented. Another is to account for the high number of accessory characteristics that are common to most soils that have a similar climate. Soil Taxonomy lists: "the amount of distribution of organic matter, the base status of the soil and the presence or absence of salt." Smith (1981) stated we "must consider all of the properties we know, realizing that there are probably many that we do not know."

Soil Taxonomy recognizes that soil moisture regimes may have changed during the history of a soil and that many actual properties may have formed during previous geological times. If those past climates left marks in the soil, which are used to differentiate orders in the classification system, then no need is felt to make an additional reference to the past climate in the suborder definition. Therefore, at the suborder level the emphasis is placed and soils are grouped on the basis of the present climatic conditions which determine the actual soil-forming processes, and not on the basis of past soil climates.

POSSIBLE CLIMATIC SUBORDERS IN ANDISOLS

Two questions may be raised. The first relates to the range of soil climatic regimes which actually occur in soils developed in volcanic ash. The second question deals with the kind of criteria which can be used to recognize soil climatic suborders.

Present knowledge seems to indicate that for well-drained sites, andic[1] properties almost exclusively develop in soils with udic and perudic moisture regimes. Maldonado (1973) found that drier soil conditions rapidly lead to the formation of crystalline clays. Langohr (1975) correlates the extent of Trumao soils in Chile to areas which receive more than 1,250 mm rain per year. Present criteria (ICOMAND, 1983) applied to soils of Hawaii eliminate from Andisols soils which are presently classified as Eutrandepts, a great group which is

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[1] The soil material has: (1) a bulk density at 1/3 bar water retention of the fine earth of less than 0.9 g/cc and has (2) P-retention value of more than 85% and has (3) either an acid oxalate extractable Al value of 2.0% or more, or a 4 M KOH extractable Al of 1.5% or more. (ICOMAND No. 5, 1983).

often thought to have an ustic moisture regime. From these observations one may draw the conclusions: (a) that the distribution of soils with andic properties probably does not justify the creation of "dry" climatic suborders such as Xerands and Ustands; (b) that in Andisols the dominance of amorphous materials is a mark of soil climate, and as such could be used to distinguish a suborder, for example, Orthands.

The younger Andisols which only display vitric[2] properties occur under a wide range of climatic conditions from perhumid to arid. Their importance in extent or specific use may or may not justify the establishment of suborders based on soil climate. The "vitric" soils do not show the marks of the environment which would be specific to Andisol formation. The absence of a climatic Andisol imprint on the soil could be used as a criterion to recognize a suborder, for example Vitrands.

Other suborders which follow subdivisions which are commonly applied in other orders need no detailed justification. Aquands and Borands would be equivalent to suborders in other orders. The criteria to recognize them in Andisols may differ, but no conceptual conflicts seem to emerge. This rationale results in four suborders with climatic background: Aquands, Borands, Vitrands, and Orthands.

The ICOMAND proposals have discussed other kinds of Andisols which may have marks of soil climate. In 1983 "melanic" great groups were recognized. They are characterized by high organic matter contents and dark colors. No clear intent in the establishment of these melanic taxa is given. If they are temperature-related, the upgrading at suborder level could be considered, and research on tailoring the differentiating properties to the intent may lead to the establishment of a solid suborder. At present it may be useful to test the significance of a Melanand suborder.

The second question relates to the kind of criteria to be used to recognize suborders in Andisols. No attempts have been made to identify morphological, mineralogical or chemical properties which could be used as sure marks of soil climatic regimes, except for Aquands. Allophanic soils are strongly reactive to environmental conditions, and are young enough not to have inherited the marks of past climates.

It may be worthwhile to test properties such as calcic horizons, soft powdery lime, hydrous properties, organic matter

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[2] The soil material has: (1) more than 60% by volume as cinders, pumice or pumice-like material or more than 40% by weight of the sand fraction as volcanic glass <u>and</u> (2) either an acid-oxalate extractable Al value of 0.4 or more, or a 4 M KOH Al value of 0.3% or more. (ICOMAND No. 5, 1983).

per unit volume, placic horizons, percentage water retention, loss on drying, etc., as indicators of processes related to soil climate.

A special case is the aquic moisture regime: in many allophanic soils reducing conditions do not seem to produce the grey colors that are usually observed in other orders, and some research to establish reliable norms is needed.

SOME SPECIAL SUBORDERS

The August 1983 proposal for Andisols recognizes six suborders: Allands, Borands, Torrands, Xerands, Ustands, and Udands. Four of them are based on soil moisture regimes. Some comments follow:

Torrands

In Soil Taxonomy (1975) not all soils with an aridic moisture regime key out as Aridisols.

The pedons which are taken out of Aridisols are those which present strong diagnostic features of "mature" orders such as the oxic horizon, the mollic epipedon, slickensides or an argillic horizon underlying a hard-setting massive surface horizon. The order of Aridisols, however, retains profiles with incipient horizon development and an aridic moisture regime.

The 1983 ICOMAND proposal departs somewhat from this approach. Vitric properties, which only indicate an initiation of soil development would be used to exclude soils from Aridisols. One may question whether vitric properties are a strong enough expression of development to override the aridic soil moisture regime and eliminate soils from Aridisols.

Tropands

Tropands were proposed by Smith in 1978. They have not been retained in the 1983 proposal.

There have been confusing statements about the meaning of the Trop-prefix. Soil Taxonomy in its chapter on nomenclature gives a connotation of "humid and continually warm." In Soil Taxonomy the separation of Trop-great groups is always based on the iso-temperature regime criterion which is only applied to soils with an udic or with an aquic moisture regime. It is only at later stages that proposals were made to introduce tropo-great groups in soils with ustic moisture regimes. They have not been implemented however.

The proposal to use the prefix Trop for designating Tropands on the basis of an isohyperthermic temperature regime (ICOMAND, 1983) departs from the original intent. Another prefix (for example, Cal, indicating heat) may be a better choice.

The reasons for introducing Tropands in 1978 were the same as those which had justified Tropepts at earlier times: the Inceptisols in the tropics could not be satisfactorily subdivided into Ochrepts and Umbrepts on the basis of criteria developed at high latitudes. Smith (1978) wrote "In warm, humid, intertropical areas, colors seem poorly related to carbon, CEC, or any other property, and somewhat different differentiae seem to be needed." For these reasons, Inceptisols occurring at low latitudes were grouped at a higher level, as Tropepts.

The classification mechanism by which a high category taxon is created in order to increase the effectiveness of a set of differentiating characteristics has not always been well understood. Histosols, for example, are recognized because mineral soil properties are ineffective to separate meaningful groups in organic soils. Andepts were established and Andisols are now proposed because the properties that are used to distinguish soils in other taxa do not isolate useful groups in soils developed from volcanic ash. Smith (1981) stated that "not any property is equally important in all soils." Conversely, criteria are said to be used above their ceiling of independence when they start to separate like things (Cline, 1949). To raise that ceiling, it is often necessary to create a taxon at a higher categorical level which then protects the new group as a kingdom in which the set of criteria satisfactorily subdivides the soils. Tropepts were established and Tropands were proposed (Smith, 1978) for that reason.

SOIL TEMPERATURE REGIMES

The rationale for classes of temperature regimes were given by Smith (1981) as follows:

> "One of the aims of Soil Taxonomy was to classify the soil series of the United States without requiring more changes in their definitions than necessary to improve interpretations. The series very commonly differed if the general type of farming or land use differed. Thus, there were few series that were extensive in both the cotton belt and the corn belt. The mean annual soil temperature limit between these belts is 15°C, and this became the limit between thermic and mesic temperature regimes. The coldest limit of the corn belt is about 8°C and this is also the limit between spring and winter wheat on the Great Plains."

> "In addition to land use at this limit, the great soil groups commonly are different and hence the series differed. So, 8°C became the limit between mesic and frigid. The distinction between the frigid and the cryic regime was intended to sort out the soils that had summers too cold for most cultivated crops, but few data were available on the summer soil temperatures and the limits do not seem entirely satisfactory. Few maps have been made of the cryic soils and few series exist. The 22°C limit coincides with the northern limit of citrus and winter vegetables in Florida, Texas and Arizona and became the limit between thermic and hyperthermic."

There have been several requests to change the lower limit of isomesic from 8°C to 10°C. The earliest one was in the 1960's; all of the requests were the result of surveys carried out in the Andes which indicated that in iso-temperature soils the 10°C mean annual soil temperature (MAST) boundary coincided more closely with vegetation types and cropping areas than the 8°C limit. This is an example of a criterion (8°C) being used above its ceiling of independence (iso-temperature) which restricts its range of applicability. A more satisfactory classification is obtained when the iso-criterion is given priority above the mean annual soil temperature.

THE ISO-TEMPERATURE CRITERION

This ICOMAND Workshop considers soils located at low and high latitudes. It is appropriate to discuss the iso-temperature concept.

Iso-temperature regimes are regimes in which the difference between the average winter and summer soil temperatures at 50 cm depth is less than 5°C. They mark the areas where variations in monthly soil temperatures are not determinants of growing seasons. The intent of iso-criteria often is to designate soils that receive more rain during the summer months than during the winter months. Except for land at very high elevation, soils with iso-temperatures never freeze.

The iso-temperature characteristic is used at different levels in Soil Taxonomy. It has a number of accessory properties which are important for the objectives of the classification.

There is no concentration of leaf fall from vegetation at the time the soil is moist. No litter is soaked by rain or snow to produce organic extracts which have a marked effect on the mobility of soil constituents and enhance the translocation of clay-size substances in the profile. Horizon differentiation in the surface layers is usually less pronounced in soils with iso-temperatures than in soils with non-iso regimes, although more statistical evidence for this is needed. Humus accumulation at low latitudes follows distinct patterns depending on N accretion and organic matter decomposition rates.

Summer rains which moisten the soil when temperatures are high increase weathering rates significantly. This, however, is not restricted to soils with iso-temperature regimes, and many soils under non-iso monsoon climates may be subject to the same decomposition intensities.

Considering practical applications, the soils that are seasonally dry and have an iso-temperature regime differ from soils in temperate regions in that (a) the growing season generally starts with a dry soil which is to be moistened by rainfall, and not with a moist soil which gradually warms up. Water shortage is seldom a problem for seed emergence and root initiation in temperate regions. On the contrary, in the tropics dry spells at the beginning of the rainy season are extremely critical for crop production; (b) at the onset of the rains after a dry season, rapid mineralization of plant residues releases an excess of nitrates which are leached very rapidly by increasing rainfall. The nitrogen flush is a typical phenomenon in seasonally wet and dry tropical regions; (c) summer rainfall areas which receive most precipitation when the sun is directly overhead, do not benefit from leaching of excess salts during a cold, wet winter. There is instead usually a hot dry season. Therefore the drainage of irrigated land is more critical to prevent soil salinization than it is in Mediterranean regions which receive rain when evapotranspiration is low; (d) there is no freezing of moist soil which may favorably alter the structure of the top layers for root growth, particularly in massive hard-setting surface horizons.

SUMMARY AND CONCLUSION

Andisols occur under many soil climatic conditions; broad classes based on soil moisture and temperature regimes can be recognized at suborder level. They are useful for naming soils on small-scale maps.

The acceptance of soil climatic properties as criteria to classify soils is a matter of agreeing on the common objectives of the classification system. The level at which these properties are used depends on the relative weight attached to each of them.

The rationale adopted by Soil Taxonomy to use soil moisture and temperature regimes for the identification of suborders can be maintained for Andisols. This can be achieved either by taking the climatic regimes themselves as suggested in the 1983 proposal, or by accepting certain morphological properties as results and sure marks of climatically induced processes. The most appropriate choice between these alternatives can be made by testing several grouping strategies on a set of Andisol pedons for which the classification would conceptually be agreed upon. Much would be gained if the importance of Xerands and Ustands having andic properties could be assessed. If not important, the Orthand concept may offer a possibility to set up the suborders.

Other considerations may help to make decisions. Proposals for amendments to Soil Taxonomy are said to need testing. However, little is known about the criteria which will be used for testing. Mapability of taxa, ease of identification, significance to land use, correspondence with the distribution of soils in the landscpe, adherence to the general framework of Soil Taxonomy, genetic implications, information content relevant to the objectives of the classification, are all considerations which may influence classification strategies.

The relative geographic importance and distribution of proposed taxa, the effectiveness of the suggested differentiating characteristics with regard to the objectives of the classification should lead to groupings of volcanic ash soils which should satisfy most of us.

LITERATURE CITED

Cline, M. G. 1949. Basic principles of soil classification. Soil Science 67:81-91.

ICOMAND. 1979-1983. Circular letters 1-5. Soil Bureau, DSIR, Private Bag, Lower Hutt, New Zealand.

Langohr, R. 1975. Bijdrage tot de kennis van de bodemgesteldheid en de kwartairgeologie van de centrale vallei in Midden Chili. Doctoral Thesis. University of Ghent, Belgium.

Maldonado, F. 1973. A climosequence in the Chota-El Angel valley in Ecuador. Doctoral Thesis. University of Ghent, Belgium.

Mill, J. Stuart. 1981. A system of logic. Longmans.

Newhall, F. 1972. Calculations of soil moisture regimes from the climatic record. Revision 4. Soil Conservation Service, U.S. Dept. Agric.

Smith, G. D. 1978. A preliminary proposal for reclassification of Andepts and some andic subgroups. Soil Bureau, DSIR, Private Bag. Lower Hutt, New Zealand.

Smith, G. D. 1981. Soil climate in Soil Taxonomy. *In* Proceedings Third Int. Soil Classification Workshop. F. H. Beinroth and A. Osman (eds.) p. 1-10. ACSAD, Damascus, Syria.

Soil Survey Staff. 1975. Soil Taxonomy. Agric. Handbook No. 436. Soil Conservation Service, U.S. Dept. Agric., U.S. Government Printing Office, Washington, D.C.

Table 1: Summary Identification Key of Soil Moisture Regimes[1] (except Aquic[2])

1) Soil moisture regimes, where the MCS[3] in most years is:

    a) dry in all parts for more than half of the time (cumulative) that the soil t° at 50 cm is >5°C, and

    b) never moist in some or all parts for as long as 90 consecutive days when the soil t° is > 8°C. ARIDIC

2) Other regimes where the MCS in 6 or more years out of 10 is:

    a) dry in all parts for 45 consecutive days or more within the four months that follow the summer solstice, and

    b) moist in all parts for 45 consecutive days or more within the four months that follow the winter solstice, and

    c) MAST[4] < 2°C, and

    d) DIF[5] ≥ XERIC

3) Other regimes in soils that have a temperature regime warmer than cryic and where in most years the MCS is dry in some or in all parts for 90 or more cumulative days. USTIC

4) Other regimes:

    a) if precipitation exceeds evapotranspiration in all months in most years PERUDIC

    b) if in most years at least one month has a higher potential evapotranspiration than rainfall. UDIC

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[1] The soil moisture regime refers to the presence or absence either of groundwater or of water held at a tension of less than 1500 kPa in the soil or in a specific horizon by periods of the year. A part of the soil in which all water is at more than 1500 kPa tension is called dry. A part of the soil which contains water at less than 1500 kPa tension is called moist.

[2] The aquic moisture regime implies a reducing regime that is virtually free of dissolved oxygen because the soil is saturated by groundwater or by water of the capillary fringe.

[3] MCS: Moisture control section: its upper boundary is the depth to which a dry (tension > 1500 kPa but not air dry)

soil will be moistened by 2.5 cm of water within 24 hours. Its lower boundary is the depth to which a dry soil will be moistened by 7.5 cm of water within 48 hours.

[4] MAST: Mean annual soil temperature in °C.

[5] DIF: Difference between winter and summer soil temperature at 50 cm depth (winter or summer t° refers to averages of June, July, August, or December, January, February).

THE CASE FOR RECOGNIZING A SUBORDER OF NON-ALLOPHANIC ANDISOLS (ALLANDS)

S. Shoji, T. Ito, M. Saigusa, and I. Yamada

ABSTRACT

The authors studied 14 pedons of non-allophanic Andisols having the udic soil moisture regime. All the pedons had distinct morphological characteristics common to allophanic Andisols, such as: 1) very dark, thick A1 horizons, 2) granular or crumby structure in the upper part of profiles, and 3) friable to very friable consistence. Non-allophanic Andisols had the clay fraction dominated by 2:1 layer silicates. Several distinctive properties of non-allophanic Andisols were certainly attributable to these minerals. Almost all of the soil samples from humus horizons contained 8% or more organic C. In contrast to allophanic Andisols, non-allophanic Andisols mostly had very strong acidity, high exchangeable Al, and high exchange acidity (Y_1). All the non-allophanic soils showed pH(NaF)>9.4 and P retention > 85%. It was indicated that the main active Al reacting with fluoride and phosphate is Al complexed with humus. Almost all the soil samples had trace to small amounts of Sio, reflecting the absence or virtual absence of allophane and imogolite. Though the Alo contents of soil samples were considerably variable, almost all of them contained Alo > 1%. Bulk density was < 0.9 for almost all soil samples. There were several significant dissimilarities between non-allophanic Andisols and allophanic ones, such as absence or virtual absence of allophane-imogolite and abundance of 2:1 layer silicates, Al complexed with humus as the main active Al, very strong soil acidity, critical pH(H_2O) of about 5, high Al saturation, high exchangeable Al, and Al toxicity. Therefore, it is reasonable to recognize a suborder of non-allophanic Andisols 'Allands.'

INTRODUCTION

There are many non-allophanic Andisols in northeastern Japan. Though they have the clay fraction dominated by 2:1

layer silicates, they show unique physical and chemical properties that are most common to allophanic Andisols (Shoji and Ono, 1978; Shoji and Fujiwara, 1984). Therefore, it is clear that the unique properties of Andisols are now always attributable to allophane or 'amorphous material.'

In order to classify adequately non-allophanic Andisols into a new soil order Andisols, it is necessary to show basic properties of non-allophanic Andisols and to establish criteria required for their classification. For these purposes, we will report: 1) morphology and genesis of non-allophanic Andisols, 2) mineralogical, chemical, and physical properties of non-allophanic Andisols, 3) necessity of recognizing a suborder of non-allophanic Andisols 'Allands,' and 4) criteria required for 'Allands.'

ENVIRONMENTAL FACTORS

As shown in Table 1, the authors studied 14 pedons of non-allophanic Andisols from different districts of Japan: 11 pedons from Tohoku (northeastern Japan), a pedon from Hokkaido (north island), and 2 pedons from Chugoku (southwestern Japan). The mean annual temperature is 7-15°C and the mean annual rainfall is 1000-3000 mm in the study areas. All the pedons have the udic soil moisture regime.

The parent materials are repeated ash falls belonging to rhyolite, dacite, or andesite. The ash is characterized by predominance of non-colored volcanic glass with very siliceous composition. The age of parent ash widely differs, reflecting intermittent volcanic activity.

Most sampling sites are flat or nearly flat uplands with very slow or no runoff under the native vegetation. All the pedons except one are well drained. Original vegetation of the sampling sites is broad-leaved trees. However, the present vegetation is divided into two kinds, namely tree vegetation such as Japanese cider (*Cryptomeria japonica*) or pine tree (*Pinus densiflora*) with Sasa, Japanese pampas grass and fern, and Japanese pampas grass (*Miscanthus sinensis*) vegetation. It is accepted that the tree vegetation is often changed to Japanese pampas grass (*Miscanthus sinensis*) vegetation by strong human impact.

MATERIALS AND METHODS

Fourteen pedons of non-allophanic Andisols examined in detail were taken for laboratory study. Full description of one pedon is given as an example of the most common non-allophanic Andisols (Melanallands) in the present paper.

All the laboratory determinations except for bulk density and water retention were conducted on air-dried materials passing a 2 mm sieve as described below.

Mineralogical analysis of clay fractions: as described by Shoji and Ono (1978).

Bulk density: measured on undisturbed soil samples.

Water retention at 15 bar: determined on undisturbed soil samples using a pressure plate apparatus.

TC: determined by dry combustion method.

pH: potentiometrically in water (1:2.5), in 1N KCl (1:2.5) and in N NaF (1:50) (Soil Survey Staff, 1975), respectively.

Exchangeable Al: 10 g air-dried soil stood overnight with 50 ml of 1N KCl, filtered and washed with another 50 ml of 1N KCl. Al was determined by atomic absorption spectroscopy.

Exchange acidity (Y_1): determined by the procedure of Daikuhara (Saigusa, et al., 1980).

Phosphate retention determination: as described by Blakemore, et al., (1981).

Acid oxalate extractable Fe, Al, and Si of bulk soil (Feo, Alo, and Sio): as described by Parfitt (1983).

Pyrophosphate extractable Fe and Al of bulk soil (Fep and Alp): as described by Wada and Higashi (1976).

RESULTS AND DISCUSSION

Morphology and genesis

According to the classification of cultivated soils in Japan by Nat. Inst. Agr. Sci. (1982) and the 1983 revision of the Andisol Proposal by Leamy (1983), 14 pedons were classified as shown in Table 2. A pedon representing Melanallands is described as follows:

Pedon No. 9: Mukaiyama soil

Classification: Melanalland (Thick High-humic Andosol)

Date of examination: June 28, 1983

Table 1 - Chemical and physical properties of non-allophanic Andisols

Horizon	Depth cm	Color moist	B. D. g/cm^3	Water ret.		T-C %	pH			Exch. Al me/100g	Y_1 ml/100g	P-ret. %	Acid oxalate			Pyrophos.	
				Field %	15bar %		H_2O	KCl	NaF				Feo %	Alo %	Sio %	Fep %	Alp %
Pedon No.1 Ohnodai soil (Ohnodai, Takanosu, Akita pref.)																	
A11	0-7	10YR 1.7/1	0.48	144		16.2	5.0	3.9	11.3	5.95	16.9	95	1.11	2.10	0.05	0.88	1.84
A12	7-35	10YR 1.7/1	0.46	158		14.9	5.2	4.0	11.8	3.90	9.1	98	1.27	3.18	0.35	1.00	2.23
A12	35-42	10YR 1.7/1	0.46	158		16.3	5.2	4.1	12.0	3.26	6.0	98	1.38	4.62	0.81	1.07	2.73
A13	42-53	10YR 3/1	0.47	155		11.6	5.0	4.1	11.9	1.72	2.7	98	1.34	6.42	1.61	0.78	1.87
B1	53-66	7.5YR 6/6	0.48	157		3.5	5.3	4.4	11.7	0.25	0.5	97	1.63	6.59	2.68	0.19	0.75
IIB2	66-80	7.5YR 5/8				0.8	5.4	4.6	11.3	0.19	0.2	96	1.26	5.51	2.71	0.05	0.43
Pedon No.2 Wakami soil (Sanbon-matsu, Wakami, Akita pref.)																	
A11	0-13	7.5YR 2/1	0.78	44		6.1	5.2	3.8	9.6	5.97	22.5	78	0.94	0.86	0.04	0.56	0.62
A12	13-28	7.5YR 1.7/1	0.83	44		7.7	4.9	3.7	9.9	9.30	34.7	88	1.29	1.15	tr.	0.81	0.93
A13	28-40	7.5YR 2/2	0.82	63		5.9	4.9	3.8	10.6	8.49	31.4	93	1.62	1.41	0.02	1.14	1.06
B2	40-65	7.5YR 4/6	0.94	61		3.1	5.0	4.0	11.2	5.48	17.8	96	1.81	2.07	0.32	1.26	1.18
B3	65 +	10YR 5/6				1.2	5.5	4.2	10.8	0.90	1.9	91	1.62	1.81	0.58	0.30	0.42
Pedon No.3 Fujisawa soil (Fujisawa, Kitakami, Iwate pref.)																	
A11	0-6	7.5YR 2/3	0.51	78		10.3	5.1	3.9	11.1	4.97	15.0	95	1.35	1.75	0.13	0.99	1.35
A12	6-25	7.5YR 2/1	0.69	67		7.1	4.9	4.0	11.6	5.66	15.9	97	1.46	2.08	0.20	0.88	1.38
A13	25-36	7.5YR 3/2	0.86	47		1.2	4.8	4.0	10.8	8.79	32.7	93	1.32	1.45	0.14	0.77	0.60
IIB2	36-49	5YR 4/6	1.07	46		0.9	5.0	4.0	10.7	7.55	28.2	93	1.25	1.08	0.14	0.71	0.83
IIC	49-65	7.5YR 4/6	0.97	56		1.0	5.3	4.0	11.0	5.92	20.3	96	1.90	1.57	0.28	0.97	0.93
IIIB2	65 +	5YR 5/6				1.5	5.7	4.8	11.6	0.12	0.3	98	1.42	7.05	5.66	0.05	0.54
Pedon No.4 Rokuhara soil (Rokuhara, Kanegasaki, Iwate pref.)																	
A11	0-13	7.5YR 2/1	0.48	70		12.0	4.4	3.9	11.1	7.47	23.9	94	1.33	1.66	0.10	1.10	1.43
A12	13-37	7.5YR 1.7/1	0.52	79		9.1	4.4	4.0	11.8	6.98	19.0	98	1.64	2.14	0.13	1.30	1.74
IIA3	37-44	7.5YR 3/2	0.58	77		4.2	4.5	4.0	11.6	5.74	17.6	96	1.56	1.71	0.19	1.35	1.20
IIB2	44 +	10YR 4/6	1.04	41		1.0	5.0	3.9	10.3	7.23	29.7	83	1.18	0.75	0.12	0.55	0.40
Pedon No.5 Meotozaka soil (Meotozaka, Kanegasaki, Iwate pref.)																	
A11	0-11	10YR 1.85/1	0.48	123		12.9	4.8	3.8	11.1	7.65	24.6	96	1.53	1.70	0.08	1.25	1.50
A12	11-23	10YR 2/1	0.54	112		13.6	4.8	3.9	11.8	7.88	21.6	98	1.63	2.27	0.12	1.37	2.06
IIA13	23-35	10YR 1.7/1	0.51	129		14.7	4.9	3.9	12.0	8.69	24.7	99	1.67	2.83	0.11	1.40	2.29
IIIA14	35-63	10YR 1.7/1	0.55	126		12.5	5.0	3.9	12.0	7.78	22.5	98	1.60	2.68	0.13	1.21	2.07
IIIA15	63-72	10YR 1.7/1	0.62	110		8.0	5.0	3.9	11.7	9.49	33.1	98	1.53	1.90	0.09	1.06	1.52
IIIB1	72-84	10YR 3/3	0.89	71		2.8	5.1	3.8	11.1	11.05	48.3	95	1.66	1.29	0.09	1.13	0.88
IIIB2	84-105	10YR 5/7	1.05	59		1.1	5.3	3.9	11.2	8.79	35.6	96	1.79	1.41	0.21	1.01	0.76

Table 1 Chemical and physical properties of non-allophanic Andisols. (continued)

Horizon	Depth cm	Color moist	B. D. g/cm³	Water ret. at 15 bar -%-	T-C %	pH			Exch. base				Total of exch. bases me/100g	CEC me/100g	Base Saturation -%-	Al sat. %	Exch. Al me/100g	Y_1 ml/100g	P-ret. %	P-abs. P_2O_5 me/100g	Acid oxalate			Pyrophos.		Alp/Alo	Fep/Feo
						H_2O	KCl	NaF	Ca	Mg	K	Na									Feo	Alo	Sio	Fep	Alp		
									me/100g												%			%			
Pedon No.8 Kitayama soil (Forest Res. Sta. Fac. of Agr., Tohoku Univ., Arayu, Naruko, Miyagi pref.)																											
A11	0-13	10YR 1.7/1	0.51		17.0	4.9	3.8	10.5	1.06	0.52	0.39	0.21	2.18	37.1	5.9	76.3	7.00	20.0	94	1850	1.53	1.37	tr.	1.10	1.37	1.00	0.72
A12	13-21	7.5YR 2/1.5	0.48		11.3	5.1	4.0	11.8	0.26	0.12	0.13	0.21	0.72	30.1	2.4	83.2	3.56	6.0	97	2310	1.41	2.12	0.21	1.28	1.79	0.34	0.91
IIA13	21-30	10YR 1.7/1	0.42		15.8	5.0	3.9	11.6	0.44	0.16	0.29	0.24	1.13	46.0	2.5	87.2	7.69	21.2	99	2460	2.00	2.46	0.04	2.02	2.42	0.98	1.00
IIIA14	30-49	10YR 1.7/1	0.41		18.9	4.9	3.3	11.3	0.64	0.22	0.27	0.24	1.37	60.9	2.2	90.3	12.74	38.6	99	2460	2.63	2.67	tr.	2.60	2.77	1.00	0.99
IIIA15	49-58	10YR 2/1	0.63		9.5	5.1	4.0	11.6	0.28	0.08	0.15	0.13	0.64	36.2	1.8	91.8	7.13	19.8	98	2360	2.09	2.55	0.08	1.79	2.03	0.80	0.36
IIIB2	58 -	7.5YR 5/6	0.83		1.7	5.3	4.1	11.4	0.18	0.06	0.16	0.11	0.51	13.9	3.7	80.5	2.11	4.4	96	1980	1.80	2.14	0.44	0.66	0.73	0.34	0.37
Pedon No.9 Mukaiyama soil (Forest Res. Sta., Fac. of Agr., Tohoku Univ., Numai, Naruko, Miyagi pref.)																											
A11	0-18	10YR 1.7/1	0.47	73	14.0	4.9	4.0	11.2	0.72	0.44	0.52	0.32	1.56	33.0	4.7	76.4	5.06	13.5	95	1950	1.18	1.63	0.03	1.07	1.54	0.94	0.91
A12	18-26	7.5YR 2/1.5	0.59	54	9.1	5.1	4.1	11.8	0.26	0.10	0.17	0.27	0.80	24.9	3.2	76.0	2.54	5.0	97	2210	1.23	2.09	0.27	1.14	1.51	0.72	0.93
IIA13	26-40	10YR 2/1	0.51	62	11.2	5.0	4.0	11.9	0.20	0.18	0.17	0.24	0.79	32.8	2.4	84.3	4.23	11.1	98	2360	1.53	2.34	0.12	1.48	2.04	0.87	0.97
IIIA14	40-68	10YR 1.7/1	0.53	58	13.6	5.0	4.0	11.9	0.24	0.16	0.18	0.20	0.78	42.1	1.9	85.6	4.65	10.6	98	2460	1.34	3.05	0.20	1.18	2.52	0.83	0.88
IVB21	68-85	10YR 5/4	0.84	41	2.6	5.1	4.2	11.7	0.16	0.04	0.08	0.16	0.44	13.2	3.3	68.3	0.95	1.6	96	1990	1.20	2.34	0.62	0.68	0.37	0.37	0.57
VB22	85 -	7.5YR 6/8		41	1.1	5.2	4.2	11.5	0.18	0.06	0.11	0.12	0.47	10.4	4.5	45.3	0.39	0.5	96	1910	1.40	2.37	0.76	0.20	0.57	0.24	0.14
Pedon No.10 Takada soil (Jotohara, Takada, Aizu, Fukushima pref.)																											
A11	0-12	7.5YR 2/1	0.60		11.7	5.1	4.0	11.5	2.46	0.72	0.36	0.21	3.75	32.9	11.4	47.6	3.41	8.9	95	1970	1.04	1.97	0.32	0.81	1.41	0.72	0.78
A12	12-30	7.5YR 1.7/1	0.60		10.2	5.1	4.1	11.8	0.96	0.42	0.38	0.22	1.98	29.4	6.7	61.1	3.11	7.0	97	2170	1.11	2.24	0.35	0.91	1.55	0.59	0.83
A13	30-38	7.5YR 3/2	0.78		3.2	5.3	4.2	11.5	0.34	0.20	0.21	0.26	1.01	13.2	7.7	40.4	0.65	1.1	92	1680	0.95	2.16	0.81	0.38	0.66	0.31	0.40
B2	38-60	7.5YR 4/4	0.96		1.0	5.2	4.2	10.7	0.32	0.16	0.22	0.18	0.88	6.1	14.4	30.2	0.38	0.6	76	1090	0.65	1.52	0.72	0.08	0.29	0.19	0.12
C	60-70	7.5YR 4/3																									
Pedon No.11 Kanayama soil (Tarōfu, Kanayama, Numazawa, Aizu, Fukushima pref.)																											
A11	0-9	7.5YR 2/1	0.50		14.7	4.8	4.1	11.0	0.38	0.26	0.31	0.24	1.19	34.8	3.4	86.5	7.62	21.2	94	1850	0.63	1.51	0.08	0.58	1.36	0.90	0.92
A12	9-30	7.5YR 1.7/1	0.67		11.4	5.0	4.1	11.9	0.16	0.12	0.07	0.15	0.50	28.3	1.8	89.4	4.23	10.0	97	2070	0.69	1.83	0.14	0.64	1.62	0.89	0.93
A13	30-36	7.5YR 2/3	0.90		6.3	5.3	4.3	11.9	0.08	0.04	0.03	0.09	0.24	17.8	1.3	83.9	1.25	2.3	97	2010	0.41	2.28	0.57	0.29	1.11	0.49	0.71
B2	36-58	10YR 5/6	1.25		1.1	5.3	4.6	11.5	0.08	0.02	0.02	0.07	0.19	5.8	3.3	56.8	0.25	0.5	83	1160	0.26	1.55	0.58	0.06	0.40	0.26	0.23
C	58-75	2.5YR 6/4	1.11			5.4	4.6	11.1	0.06	0.02	0.01	0.02	0.11	3.1	3.3	56	0.14	0.3	73	980	0.14	1.35	0.57	0.03	0.28	0.21	0.21
Pedon No.12 Erimo soil* (Toyo, Erimo, Hokkaido)																											
Ap	0-19	10YR 1.7/1	0.74	71	15.9	4.6	4.1	9.4	8.01	5.09	0.65	1.83	15.58	52.4	29.7	24.6	5.09	12.2	91	1710	0.99	1.26	0.04	0.89	1.11	0.88	0.90
A12	19-35	10YR 1.7/1	0.61	72	16.8	5.0	4.1	10.9	4.64	2.54	0.39	1.94	9.51	53.5	17.8	50.6	9.76	24.5	97	2300	1.70	2.26	0.08	1.66	2.08	0.92	0.98
A13	35-45	10YR 2/1	0.57		15.9	5.1	4.2	11.8	2.30	1.27	0.27	1.52	5.36	50.3	10.7	58.3	7.49	19.6	98	2260	1.39	2.80	0.14	1.20	2.31	0.83	0.86
B1	45-68	10YR 3/3	0.60	77	6.4	5.2	4.3	11.8	1.08	0.52	0.32	0.95	2.87	26.9	10.7	56.3	3.70	9.3	96	2090	1.47	2.78	0.53	0.85	1.35	0.49	0.58
B21	68-100	10YR 6/7			1.6	5.3	4.3	11.2	0.84	0.77	0.46	1.27	3.34	16.0	20.9	50.7	3.44	12.2	91	1510	1.30	1.65	0.36	0.68	0.60	0.36	0.52
Pedon No.13 Koyama soil† (Tottori Univ., Koyama, Tottori, Tottori pref.)																											
A11	0-18	7.5YR 2/2	0.56	39	8.8	5.1	4.0	11.6	1.87	0.85	0.69	0.23	3.64	29.4	12.4	53.7	4.23	10.1	96	1970	0.98	2.20	0.29	0.63	1.32	0.60	0.64
A12	18-50	7.5YR 2/1	0.76	27	8.0	5.3	4.1	11.3	2.05	0.53	0.31	0.36	3.25	29.8	10.9	57.1	4.33	9.8	97	2050	0.99	2.22	0.22	0.70	1.38	0.62	0.71
A3	50-70	7.5YR 3/4	0.67	56	6.1	5.2	4.2	11.8	1.03	0.35	0.28	0.37	2.03	25.9	7.8	50.2	2.05	4.2	98	2300	1.11	3.49	0.94	0.64	1.26	0.36	0.58
B2	70-105	7.5YR 5/6	1.03	42	0.8	5.1	3.9	10.6	0.80	0.47	0.37	0.44	2.08	15.4	13.5	73.7	5.82	19.7	91	1610	0.91	1.14	0.10	0.45	0.51	0.45	0.49
Pedon No.14 Sasaganaru soil† (Sasaganaru, Sekigane, Tohaku, Tottori pref.)																											
A11	0-19	5YR 2/1	0.38		21.2	4.9	4.0	11.8	0.70	0.30	0.23	0.23	1.46	52.0	2.8	83.8	7.56	17.9	98	2360	1.20	2.66	0.06	1.12	2.46	0.92	0.93
A12	19-31	7.5YR 1.7/1	0.46		16.5	5.1	4.2	12.0	0.26	0.12	0.05	0.12	0.59	41.0	1.4	87.8	4.24	8.2	98	2410	0.74	2.91	0.26	0.68	2.83	0.97	0.91
B2	31-40	7.5YR 3/4	1.05		2.8	5.2	4.6	11.7	0.08	0.02	0.01	0.07	0.18	8.9	2.0	75.3	0.55	1.1	89	1510	0.42	1.58	0.46	0.20	0.62	0.39	0.48
IIA1	40-61	5YR 1.7/1	0.43		18.1	4.9	4.1	12.0	0.10	0.06	0.06	0.13	0.35	44.9	0.8	94.9	6.56	14.4	99	2420	1.72	2.94	0.11	1.66	2.70	0.92	0.97
IIA3	61-65	7.5YR 4/4	—		13.0	4.9	4.1	11.9	0.07	0.05	0.05	0.11	0.28	34.9	0.8	94.2	4.55	9.2	98	2420	1.81	3.35	0.44	1.62	2.23	0.67	0.90
IIB2	65-100	10YR 4/6	0.62		3.2	5.0	4.6	11.5	0.03	0.02	0.04	0.05	0.14	11.9	1.2	67.4	0.29	0.5	98	2190	1.10	1.88	1.69	0.14	0.60	0.32	0.13

* Data except acid oxalate-extractable and pyrophosphate-extractable components were cited from the report of group study of Andisols (Wada, 1983).

† Described and taken by Prof. H. Takada and Dr. T. Honna, Faculty of Agriculture, Tottori University.

Table 1 Chemical and physical properties of non-allophanic Andisols.

Horizon	Depth	Color	B. D.	Water ret. at 15 bar	T-C	pH			Exch. base				Total of exch. bases	CEC	Base Saturation	Al sat.	Exch. Al	T_1	P-ret.	P-abs.	Acid oxalate			Pyrophos.		Alp/Alo	Fep/Feo
	cm	moist	g/cm³	%	%	H_2O	KCl	NaF	Ca	Mg	K	Na	me/100g	me/100g	%	%	me/100g	ml/100g	%	P_2O_5 mg/100g	Feo	Alo	Sio	Fep	Alp		
									me/100g												%			%			
Pedon No.1 Ohnodai soil (Ohnodai, Takanosu, Akita pref.)																											
A11	0-7	10YR 1.7/1	0.48		16.2	5.0	3.9	11.3	1.14	0.37	0.76	0.30	2.77	40.7	6.8	68.2	5.95	16.9	95	2130	1.11	2.10	0.05	0.88	1.84	0.38	0.79
A12	7-35	10YR 1.7/1	0.46		14.9	5.2	4.0	11.8	0.36	0.20	0.43	0.21	1.40	38.5	3.6	73.6	3.90	9.1	98	2390	1.27	3.18	0.35	1.00	2.23	0.70	0.79
A12	35-42	10YR 1.7/1	0.46		16.3	5.2	4.1	12.0	0.56	0.16	0.31	0.28	1.31	44.0	3.0	71.3	3.26	6.0	98	2510	1.38	4.62	0.81	1.07	2.73	0.59	0.78
A13	42-53	10YR 3/1	0.47		11.6	5.0	4.1	11.9	0.34	0.11	0.27	0.15	0.87	33.5	2.6	66.4	1.72	2.7	98	2520	1.34	6.42	1.61	0.78	1.87	0.29	0.58
B1	53-66	7.5YR 6/6	0.45		3.5	5.3	4.4	11.7	0.17	0.07	0.30	0.31	0.85	14.4	5.9	22.7	0.25	0.5	97	2340	1.63	6.59	2.68	0.19	0.75	0.11	0.12
IIB2	66-80	7.5YR 5/8			0.8	5.4	4.6	11.3	0.35	0.06	0.46	0,79	1.66	8.5	19.5	10.3	0.19	0.2	96	1960	1.26	5.31	2.71	0.05	0.43	0.08	0.04
Pedon No.2 Wakami soil (Sanbon-matsu, Wakami, Akita pref.)																											
A11	0-13	7.5YR 2/1	0.78		6.1	5.2	3.8	9.6	2.27	1.57	0.38	0.51	5.23	29.8	17.5	33.3	5.97	22.5	78	1270	0.94	0.86	0.04	0.56	0.62	0.72	0.60
A12	13-25	7.5YR 1.7/1	0.83		7.7	4.9	3.7	9.9	0.65	0.81	0.64	0.45	2.55	33.9	7.5	78.5	9.30	34.7	88	1660	1.29	1.15	tr.	0.31	0.93	0.81	0.63
A13	25-40	7.5YR 2/2	0.82		5.9	4.9	3.8	10.6	0.36	0.62	0.59	0.41	1.98	31.4	6.3	81.1	8.49	31.4	93	1820	1.62	1.41	0.02	1.14	1.06	0.75	0.70
B2	40-65	7.5YR 4/6	0.94		3.1	5.0	4.0	11.2	0.40	0.59	0.68	0.50	2.17	22.0	9.9	71.6	5.48	17.8	96	2010	1.81	2.07	0.32	1.26	1.18	0.57	0.70
B3	65 +	10YR 5/6			1.2	5.5	4.2	10.3	0.35	1.09	0.10	0.61	2.65	12.0	22.1	25.4	0.90	1.9	91	1630	1.62	1.81	0.56	0.30	0.42	0.23	0.19
Pedon No.3 Fujisawa soil (Fujisawa, Kitakami, Iwate pref.)																											
A11	0-6	7.5YR 2/3	0.51	51	10.3	5.1	3.9	11.1	2.72	1.08	0.65	0.32	4.77	33.5	14.2	51.0	4.97	15.0	95	1980	1.35	1.75	0.13	0.99	1.35	0.77	0.73
A12	6-36	7.5YR 2/1	0.69	33	7.1	4.9	4.0	11.6	0.46	0.22	0.36	0.22	1.26	26.0	4.8	81.8	5.66	15.9	97	2100	1.46	2.08	0.20	0.88	1.38	0.66	0.60
IIB2	36-49	5YR 4/6	0.86	39	1.2	4.8	4.0	10.8	0.30	0.32	0.34	0.23	1.19	15.7	7.6	88.1	8.79	32.7	93	1720	1.32	1.45	0.14	0.77	0.60	0.41	0.58
IIC	49-65	7.5YR 4/6	1.07	38	0.9	5.0	4.0	10.7	0.32	0.84	0.14	0.35	1.65	15.1	10.9	82.1	7.55	28.2	93	1640	1.25	1.08	0.14	0.71	0.83	0.77	0.57
IIIB2	65-100	5YR 5/6	0.97	55	1.0	5.3	4.0	11.0	0.20	1.48	0.16	0.48	2.32	18.9	12.3	71.8	5.92	20.3	96	1930	1.90	1.57	0.28	0.97	0.93	0.59	0.51
IIIC	100 +	7.5YR 6/8			1.5	5.7	4.8	11.6	0.12	0.26	0.02	0.33	0.73	17.2	4.2	14.1	0.12	0.3	93	2510	1.47	7.05	5.66	0.05	0.54	0.08	0.04
Pedon No.4 Rokuhara soil (Rokuhara, Kanegasaki, Iwate pref.)																											
A11	0-13	7.5YR 2/1	0.48		12.0	4.4	3.9	11.1	1.06	0.40	0.50	0.34	2.30	35.2	6.5	76.5	7.47	23.9	94	2000	1.33	1.66	0.10	1.10	1.43	0.86	0.83
A12	13-37	7.5YR 1.7/1	0.52		9.1	4.4	4.0	11.8	0.30	0.14	0.33	0.27	1.04	33.4	3.1	87.0	6.98	19.0	96	2300	1.64	2.14	0.13	1.30	1.74	0.81	0.79
IIA3	37-44	7.5YR 3/2	0.58		4.2	4.5	4.0	11.6	0.22	0.12	0.26	0.29	0.89	19.4	4.6	86.6	5.74	17.6	96	2090	1.56	1.71	0.19	1.35	1.20	0.70	0.87
IIB2	44 +	10YR 4/6	1.04		1.0	5.0	3.9	10.3	0.41	2.91	0.14	0.24	3.70	15.6	23.7	66.1	7.23	29.7	83	1350	1.18	0.75	0.12	0.35	0.40	0.53	0.47
Pedon No.5 Meotozaka soil (Meotozaka, Kanegasaki, Iwate pref.)																											
A11	0-11	10YR 1.85/1	0.48		12.9	4.8	3.8	11.1	0.72	0.52	0.50	0.23	1.97	37.9	5.2	79.5	7.65	24.6	96	2040	1.53	1.70	0.08	1.25	1.50	0.88	0.82
A12	11-23	10YR 2/1	0.54		13.6	4.8	3.9	11.8	0.26	0.14	0.16	0.18	0.74	43.3	1.7	91.4	7.88	21.6	98	2350	1.63	2.27	0.12	1.37	2.06	0.91	0.84
IIA13	23-35	10YR 1.7/1	0.51		14.7	4.9	3.9	12.0	0.34	0.10	0.11	0.26	0.81	48.6	1.7	91.5	8.69	24.7	99	2470	1.67	2.83	0.11	1.40	2.29	0.81	0.84
IIIA14	35-63	10YR 1.7/1	0.55		12.5	5.0	3.9	12.0	0.28	0.08	0.10	0.24	0.70	46.0	1.5	91.7	7.78	22.5	98	2440	1.60	2.68	0.13	1.21	2.07	0.77	0.76
IIIA15	63-72	10YR 1.7/1	0.62		8.0	5.0	3.9	11.7	0.36	0.12	0.10	0.24	0.82	37.5	2.2	92.0	9.49	33.1	98	2210	1.53	1.90	0.09	1.06	1.52	0.80	0.69
IIIB1	72-84	10YR 3/3	0.89		2.8	5.1	3.8	11.1	0.48	0.42	0.08	0.22	1.20	26.2	4.6	90.2	11.05	48.3	95	1770	1.66	1.29	0.09	1.13	0.88	0.58	0.68
IIIB2	84-105	10YR 5/7	1.05		1.1	5.3	3.9	11.2	0.68	0.74	0.08	0.33	1.83	20.9	8.8	82.8	8.79	35.6	96	1900	1.79	1.41	0.21	1.01	0.76	0.54	0.56
Pedon No.6 Shinjo soil (Ohkan, Shinjo, Yamagata pref.)																											
A11	0-10	7.5YR 2/1.7	0.47		14.5	4.9	3.8	9.4	3.94	1.66	0.63	0.46	6.69	36.5	18.3	44.1	5.28	20.6	88	1630	1.03	1.10	0.04	1.02	1.00	0.91	0.99
A12	10-25	7.5YR 2/1.5	0.56		10.9	5.2	3.9	10.0	3.18	1.74	0.50	0.38	5.80	31.0	18.7	40.5	3.94	14.5	91	1760	1.10	1.14	0.04	1.10	1.03	0.90	1.00
IIA13	25-40	7.5YR 2/1.5	0.59		9.4	5.1	3.9	10.2	1.62	1.18	0.42	0.34	3.56	27.7	12.9	58.8	5.08	18.8	92	1780	1.09	1.15	0.04	1.09	1.03	0.90	1.00
IIB1	40-50	7.5YR 3/3	0.78		4.9	5.1	3.8	10.9	0.38	0.38	0.45	0.22	1.43	21.4	6.7	79.1	5.42	18.0	94	1900	1.14	1.94	0.10	1.14	1.06	0.55	1.00
IIB2	50 +	7.5YR 5/8	1.12		1.1	5.0	3.8	9.7	0.22	0.34	0.18	0.25	0.99	14.1	7.0	88.1	7.34	32.2	79	1320	0.75	0.64	0.05	0.74	0.48	0.75	0.99
Pedon No.7 Ohkura soil (Ohkura, Mogami, Yamagata pref.)																											
A11	0-10	10YR 1.7/1	0.55		16.2	4.8	3.7	10.0	0.64	0.46	0.44	0.27	1.81	37.0	4.9	77.2	6.14	20.0	86	1550	0.87	1.25	0.08	0.83	1.12	0.90	0.95
A12	10-23	10YR 1.7/1	0.55		12.6	5.0	3.9	11.1	0.38	0.18	0.27	0.23	1.06	20.6	3.5	81.6	4.69	14.0	92	1810	1.00	1.38	0.04	0.95	1.33	0.96	0.95
A13	23-38	10YR 2/2.5	0.68		4.6	5.1	4.2	11.2	0.18	0.06	0.07	0.14	0.45	14.8	3.0	82.9	2.18	5.0	88	1640	1.34	1.07	0.06	1.33	0.92	0.86	0.99
IIA14	38-58	7.5YR 2/2	0.70		6.4	5.2	4.3	11.8	0.16	0.06	0.06	0.14	0.42	20.6	2.0	73.1	1.16	2.4	97	2260	1.12	2.87	0.63	0.96	1.40	0.49	0.86
IIB2	58-65	10YR 4/6			2.9	5.3	4.5	11.8	0.18	0.04	0.17	0.20	0.59	12.0	4.9	41.6	0.42	0.8	95	1870	0.39	2.53	0.74	0.20	0.82	0.32	0.51

Table 2. Classification of 14 pedons.

Pedon No.	Classification of Andosols by Nat. Inst. Agr. Sci. (1982)	Classification of Andisols by 1983 revision of Andisol Proposal
1	thick high-humic	Melanalland
2	high-humic	*
3	high-humic	Haplalland
4	high-humic	*
5	thick high-humic	Melanalland
6	high-humic	*
7	thick high-humic	Melanalland
8	thick high-humic	Melanalland
9	thick high-humic	Melanalland
10	high-humic	*
11	high-humic	*
12	high-humic	Melanalland
13	thick high-humic	Melanalland
14	thick high-humic	Melanalland

*Alo $<$ 2%

Location: Forest Res. Sta., Fac. of Agric., Tohoku Univ., Forest compart. No. 22, Humai, Naruko, Miyagi pref.

Physiographic position: Flat land of mountainous upland; 500 m elevation

Topography: 3°-5° south-facing slope

Drainage: Well-drained; moderate permeability

Vegetation: Japanese pampas grass (*Miscanthus sinensis*).

Parent material: Felsic volcanic ash

O1 - 3-0 cm. Leaves of *Miscanthus sinensis*

A11 - 0-18 cm. Black (10YR 1.7/1) light clay; moderate medium granular structure; very friable, slightly sticky and slightly plastic; abundant roots; abrupt, smooth boundary

A12 - 18-26 cm. Black (7.5YR 2/1.5) clay loam; weak medium granular structure; friable, slightly sticky and slightly plastic; abrupt, smooth boundary (few ash blocks of 1,000 years old are observed)

IIA13 - 26-40 cm. Black (10YR 2/1) light clay; weak medium subangular blocky structure; friable, moderately sticky and moderately plastic; clear, smooth boundary (a few ash blocks of 10,000 YBP were observed at the bottom of this horizon).

IVB21 - 68-85 cm. Dull yellowish brown (10YR 5/4) light clay; weak coarse subangular blocky structure; slightly firm, sticky and plastic; few percent rock fragments; clear, smooth boundary.

VB22 - 85+ cm. Orange (7.5YR 6/8) light clay; massive; slightly firm; sticky and plastic.

As seen in the above description, the pedons of non-allophanic Andisols have distinctive morphological characteristics, such as: 1) the A1 horizons are black and thicker than 35 cm (see Table 1); 2) the structure is granular or crumby in the upper part of A1 horizons and subangular blocky in the lower part of A1 horizons and B horizons; and 3) the consistence of the A1 horizons are friable to very friable when moist. It is noticeable that these characteristics are also common to most allophanic Andisols.

Main concerns on the genesis of non-allophanic Andisols are: 1) absence or virtual absence of allophane and imogolite; 2) abundance of 2:1 layer silicates mainly consisting of chloritized 2:1 minerals; and 3) development of thick A1 horizons.

Formation of allophane and imogolite in Andisols is closely related to the soil acidity and supply of organic matter (Shoji, et al., 1982; Shoji and Fujiwara, 1984). When the soils are supplied with a large quantity of organic matter from the vegetation and have pH values of about 5 or less, Al ions released from the parent ash hardly react with silica, but form the stable complex with soil organic matter. It is considered that this process inhibits the formation of allophane and imogolite in the surface soils.

Various hypotheses have been proposed concerning the sources of 2:1 layer silicates in non-allophanic Andisols and the source problem has come to no definite conclusion yet (Shoji and Fujiwara, 1984). However, it is of great importance to know that several distinctive characteristics of non-allophanic Andisols differing from allophanic Andisols are attributable to 2:1 layer silicates.

Intermittent accumulation of volcanic ash greatly contributes to the genesis of thick humus horizons of Andisols. As described for pedon No. 9, all the non-allophanic Andisols we studied are cumulative and developed upward with addition of new ash, resulting in the formation of thick humus horizons. It is also well known that grass vegetation such as *Miscanthus sinensis* having a deep-rooting system significantly contributes to the development of thick humus horizons.

Clay mineralogical, chemical, and physical properties

Absence or virtual absence of allophane and imogolite in almost all of the soil samples is easily confirmed by the analysis of Sio and the electron microscopic observation of the clay specimens. The X-ray analysis indicates that the clay fractions of non-allophanic Andisols are domianted by 2:1 layer silicates consisting mainly of chloritized 2:1 layer silicates. (The data of X-ray and electron microscopic studies on clays were omitted here.)

All the pedons of non-allophanic Andisols except pedons No. 2 and 3 have 8% or more organic carbon and have black color to a depth of 30 cm or more. Therefore, as given in Table 2, most of non-allophanic Andisols are classified as Melanallands.

Acidity of soil samples reflects their low base saturation and high contents of 2:1 layer silicates. Humus horizon soils have mostly $pH(H_2O)$ values of about 5 or less that are slightly lower than those of non-humus horizon soils. All the soil samples have pH(KCl) values lower than $pH(H_2O)$ values. The differences between the two values are greater than one unit for most soil samples. Almost all of the soil samples show high KCl-exchangeable Al and high KCl-exchangeable acidity (Y_1). KCl-exchangeable Al originates largely from exchangeable Al of 2:1 layer silicates (Yoshida, 1979).

As Shoji and Ono (1978) and Shoji and Fujiwara (1984) observed, all the non-allophanic Andisols show pH(NaF) greater than 9.4 and phosphate retention larger than 85%. High Alp/Alo ratios of humus horizon soils indicate that Al complexed with humus is the main active Al or major component reacting with fluoride and phosphate.

Almost all the soil samples except several have trace to small amounts of Sio, reflecting the absence or virtual absence of allophane and imogolite as already mentioned. The Alo contents of the soil samples are considerably variable. It is, however, noticeable that about half of the samples contain Alo ranging from 1-2%. The Feo contents of the soil samples range mostly from 1-2%.

Bulk density is less than 0.8 for almost all of the soil samples. Water retention at 15 bar is less than 100% for all the soil samples.

correlation study was conducted on the relationships between soil properties used for defining andic and vitric soil properties. The selected results are given in Figs. 1 and 2.

Both phosphate retention and pH(NaF) have positive correlations with the Alo contents which are considered to be a useful measure of Al present in allophane, imogolite, and Al-humus complexes. It is noteworthy that even the non-allophanic soil samples having 1-2% Alo show phosphate retention larger than 85% and pH(NaF) values higher than 9.4. Bulk density of soil samples is closely correlated with total carbon.

Necessity of recognizing a suborder of non-allophanic Andisols 'Allands.'

Though there are many similarities between allophanic Andisols and non-allophanic Andisols, there are some significant dissimilarities between the two groups of soils. These dissimilarities are listed as follows:

	Non-allophanic Andisols	Allophanic Andisols
Major clay minerals	2:1 layer silicates	Allophane-imogolite
Main active Al	Al-humus complex	Allophane-imogolite
Soil acidity	very strong	weak
Critical pH(H_2O)	about 5	none
Al saturation	high	none to very low
KCl-exchangeable Al^{3+}	high	none to very low
Al toxity	common	rare

Agricultural plants grown on non-allophanic Andisols are subject not only to the direct effects of soil acidity or Al toxicity (Shoji, et al., 1980; Saigusa, et al., 1980),

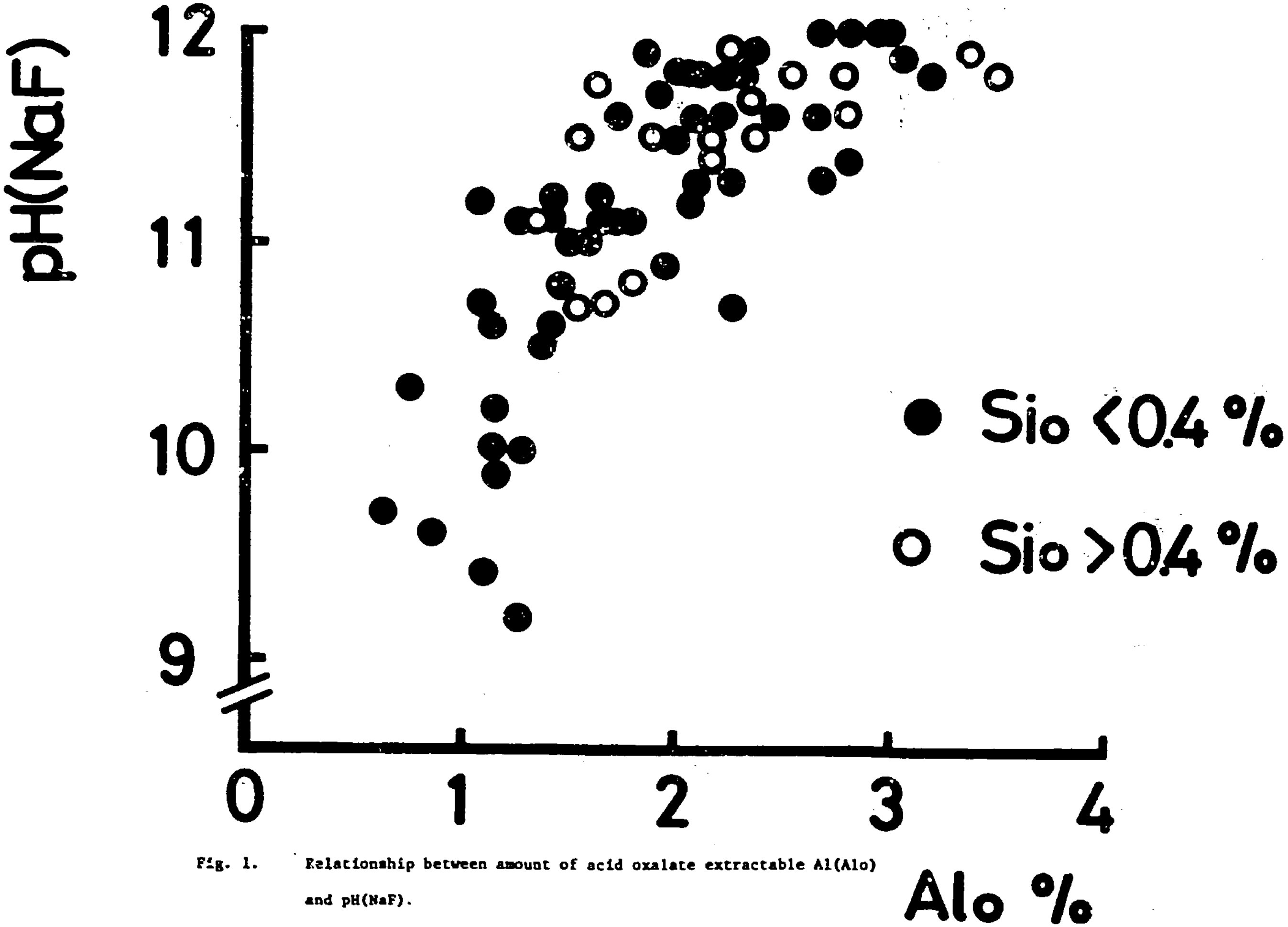

Fig. 1. Relationship between amount of acid oxalate extractable Al(Alo) and pH(NaF).

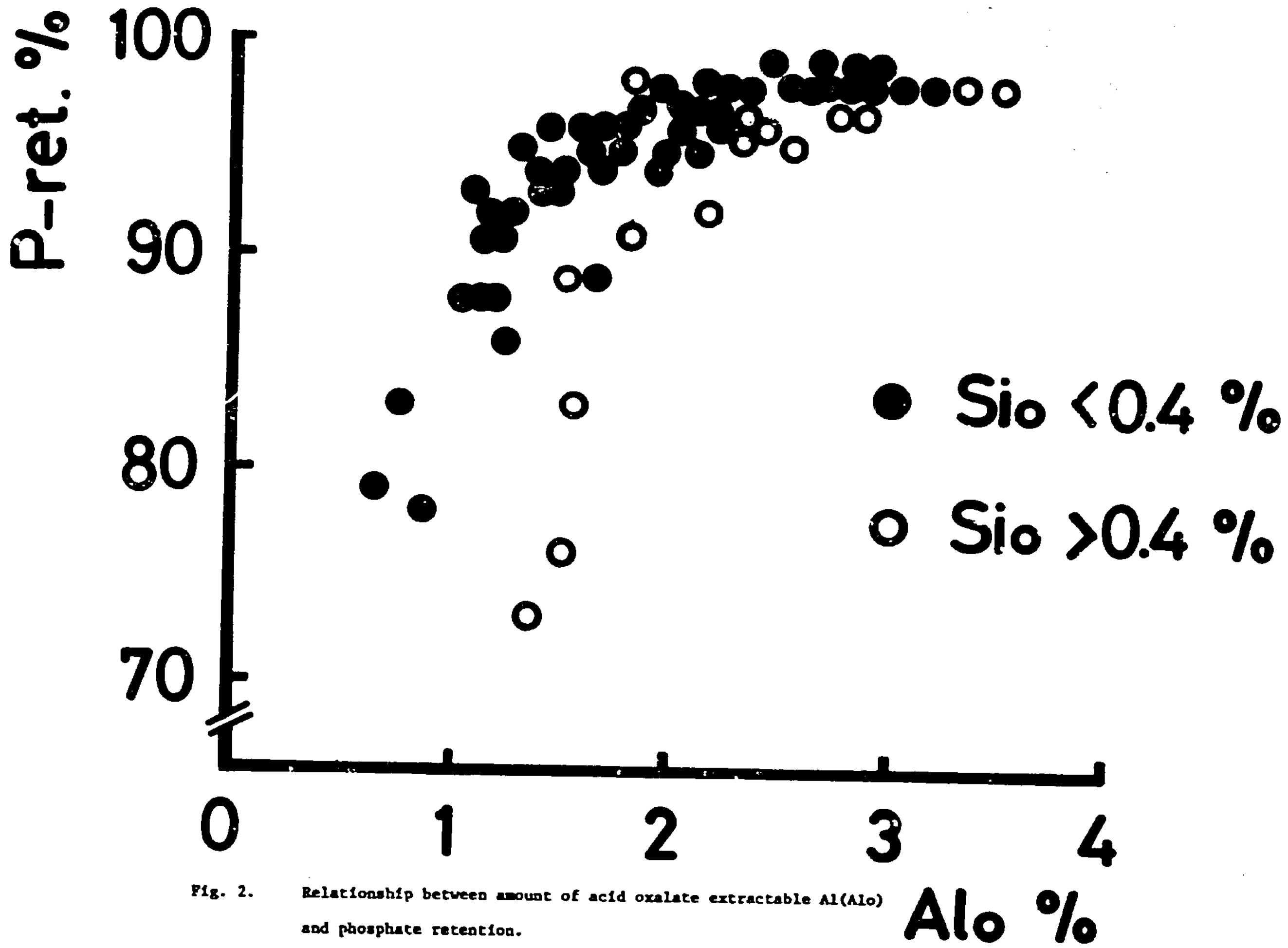

Fig. 2. Relationship between amount of acid oxalate extractable Al(Alo) and phosphate retention.

but also to various indirect effects of soil acidity such as decrease in nutrient availability and lowering of microbial activity. Therefore, careful managements such as liming, fertilizer application, subsoil amelioration, etc., are necessary for increasing soil productivity.

According to the dissimilarities in soil process, clay mineralogy, and physical and chemical properties between non-allophanic Andisols and allophanic Andisols, we consider that non-allophanic Andisols should be discriminated against allophanic Andisols and that it is reasonable to recognize a suborder of non-allophanic Andisols. The term "Allands" for the non-allophanic Andisols has been proposed by Leamy (1983).

Criteria for Allands

All the pedons studied satisfy the requirements for andic properties such as bulk density <0.9 g/cm^3 and phosphate retention $>85\%$ and show high pH(NaF), mostly greater than 10. However, 5 pedons do not meet the criterion of Alo $> 2\%$ as shown in Table 2.

"Allands" was defined by Leamy (1983) as Andisols that have to a depth of 35 cm or more, KCl-extractable Al, expressed as Al^{3+} that is more than 1 me/100 g soil. Since this parameter expresses potential Al toxicity for crops that have low tolerance to Al toxicity (Saigusa, et al., 1980), we consider that the parameter should be modified as more than 2 me/100 g soil. All the pedons studied meet this requirement.

The criterion using KCl-extractable Al^{3+} is very convenient for unlimed soils. However, when the soils are limed, KCl-extractable Al^{3+} remarkably decreases in amount. Finally, we proposed to define the Allands as follows:

> "Other Andisols that have, within the top 35 cm, acid oxalate extractable Si less than 0.4%, and either KCl-extractable Al^{3+} more than 2 me/100 g, or if there is an Ap horizon, there is a layer at least 10 cm thick between the base of Ap horizon and 50 cm having KCl-extractable Al^{3+} more than 2 me/100 g soil."

Acid oxalate Si $< 0.4\%$ indicates that the soils are non-allophanic. The root development of common agricultural plants is severely inhibited by the existence of an exchangeable Al^{3+} rich soil layer having at least 10 cm thickness below the Ap horizon.

LITERATURE CITED

Blakemore, L. C., P. L. Searle, and B. K. Daly. 1981. Phosphate retention determination. A5.9-A5.10. *In* Methods for chemical analysis of soils. New Zealand Soil Bureau Sci. Report 10A, DSIR, New Zealand.

Leamy, M. L. 1983. Proposed revision of the Andisol Proposal. International committee on the classification of Andisols (ICOMAND), Circular No. 5:3-29.

Nat. Inst. Agr. Sci. 1982. Classification of cultivated soils in Japan. Ministry of Agriculture, Forestry and Fishery, Japan.

Parfitt, R. L. 1983. Identification of allophane in Inceptisols and Spodosols. Soil Taxonomy News 5:11 and 18.

Saigusa, M., S. Shoji, and T. Takahashi. 1980. Plant root growth in acid Andosols from northeastern Japan: 2. Exchange acidity Y_1 as a realistic measure of aluminum toxicity potential. Soil Sci. 130:242-250.

Shoji, S., Y. Fujiwara, I. Yamada, and M. Saigusa. 1982. Chemistry and clay mineralogy of Ando soils, Brown forest soils, and Podozolic soils formed from recent Towada ashes, northeastern Japan. Soil Sci. 133:69-86.

Shoji, S., and Y. Fujiwara. 1984. Active Al and Fe in the humus horizons of Andosols from northeastern Japan: their forms, properties and significance in clay weathering. Soil Sci. 137:216-226.

Shoji, S., M. Saigusa, and T. Takahashi. 1980. Plant root growth in acid Andosols from northeastern Japan: 1. Soil properties and root growth of burdock, barley, and orchard grass. Soil Sci. 130:124-131.

Shoji, S., and T. Ono. 1978. Physical and chemical properties and clay mineralogy of Andosols from Kitakami, Japan. Soil Sci. 126:297-312.

Soil Survey Staff. 1975. Soil taxonomy, a basic system of soil classification for making and interpreting soil surveys. Soil Conservation Service, USDA, AH 436.

Wada, K. (ed.) 1983. Study on international correlation of Andisols and related soils. Report of group study of Andisols submitted to the Ministry of Education, Japanese Government.

Wada, K., and T. Higashi. 1976. The categories of aluminum- and iron-humus complexes in Ando soils determined by selective dissolution. J. Soil Sci. 27:357-368.

Yoshida, M. 1979. Some aspects on soil acidity and its measurement. J. Sci. Soil Manure, Japan 50:171-180.

CRITERIA OF GREAT GROUPS OF ANDISOLS

M. Otowa

ABSTRACT

Classification of soils developed from volcanic ash in Hokkaido is quite similar to the Andisol proposal. On the other hand, designations such as Borands, Udands, and Aquands are appropriate for understanding our soils in the framework of global distribution of soils. The principles and structure of the Andisol proposal, therefore, are acceptable.

Of great groups mentioned in the proposal, those found in the udic moisture regime and some related subgroups were discussed.

As for criteria related to organic matter, this paper proposes a new "fulvic" (L. fulvus, dull yellow) great group for soils comparable to malanic great groups in organic carbon content, but not black. As far as is known, they are mainly found in forest regions of central and northern Japan. The concept of umbric horizon is not applicable to Andisols. An entic subgroup defined by organic carbon content in the surface 25 cm represents an important group of Japanese Andisols--Ando loams brown and light-colored or brown Andosols.

For the definition of vitric properties, besides acid oxalate extractable Al, phosphate retention should be taken into consideration. As a criterion of Andents organic carbon content may be useful.

Concerning 15 bar water retention, the present criteria bring about artificial grouping of some Japanese Andisols. To overcome this difficulty, the order of key out of great groups should be changed as follows: melanic- fulvic- hydric.

INTRODUCTION

Andisols occupy about one-sixth of the whole land area and 27% of the total arable land in Japan. But we do not have Torrands, Xerands, and Ustands at all, reflecting a udic moisture regime. The scope for discussion in this paper, therefore, is restricted to the other suborders. As for great groups, we almost lack any experience of studying cryic, duric, placic, and tropic soils. Under these circumstances, criteria relating to Japanese conditions will be discussed in the following.

CLASSIFICATION OF SOILS DEVELOPED FROM VOLCANIC ASH IN HOKKAIDO

Before the discussion of criteria of great groups of Andisols, a brief sketch of soils developed from volcanic ash in Hokkaido should be made. In Hokkaido, the northernmost island in Japan and characterized by recent settlement and cool climate, many recent and older volcanic ash layers have been identified so far. During soil surveys their distribution was thoroughly studied to compile a map showing distribution of late Quaternary pyroclastic deposits at a scale of 1:600,000 (Sasaki, 1977). An outline of the classification of soils derived from these ash layers is shown in Table 1.

Table 1. Classification of soils derived from volcanic ash in Hokkaido (from Hokkaido Soil Classification Committee, 1979).

Major Group	Group	Criteria[a]		Equivalence in Andisol proposal
		Organic Matter and Color	Phosphate absorption coeff. mg/100g	
Regosols	Volcanogenous Regosols	less than 5% org. matter	less than 1,500[b]	Andents
Andosols	Regosolic Andosols	5% or more org. matter	less than 1,500[b]	Vitriborands Vitrudands
	Cumulic Andosols	12% or more averaged org. matter in 30 cm	1,500 or more	Melanoborands Melanudands
	Ordinary Andosols	value/chroma; 1.7/1, 2/1, 3/1, 2/2, N1.5-3	1,500 or more	Haploborands Hapludands
	Brown Andosols	other Andosols	1,500 or more	Entic subgroup of Hapludands

[a] 25 cm or more in 50 cm of the soil surface, except for Cumulic Andosols.

[b] comparable to phosphate retention 85%.

Andisol proposal (Smith, 1978) and our classification (Hokkaido Soil Classification Committee, 1979) are quite similar, especially if a new suborder Andents is approved (Leamy, 1983). Only slight differences are observed in both systems. In our system, bulk density is not used as a criterion because soils developed only from stratigraphically confirmed volcanic ash are taken into account.

A distribution pattern of soils in eastern Hokkaido is illustrated in Fig. 1. Near the volcano (Mt. Kamuinupuri) Volcanogenous Regosols and Regosolic Andosols are found. Cumulic Andosols predominate in the farthest area from the volcano where each volcanic ash layer becomes thinner, and on the flat terraces where abundant soil moisture favors the accumulation and humification of organic matter. Ordinary Andosols occupy the intermediate area, and the southern area where hilly topography predominates.

On the other hand, suborder designations such as **Borands**, Udands, and Aquands are considered to be suitable for understanding Japanese soils in the framework of global distribution of soils.

CRITERIA RELATED TO ORGANIC MATTER

Thick and black A horizons are one of the most conspicuous properties of Japanese Andisols. The Japanese designation Kuroboku for Andisols, which means black and fluffy soils, reflects the Japanese central concept.

Some pedons are arranged in the following four groups (Table 2): A, melanic (8% or more organic carbon and black in the upper 30 cm); B, fulvic (a proposed great group by the author, mentioned below), (8% or more organic carbon and not black in the upper 30 cm); C, entic (less than 5% organic carbon in the upper 25 cm); D, other than A, B, and C.

Since most horizons of Andisols have 0.6% or more organic carbon, many of them would be qualified as umbric if their color value is less than 3.5. As seen in Table 2, many soils can be designated as cumulic (umbric epipedon more than 50 cm thick) and even pachic (umbric epipedon more than 100 cm thick), irrespective of their organic matter content. Miyagasaki and Jonouchi soils of Group C found in the southern Kanto Plain are the representative soils for Ando Loams Brown (Natural Resources Section, 1948), Japanese designation: Light-colored or Brown Andosols). On the other hand, Hirusen soils in group A regarded as typical Kuroboku in Japan can be also designated as cumulic. From these facts it necessarily follows that the concept of the umbric epipedon is not fit for Andisols. Concerning the significance of the diagnostic horizons in general, the revised definition of Andisols omitting

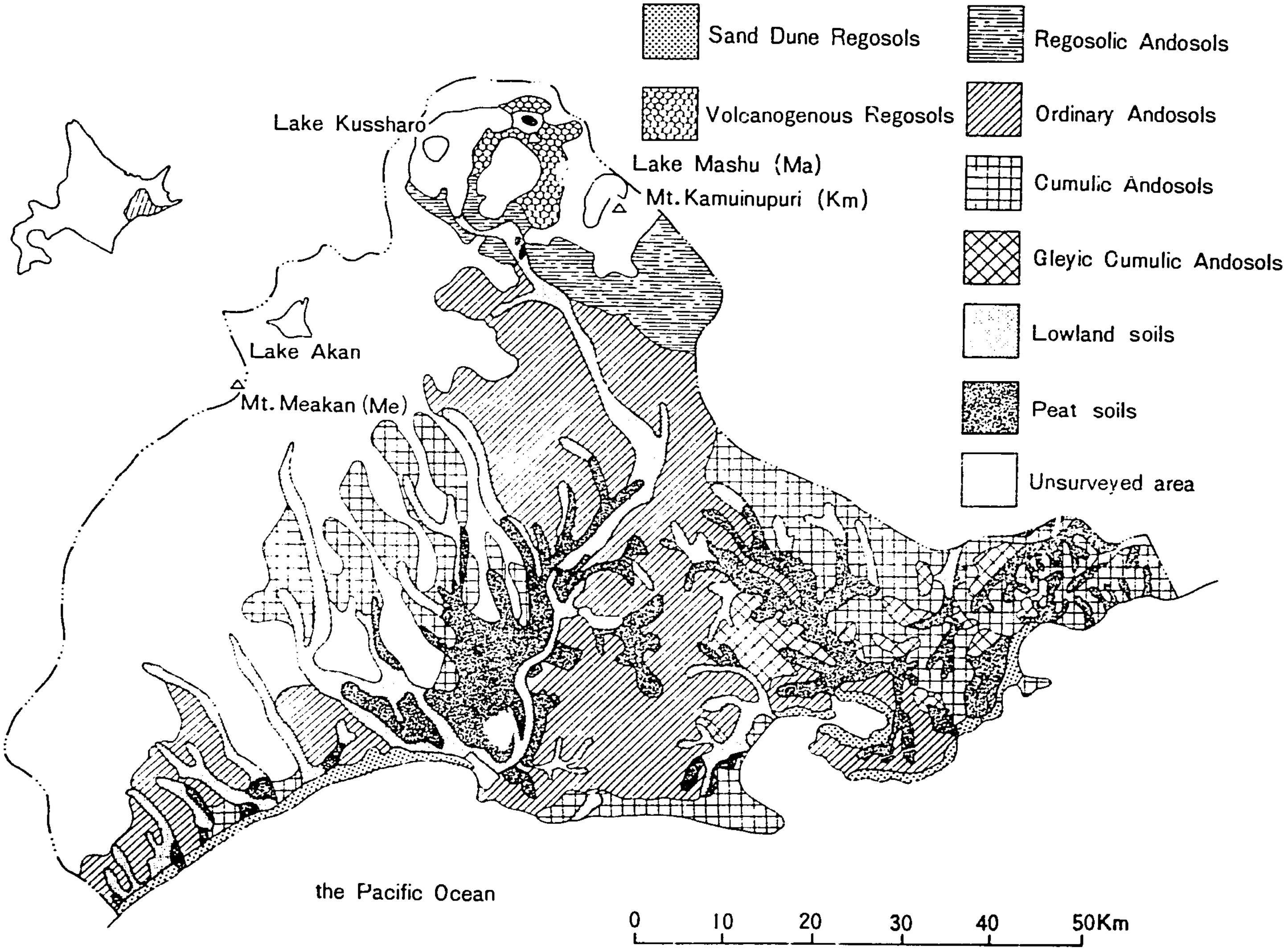

Fig. 1. Generalized soil map of Kushiro Subprefecture, Hokkaido
(from Katayama, 1976)

Table 2. The relation between organic carbon and color in some Japanese Andisols (from Third Division of Soils, 1964).

Horizon	Depth (cm)	Color moist	Organic carbon (%)
		A: Melanic	
Kanuma (Tochigi pref.)			
Ap	0-18	10YR2/1.5	8.61
A12	18-31	10YR1.5/1.5	7.62
A13	31-62	10YR2/1.5	6.32
B1	62-80	10YR3/4	2.51
B21	80-97	10YR4/6	1.51
B22	97-120	10YR4/6	2.54
Sagamihara (Kanagawa pref.)			
Ap	0-21	7.5YR1/1	8.69
A12	21-33	7.5YR1/1	8.84
A13	33-50	7.5YR2/1	9.04
A14	50-80	7.5YR2/2	11.69
A3	80-110	7.5YR2/3	4.93
Hirusen (Okayama pref.)			
A11	0-13	5YR1/1	17.92
A12	13-46	N1	17.17
B1	46-64	10YR2/2	5.04
B2	64-90	10YR5.5/4	1.63
IIC	90-100+	10YR5/4	0.84
Kuju (Oita pref.)			
A11	0-20	7.5YR1/1	21.08
A12	20-38	N1	21.47
A13	38-63	5YR1/1	13.04
A14	63-82	5YR1/1	9.95
A3	82-109	10YR2/1	5.77
		B: Fulvic	
Hachimantai (Iwate pref.)			
O1	1-0		
A11	0-8	5YR2/1	18.31
A12	8-16	5YR3/2	17.93
B1	16-21	7.5YR5/3	6.25
IIB21	21-37	7.5YR4/6	4.73
IIB22	37-64	7.5YR5/8	1.74
IIIC1	64-94	7.5YR5/3	0.40
Takaosan (Tokyo)			
O1	1-0		
A11	0-6	5YR2/2	15.48
A12	6-16	7.5YR2/2	6.93

Table 2. (continued)

Horizon	Depth (cm)	Color moist	Organic carbon (%)
Takaosan (Tokyo) cont.			
A13	16-41	7.5YR2/3	6.83
B1	41-81	7.5YR3/4	3.06
B2	81-100+	7.5YR3/4	2.30
Asakawa (Tokyo)			
O1	5-3		
O2	3-0		
A11	0-12	7.5YR3/2	13.33
A12	12-25	7.5YR3/4	6.32
A3	25-50	7.5YR3/4	4.80
B2	50-100	7.5YR4/4	2.79
Amagi (Shizuoka pref.)			
O1	1-0		
A1	0-17	10YR2/3	17.50
A3	17-31	10YR3.5/3	8.35
B1	31-65	10YR4/4	4.46
B2	65-105	10YR4/6	2.99
C: Entic			
Kurosawajiri (Iwate pref.)			
A1	0-15	5YR3/2	3.20
B2	15-75	7.5YR6/8	0.75
IIC	75-100+	5YR5.5/8	0.64
Maebashi (Gunma pref.)			
Ap	0-18	7.5YR4/4	1.98
A12	18-38	7.5YR3/4	2.05
B1	38-60	7.5YR5/5	1.05
B21	60-88	7.5YR6/8	0.79
B22	88-109	7.5YR6/8	0.55
Miyagasaki (Ibaraki pref.)			
Ap	0-18	7.5YR2/2	5.22
A12	18-25	7.5YR2/2	4.05
B1	25-60	7.5YR3/3	2.95
B21	60-90	10YR4/6	0.88
B22	90-135	10YR4/6	1.23
Jonouchi (Ibaraki pref.)			
Ap	0-25	7.5YR3/4	3.78
B21	25-98	5YR3/6	1.48

Table 2. (continued)

Horizon	Depth (cm)	Color moist	Organic carbon (%)
	D: Other than A, B, and C		
Miura (Kanagawa pref.)			
Ap	0-18	7.5YR2/2	5.31
A12	18-30	7.5YR2/1	6.10
A3	30-40	7.5YR2/3	5.91
B1	40-60	7.5YR3/3	3.93
B21	60-100	7.5YR3/4	2.11
Yatsugatake (Yamanashi pref.)			
Ap	0-8	7.5YR3/2	6.64
A12	8-38	7.5YR3/3	5.19
B1	38-52	7.5YR4/4	1.38
B21	52-70	7.5YR5/6	1.69
B22	70-100+	7.5YR5/6	1.92

the requirements of these horizons (Leamy, 1983) is considered to be reflecting the actual aspects of Andisols.

As shown in Table 2 melanic criteria are suitable for grouping typical Japanese Kuroboku. Some other properties of melanic horizons are shown in Table 3. Of these three pedons, Erimo soils have allic properties and some subhorizons in Erimo and Nishigoshi soils are hydric. Kuju soils in Table 2 have more than 20% organic carbon; even in Japan this is not a usual case. For soils like Kuju, a histic subgroup may be necessary. But soils that can be qualified as histic subgroups of melanic great groups of Andisols should not be keyed out as Histosols because properties of organic matter in these two kinds of soils are quite different.

In forest regions of northern and central Honshu soils developed from volcanic ash often have high organic carbon content in spite of lighter colors. Examples are four pedons cited in B of Table 2. Compared with soils of melanic great groups with A-type humic acid of advanced stage of humification (Table 3), organic matter of these soils is characterized by B and/or P-type humic acids. Although limited as far as is known to forest regions in northern and central Japan, these soils are supposed to occur in other climatic regions. This paper proposes a new "fulvic" (L.fulvus, dull yellow or yellowish-brown) great group for these soils. Besides Fulvudands, Fulvoborands may be necessary for cooler regions. A pedon described at the foot of Mt. Fuju is shown in Table 4. Originally the pedon was under beech (*Fagus crenata*), and at present is planted with Japanese cypress (*Chamaecyparis obtusa*).

The subgroup designation entic is used to indicate less organic carbon in Andisols. But vitric great groups being understood to connote the "entic" stage of soil development in the framework of Andisols, the designation should be changed to another word meaning less organic carbon or light-colored A horizons.

Concerning the criteria related to organic matter, we now have melanic, fulvic, and haplic great groups and the "entic" subgroup. They will be satisfactory for various Andisols in view of Japanese experience.

CRITERIA FOR VITRIC PROPERTIES

Some properties of vitric and related materials in Hokkaido are shown in Table 5. According to the revised proposal (Leamy, 1983) very recent pumiceous sand and pumice layers are grouped into entic material. Pumice layers have weathered for a considerable span of time to be qualified as vitric like Ta-cl in Hayakita soil.

Table 3. Some properties of horizons qualified as melanic (from Wada, 1983).

Horizon	Depth (cm)	Color Moist	Organic carbon (%)	Humic acid type	Bulk density g/cm^3	Water retention 15bar %	pH (NaF)	Exch. Al me/100g	Phosphate retention (%)
				Erimo (Hokkaido)					
Ap	0-19	10YR1.7/1	15.88	A	0.74	71	9.2	5.09	92.3
A12	19-35	10YR1.7/1	16.80	A	0.61	72	10.7	9.76	97.9
A13	35-45	10YR2/1	15.85	A	0.53	113	11.4	7.49	97.8
				Shizukuishi (Iwate pref.)					
Ap	0-19	7.5YR1.7/1	11.42	A			11.1	0.84	94.4
A12	19-27	7.5YR2/2	9.33	A			11.2	0.00	97.6
IIA13	27-41	7.5YR2/1.5	10.60	A			11.3	0.00	98.6
IIIA14	41-63	7.5YR1/85/1	11.38	A			11.3	0.00	99.0
				Nishigoshi (Kumamoto pref.)					
Ap	0-30	10YR2/1.5	9.87	A	0.61	67	10.9	0.18	98.9
IIA12	30-50	10YR2/1	10.37		0.49	102	11.5	0.12	99.5
IIA13	50-72	10YR2/1	9.81	A	0.50	117	11.3	0.06	99.6
IIIA14	72-93	10YR2/1	8.33	A	0.61	95	11.1	0.22	99.6

Table 4. A pedon of proposed fulvic great groups (Shizuoka pref.) (from Wada, unpublished data).

A11	0-8	7.5YR2.5/2	19.55	P	0.32	146	11.0	0.30	98.4
A12	8-19	7.5YR3/3	13.54	P	0.31	144	11.1	0.10	99.1
B21	19-55	7.5YR3.5/3	8.62	P	0.34	158	11.1	0.00	99.3
IIB22	55-78	7.5YR4/5	4.27		0.50	118	10.7	0.10	99.2
IIIC1	78-88	6.25YR3/3	2.22		0.79	35	10.5	0.10	98.9

Horizon	Depth cm	Color moist	Organic carbon %	Humic acid type	Bulk density g/cm3	Water retention 15bar %	pH (NaF)	Exch. Al me/100g	Phosphate retention %
A11	0–8	7.5YR2.5/2	19.55	P	0.32	146	11.0	0.3	98.4
A12	8–19	7.5YR3/3	13.54	P	0.31	144	11.1	0.1	99.1
B21	19–55	7.5YR3.5/3	8.62	P	0.34	158	11.1	0.0	99.3
IIB22	55–78	7.5YR4/5	4.27		0.50	118	10.7	0.1	99.2
IIIC1	78–88	6.25YR3/3	2.22		0.79	35	10.5	0.1	98.9

Table 4 A pedon of proposed fulvic great groups
(Shizuoka pref.)
(from Wada, unpublished data)

Table 5. Some properties of vitric and related materials in Hokkaido (from Seo, et al., 1970; Ogaki, et al., 1979; I. Yamada, unpublished data).

Horizon	Depth cm	Name of tephra [a]	Age	Color moist	Field texture	Organic carbon %	Bulk density g/cm3	Phosphate retention %	Acid oxalate Al %	Grouping by 1983 Proposal
				Hayakita(Iburi subpref.)						
A1	0-12	Ta-a	1739	10YR2/1	LS	5.71	0.79	35	0.24	Entic
C	12-29	"	"	10YR6/3	S	0.39	1.11	11	0.11	"
IIIA11	31-42	Ta-c1	1640±90BP	10YR1.7/1	L	6.49	0.72	88	1.25	Vitric
IIIA12	42-55	"	"	"	"	4.32		87	2.46	Andic
IIIC	55-66	"	"	10YR6/6	LS	0.56	1.01	44	0.96	Vitric
				Sapporo(Ishikari subpref.)						
A1	0-5	Ta-a	1739	7.5YR2/2	SL	8.05	0.72	24	0.21	Entic
C	5-8	"	"	8.75YR6/3	LS	1.33	1.13	22	0.27	"
				Shikabe(Oshima subpref.)						
A1	0-3	Ko-a	1929	2.5Y4/1	SL	3.73	0.97	10	o.11	Entic
C1	3-65	"	"	2.5Y8/3	pumice	0.86	1.23	2	0.03	"
IIC2	65-120	Ko-c1	1856	2.5Y7/3	"	0.74	1.23	13	0.11	"
				Mori(Oshima subpref.)						
IIC2+C3	25-78	Ko-d2	1640	2.5Y7/3	S	0.74	1.32	3	0.05	Entic
IIC4	78-143	"	"	2.5Y8/2	pumice	0.37	1.27	2	0.03	"
IIC5	143-163	"	"	"	S	0.49	1.28	16	0.02	"
IIIA1	163-170	Ko-e	1700±130BP	2.5Y2.5/1	L	11.69	0.57	92	1.35	Vitric

[a] Ta=Tarumae;Ko=Komagatake

Table 6 shows a pedon of Regosolic Andosols in Kushiro subprefecture, Hokkaido. Horizons down to 62 cm of the profile are vitric according to the revised proposal. In Nemuro subprefecture located on the eastern side of Kushiro subprefecture, each tephra layer becomes thinner due to the longer distance from the volcanoes to give Cumulic Andosols having thick and black A horizons. Table 7 shows a pedon of Cumulic Andosols, only the upper 24 cm being vitric.

In general, criteria for vitric properties of the revised definition are acceptable. Yamada, et al., (1975) and Kobayashi, et al., (1976), however, suggest the following difficulties in using the criteria: low glass contents often encountered in andesitic ashes, unsuitable range of the sand fraction for the identification of glasses under a microscope, and glass coatings on crystal grains. Shoji (unpublished data) also suggests the adoption of a phosphate retention criterion, indicating that acid oxalate extractable Al value of 0.4% corresponds to phosphate retention of about 30%.

CRITERIA RELATED TO WATER RETENTION

In the Andisol proposal 15 bar water retention is heavily used as criteria at various categorical levels. As for great groups, hydric ones are defined as 15 bar water of undried samples of 100% or more on the weighted average of all horizons between 25 cm and 1 m. As a basis of a limit of 100%, it is regarded as a very good natural limit because few samples are close to this limit (Smith, 1978).

Fig. 2 shows the relation between water retention and bulk density in Andisols from Japan, New Zealand, and U.S.A. Different from the assumption, Japanese soils are distributed around 100%.

Fig. 3 illustrates the relation between water retention and organic matter content. Water retention increases with an increase in organic matter content.

The applicability of 15 bar water retention criteria to Japanese soils is questionable, because it seems that the criteria bring about artificial groupings.

To overcome this difficulty, the order of key out of great groups should be changed as follows: e.g., Placudands- Melanudands- Fulvudands- Hydrudands- Vitrudands- Hapludands. By means of this order soils having high water retention due to high organic matter content can be previously separated from those low in organic matter. In melanic and fulvic great groups hydric properties, if necessary, can be indicated by hydric subgroups.

Table 6. Some properties of Regosolic Andosols (Vitriborands) in Shibecha, Kushiro subprefecture (M. Orowa and M. Saigusa, unpublished data).

Horizon	Depth cm	Name of tephra[a]	Age	Color moist	Field texture	Organic carbon %	Bulk density g/cm3	pH(NaF)	Phosphate retention %	Acid Oxalate Al %
A1	0-10	Me-a	200BP	10YR2/2	L	7.07	0.58	9.50	53.4	0.45
IIA1	13-26	Km-2a	500BP	10YR1.85/1	CL	6.04	0.60	11.30	82.9	0.98
IIC1	26-41	"	"	2.5Y4/3	SL	1.02	0.88	11.20	55.4	0.62
IIIC2	41-49	Km-4a	"	5Y5/1	"	0.62	1.07	11.00	40.7	0.55
IVA1	49-58	Km-c	750BP	7.5YR1.85/1	CL	4.11	0.65	11.80	86.8	1.49
VA11	62-68	Km-d	750-1150BP	10YR2/3	L	2.29	0.70	11.97	89.4	2.00
VIIA13	73-82	Km-1f	1150BP	7.5YR1.85/1	CL	5.05	0.57	12.20	95.9	3.00
VIIIA14	82-88	Km-2f	"	10YR2/3	SL	2.95	0.76	12.10	93.3	2.61
IXA15	88-93	Ma-e	1500BP	10YR2/1	L	3.50	0.78	12.18	95.1	3.02
IXC	93-106	"	"	2.5Y4/3	"	2.11	0.76	11.98	93.0	2.97
XA1	106-118	Ma-f1	6,460±130BP	10YR2.5/2	"	3.25	0.65	12.10	95.6	4.00
XB2	118-131	"	"	10YR4/5	"	1.58	0.73	11.68	92.8	3.96

[a] Me=Meakan; Km=Kamuinupuri; Ma=Mashu

Table 7. Some properties of Cumulic Andosols (Melanoborands) in Shibetsu, Nemuro subprefecture (M. Otowa and M. Saigusa, unpublished data).

Horizon	Depth cm	Name of tephra [a]	Age	Color moist	Field texture	Organic carbon %	Bulk density g/cm3	pH(NaF)	Phosphate retention %	Acid oxalate Al %
A1	0-16	Me-a	200BP	10YR1.85/1	L	7.70	0.51	11.00	77.7	0.90
IIA12	16-24	Km-2a	500BP	"	"	10.73	0.55	11.20	85.8	1.20
IIIA13	24-34	Yausubetsu	750-1150BP	"	CL	10.60	0.53	12.33	97.4	3.09
IVA14	34-44	Km-1f	1150BP	10YR2/1	L-CL	7.47	0.57	12.30	97.4	3.85
VA15	44-50	Ma-f1	6,460±130BP	10YR1.85/1	CL	8.82	0.57	12.32	97.9	4.98
VB2	50-63	"	"	10YR4/4	"	4.35	0.48	12.22	97.4	5.87
VIC1	63-80	Ma-g		8.75YR4/6	pumice	1.17	0.60	11.65	92.0	3.71
VIIC2	80-86	Ma-h		10YR4/6+ 7.5Y4/1	"	0.44		11.10	81.6	2.47
VIIIC3	86-104	Ma-i		10YR5/5	"	0.45	0.45	11.37	85.0	3.41
IXC4	104-106	Ma-j		10YR5/1	SL					
XA1	106-116	Ma-k	7,120±180BP	10YR1.85/1	CL					

[a] Me=Meakan; Km=kamuinupuri; Ma=Mashu

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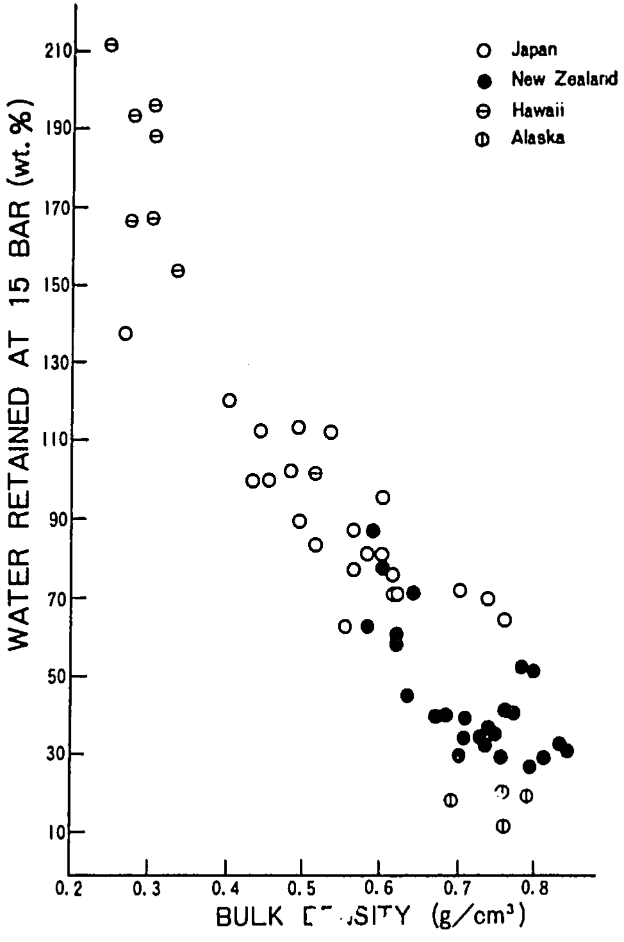

Fig. 2. The relation between water retained at 15 bar and bulk density in Andisols (from Maeda et al., 1983)

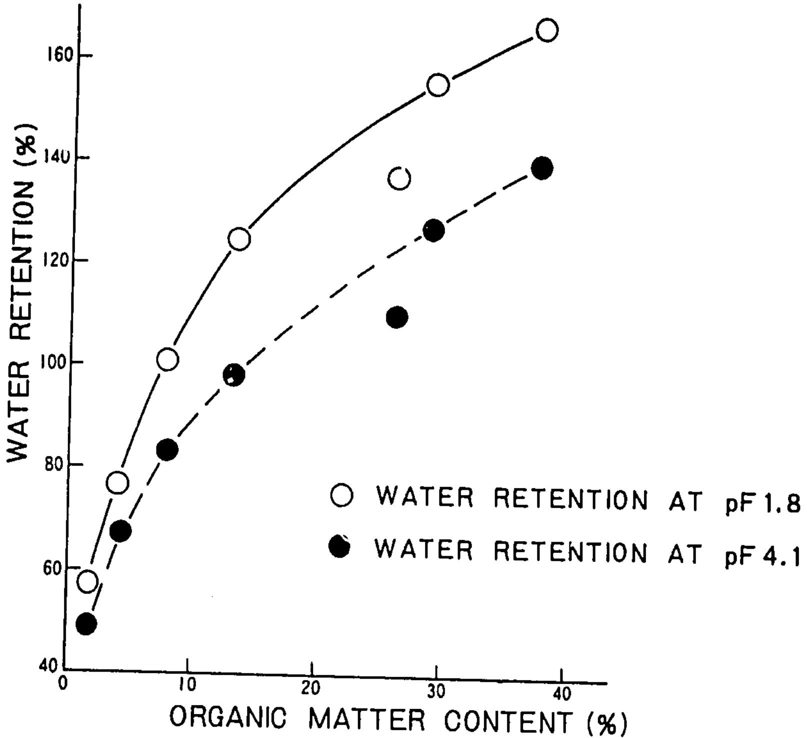

Fig. 3. The relation between water retention and organic matter content in Andisols (from Maeda et al., 1978)

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LITERATURE CITED

Hokkaido Soil Classification Committee. 1979. Soil classification of agricultural land in Hokkaido. 2nd approximation. Misc. Pub. 17. Hokkaido Natl. Agric. Exp. Stn.

Katayama, M. 1976. Tsuchi-tsukuri no subete (how to improve soil productivity). p. 40. Hokkaido Kyodokumiai Tsushinsha. Sapporo.

Kobayashi, S., S. Shoji, I. Yamada, and J. Masui. 1976. Chemical and mineralogical studies on volcanic ashes. III. Some mineralogical and chemical properties of volcanic glasses with special reference to the rock types of volcanic ashes. Soil Sci. Plant Nutr. 22:7-13.

Leamy, M. L. 1983. Proposed revision of the Andisol proposal. International committee on the classification of Andisols (ICOMAND), Circular No. 5:3-29.

Maeda, T., S. Tsutsumi, and K. Soma. 1978. Physical characteristics of Kuroboku with reference to agricultural engineering. J. Japanese Soc. Irrigation, Drainage, and Reclamation Engineering. 46:877-883.

Maeda, T., K. Soma, and B. P. Warkentin. 1983. Physical and engineering characteristics of volcanic ash soils in Japan compared with those in other countries. J. Irrigation Engineering and Rural Planning. 3:16-31.

Natural Resources Section. 1948. Reconnaissance soil survey of Japan. Kanto Plain area. Report No. 110-A. GHQ. SCAP. Tokyo.

Ogaki, S., et al. 1979. Excursion guidebook for soils of the Southern Sorachi. The Group of Japanese Pedologists.

Sasaki, T. 1974. Distribution of the late Quaternary pyroclastic deposit in Hokkaido, Japan. Misc. Pub. 4. Hokkaido Natl. Agric. Exp. Stn.

Seo, H., M. Katayama, M. Otowa, Y. Amano, and S. Dobashi. 1970. Soil survey of Oshima subprefecture. Soil Survey Report. 20. Hokkaido Natl. Agric. Exp. Stn.

Smith, G. D. 1978. A Preliminary proposal for reclassification of Andepts and some andic subgroups. Soil Bureau. DSIR. New Zealand.

Third Division of Soils. 1964. Profile descriptions and laboratory data of various kinds of volcanic ash soils in Japan. Natl. Inst. Agric. Sci.

Wada, K. (ed.) 1983. Study of international correlation of Andisols and related soils. Report of group study of Andisols submitted to the Ministry of Education, Japanese Government.

Yamada, I. and S. Shoji. 1975. Relationships between particle size and mineral composition of volcanic ashes. Tohoku J. Agric. Res. 26:7-10.

PROBLEMS OF ANDISOLS

ANALYTICAL CHARACTERIZATION OF ANDEPTS AND ANDISOLS

J. M. Kimble and W. D. Nettleton

This paper is a review of the criteria used to characterize Andepts and those for the proposed order of Andisols. The limitations of each criterion are pointed out. We review field techniques for determining bulk density content of amorphous aluminum, and phosphate retention, and describe in detail the practical aspects of field identification of Andepts and/or Andisols.

PROCEDURES FOR CHARACTERIZING ANDEPTS

Soil Taxonomy (Soil Survey Staff, 1975) requires that an Andept, to a depth of 35 cm or more: (1) have an exchange complex dominated by amorphous matêrial and a bulk density (at 1/3-bar water retention) of the fine earth fraction that is < 0.85 Mg/m^3, or (2) more than 60% of the soil (by weight) to a depth of 35 cm must be vitric volcanic ash, cinders, or other pyroclastic material.

Amorphous material is colloidal material that includes allophane; it may contain enough crystalline material to cause small and disordered X-ray diffraction peaks (Soil Survey Staff, 1975). A major task is to establish that the exchange complex is dominated by amorphous material.

Soil Taxonomy lists six conditions for an "exchange complex dominated by amorphous material":

1. CEC at pH 8.2 $>$150 meq/100 g measured clay.
2. If 15-bar water content $>$ 20%, pH in 1N NaF 9.4.
3. Ratio of 15-bar water content to measured clay $>$ 1.0.
4. Organic carbon content $>$ 0.6%.
5. DTA shows a low temperature endotherm.
6. Bulk density of fine earth (at 1/3 bar) $<$ 0.85 Mg/m^3.

These conditions infer the presence of amorphous material but do not measure the material directly.

CEC at pH 8.2

The ratio of CEC at pH 8.2 to measured clay is > 150. The ratios are enhanced because of poor dispersion of clay in the particle size analysis. Amorphous material has a high CEC (143 cmol/kg, Uehara, 1978; 163 cmol/kg, unpublished data, NSSL) along with a high specific surface (1,000 m^2/g, Uehara, 1978; 300 m^2/g, unpublished data, NSSL). The measured values may be too high because of the poor dispersion.

Measurements of the actual CEC of allophane of established purity are scarce. Wada (1977) states that charge development depends on pH, ion concentration, and temperature. Because the definition of amorphous material in Soil Taxonomy is based on the incomplete dispersion of clay (Soil Survey Staff, 1975), a change in the method for determining particle size or lack of precision in the analysis could change the placement of a soil. There probably would actually be few changes, however, because in the United States in the Pacific northwest, it has been found that the CEC at pH 8.2/clay and 15-bar water content/clay minimum limits for the ratios set by Soil Taxonomy include both the Andepts and andic subgroups (Nettleton and Engel, 1984).

Naf pH, 15-bar water > 20%

The rise in pH in NaF is a rapid test for amorphous material (Fields and Parrott, 1966). The rise in pH is presumed to result from the release of hydroxides from organic and inorganic amorphous hydroxy aluminum species as the fluoride salts precipitate.

The NaF pH test is very useful, but it does have some problems if it is applied outside the highly leaching environment typical of Andepts. It measures exchangeable aluminum (Al^{+++}) as well as organic and inorganic hydroxy aluminum species. Presumably, exposed aluminum hydroxy ions may have either a charge of +1 or +2; hence, the test can only be a general measure for amorphous material. The NaF reacts with any calcium carbonate present; this reaction also raises the pH and can be confused with the previous reaction. However, in an environment where Andepts or andic subgroups occur, calcium carbonate is present only where (1) very large amounts have been applied to soils that contain amorphous material or (2) Andepts or andic subgroups are in areas within the reach of desert dust storms that deposit $CaCO_3$.

High qualify NaF for the test is hard to find. Impure NaF may be used, however, if acid or base is added to adjust the initial pH to 8.2. Dry phenolphthalein-saturated filter paper and NaF solution to moisten the sample can be used in the field to test for the presence of amorphous material. This test may be used for mapping purposes. Field tests such as the NaF test are used to relate one pedon or a body of soils to similar soils that have been more thoroughly tested.

15-bar water content/clay

Clay dispersion in samples from Andepts can be improved (Table 1). Dispersion in a 2% HCl solution (Eswaran, unpublished procedure) produces values higher than those for the standard hexametaphosphate dispersion. The minimum content for the 2% acid dispersion was 1.5 times as high as that for the standard procedure. The average increase was 390%. In some cases where no clay was found with the standard procedure, up to 10% clay was measured using the 2% HCl dispersion. In most samples, however, even with the acid dispersion we apparently are not measuring all of the clay if we accept the value of 150 meq of CEC/100 g of clay as typical for allophane.

For most of the samples, the CEC at pH 8.2 and 15-bar water-to-clay ratios for the acid dispersion do not differ sufficiently to change the placement of the soils. In all but one of the samples the 15-bar water-to-clay ratio (acid dispersion) was greater than 1.0 and the CEC at pH 8.2 per 100 g measured clay was less than 150 in only two. Even though all the fine material may not disperse by the acid dispersion, it appears to give a more representative indication of the clay size material present

The determination of the particle size distribution of Andepts is of little use except for their classification. The physical properties of Andepts such as water-holding capacity, infiltration rate, permeability, and resistance to erosion (when covered with plants or residue) are more closely related to their moist bulk density and content of amorphous material than to clay content because the clay does not disperse under field conditions either.

Determining particle size on field-moist samples provides more information, but the distribution shows little relation to other physical properties. Analysis of particle size distribution analyses of these soils should be discontinued.

Organic carbon

Other taxons besides Andepts and andic subgroups have > 0.6% organic carbon to depths greater than 35 cm. Many Mollisols have similar amounts of organic matter, but their organic matter has a high calcium content, whereas the organic matter associated with amorphous material in Andepts and andic subgroups has a high aluminum content. Andepts that contain little if any KCl-extractable Al release large amounts of Al following destruction of the organic matter by H_2O_2 (Nelson and Nettleton, 1975).

Table 1. Standard Hexametaphosphate Dispersion and 2% HCl Dispersion.

Sample Number	----Clay----		-15-bar/clay-		CEC-8.2/100 g clay	
	Hexa	2% HCl	Hexa	2% HCl	Hexa	2% HCl
	---- % ----		-------------- Ratio --------------			
82P2074	1.1	13.5	30.5	2.5	6060	490
82P2076	*	10.5	*	2.8	a	350
82P2077	*	7.5	*	4.3	a	590
82P2079	*	8.6	*	4.3	a	540
82P1967	3.8	15.2	6.9	1.7	1380	350
82P1969	0.1	9.9	272.0	2.8	47600	480
82P1971	1.5	11.1	19.2	2.6	4290	580
82P1973	5.4	10.4	5.6	2.9	640	330
83P2247	5.9	18.7	5.0	1.6	880	280
83P2248	1.0	12.7	27.9	2.2	4080	320
83P2250	3.6	10.6	6.7	2.3	740	250
83P2253	3.7	14.7	7.1	1.8	950	240
83P2262	0.3	21.1	115.0	1.6	17070	240
83P2265	8.0	11.3	1.7	1.2	180	130
83P2293	2.3	8.4	12.0	3.3	2170	590
83P2295	0.8	6.5	24.3	3.0	5200	640
83P2297	0.9	8.3	23.6	2.6	4140	450
83P2304	0.6	5.1	10.8	1.3	1520	180
83P2305	*	4.3	*	0.7	*	030
83P2328	4.6	13.6	4.5	1.5	650	310
83P2330	0.4	8.2	84.0	4.1	14650	720
83P2332	0.4	7.9	79.8	4.0	3360	680
83P2352	1.4	12.2	25.4	2.5	4550	520
83P2354	1.6	14.0	21.7	2.5	2410	280
	n = 20 x = 2.37	n = 20 x - 11.67				

[a] no clay measured

DTA endotherm

Because of poor dispersion, the clay analyzed for the presence of a low temperature endotherm by DTA and crystalline minerals in the X-ray patterns may not represent the true colloidal fraction of the soil. Samples for DTA should be ground to dryness in alcohol or acetone to maintain clay dispersion before DTA. Although DTA can give a quantitative measure of the amorphous material present in the absence of smectite or halloysite, we generally use the DTA endotherm only to indicate whether any amorphous material is present. By convention, we do not report the endotherm for amorphous material if crystalline material is present.

Bulk density

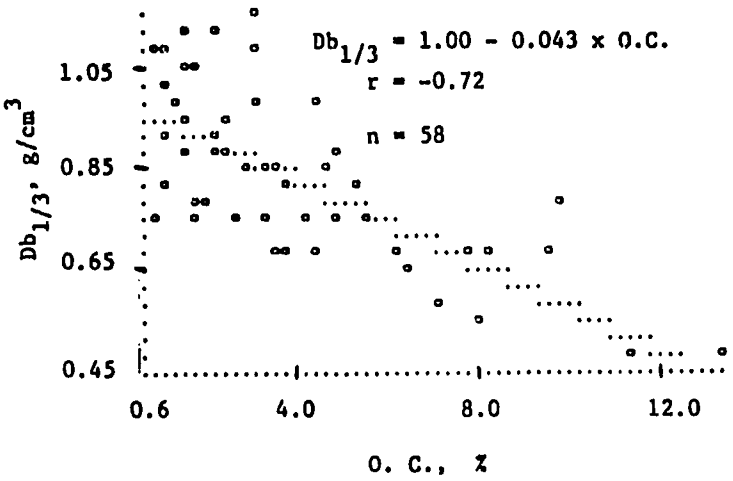
Amorphous material has a bulk density < 0.85 Mg/m^3. Allophane and tephra, as well as organic matter, influences the bulk density of Andepts and andic subgroups (Fig. 1). In general, Andepts have large amounts of organic matter (Table 2). Organic carbon contents > 5% to a depth of a meter or more are not uncommon. Because allophane and organic matter are associated in these soils and the uncertainty in separating the effect of each, the definition of amorphous material in Soil Taxonomy includes both. Hence, no adjustment is made for the effect of organic carbon on the measured bulk density. The effect of organic matter on bulk density is well known. Adams (1973), for example, showed that as organic matter increased, the measured bulk density decreased. In a study of 87 Xeroll and Boroll pedons from five western states, Nettleton and Brasher (personal ccommunication, 1983) found that the bulk density at 1/3-bar water was reduced by 0.07 to 0.09 Mg/m^3 for each percentage point of increase in organic carbon in the soil. Soils that were more than 4 to 5% organic carbon had bulk densities in the range for andic subgroups and soils that were more than 5 to 6% organic carbon were in the range for Andept. Therefore, bulk density alone is not a safe criterion to use for Andepts.

Table 2. Percentage of organic carbon in 58 Andepts.

Content of Organic Carbon (percentage)	Number of Soils	Percentage	Cumulative %
0.630 to 3.163	31	53.45	53.45
3.164 to 5.697	16	27.59	81.03
5.698 to 8.231	7	12.09	93.10
8.232 to 10.765	2	3.45	96.55
10.766 to 13.300	2	3.45	100.00

Figure 1.

BULK DENSITY vs ORGANIC CARBON



When the exchange complex is dominated by amorphous material, the conditions just covered are met (Soil Survey Staff, 1975). However, as mentioned earlier, the properties used only imply the presence of amorphous material. For characterizing Andepts, insofar as practicable, procedures that actually measure the content of amorphous material should be used rather than those that just imply its presence.

PROCEDURES FOR CHARACTERIZING ANDISOLS

Andisols (ICOMAND, 1984) are mineral soils that do not have an argillic, spodic or oxic horizon unless it is a buried genetic horizon occurring at a depth of 50 cm or more, and which have andic soil properties throughout a continuous thickness of 35 cm or more beginning at or within 25 cm of the surface. This is a modification of ICOMAND, 1983.

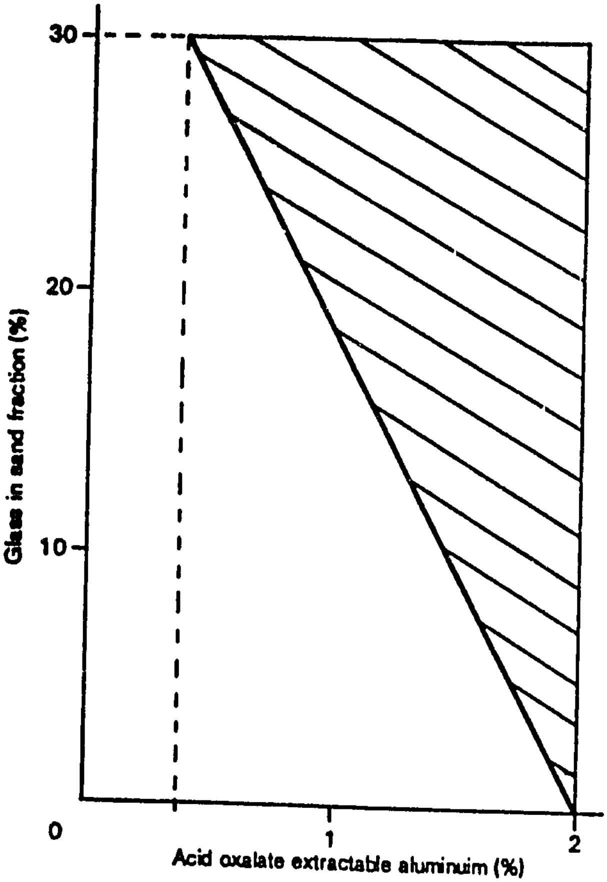
Andic soil properties

The soil material meets one or more of the following three requirements (ICOMAND, 1984):

1. a. Acid oxalate extractable aluminum is 2% or more, or 4N KOH extractable aluminum is 1.5% or more,
   b. Bulk density of the fine earth, measured in the field moist state, is less than 0.9 g/cm^3, and
   c. Phosphate retention is more than 85%.

2. a. Acid oxalate extractable aluminum is 0.4% or more, or 4N KOH extractable aluminum is 0.3% or more, and
   b. (1) The sand fraction is at least 30% of the fine earth and there is more than 30% by weight of volcanic glass (or crystals coated with glass) in the sand fraction, or
      (2) More than 60% by volume of the whole soil is volcaniclastic material coarser than 2 mm.
3. a. Acid oxalate extractable aluminum is between 0.4% and 2%, or 4N KOH extractable aluminum is between 0.3% and 1.5%,
   b. The sand fraction is at least 30% of the fine earth, and
   c. There is enough glass in the sand fraction that the percentage of glass, when plotted against the percentage of acid oxalate extractable aluminum, gives a point within the shaded area of Fig. 2.

Figure 2.


Glass in sand fraction (%)
30
20
10
0
1
2
Acid oxalate extractable aluminuim (%)

Volcanic glass. Volcanic glass is determined by the petrographic microscope on the < 2 mm material, commonly in the very fine sand, and by either an acid-oxalate or 4N KOH extraction of aluminum in the < 2 mm soil.

Bulk density. Bulk density is determined by weighing clods or cores in air and then in water, with clod volume being the difference. Bulk density alone is not a safe criterion for the classification of Andisols for the same reasons discussed earlier for the Andepts.

Acid-oxalate extractable aluminum (Blakemore, et al., 1981). This is measured by shaking 1 gram of soil for 4 hours in the dark with 100 ml of 0.2N ammonium oxalate acidified to pH 3.0 with oxalic acid, centrifuging and determining aluminum in the centrifugate.

4N KOH-extractable aluminum (Holmgren and Kimble, 1984) is determined by treating 0.2 g soil for 10 minutes with 2 ml 4N KOH, diluting to 20 ml and neutralizing with HCl to a phenolphthalein end point. Then 2 ml of 1N KF are added and the suspension re-titrated to the same end point with drop-count additions of 0.1N HCl. Convert drops to percent Al by the following formula:

Al(%) = drops x N/n x 9/(10xW)
where N = normality of HCl
n = drops per ml delivered by dropper
W = weight of one scoop of soil
9 = equivalent weight of aluminum

In the laboratory, after the dilution step, samples are filtered and Al determined in the filtrate by atomic absorption.

Both the KOH-extractable aluminum (Holmgren and Kimble, 1984; Kimble, et al., 1984) and the acid-oxalate extractable aluminum (Parfitt and Hemni, 1982; Wada, 1977) directly measure the amorphous material present. The aluminum measured by both the acid-oxalate and KOH procedures includes not only aluminum from allophane but also exchangeable and organically bound aluminum as well. Eswaran (personal communication) questioned whether all of the allophane is being measured by the procedures, and we cannot say that it is. However, amorphous material as used in Soil Taxonomy includes both the allophane and organic matter. Andisols and Andepts have exchange complexes dominated by amorphous material. Both the acid-oxalate and KOH procedures do measure the influence of allophane and organic matter, whereas the other procedures described do this to a lesser extent. Even though the acid-oxalate and KOH procedures may not measure all of the allophane, they are useful for taxonomic purposes because they provide a standard measure for comparison of soils.

Parfitt and Hemni (1962) and Russell, et al., (1981) have found close agreement between the results of acid-oxalate procedure and the results of infrared determinations of allophane. The relationship between the KOH and the acid-oxalate values (Fig. 3) is discussed by Holmgren and Kimble (1984). Below 2% Al, the KOH and oxalate procedures are nearly equal. Above 2% Al, the KOH value is lower than the cxalate value for two-thirds of the soils. If the atomic equivalent of the acid-oxalate-extractable silica is added to the KOH-extractable Al, a more nearly linear relationship results (Fig. 4). Blakemore (1983) also found a close relationship between the results of the two procedures but concluded that the acid-oxalate procedure would be preferable to the KOH procedure. The major advantage of the KOH procedure is that it is a field procedure that can be run during a soil survey, increasing the validity of the mapping without collecting and sending samples to a laboratory. This does not mean that reference samples should not be collected and subsequently analyzed by a laboratory analysis. Both should be done to increase confidence in the field data.

Phosphate retention capacity. This is determined by shaking 5 g of air-dry soil (< 2 mm) with 25 ml of 1,000 ppm P-retention solution in a 50-ml polypropylene centrifuge tube for 24 hours (Blakemore, et al., 1981). Tubes are centrifuged and the P remaining in solution measured. The procedure has been modified so that it can be used as a "field" procedure (Blakemore, personal communications).

Fig. 5 shows the relationship of KOH extractable aluminum and P-retention (Kimble, et al., 1984). A value of > 2% Al relates to > 95% P-retention. The 2% Al level is significant because it is the criterion for andic material. A similar relationship would exist for the acid-oxalate-extractable aluminum. If P-retention is to be used to stratify soils, a greater amount of phosphorous will need to be added. The present procedure acts only as a cross check for the acid-oxalate procedure.

OTHER PROCEDURES

Laboratory procedures

The procedures listed to this point are the ones required to classify a soil as an Andept or Andisol. Many other analytical procedures can be used to help in the characterization and classification of Andepts and Andisols. These are not discussed in detail, but some of them are: (1) electron microscopy; (2) electron diffraction; (3) infrared spectroscopy; (4) chemical analysis; (5) dissolution analysis; (6) X-ray fluoresence spectroscopy; and (7) surface area measurement. The relationships among different chemical procedures are

Figure 3.

Comparison of aluminum extracted from Spodosols and Andepts by 4N KOH and by ammonium oxalate.

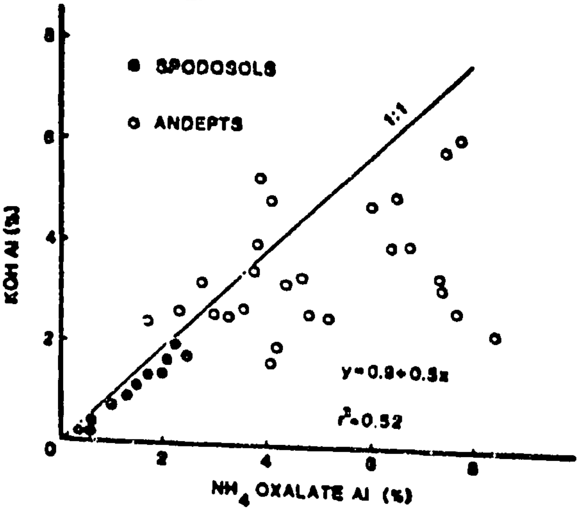


Figure 4.

Ammonium-oxalate-extracted aluminum compared with KOH-extracted aluminum plus atomic equivalence of ammonium-oxalate-extracted silica.

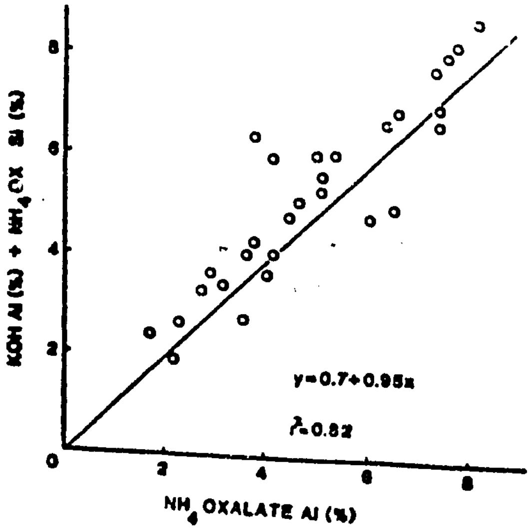
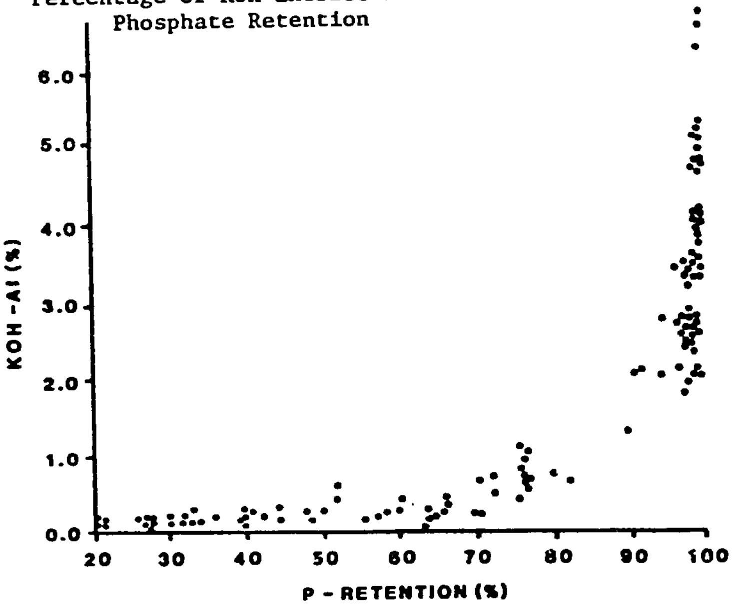


Figure 5.

Percentage of KOH-Extractable Aluminum vs Percentage of Phosphate Retention



described in Holmgren and Kimble (1984), a general discussion of each is in Wada (1977), and a comparison of the acid-oxalate extraction method and an infrared spectroscopic method is in Parfitt and Hemni (1982). These procedures serve to characterize allophane and not to classify soils. Because most of these procedures can only be conducted in large, well-equipped laboratories, their practical use is limited.

Surface area. The NSSL now measures surface area using the ethylene glycol monoethyl ether (EGME) procedure of Heilman, et al., (1965) and Carter, et al., (1965). Wada and Harward (1974) show that allophane has a very large surface area (1,400-1,500 m^2/g). Examination of surface area data shows a natural stratification. Not enough samples have been run to set the class limits for the separations, but the procedure shows promise. Because dispersion is poor, all material < 2 mm is analyzed. Hence, if results were expressed on a measured clay basis, the surface area/unit clay values for the soils with allophane would be much larger. The incomplete dispersion also makes it impossible to determine the surface area of the allophane. Yet even on the whole soil basis, the surface area of the samples is large. The large amount of organic matter in these soils also presents a problem in measuring surface area.

Bulk density. Grossman (personal communication) has developed a field procedure to measure bulk density. The procedure is a variation of the excavation method and uses compliant cavities formed of a lower, resilient ring of foam plastic and an upper, rigid ring of acrylic plastic (Bradford and Grossman, 1982). This procedure may be useful in classifying Andepts and Andisols if bulk density becomes a criterion. When the soils are air-dry, clods are difficult to collect in these fluffy, low bulk density soils. Field soil scientists can use the compliant cavity procedure to measure bulk densities even when the soils are dry.

Effects of drying. The air-drying of samples having amorphous material affects the results of analyses. Tables 3 and 4 show data for a pedon where determinations were made on undried (or field moist) samples (Table 3) and on air-dried samples (Table 4). The 15-bar water is greatly reduced by drying as are several other values. Very little clay was measured in the air-dried samples; whereas, much clay was measured in the moist samples. However, even for the moist samples, the ratio of CEC at pH 8.2 to 100 g clay still meets the criterion for Andepts, indicating dispersion may be poor. The effect drying has on values of other properties is not as striking but should be considered when interpreting results. If air-drying is expected to affect the results, samples should be kept moist for at least some determinations. However, because analysis of moist samples is more tedious, perhaps only the test for 15-bar water content should be run on moist samples and air-dry samples used for other analyses.

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       PNG NO. 8 (MOIST
                                                                                              PAGE 1 OF 2 PAGES
       LAB CLASSIF:     MEDIAL, ISOTHERMIC THAPTO-HEMISTIC ANDAQUEPT

       S 82FN-650 -008A               DATE  08/20/85     SAMPLE NO.  82P4138-4142         U. S. DEPARTMENT OF AGRICULTURE
                                                         PEDON NO.   82P 803              SOIL CONSERVATION SERVICE
       SMSS-PAPUA NEW GUINEA                             PROJECT NO. 82P 130              NATIONAL SOIL SURVEY LABORATORY
                                                                                          LINCOLN, NEBRASKA 68508-3866
       GENERAL METHODS   1B1A, 2A1, 2B

          -1-- -2-- -3-- -4-- -5-- -6-- -7-- -8-- -9-- -10- -11- -12- -13- -14- -15- -16- -17- -18- -19- -20-

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                        (- - -TOTAL - - -)(- -CLAY- -)(- -SILT- -)(- - - -  - -SAND- -  - - - -)(-COARSE FRACTIONS(MM)-)(>2MM)
                         CLAY SILT SAND FINE  CO3 FINE COARSE VF    F    M    C   VC - - - - WEIGHT - - - -  WT
SAMPLE HZN DEPTH  HORIZON LT  .002  .05   LT   LT .002  .02  .05  .10  .25   .5    1 2    5    20    .1- PCT OF
  NO.  NO. (CM)          .002 -.05   -2 .0002 .002 -.02 -.05 -.10 -.25 -.50   -1   -2 -5  -20   -75    75 WHOLE
                         <- - - - - - - - - - - - - PCT OF <2MM  (3A1) - - - - - - - - - - - - - -> <- PCT OF <75MM(3B1)-> SOIL

824138  1S  0- 20   AP    36.9 49.2 13.9           41.5  7.7  7.3  3.6  1.4  1.1  0.5 --   --   --      7 --
824139  2S 20- 54   BW1   49.4 44.8  5.8           33.9 10.9  2.3  2.5  0.8  0.2   -- --   --   --      3 --
824140  3S 54- 82   BW2   45.0 49.2  5.8           31.0 18.2  3.2  2.0  0.4  0.2   -- --   --   --      3 --
824141  4S 82- 85   BW3   34.5 55.5 10.0           43.5 12.0  7.6  1.9  0.3  0.2   -- --   --   --      2 --
824142  5S 85-140  2C     23.6 49.0 27.4           43.9  5.1   --  1.3  2.3  3.9 19.9 --   --   --     27 --

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          ORGN TOTAL  EXTR TOTAL (- - DITH-CIT - -)(RATIO/CLAY)(ATTERBERG )(- BULK DENSITY -) COLE (- - -WATER CONTENT - -)  WRD
           C    N     P    S          EXTRACTABLE       15    - LIMITS -  FIELD  1/3  OVEN WHOLE FIELD  1/10   1/3   15  WHOLE
SAMPLE HZN                           FE   AL   MN   CEC  BAR   LL    PI  MOIST  BAR  DRY  SOIL MOIST  BAR   BAR  BAR  SOIL
  NO.  NO. 6A1C 6B3A      6R3A 6C2B 6G7A 6D2A  8D1  8D1  4F1   4F  4A3A 4A1D 4A1H  4D1  4B4  4B1C 4B1C 4B2A  4C1
          <- - - - - - - -PCT OF <2MM - - - - - - - ->      PCT <0.4MM <- - G/CC - - -> CM/CM <- - -PCT OF <2MM - -> CM/CM

824138   1 15.2 1.025                          1.35
824139   2 5.52 0.434                          1.50
824140   3 9.03 0.446                          1.26
824141   4
824142   5
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                                   ***   C O N T I N U A T I O N   O N   N E X T   P A G E   ***
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                                                                                                                 PAGE 2 OF 2 PAGES
        PNG NO. 8 (MOIST          S 82FN-650 -008A       DATE 08/20/85        PEDON NO. 82P 803     NATIONAL SOIL SURVEY LABORATORY

            -1--  -2--  -3--  -4--  -5--  -6--  -7--  -8--  -9--  -10-  -11-  -12-  -13-  -14-  -15-  -16-  -17-  -18-  -19-  -20-

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           (- NH4OAC EXTRACTABLE BASES -) ACID- EXTR (- - - -CEC - - -)  AL   -BASE SAT- CO3 AS RES.        COND.(- - - -PH - - -)
             CA    MG    NA     K   SUM    ITY   AL   SUM   NH4-  BASES  SAT   SUM   NH4  CACO3 OHMS        MMHOS NAF  CACL2  H2O
SAMPLE  HZN 5B5A  5B5A  5B5A  5B5A BASES              CATS   OAC  + AL               OAC  <2MM   /CM         /CM        .01M
 NO.    NO. 6N2E  6O2D  6P2B  6Q2B        6H5A  6G9A  5A3A  5A8B  5A3B   5G1   5C3   5C1  6E1G  8E1           81  8C1D  8C1F  8C1F
            <- - - - - - - - - - - -MEQ / 100 G - - - - - - - - - - ->  <- - - - -PCT - - - ->                           1:2   1:1

824138  1    3.3   1.2   0.1   0.5   5.1  77.6   3.4  82.7  49.7   8.5    40     6    10                          10.2   4.4   4.5
824139  2    5.5   0.8   0.2   0.7   7.2  56.5   3.7  63.7  74.2  10.9    34    11    10                          10.3   5.2   5.2
824140  3     --    --    --    --    --  75.5   3.6  75.5  56.9   3.6   100          TR                          10.4   5.1   5.2
824141  4
824142  5

------  ---------------------------------------------------------------------------------------------------------------------------
           (- - - -SPODIC HORIZON CRITERIA - - - - - )                             (- - - - - - - -MINERALOGY - - - - - - - - - -)
           (- -NA PYROPHOSPHATE EXTRACTABLE- -) INDEX                              (- - - - - - - - CLAY  - -  - - - - -)
              C    FE    AL   FE+AL FE+AL AL+C   OF                                (- - - -  X-RAY - - - -)(- -DTA - -) TOTAL DOM
SAMPLE  HZN                  (- -DIVIDED BY- -) ACCUM                                                                    RES WEATH
 NO.    NO. 6A4A  6C8A  6G10  DI-C' PCT   PCT                                       7A21  7A21  7A21  7A21  7A3   7A3   7B1A  7B1A
            <- PCT OF <2MM->  FE+AL CLAY  CLAY                                      <- RELATIVE AMOUNTS ->  <- - - - -PCT - - - ->

824138  1          0.8   1.8
824139  2          0.3   1.1
824140  3          0.3   1.1
824141  4
824142  5
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        ANALYSES:  S= ALL ON SIEVED <2MM BASIS
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        PNG NO. 8
                                                                                                                 PAGE 1 OF 2 PAGES
        LAB CLASSIF:    MEDIAL, ISOTHERMIC THAPTO-HEMISTIC ANDAQUEPT

        S 82FN-650 -008                     DATE  08/20/85     SAMPLE NO.  82P4133-4137            U. S. DEPARTMENT OF AGRICULTURE
                                                               PEDON NO.   82P 802                 SOIL CONSERVATION SERVICE
        SMSS-PAPUA NEW GUINEA                                  PROJECT NO. 82P 130                 NATIONAL SOIL SURVEY LABORATORY
                                                                                                   LINCOLN, NEBRASKA 68508-3866
        GENERAL METHODS   1B1A. 2A1, 2B

            -1--  -2--  -3--  -4--  -5--  -6--  -7--  -8--  -9--  -10-  -11-  -12-  -13-  -14-  -15-  -16-  -17-  -18-  -19-  -20-

------  ---------------------------------------------------------------------------------------------------------------------------
                             (- - -TOTAL - - -)(- -CLAY- -)(- -SILT- -)(- - - -   - -SAND- -  - - - -)(-COARSE FRACTIONS(MM)-)(>2MM)
                              CLAY  SILT  SAND  FINE   CO3  FINE COARSE  VF     F     M     C    VC   - - - - WEIGHT - - - -   WT
SAMPLE  HZN  DEPTH   HORIZON   LT   .002  .05    LT    LT   .002  .02   .05   .10    .25   .5     1    2    5     20     .1- PCT OF
  NO.   NO.  (CM)             .002  -.05   -2  .0002   .002 -.02  -.05  -.10  -.25  -.50   -1     -2   -5  -20    -75    75  WHOLE
                              <- - - - - - - - - - - - - PCT OF <2MM  (3A1) - - - - - - - - - - - - - ->  <- PCT OF <75MM(3B1)->  SOIL

824133   1S   0- 20    AP      8.7  58.7  32.6              41.0  17.7  17.8   7.5   3.1   4.0   0.2  TR    --    --      15  --
824134   2S  20- 54    BW1    16.4  38.2  45.4              26.7  11.5  12.7  17.2   9.4   5.2   0.9  16    --    --      43  16
824135   3S  54- 82    BW2    20.5  20.3  59.2              11.8   8.5   9.7  16.1  15.1  13.5   4.8  20    --    --      60  20
824136   4S  82- 85    BW3     2.5  51.2  46.3              36.1  15.1  13.1   6.5  11.1  14.8   0.8  --    --    --      33  --
824137   5S  85-140   2C       1.2  84.1  14.7               2.5  81.6   0.5   2.1   2.6   3.6   5.9  13     7    --      31  20

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            ORGN TOTAL  EXTR TOTAL (- - DITH-CIT - -)(RATIO/CLAY)(ATTERBERG )(- BULK DENSITY -) COLE (- - -WATER CONTENT - -)  WRD
             C     N     P     S       EXTRACTABLE           15    - LIMITS -   FIELD  1/3  OVEN WHOLE FIELD  1/10   1/3    15  WHOLE
SAMPLE  HZN                          FE    AL    MN    CEC   BAR   LL    PI   MOIST  BAR  DRY   SOIL MOIST   BAR   BAR   BAR  SOIL
  NO.   NO. 6A1C  6B3A        6R3A  6C2B  6G7A  6D2A   8D1   8D1  4F1    4F   4A3A  4A1D  4A1H  4D1   4B4   4B1C  4B1C  4B2A  4C1
            <- - - - - - -PCT OF <2MM - - - - - - - ->            PCT <0.4MM  <- - G/CC - - -> CM/CM  <- - -PCT OF <2MM - -> CM/CM

824133   1  11.4 1.138                                6.64  5.22          NP          0.50  0.85 0.193             118.9  45.4  0.37
824134   2  6.65 0.441                                3.04  2.10                      0.64  1.18 0.211              93.2  34.4  0.36
824135   3  6.22                                      2.83  1.56          NP          0.51  1.28 0.329             127.2  31.9  0.46
824136   4  4.68                TR
824137   5  24.1                                     77.92 66.25                      0.13  0.60 0.641             558.4  79.5  0.62

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                                  ***  C O N T I N U A T I O N   O N   N E X T   P A G E  ***
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PNG NO. 8 S 82FN-650 -008 DATE 08/20/85 PEDON NO. 82P 802 NATIONAL SOIL SURVEY LABORATORY

SAMPLE NO.	HZN NO.	-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-	-18-	-19-	-20-
		(- NH4OAC EXTRACTABLE BASES -)					ACID-	EXTR	(- - - -CEC - - -)			AL	-BASE SAT-		CO3 AS	RES.		COND.	(- - - -PH - - -)		
		CA 5B5A 6N2E	MG 5B5A 6O2D	NA 5B5A 6P2B	K 5B5A 6Q2B	SUM BASES	ITY 6H5A	AL 6G9A	SUM CATS 5A3A	NH4-OAC 5A8B	BASES + AL 5A3B	SAT 5G1	SUM 5C3	NH4 OAC 5C1	CACO3 <2MM 6E1G	OHMS /CM 8E1		MMHOS /CM 8I	NAF 8C1D	CACL2 .01M 8C1F 1:2	H2O 8C1F 1:1
		<- - - - - - - - - - - - - -MEQ / 100 G - - - - - - - - - - - - ->										<- - - - -PCT - - - - ->									
824133	1	3.4	1.3	0.1	0.6	5.4	57.6	2.8	63.0	57.8	8.2	34	9	9					10.4	4.5	4.6
824134	2	3.9	0.6	0.1	0.6	5.2	48.3	1.8	53.5	49.9	7.0	26	10	10					10.8	4.9	5.2
824135	3	4.8	0.9	0.3	TR	6.0	46.9	1.8	52.9	58.1	7.8	23	11	10					10.6	5.0	5.4
824136	4																				
824137	5	9.1	2.6	0.6	0.1	12.4	43.0	1.9	55.4	93.5	14.3	13	22	13					7.3	4.1	4.6

SAMPLE NO.	HZN NO.	(- - - -SPODIC HORIZON CRITERIA - - - - - -)							(- - - - - - - - - -MINERALOGY - - - - - - - - - -)							
		(- -NA PYROPHOSPHATE EXTRACTABLE- -)						INDEX OF ACCUM	(- - - - - - - - CLAY - - - - - - - - -)						(- - -) TOTAL RES	-) DOM WEATH
		C 6A4A	FE 6C8A	AL 6G10	FE+AL (- -DIVIDED BY- -) DI-CI FE+AL	FE+AL PCT CLAY	AL+C PCT CLAY		(- - - - X-RAY - - - -) (- - - - - - <2U - - - -) 7A2I	7A2I	7A2I	7A2I	(- -DTA - -) (- -<2U - -) 7A3	7A3	7B1A	7B1A
		<- PCT OF <2MM->							<- RELATIVE AMOUNTS ->				<- - - - -PCT - - - ->			
824133	1		0.8	1.8												
824134	2		0.4	1.3					KH 2	GE 1			KH69		98	FP 1
824135	3		0.3	1.0					KH 2	VR 1			KH74		99	GS 1
824136	4															
824137	5		0.6	0.8												

ANALYSES: S= ALL ON SIEVED <2MM BASIS

MINERALOGY. KIND OF MINERAL KH HALLOYSITE GE GOETHITE FP PLAG-FELD VR VERMICULITE GS GLASS

RELATIVE AMOUNT 6 INDETERMINATE 5 DOMINANT 4 ABUNDANT 3 MODERATE 2 SMALL 1 TRACE

Physical characteristics

Liquid and plastic limits are greatly affected by amorphous material so they would seem to be possible criteria for identifying Andepts and Andisols, although testing of this approach is not now possible because values for liquid and plastic limits have been established for only a few Andepts. From data available (Table 5), liquid limits appear high relative to plastic limits. In many cases, the only result reported is that the samples are nonplastic. The material actually slides together instead of flowing together. Warkentin and Maeda (1974) proposed using the high liquid limit, low plastic index, and the decrease in the plastic index on drying as a rating system for allophane in soils. They state that the plastic index, despite some problems, is a good criterion to characterize allophane.

Table 5. Liquid limits, plastic limits, and plastic indices for two representative Andepts.

NSSL No.	Liquid Limit	Plastic Limit	Plastic Index
Thixotropic, isohyperthermic, Hydric Dystrandept			
82P2074	75	72	2
82P2075	70	68	2
82P2076		a	
82P2077		a	
82P2078		a	
82P2079		a	
Thixotropic, isothermic, Hydric Dystrandept			
82P1974	67	60	7
82P1975		a	
82P1976		a	
82P1977		a	
82P1978		a	
82P1979		a	
82P1980		a	
82P1981		a	

[a] Nonplastic

The use of physical characteristics to characterize Andisols is discussed in detail by Warkentin and Maeda (1980). More attention needs to be given to the study of the physical properties of these soils other than bulk density. Presently, we look mostly at chemical properties. An advantage of looking at physical properties is that many measurements can be done simply, some even in the field.

DATA ON A VOLUME BASIS

All of the data that we have discussed except bulk density have been on a weight basis. When data for soils with low bulk densities are expressed on a weight basis, they differ greatly from data for soils with higher bulk densities. Profiles having horizons with very different values for bulk density cause similar problems. To get a more realistic comparison of the data, the results should be expressed on a volume basis. Expressing data on a volume basis substantially changes the appearance of the results (Table 6). Expressing data on a volume basis by horizon, or cm by cm, or by any predetermined depth for a given cross sectional area (i.e., organic carbon per meter^2.m) is useful. Expressing the primary data by volume allows one to calculate values for any desired depth interval, such as the control section, the rooting zone, or above a restricting layer. A volume comparison of data within a pedon, or between pedons where there are different bulk densities, may be more useful than a comparison of data by weight. For example, consider two pedons, each with 2% organic carbon by weight to a depth of 1 meter, but each having different bulk densities--one has a bulk density of 0.50 mg/m^3 and the other has a bulk density of 1.20 Mg/m^3. Although the pedons have equal percentages of organic carbon weight, the one with the lower bulk density has only 10 kg/m^2·m of organic carbon. If we were looking at the contribution the organic matter makes to the CEC, the contribution in the one would be 2.4 times as much as that in the other, figuring an equal CEC per gram of carbon by volume. Adjustments made to the CEC based on the percent organic carbon would be the same for both pedons and, for the above figures, it is apparent that a straight adjustment for each percent would not be correct.

Under the propoed criteria, a soil would be considered an Andisol if it had 2% acid-oxalate extractable Al and a bulk density of $<$ 0.90 Mg/m^3 to a depth of 35 cm. Expressed on a volume basis, this would be 6.3 kg Al/(m^2.m). Another Andisol with a bulk density of 0.50 Mg/m^3 and 2% Al would have only 3.5 kg Al/(m^2.m). This major difference in the amount of acid-oxalate extractable aluminum would be expected to effect the phosphorus fixation, the lime requirement, and perhaps other properties of the soils.

Table 6. Comparison of data on a volume and weight basis.

NSSL No.	Depth	Bd 1/3 Bar	Organic Carbon	CEC Sum of Cations	Exchangeable Acidity	Acid Oxalate Al
			---------- Data Dry Weight Basis			----------
	(cm)	(g/cc)	(%)	- (meq/100 g)-		(%)
824133	0-.20	0.50	11.4	63.0	57.6	2.8
824134	20-. 54	0.64	6.7	53.5	48.3	2.8
824135	54- 82	0.51	6.2	52.9	46.9	3.5
824136	82- 85	--	4.7	--	--	--
824137	85-140	0.13	24.1	55.4	43.0	0.8
			---------- Data Volume Basis			----------
	(cm)	(g/cc)	$(kg/m^2.cm)$	$--(meq/m^2.cm)--$		$(kg/m^2.cm)$
824133	0- 20	0.50	0.57	3150	2880	0.14
824134	20- 54	0.64	0.43	3420	3090	0.18
824135	54- 82	0.51	0.32	2700	2390	0.18
824136	82- 85	--	--	--	--	--
824137	85-140	0.13	0.31	7200	5590	0.01
Sum	0- 35 cm	--	17.9	114300	103950	5.50

SUMMARY

The tests for the classification of a pedon as an Andisol at first appear much simpler than those required for an Andept (Soil Survey Staff, 1975). Because Andepts do not disperse well, the tests for their placement are four: NaF pH, % OC, low temperature DTA andotherm, and their bulk density must be < 0.85 Mg/m^3 to a depth of 35 cm. The procedures proposed for characterizing the Andisol order measure amorphous material more directly than do those used for Andepts. Not all pedons that formed in vitric pyroclastic parent material would classify as Andisols. If amorphous material is a required criterion, the proposed tests do a good job classifying these soils.

LITERATURE CITED

Adams, W. A. 1973. The effect of organic matter on the bulk and true densities of some uncultivated Podzolic soils. J. Soil Sci. 24:(1):10-17.

Blakemore, L. C. 1983. An evaluation of the KOH/Al extraction for New Zealand Soils and comparison with acid-oxalate extractable aluminum. *In* Soil Taxonomy News No. 6.

Blakemore, L. C., P. L. Searle, and B. K. Daly. 1981. Soil Bureau laboratory methods. A. Methods for chemical analysis of soils. New Zealand Soil Bureau Scientific Report 10A. DSIRO, New Zealand.

Bradford, J. M., and R. B. Grossman. 1982. In-situ measurement of near-surface soil strength by the fall-cone device. Soil Sci. Soc. Am. J. 4:685-688.

Carter, D. L., M. D. Heilman, and C. L. Gonzalez. 1965. Ethylene glycol monoethyl ether for determining surface area of silicate minerals. Soil Sci. 100:356-360.

Fields, M., and K. W. Parrot. 1966. The nature of allophane in soil. III. Rapid field and laboratory test for allophane. N. Z. J. Sci. 9:623-629.

Heilman, M. D., D. L. Carter, and C. L. Gonzolez. 1965. The ethylene glycol monoethyl ether (EGME) technique for determining soil surface area. Soil Sci. 100:409-413.

Holmgren, G. G. S., and J. M. Kimble. 1984. Field estimation of amorphous aluminum with 4N KOH. (In press)

International committee on the classification of Andisols (ICOMAND). 1983. Circular No. 5; October, 1983. Soil Bureau, DSIR, Lower Hutt, New Zealand.

International committee on the classification of Andisols (ICOMAND) 1984. Circular letter No. 6; April 2, 1984. Soil Bureau, DSIR, Lower Hutt, New Zealand.

Kimble, J. M., C. S. Holzhey, and G. G. S. Holmgren. 1984. An evaluation of KOH extractable aluminum in Andepts (Andisols). (In press)

Nelson, R., and W. D. Nettleton. 1975. Release of aluminum from soils following hydrogen peroxide treatment. Agron. Abstracts: 179.

Nettleton, W. D., and R. J. Engel. 1984. Problems associated with Soil Taxonomy mineral classes in the Pacific Northwest (In press)

Parfitt, R. L., and T. Hemni. 1982. Comparison of an oxalate-extraction method and an infrared spectroscopic method for determining allophane in soil clays. Soil Sci. Plant Nutr. 28:161-168.

Russell, M., R. L. Parfitt, and G. C. Claridge. 1981. Estimation of amounts of allophane and other minerals in the clay fraction of Egmont loam profile and other volcanic ash soils, New Zealand. Aust. J. Soil Res. 19:185-195.

Soil Survey Staff. 1975. Soil taxonomy. Agric. Handbook No. 436. Soil Conservation Service, U. S. Dept. Agric., U. S. Govt. Printing Office, Washington, D. C.

Uehara, G. 1979. Mineralo-chemical properties of Oxisols. p. 45-60. *In* F. H. Beinroth and S. Paramananthan (eds.) Proc. Second Int. Soil Class. Workshop. Part I:Malaysia. Soil Survey Division, Land Development Department. Bangkok, Thailand.

Wada, K. 1977. Allophane and imogolite. *In* J. B. Dixon and S. B. Weed (eds.) Minerals in Soil Environment. Am. Soc. of Agron., Madison, WI.

Wada, K., and M. E. Harward. 1974. Amorphous clay constituents of soils. Adv. Agron. 26:211-260.

Warkentin, B. P., and T. Maeda. 1974. Physical properties of allophane soils from West Indies and Japan. Soil Sci. Soc. Amer. Proc. 38:372-377.

FIELD IDENTIFICATION AND MAPPING OF SOME SOILS WITH ANDIC OR VITRIC PROPERTIES

T. D. Cook

INTRODUCTION

Soils derived from volcanic ash or mixtures of ash and other materials occur throughout the world under varying climates and topography and support different vegetation types. Many of these soils have andic or vitric properties (ICOMAND, 1983) as defined in the proposed order of Andisols. This paper points out problems that face a soil mapper in recognizing and identifying soils with andic or vitric properties consistently without supporting laboratory data.

Some chemical and physical field methods are given for identifying andic properties. General morphological characteristics are also described. Some problems in mapping volcanoclastic soils at the series level are described. No attempt is made to discuss the standard procedures or techniques required to conduct a soil survey.

PREVIOUS WORK

In 1947, W. S. Ligon (Simonson and Rieger, 1967) proposed the term "Andisols" for the dark soils formed from volcanic ash that did not fit well into any of the great soil groups used in the United States. A broad group of soils with similar characteristics had previously been identified by several other names. In 1932, Seki called a group of soils "volcanic ash soils." Kanno used the same name in 1956. Other names have included Ando, Black soils, Brown Forest soils, Yellow brown loams, prairie-like Brown Forest soils, Eutrophic Brown soils, Braunderde, Onji, Alvic soils, Humic Allophane soils, Trumao soils, and Kuroboku soils (Simonson and Rieger, 1967). Subsequently, this group of soils was identified as the Andepts in Soil Taxonomy, and is now redefined in the proposed order of Andisols.

These "Ando"-like soils occur in an extremely wide variety of climates, topography, and geomorphology. They can be very young, days, or can be very old, tens or hundreds of thousands of years. Ando soils have been recognized from the cold subalpine regions (cryic) to the hot humid equatorial tropics (perudic and isohyperthermic) and the dry hot regions (aridic). Vegetation varies from very little in some recent deposits to grasses, shrubs, conifers, or dense tropical forests in other deposits. These soils are at elevations of sea level to well over 4,000 m. They occur on level lowlands to steep mountain slopes and on floodplains, terraces, fans, and hillslopes. Depending on the age of the deposit, slope appears to have little effect on the cccurrence or thickness of deposition of ash deposits. Wind direction, distance, sorting of different sizes of ash, and direction and force of explosive events all influence the deposition of volcanoclastic materials. The size of fragments vary considerably from boulders more than 1 m in diameter to fine silt-size ash.

Several international conferences and meetings have specifically addressed the problems and characteristics of soils that formed in volcanic ash or have andic properties. Four of the most notable conferences are the "Meeting on the classification and correlation of Soils from Volcanic Ash" in Tokyo, 1964 (FAO World Soil Resources Report No. 14, 1964), the "Panel on Volcanic Ash Soils in Latin America" in Costa Rica, 1969 (IAIAS, Turrialba, Costa Rica, 1969), the "II Panel on Volcanic Ash Soils of America" in Columbia, 1972 (IAIAS, Pasto, Columbia, 1972), and the "Conference on Variable Charge" in New Zealand, 1981 (Theng, 1980).

Several authors have summarized these special features; Wright (1964) listed common features recognized to 1964. Most of the properties occur to some extent in all of these soils regardless of location.

The special features of Andosols include:

- deep soil profiles, usually with distinct depositional stratification, and normally "mellow" and friable in the upper part;
- the formation of intensely dark humic compounds in the topsoils which may pervade the soil profile to a considerable depth, and which are comparatively resistant to microbial decomposition;
- prominent yellowish brown subsoil colors and a marked "greasy," "slippery," "soapy," or "smeary" sensation when this material is squeezed between the fingers;
- very light and porous physical condition ("fluffyness") with a very low bulk density, low volume weight, high water-holding capacity and high water-retaining capacity;

- rather weak structural aggregation, with easily destroyed porous peds lacking in cutans;

- almost complete lack of any degree of stickyness or plasticity when moist (except in older and deeper stratified layers) but on drying thoroughly the powdery soil particles and fine peds are often very slow to rewet and may float on the surface of water;

- possess soil clay that has a high iso-electric point, is extremely difficult to disperse properly in textural analysis, and has a very high cation exchange capacity.

Wright (1964) summarizes the general morphological characteristics as follows:

> These soils have AC, A(B)C or ABC profiles, ranging from about 50 cm to over 100 cm in depth. The very dark A horizon is sharply differentiated from the yellowish brown B or C horizons and any of these horizons may show depositional stratification which may attenuate or accentuate their true genetic characteristics. The A horizon has a crumb or fine granular structure and has a moderate or high organic matter content (8 - 28%) often consisting largely of fulvic acids. The organic matter responsible for the intense melanisation is in relatively stable forms. The B horizon, if present, has a weakly developed blocky structure, often difficult to detect the mass when moist, but prominently displayed along with large shrinkage fissures when the soil is subject to drying out on road banks. The soil immediately below the A horizon is usually the most friable part of the profile, but the whole profile has a low bulk density. Soluble salts do not normally occur in the profile, carbonate accumulation and eluviation of clay are also uncommon. Although some mobilization, transportation and deposition of iron and manganese can occur, it is not a widespread feature of these soils. Segregation of aluminum in the form of soft, "waxy" nodules of gibbsite may occur in the B or C horizons. When moist, the soils are "mellow," friable and yield moisture when sheared in the fingers, and have low plasticity and stickyness; when wet they are "greasy" or smeary. They are porous soils and have low volume weight and high waterholding capacity. One or more hardpan layers may be present in the profile, but these are usually inherited depositional features whose intrinsic properties may become reduced or accentuated by soil-forming processes.

A summary of the relationship between climate and soil properties is reported by Swindale and Sherman (1964) for Hawaiian soils.

1. The color of the soils darkens as the rainfall and hence the amount of organic matter increases and then becomes redder as the amount of free iron oxide increases;

2. The degree of weathering, as measured by rainfall and temperature, increases, the textures become finer;

3. Structures of the A horizons are strong in the subhumid warm regions and generally decrease in grade as the soils become either wetter or drier;

4. The structures of the subsoil horizons are nearly always weak;

5. Consistencies are friable and become increasingly smeary as the rainfall increases;

6. The value of pH is high considering the apparent base status, but decreases with increasing rainfall;

7. The organic matter content is highest in the subhumid soils;

8. Cation exchange capacities are always high;

9. Base saturation decreases with increasing rainfall;

10. The clay-size minerals contain allophane or amorphous oxides in large amounts;

11. In the soils from dry regions, the amorphous minerals are accompanied by crystalline silicates, in the wetter regions by crystalline oxides.

According to Flach (1964), volcanic ash soils have a wide range of properties depending on the kind of parent material and differences in environment and age. Such properties may be relatively weakly expressed in soils of intermediate age, and the expression becomes less in very old, mature soils.

Soils of intermediate age have a deep A horizon with moderate to strong structure and low chromas and hues. Below the A horizon, there are commonly no strongly expressed horizons except in buried soils. Very old soils may have a B horizon that appears to contain more clay than underlying horizons. There may be a few clay cutans, but even in such soils, there is typically very little evidence of illuviation of clay. Very young soils are usually coarse-textured, and extremely old ones may feel like clays with textural B horizons. Texture and particle size classes do not have the same significance as in other soils because of the poor dispersibility of the clays.

Characteristics and properties for soils with andic properties in arid areas are summarized by Kabbara (1983) as follows:

They have:

- weakly developed A/C profiles, lacking a B horizon. The A horizon is friable, platy to fine platy, slightly plastic to plastic, light brownish-grey to brown and pale brown to dark yellowish-brown in color and has low organic matter content, is calcareous and lapilli ranges between 15 to 35% and up to 100% in some cases as found in S-3. The C horizon weakly developed, fine to medium subangular blocky, very friable to nonfriable, nonsticky to sticky, nonplastic to plastic, calcareous to noncalcareous, lapilli ranges between 35 to 95% by volume;

- low bulk density, high porosity and high permeability;
- the pH is high and ranges between 7.9 and 9.1 (alkaline soils);
- CEC is low (less than 20 meq/100 g);
- the soils are poor in organic matter content which ranges between traces to very low percentages, which indicates low biological activity in these soils;
- the profiles have a high content of lime and very low content gypsum.

Genesis and morphology

The morphology of older volcanic ash soils develop downward through the normal processes of transformation, transfer, addition, and removal. Where soils develop in areas of active ash deposition, however, they also develop upward by means of additions of new ash. In a paper on volcanic ash soils of Costa Rica, Martini (1964) discusses soil properties as they relate to genesis from very young soils to mature soils.

Young soils have shallow A/C profiles. Changes that have occurred are:

- leaching of bases and some silica
- formation of secondary amorphous materials
- accumulation of organic matter
- development of weak fine subangular blocky structure with incipient granulation

Next in the age sequence, soils develop A(B)C horizons and are followed by deep ABC profiles. These soils have:

- accumulation of high levels of organic matter
- strong formation of amorphous materials
- development of strong fine granular structure
- high CEC
- well aerated and high water-holding capacity
- (B) horizons that represent a color change or have structure that qualifies as a cambic horizon.

At the ABC stage in development, profile depth increases downward, and if new ash is deposited, upward. These soils have thick A horizons that may be subdivided on the basis of color, structure, consistence, and root content. According to Martini (1964), profile 9 in Fig. 1 is the closest to the model concept of Ando soils. Antillanca (Chile 005) soils represent profile 2 in Fig. 1, Puyehue (Chile 007) soils represent profile 9, and Los Ulmos (Chile 003) soils represent profile 12 or 13. (Soil Management Support Services, et al., 1984, Tour Guide Part 1: Chile, for profile descriptions and lab analysis). With age, the amorphous materials are progressively transformed into 2:1 and 1:1 lattice clays and finally into the sesquioxides present in Alfisols, Mollisols, Oxisols, or Ultisols.

Most of the observations and descriptions of the morphologic properties for volcanic soils previously published are essentially the same observations that are currently recognized.

IDENTIFICATION OF PROPERTIES IN THE FIELD

This paper is not a discussion on the techniques and criteria used for mapping Andisols or for placing soil boundaries on field sheets. The procedures for mapping volcanic ash soils are similar to those of any natural landscape body regardless of the kinds of taxonomic units or components in the delineation or the kind of parent material. The problem this paper discusses is the difficulty in identifying soils that have andic or vitric properties without the aid of a field laboratory for determining chemistry, x-ray, or water-retention values. These are properties that would qualify a soil for placement in the Andepts and subsequently in the proposed order of Andisols.

What kinds of morphological features can the field mapper use to recognize those unique properties influenced by volcanoclastic materials? The field soil scientist has a handlens, color book, pH kit, spade, auger, and fingers for subjective judgments of texture, mineralogy, consistence, and other properties.

Volcanic soils that have deposits or strata of coarse ash, pumice, or cinders are not difficult to identify. Other clues may be the presence of strongly contrasting or stratified layers, discontinuities, or stone or gravel lines. Larger fragments of obsidian, basalt, cinders, pumice, or other volcanoclastic materials can be identified through visual examination with a handlens.

From the earlier studies, conclusions may be made about the general field properties or features of soils formed in

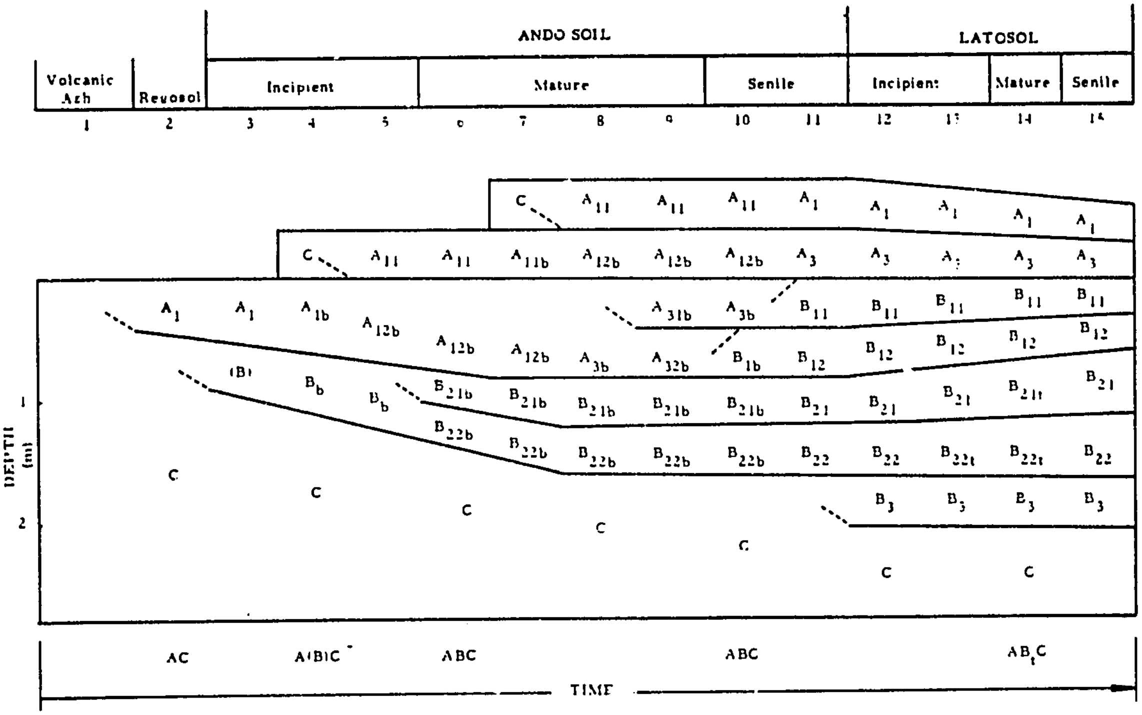


Fig. 1—Time sequence in the genesis of volcanic ash soils and the evolution of profile horizonation.

Martini. Evaluation of soil properties as it relates to the genesis of volcanic ash soils

Soil Sci. Soc. A. J., Vol. 40, 1976

volcanoclastic materials. Following are comments on location and distribution of deposits, color, organic carbon, texture, structure, consistence, reaction, and bulk density for volcanoclastic soils that feel "loamy" and lack obvious stratification or strongly contrasting strata. These soils are difficult to identify as andic or vitric.

Location

Locating the origin of parent materials may be useful in identifying volcanic ash soils. It may be very difficult, however, to identify the point of origin of ejected materials. There may be multiple deposits from a single source, or different kinds of parent materials may be ejected from the same volcano. Finer ash deposits may be hundreds or thousands of miles from the source. If ash beds are present and can be identified macroscopically, however, isopach maps (Figs. 2 and 3) can be prepared. These maps can show depth to a deposit or thickness and distribution of tephra deposits and the most likely source (Pullar, 1980).

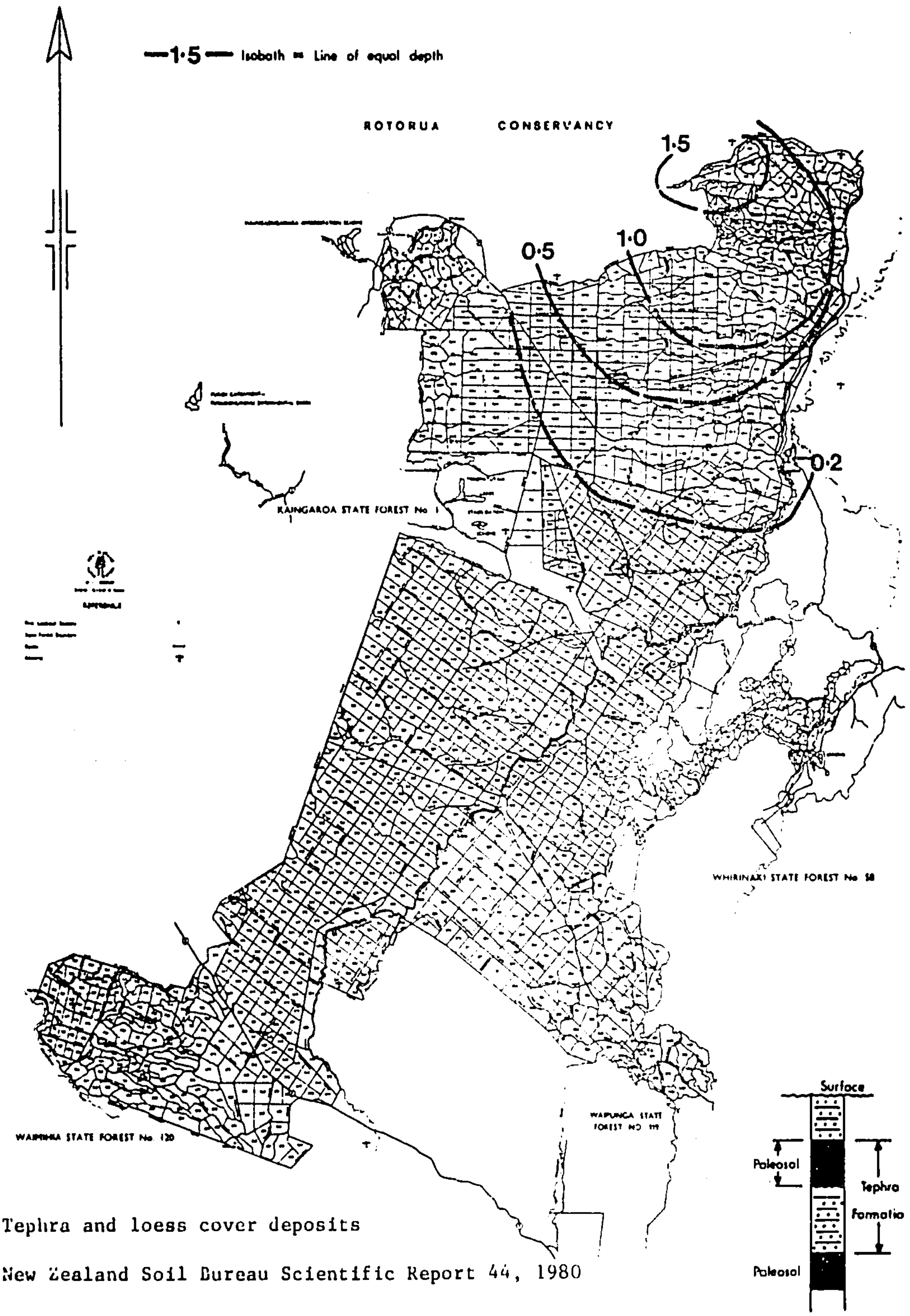
Locating the source and proximity to a volcano does not ensure that all soils are influenced by volcanoclastic materials. Influence of these materials depends on the direction of winds, sorting, and kind and number of explosive events. An example is an eruption that took place in southeastern California. Ash from this eruption is estimated to have been deposited as far away as Kansas and Nebraska (Fig. 4).

Color

Color of volcanic ash soils varies from low to high values and chromas and from a hue of 2.5Y in arid climates to 2.5YR in humid climates. Color is, in many cases, directly related to the chemical composition of the material and not to the weathering processes. Color of fresh ash deposits varies greatly, from white to red to black. Some deposits have high amounts of free iron, and the soils may become reddish. Many of these soils have a thick, very dark brown or black (10YR 2/2, 2/1, N 2/0) A horizon. In some soils, color changes very little with depth. More commonly, these soils have weak "color" B horizons that have brighter hue or chroma than the A horizon. Examples can be seen in profiles described in nearly all continents.

Organic carbon

For most volcanoclastic soils, content of organic carbon in the A horizon is higher than in other nonvolcanic soils in the area and the organic carbon extends deeper in the profile. In some soils, high organic carbon contents extend



DEPTH OF TAUPO PUMICE FROM SURFACE

ISOBATHS IN METRES

Figure 2.

Pullar. Tephra and loess cover deposits

New Zealand Soil Bureau Scientific Report 44, 1980

THICKNESS OF TAUPO PUMICE

ISOPACHS IN CENTIMETRES

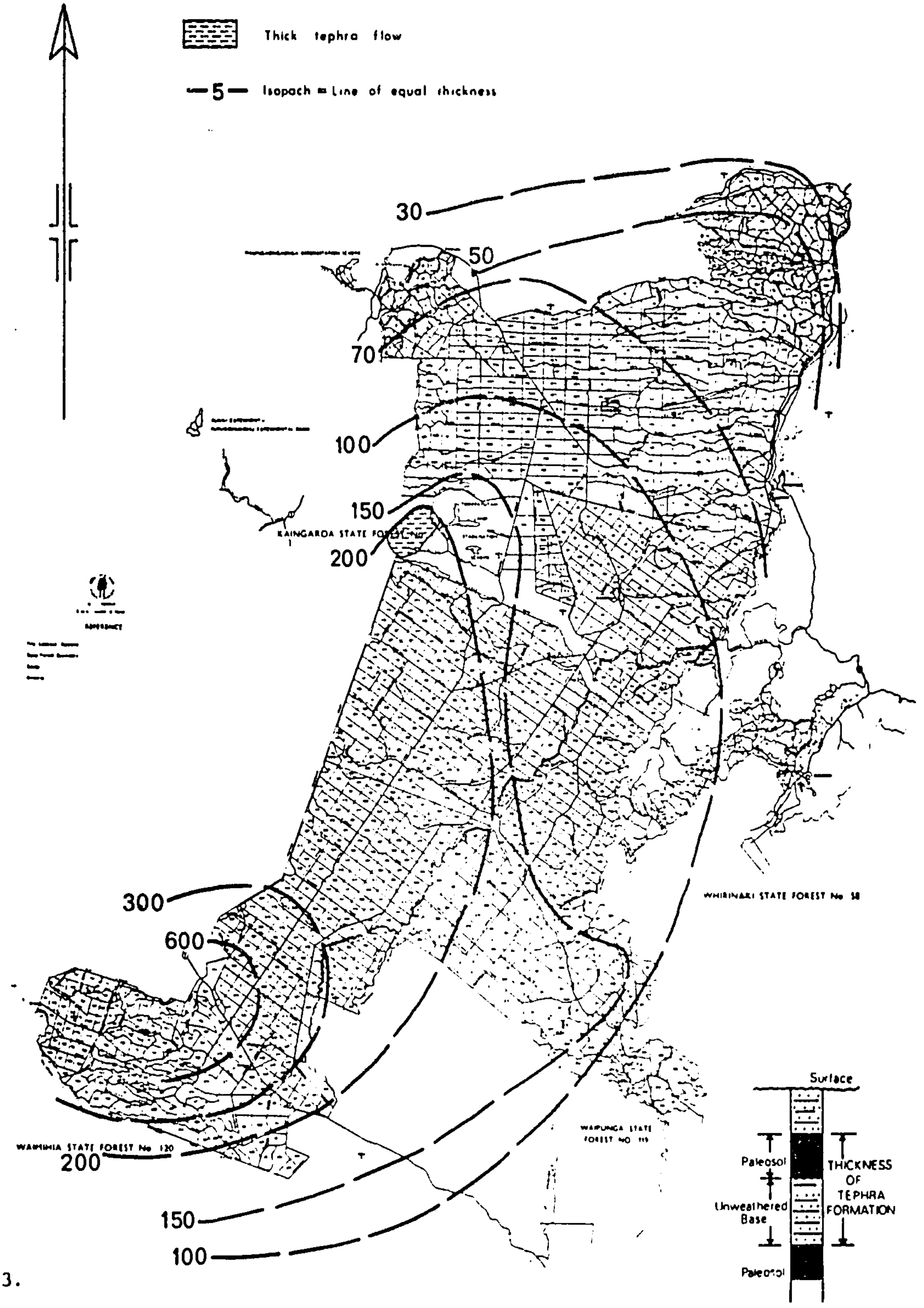


Figure 3.

Pullar. Tephra and loess cover deposits

New Zealand Soil Bureau Scientific Report, 1980

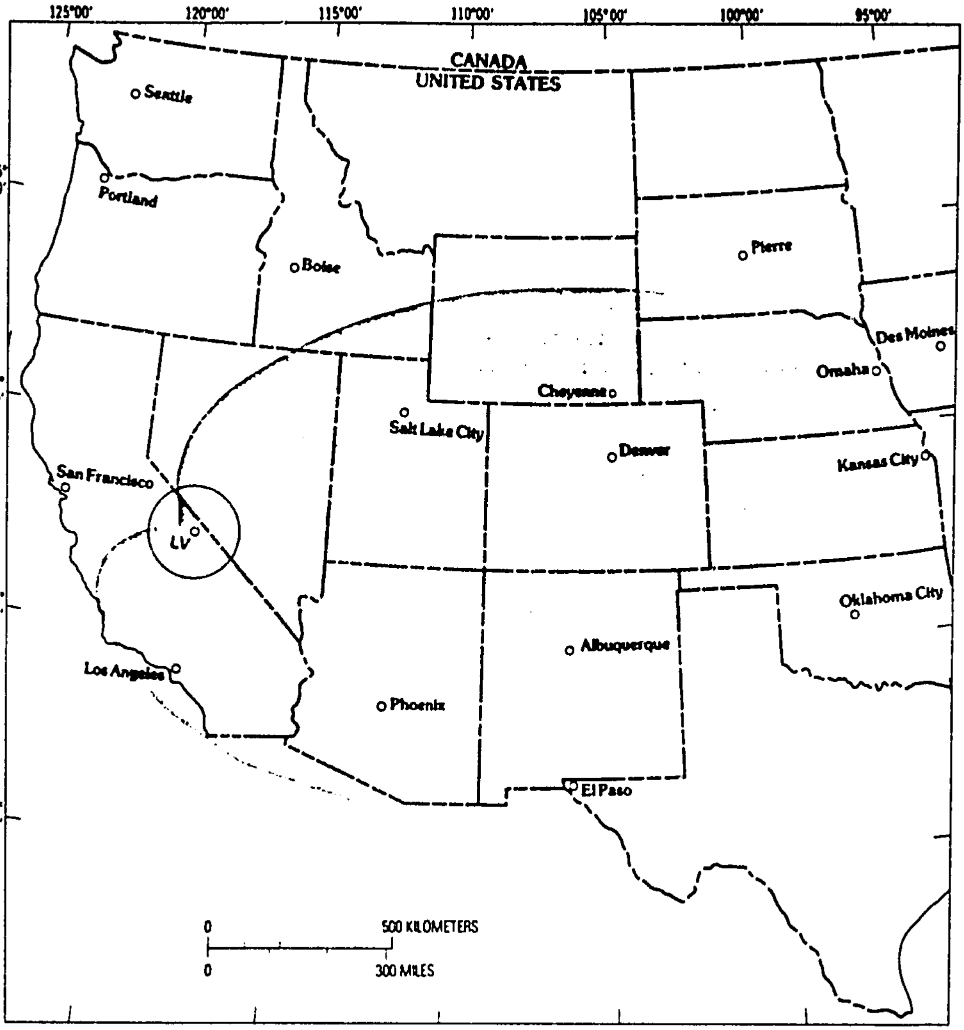


FIGURE 4 —Distribution of Bishop ash beds from eruption at Long Valley caldera (LV)

Miller et al. - Potential volcanic hazards in the
Long Valley - Mono Lake area

Geological Survey Circular 877, 1982

to a depth of greater than 2 m. Volcanoclastic soils in arid climates are lower in organic carbon content, averaging less than 0.2% to about 1%, whereas in more humid areas it ranges from 2% to about 30%. High organic carbon content does not necessarily indicate that the soils have dark colors in the A horizon (Ilaiwi, 1983). Dark colors generally bear little relationship to the organic carbon content.

Field texture

> "Particle size for soils dominated by amorphous materials is a meaningless concept because, presumably, the soil consists of a mixture of discrete mineral particles and of gels. The concept of either texture or particle size is not applicable to a gel particularly if the gel cannot be dispersed" (Soil Taxonomy).

That field texture of volcanoclastic soils is meaningless is shown by the laboratory data for soils that "feel" like clay loams but are less than 10% clay by the standard pipette method. It is also not uncommon to determine the field texture volcanoclastic soils as loam or silty clay loam only to have lab data for particle size reported as 70 to 80% clay. An example is the Los Ulmos (Chile 003) soil (See Tour Guide). A field soil scientist who suspects andic properties should work samples in the hand, when determining field texture, for several minutes to break down any aggregates that may consist of clay-size particles. The dried material left on the fingers after the texture is determined imparts a very fine sand "gritty" feel like miniature glass shards; when the fingers are rubbed, a distinct rasping or very fine sandpaper sound is heard. Another problem in comparing the textures of volcanoclastic as well as nonvolcanic soils described internationally is the use of field manuals with textural triangles using variable or different parameters of sand, silt, and clay. The most commonly described field textures are loams and silt loams. These are the textures that a soil scientist "feels" irrespective of the results of lab tests. Soils dominated by volcanoclastic materials coarser than loams do not exhibit the properties just described. Experienced pedologists usually have little difficulty in recognizing the difference in field textures that contain smectite or kaolinitic crystalline clays.

Structure

Structure of the A horizon is most commonly granular or fine subangular blocky. It ranges from weak to very strong, depending on the moisture content and content of organic carbon. Typically, structure of the B horizon is weaker than the A horizon and commonly is subangular blocky but may be granular.

Rarely, if ever, is the structure angular blocky, prismatic, or columnar. Coarse or very coarse weak prisms may be present but part very easily to subangular or granular structure under only slight pressure.

Consistence

Soils dominated by short-range order minerals have distinct and unique properties when wet, moist, or dry.

Thixotropic properties. When wet, these soils have a high degree of cohesion. When the soils appear to be only slightly moist, water can be squeezed from them. The soils also have a distinct feeling of being slippery, greasy, soapy, unctuous, or smeary. Smeariness has been defined by Flach (1964) as the tendency of a soil to appear moist when undisturbed and wet when crushed. In the soil survey report for the Island of Hawaii, (USDA, SCS, 1973), three classes of smeariness are defined:

Weakly smeary:	When strong pressure is applied, soil material exhibits only weak thixotropic properties as evidenced by changing suddenly to fluid; the fingers "skid," and the soil smears. After the soil smears, there is little or no evidence of free water on the fingers.
Moderately smeary:	Under moderate to strong pressure, soil material changes suddenly to fluid; the fingers "skid," and the soil smears and is slippery. After the soil smears, there is evidence of free water on the fingers.
Strongly smeary:	Under moderate pressure, the soil material changes suddenly to fluid; the fingers "skid," and the soil smears and is very slippery. After the soil smears, free water is easily seen on the fingers.

Many soil scientists have equated weakly or moderately smeary to the medial particle size class and strongly smeary to the thixotropic class. When the soil moisture content at 1/3 bar is about 20 to 50%, the soil does not exhibit smeariness and has weak cohesion; at 50 to 100%, the soil is smeary and has strong cohesion as a long, continuous, rubbery ribbon when shaken in the hand (Leamy, et al., 1980). Though this property is subjective, it is unique and distinctive and can be recognized by most soil scientists.

Another indication of thixotropic properties is the presence of gel-like coatings in pores, on sand grains, and surrounding root hairs. These coatings are commonly transparent and have moist colors that range from 7.5YR 4/4 to 5YR 5/8. The coating material itself is strongly smeary and commonly is identified as imogolite.

Wet consistence. When wet, these soils are usually slightly plastic or nonplastic, and are nonsticky or only slightly sticky. They do not adhere appreciably to the fingers when wet. Smalley (1981) and Warkentin and Maeda (1974) have suggested that a very useful field tool to determine the presence or absence of imogolite and/or allophane is the use of shrinkage curves and plastic index and liquid limit. By the use of the Atterberg limits, one can easily group soils into relative classes of allophanic characteristics that decreased from class I to class V (Fig. 5).

Moist and dry consistence. When moist, these soils are friable or extremely friable even with relatively high content of apparent clay.

When these soils dry, they quickly lose their dilatancy and smeariness, and crush easily to a powder or single grain. These soils are sometimes described as "fluffy," "powdery," "putty," or soft. Dust is a very serious problem where the soils are used for unpaved roads.

When some soils become very dry, the micro-aggregates may harden irreversibly. Soils that have this property commonly have high amounts of amorphous materials. These micro-aggregates are very stable and behave like sand. To identify soils with this property in the field, samples can be thoroughly dried, then wet-sieved to observe the stability of the aggregates (Tuncer, et al., 1977). Aggregates may adhere to roots like small nodules.

These soils are very porous and are loosely packed. They are typically very permeable. These drastic changes in physical properties are striking and are detectable morphological characteristics that can be recognized by the field soil scientist.

Reaction

With the exception of volcanoclastic soils of arid regions, the reaction in 1:1 water usually is less than pH 7. The pH commonly ranges from 4 to 6. These soils in arid regions have been described with calcareous profiles. It has not been clearly shown that the ash material is calcareous or the carbonates are from dust or other sources as secondary enrichment.

Reaction determined by using NaF is not a definitive property of andic or vitric materials, although it can be used as a field indicator of soils with amorphous properties.

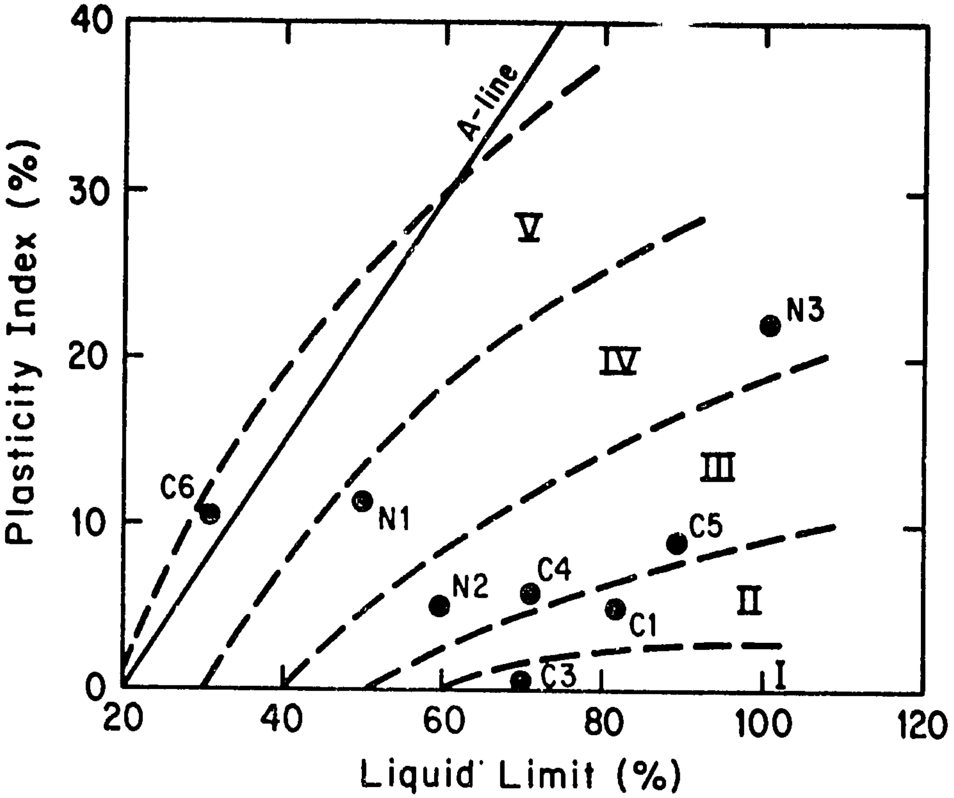


Figure 5.

Warkentin & Maeda. Physical Properties of allophane soils

Soil Sci. Soc. Proc., Vol. 38, 1974

Bulk density

Bulk density is a property that is not easily determined in the field, but it can be approximated. Most "loamy" soils with andic properties have low bulk densities that range from 0.2 to about 1 g/cc. Coarser vitric soils commonly have bulk densities in the range of 1.0 to 1.2 g/cc. These vitric deposits are more easily identified with the aid of a hand lens and have sandier textures than the "loamy" soils. The loamy soils that have clods or aggregates have a distinctive light feel, even though actual values are not commonly measured in the field. When placed in water, some clods will float for a moment. If the clod floats, a bulk density of less than one may be estimated.

Field texture, consistence, thixotropic properties, NaF pH, and bulk density can be used to correlate soils with andic properties (Leamy, et al., 1980).

FIELD TESTS

Though morphology is weakly expressed, there are features or conditions that can aid in the field recognition of soils influenced by amorphous properties. These physical and chemical features can be observed and described by field soil scientists as they are mapping. If vitric materials are present, some pyroclastic fragments may be identified with the use of a hand lens. The presence of contrasting discontinuities can also indicate that volcanoclastic materials are present. These soils commonly lack strong horizonation, such as argillic horizons, and profile development.

The physical properties related to texture, smeariness, dilatancy, and strong granular structure can be observed, felt, or tested. Atterberg limits may provide strong indications that amorphous materials are present. Soils with these materials occur mostly well below the "A" line. Soils that are strongly thixotropic harden irreversibly when dried. The amount of shrinkage upon drying and expansion when moistened is another field test to determine the physical properties or soil behavior.

Though not a precise measurement of active Al, NaF pH can indicate the presence of short-range order minerals. Values greater than 9.4 may indicate these minerals are present. Kimble, et al. (1983) have proposed a simple chemical test for field use to measure that Al in soils with vitric or andic properties. The proposal is to extract Al by a strong solution of KOH. Values of greater than 2 KOH-extractable Al is a strong indication that the soils have formed from volcanoclastic materials.

Phosphate retention can be determined by mixing a small sample of air-dried soil with a phosphate retention solution and soaking overnight. Color is compared with standards to estimate percentage of P-retention. Values greater than 80% indicate amorphous properties common to allophane and imogolite (Blakemore).

Another field test for allophane and imogolite is to mix a 0.02% solution of toluidine blue with a small soil sample in a spot plate. If the color of the supernatant remains blue, it suggests a positive reaction and the presence of allophane and imogolite. If the supernatant becomes colorless and the color of the sedimented soil turns to purple or purplish red, it indicates negatively charged humus and/or layer silicates (Wada, 1984).

CLASSIFICATION AND MAPPING

Classification

In Soil Taxonomy (Soil Survey Staff, 1975) soils with amorphous properties are recognized at various categorical levels. The highest category is the suborder Andepts. Other categories are the "Andi" subgroups; cindery, ashy, medial, and thixotropic families; and series influenced by ash. Pedogenetic features are few or are weak in the Andepts or Andisols. These soils may have mollic, umbric, histic, or ochric epipedons and/or cambic, placic, or duripan subsurface horizons. They are not permitted to have argillic, natric, spodic, or oxic horizons. There is no distinctive diagnostic horizon that is central to the concept of Andepts or Andisols. The principal feature common to these soils is their mineralogy or source of parent material. Andisols may have aquic, perudic, udic, ustic, xeric, or aridic moisture regimes and hyperthermic, thermic, mesic, frigid, or cryic soil temperature regimes, including iso temperatures (ICOMAND, 1983).

Mapping

Many unique problems face the field soil scientist when mapping volcanic ash soils, especially if soil series and phases of series are mapped at scales of about 1:25,000. Before soils can be recognized at the order level, the soil scientist must determine if the soil is "buried." Some volcanoclastic deposits are not thick enough to classify and should be recognized as phases of the classified buried soil. When recent deposits are more than 50 cm thick, the upper soil determines the classification. Because volcanoclastic soils may have strongly contrasting layers or strata at any depth from the surface to over 2 m, the classification of the soils may be affected at any level in Soil Taxonomy. These deposits may be fairly uniform or extremely variable over short vertical or horizontal distances.

Surface topography often does not reflect the depth to the deposits, variations in thickness, or size of particles or fragments in the deposits. Multiple beds of ash, basalt flows, pumice, cinders, or obsidian may be exposed at various positions on the landscape or may occur at any depth within the profile. The identification of representative taxonomic units is difficult because of this complexity and variation within a mapping unit.

The concept of modality for a soil series may need to be revised to accommodate the abrupt variations. In addition, larger numbers of pedons need to be described and sampled for lab analysis to characterize the concept of a taxonomic unit. Also many satellite observations need to be made to verify the modal site and point lab samples collected within the profile to express the variability or similarity.

Because of abrupt changes and differences among pedons, many map units by necessity must be complexes with a minimum of three named soil components. The map units will also have a larger number of included similar and contrasting dissimilar soils.

Those that work with volcanoclastic soils need to develop methods and techniques that can be used by the field soil scientist, who will have to separate the many new categories that will be created if the proposed order of Andisols is established.

Can these new categories be easily recognized by morphological properties, or will many of the categories be determined only after extensive laboratory analysis?

LITERATURE CITED

Blakemore, L. C. Phosphate retention ("standing") method. Soil Bureau, DSIR, Private Bag, Lower Hutt, New Zealand.

Flach, K. W. 1964. Genesis and morphology of ash-derived soils in the U.S. p. 61-64. FAO World Soil Resources Report No. 14, Rome.

Food and Agriculture Organization of the United Nations and United Nations Educational, Scientific and Cultural Organizations (FAO/UNESCO). 1964. Meeting on the classification and correlation of soils from volcanic ash. Tokyo, Japan. World Soil Resources Report No. 14, Rome.

Ilawi, M. 1983. Contribution to the knowledge of the soils of Syria. A thesis for Doctor of Science, State University of Ghent, Belgium.

Inter-American Institute of Agricultural Sciences of the Organization of American States (IAIAS/OAS) and Food and Agriculture Organization of the United Nations (FAO). 1969. Panel on volcanic ash soils in Latin America. Training and Research Center of the IAIAS, Turrialba, Costa Rica.

Inter-American Institute of Agricultural Sciences of the Organization of American States (IAIAS/OAS) and Faculty of Agricultural Sciences, University of Narino, Columbia. 1972. II penal on volcanic soils of America. Pasto, Columbia. (English and Spanish)

International Committees on the Classification of Andisols (ICOMAND). 1983. Circular Letter No. 5. M. L. Leamy, New Zealand Soil Bureau, DSIR, Private Bag, Lower Hutt, New Zealand.

Kabbara, B. A. G. 1983. Mineralogy and micromorphology of some volcanic ash soils from arid areas. A thesis for a Master in Soil Science, State University of Ghent, Belgium.

Kimble, J. M., S. C. Holzhey, and G. G. S. Holmgren, 1983. An evaluation of KOH-extractable aluminum in Andepts (Andisols). Presented before Div. S5 SSSA at Washington, D.C.

Leamy, M. L., G. D. Smith, F. Colmet-Daage, and M. Otowa. 1980. The morphological characteristics of andisols, p. 17-33. *In* B. K. G. Theng (ed.). Soils with variable charge. Palmerston North, New Zealand.

Martini, J. A. 1976. The evolution of soil properties as it relates to the genesis of volcanic ash soils in Costa Rica. Soil Sci. Soc. Am. J. 40:895-900.

Pullar, W. A. 1980. Tephra and loess cover deposits on Kaingaroa Plateau including detailed lithology of Upper Taupo Pumice. New Zealand Soil Bureau Scientific Report 44. DSIR, New Zealand.

Simonson, R. W., and S. Rieger. 1967. Soils of the Andept suborder in Alaska. Soil Sci. Soc. Am. Proc. 31:692-699.

Smalley, I. J. 1981. Physical and engineering properties of soils with variable charge. p. 87-92. *In* P. C. Rankin and G. J. Churchman (ed.) Soils with variable charge, conference proceedings. Massey University, Palmerston North, New Zealand.

Soil Survey Staff. 1975. Soil taxonomy. Agriculture Handbook No. 436. Soil Conservation Service, U. S. Dept. Agric., U. S. Govt. Printing Office, Washington, D. C.

Swindale, L. D., and G. D. Sherman. 1964. Hawaiian soils from volcanic ash. p. 36-44. FAO World Soil Resources Report No. 14, Rome.

Theng, B. K. G. (ed.) 1980. Soils with variable charge. New Zealand Soc. Soil Sci., DSIR, Private Bag, Lower Hutt, New Zealand.

Tuncer, E. R., R. A. Lohnes, and T. Demirel. 1977. Desiccation of soils derived from volcanic ash. p. 44-49. *In* Soil taxonomy and soil properties. Transportation Research Record 642.

U. S. Dept. of Agriculture, Soil Conservation Service. 1973. Soil Survey of the Island of Hawaii. U. S. Govt. Printing Office, Washington, D. C.

Wada, K., and Y. Kakuto. 1984. Spot test with toluidine blue for allophane and imogolite. Contribution from the Faculty of Agriculture, Kysushu University, Fukuoka 812, Japan.

Warkentin, B. P., and T. Maeda. 1974. Physical properties of allophane soils from the West Indies and Japan. Soil Sci. Soc. Am. Proc. 38:372-377.

Wright, A. C. S. 1964. The "Andisols" or "Humic Allophane" soils of South America. p. 9-20. *In* Meeting on the classification and correlation of soils from volcanic ash. FAO World Soil Resources Report No. 14, Rome.

INTERGRADES OF ANDISOLS IN OTHER SOIL ORDERS

R. W. Arnold

Intergrades are soils whose properties result from a blending of soil-forming processes. Properties that reflect dominant processes and controls of current processes are recognized at the order, suborder, and great group levels in Soil Taxonomy. Properties that result from a blending of processes are commonly recognized at the subgroup level. For example, a certain soil with an argillic horizon and an aquic moisture regime is classed as a Typic Ochraqualf. A similar soil differs in having better aeration and less evidence of an iron-reducing environment; its properties lie between those of wetter and drier associates; it could be classed as an Aeric Ochraqualf.

While reviewing the proposed criteria for Andisols and the kinds of intergrades to other soils, I noted that the defined thickness of materials and the concept of buried soils would affect much more than intergrades. Without some clarification there could be disagreement about whether a soil is present or not, and if more than one are present, which has the highest priority for the purpose of classification.

Although these aspects of classification do not directly help us select intergrades, they are important enough to preclude intergrades in some situations. Thus I would like to bring these items to your attention before discussing soils that intergrade to the Andisols.

SOIL PROPERTIES AND PRIORITY DECISIONS

Thickness of mineral soil

Andisols are proposed as an order of mineral soils. For some situations, it is important to know the thickness limits specified for mineral soils.

Although Soil Taxonomy indicates that a rock surface should support vegetation other than lichens, a minimum thickness of soil is not given. In the discussion of mineral and organic soils it states that a mineral soil should consist of at least 10 cm of mineral material overlying a lithic contact, but where the mineral is overlain by organic material the mineral portion must be half or more as thick as the organic portion. This implies that as little as 1 cm of mineral material overlain by about 2 cm of organic material could be considered a mineral soil. At a limiting depth of 40 cm to a lithic contact, 14 cm of mineral material adjacent to the rock overlain by 26 cm of organic material would qualify as a mineral soil.

Mineral soil materials have specified contents of organic carbon; less than 20% by weight for drier materials, and proportionate amounts between 12 and 18% for wet materials. The intent in Soil Taxonomy is to classify as mineral soils those that have less organic material than the amount permitted in a histic epipedon.

Organic soils include organic materials of any thickness over a lithic contact; thus it seems likely that a parallel statement was intended, though not specifically stated, for mineral soils.

Surficial mantle and buried soils

Many Andisols occur in mantles of volcaniclastic materials overlying other earthy materials or previously developed soils. If the mantling materials have not been altered sufficiently to meet the requirements for "andic" or "vitric" soil properties, suggestions for classifying are given in Soil Taxonomy. Handling other situations--for example, thin Andisols overlying argillic or oxic horizons--is not as clear.

A surficial mantle of largely unaltered materials less than 30 cm thick is handled as a phase of any taxa if its presence is important to the use and management of the soil. A unit called "X ashy" might represent an ashy surface texture phase (soil type) of soil series X in which volcanic ash is less than 30 cm thick over soil series X.

A mantle that is 30 to 50 cm thick is not classified as a soil if the underlying-named diagnostic horizons are twice as thick as the mantle, 60 to 100 cm respectively. In these situations the mantle would commonly be recognized as a phase of the underlying soil.

Where the mantle is 30 to 50 cm thick and the underlying diagnostic horizons are less than twice as thick as the mantle, or the surficial mantle is more than 50 cm thick, the soil in the mantle is classified. Because the mantle is considered to be largely unaltered the soils are usually classified as Entisols, often Orthents or Fluvents.

In Soil Taxonomy the subgroup "thapto' implies a buried soil or buried diagnostic horizons. In the United States, thapto- subgroups have only been used to identify dark-colored, buried epipedons, namely thapto-histic and thapto-mollic subgroups. At present, thapto- subgroups have not been used to recognize diagnostic subsurface horizons that have been buried, such as thapto-oxic or thapto-argillic. These conditions have been recognized by: (1) family criteria, usually contrasting texture and mineralogy classes, (2) intergrades or other types of extragrades rather than thapto- subgroups, such as the Ochreptic Fragiudalfs, or (3) as another soil series within a family.

The soils we classify

The classification of a soil in Soil Taxonomy is accomplished by follcwing a key and placing the soil in the first class for which it qualifies. The placement is made according to the presence or absence of diagnostic horizons and features. With few exceptions, the diagnostic properties should be present throughout the pedons of a polypedon that is to be classified.

The development and use of keys indicate that priorities have been set in the selection of properties and in their location within the keys. All soils with mollic epipedons are not Mollisols because other properties have precedence over the mollic epipedon, such as aridic moisture regimes of Camborthids and vertic features of Pelluderts.

Within pedons of mineral soils that do not have cryic or pergelic temperature regimes, the epipedons are determined after mixing the upper 18 cm. Mollic, umbric, and anthropic epipedons are commonly more than 18 cm thick; however, they can be as thin as 10 cm if resting on a lithic contact. Dark-colored epipedons with similar properties but less than 10 cm thick would be ochric epipedons. An ochric epipedon does not exhibit rock structure, yet the mixing of the soil to 18 cm or less if resting on rock usually destroys any rock structure associated with finely stratified sediments of a recent mantle.

Certain soils may appear to be Entisols, Inceptisols, Andisols, or Mollisols; thus a priority system is necessary to obtain consistent placement of soils into classes.

In a similar manner a histic epipedon consists of organic materials at least 20 cm thick, or if they are thinner the organic carbon ccontent limits can be met after mixing the soil to a depth of 25 cm. It is possible, therefore, to have an organic soil that does not have a histic epipedon.

It is sometimes difficult to remember all the thickness and depth criteria used throughout Soil Taxonomy. The Andisol proposal suggests that a 35 cm layer within the upper 60 cm of soil should be dominated by andic or vitric soil properties. One must also keep in mind the following: A spodic horizon in a soil that is not cryic or pergelic must be recognized below a depth of 12.5 cm or below an Ap if it is thicker; a cambic horizon in a noncryic or pergelic soil must be thick enough that its base is at least 25 cm below the soil surface; an oxic horizon must be at least 30 cm thick; and loamy and clayey argillic horizons need only be 7.5 cm thick.

Imagine a soil with dark colors, high base content, and an 8 cm thick argillic horizon all within a depth of 18 cm. When mixed to 18 cm many of the diagnostic features will be obliterated and seemingly the classification of the soil will change. The intent in Soil Taxonomy was to keep similar soils together whether cultivated or under other types of vegetation. Specific guidelines are often very difficult to write in order to convey the intent, as noted in the above discussion.

INTERGRADES AND EXTRAGRADES

Except for the Entisols, soils in other orders have distinctive soil properties and horizon characteristics of those taxa. Properties used at the subgroup level in Soil Taxonomy are intended either (a) to reflect a blending or mixture of sets of processes that cause one kind of soil to develop from or toward another kind of soil recognized at the great group, suborder, or order level, or (b) to indicate properties that are not representative of the great group but which reflect sets of processes or conditions that have not been used as criteria for any taxon at a higher level. Soils with properties of the first kind are intergrades and the others are extragrades.

Use in relation to Andepts

In Soil Taxonomy, Inceptisols that have some properties in common or are similar to Andepts are recognized by extragrade subgroups. They are recognized by "Andic" subgroup modifiers and the most common feature is the presence of a layer more than 18 cm thick in the upper 75 cm of the soil that has the properties associated with volcaniclastics, similar to the proposed "andic" properties. Extragrade subgroups are identified in one great group of Aquepts, six great groups of Ochrepts, three great groups of Tropepts, and in five great groups of Umbrepts.

Soils in other orders that have properties similar to Andepts are indicated by intergrade subgroups that have a blending or merging of features common to the suborder of Andepts and in a few instances to the great group of Andaquepts.

A subgroup intergrade (Andaqueptic or Andeptic) is recognized in one great group of Aqualfs, Boralfs, Udalfs, Aquolls, Borolls, Humults, and Fluvents. Two subgroup intergrades are recognized in Aquents, and four in Orthents. At present, there are 16 extragrade and 12 intergrade subgroups having "andept-like" properties recognized in Soil Taxonomy.

Throughout Soil Taxonomy it is common to list a criteria for a typic subgroup that is not to be permitted. If a soil is observed with the feature, it usually will be placed in a stated, or implied, subgroup that is like the typic except for the designated feature.

It is of interest that typic subgroups in 18 great groups carry "andeptic" exclusions that would provide for "implied" subgroup but soils have not yet been recognized for such taxa. There currently are no extra- or intergrades recognized for "andeptic properties" in Histosols, Spodcsols, Oxisols, Vertisols, or Aridisols. For our purposes we can consider these statements as representing an earlier state-of-the-art recognition of the influence of volcaniclastic materials on soil properties. I think perhaps it serves as a caution not to establish "implied" subgroups until satisfactory evidence is available to support such taxa or unless there is a particular need to exclude the properties in typic subgroups.

Proposed use in relation to Andisols

The characteristics of "andic and vitric soil properties" are similar to those of cambic horizons; namely absence of rock structure, evidence of alteration, significant amounts of weatherable components, and sufficient thickness for consistent recognition.

The International Committee on Andisols (ICOMAND) suggests that the limits proposed for andic and vitric soil properties should be important in defining subgroups for intergrades in other orders. It also suggests that "andic" and "vitric" subgroups likely are appropriate. Although the soil properties have several ccharacteristics, it is proposed that an "andic" or "vitric" subgroup would generally be considered where a layer more than 18 cm thick having andic-like or vitric-like properties occurs within the upper 75 cm of a soil.

Where materials have properties similar to "andic" except for lower phosphate retention they might be included as "andic" subgroups in other orders. Where the materials are andic except for a bulk density of greater than 1.0 g/cc this could be indicated by an amorphic mineralogy at the family level.

Thus the current proposal suggests the use of soil property intergrades. Andic subgroups likely would indicate soil materials that have equivalent levels of extractable aluminum and are (a) 18 to 35 cm thick within the upper 75 cm of soil, or (b) have phosphate retention values somewhat less than 85%, or (c) have bulk density of 1.0 g/cc or more, or (d) some combination of the above properties.

Vitric subgroups likely would indicate soil materials that have equivalent levels of extractable aluminum and are (a) 18 to 35 cm thick within the upper 75 cm of soil, or (b) have somewhat less than 60% by volume of vitric components or somewhat less than 40% by weight of volcanic glass.

The use of an "andic" subgroup in another order suggests soil properties that are similar to those of Andisols, thereby indicating an intergrade at the order level.

At present, the use of a "vitric" subgroup for an intergrade to the Andisol order would be inappropriate terminology because vitric soil properties are proposed for use in the great group category of Andisols, for example, Vitrudands. In these situations, an intergrade between two great groups should be considered, for example, Vitrudandic Hapludalfs.

It would be possible to consider "vitric" as an extragrade feature but this would violate its common use as a great group property reflecting an additional control on soil processes. Similar contradictions do exist in Soil Taxonomy and by consensus we could agree to use a "vitric" subgroup as a special type of intergrade to the Andisol order.

A suborder of Andents

It has been suggested that a suborder of Andents might be useful to handle soil materials less than 35 cm over a lithic contact that have andic soil properties. At the suborder level, these properties should reflect a major control of current processes, whereas at the order level the same soil properties result from, or reflect, a major set of soil-forming processes. It is awkward to have the same set of properties change significance because of the depth to bedrock. Unless specifically excluded from a cambic horizon, a soil with an ochric epipedon and a cambic horizon could be recognized between the depths of 25 to 35 cm over a lithic contact and be classed as an Inceptisol. If a mollic, umbric, or anthropic epipedon developed in this material, a soil as thin as 10 cm to a lithic contact might be classed as an Inceptisol or a Mollisol.

It is also proposed that the Andents have vitric-like properties except for a lower extractable-aluminum value to depths of 35 cm or more.

In the Entisols, the Aquents are wet, the Fluvents exhibit periodic accretion, the Arents are highly disturbed, the Psamments cannot readily be altered by the current process, and the Orthents contain components that can be altered. Each of these is an indication of a major control on current processes, and the andic/vitric properties appear to be consistent with the intent of the Orthents. They could be included with Fluvents; however, the Orthents may make a better grouping.

The subordinate or secondary controls of current processes in Orthents are the soil moisture and temperature regimes. In the Aquents soil materials high in sand or with high n values are thought to be additional controls of processes. Thus, andic/vitric soil properties would be appropriate for intergrades of the drier Entisols at the subgroup level, for example, Andic Lithic Udorthents. The andic/vitric soil properties would be appropriate as a secondary control of processes in the wetter Entisols at the great group level, for example, Andaquents.

CONCLUSIONS

1. To readily accommodate Andisols as mineral soils and close an existing gap, the definition of "mineral soil" should be amended so that mineral soil materials of any thickness over a lithic contact would be considered a mineral soil. It currently is limited to a 10 cm thickness unless overlain by thin layers of organic soil materials.

2. Most Andisols consist of layered sediments and often overlie previously developed soils. Improved definitions of buried soils and guidelines for recognizing recent mantles, polygenetic soils, and relict soils are needed to assist in developing and testing taxonomic concepts in Soil Taxonomy.

3. Because Andisols likely will key out early in Soil Taxonomy, there may not be much of a problem with the overlap of andic soil properties and a cambic horizon, or the overlap with mollic, umbric, and anthropic epipedons. If the diagnostic features are defined to stand alone, however, then additional characteristics should be mentioned in definitions of other horizons.

4. Intergrades to Andisols appear to be most appropriate at the subgroup level. The soil materials important to Andisols have limits on thickness, component content, bulk density, phosphate retention, and extractable aluminum. Because each of these properties has a limit of acceptance, there are several possibilities for intergrade characteristics. It may be desirable to allow deviations in any or all limits to obtain a broader test of the resulting groups.

5. Insofar as possible the properties or features selected for intergrades should be consistent with the category definitions. The properties selected for an order are the result of, or reflect a major set of soil processes; for a suborder the properties are major controls of the current processes; for a great group the properties are subordinate or additional controls of processes; and for a subgroup the properties represent either a blending of processes or are not related to criteria used to define higher level taxa (extragrades).

6. If Andepts are raised to the order level the arguments for another suborder, Andents, will be difficult to justify. Andic and Andic Lithic subgroups of Orthents would seem logical. The proposed suborder of Aquands would eliminate the andic properties at the great group level in other orders, such as the Andaquepts. The remaining use of andic/vitric is for subgroup intergrades and this seems to be consistent with the definition of the subgroup category.

7. Thapto- subgroups have traditionally only been used to recognize buried histic, mollic, or umbric horizons and not to indicate a buried soil material or diagnostic subsurface horizon. The rationale and use of these subgroups should derive from improved definitions of buried soils and procedures for recognizing them in Soil Taxonomy.

EROSION AND CONSERVATION OF VOLCANIC ASH SOILS IN THE HIGHLANDS OF ECUADOR : A CASE STUDY

G. De Noni, J.-F. Nouvelot, and G. Trujillo

Though the soils of Eduador are diversified, which is mainly a consequence of contrasted climatic conditions, the original material is relatively homogeneous for it is derived from volcanic formations. In the Sierra where nearly three-fourths of the soils are of volcanic origin, this pedological situation is particularly significant.

It can be said that about 12% of the total area of Ecuador is affected by an erosion process; nevertheless this phenomenon can be observed chiefly on the volcanic soils of the Sierra. It is worth pointing out that the "demographic pressure" in the Sierra largely explains the acceleration and the extension of the erosion process, the development of small farms (minifundios) on steep slopes being the normal pattern.

The gravity of the problem led both PRONAREG[1] and PRONACOS[2] with the technical assistance of the ORSTOM[3] to start studying erosion, the aim being the conservation of soils. The first step was mainly a qualitative study in order to evaluate the different erosion processes; the second one based on observations made on experimental plots is under way and it is hoped that it will aid analysis of the conditional factors of erosion.

Undoubtedly water may be regarded as the principal agent of erosion. That is the reason why the following example deals with water erosion.

LOCATION OF THE STUDY

In the chosen region, soils are representative of the septentrional and central part of the Sierra and acutely

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[1] Programa Nacional de Regionalizacion Agraria.

[2] Programa Nacional de Conservacion de Suelos.

[3] Office de la Recherche Scientifique et Technique Outre-Mer (France).

affected by water erosion.

Climatic and "morpho-pedological" aspects

The zone of the study is located in the Interandin Valley near the village of Alangasi at an altitude of 2600 m, 30 kms east of Quito. The current land use is characterized by natural pastures where "kikuyo" (Pennisetum Clandestinum) prevails and by small corn fields.

The study is being conducted on the hillslope in front of Alangasi. This slope, with a difference of level of about 60 m, presents an irregular profile. The two following morphological characteristics can be observed:

- The upper part of the hill presents a gentle slope (from 10 to 15%) where can be observed "erosion abrupts" which limit small residual hillocks with a difference of level varying from 2 to 3 m. What we call "erosion abrupts" are small vertical irregularities along the slope profile with differences of level ranging from 0.50 to 3.00 m.

- The lower part is characterized by a convex profile and strong slope (from 40 to 50%), and at the line of contact between these two parts, semi-circular forms of erosion can be seen.

The soil profiles which can be seen allow to differentiate a black soil above a formation color yellow-coffee, called "cangahua"[1]. The analysis of a characteristic soil profile gave the following results:

0 - 10 cm	clay-silt to clay-silt-sand mixtures, greyish, cohesive with numerous roots.
10 - 40 cm	clay mixture, darker, friable, with polyhedrons from 1 cm to 3 cm.
40 - 70 cm	upper part of the "cangahua," chestnut-yellow, slightly friable near the surface becoming hard deeper, with little black shining coating of less than 0.5 cm.
more than 70 cm	Lower cangahua, yellowish-brown, very hard, which when broken takes the form of prisms from 10 to 15 cm, with numerous whitish concretions ($CACO_3$?)and a few black shining coatings inside internal little fissures (MnO ?).

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[1] Old volcanic formation of great occurrence in the Sierra.

The soil described above presents the following grain-size distribution.[1] (in %)

Horizons	H	M.O	clay 2µ	fine silt 2-20µ	coarse silt 20-50µ	fine sand 50-200µ	coarse sand 200-2000µ	TOTAL
0-10 cm	3.8	2.38	18.38	19.75	13.24	23.06	19.36	99.97
10-40 cm	5.99	1.82	23.13	21.93	11.47	18.66	14.94	97.94
40-70 cm	5.86	1.04	17.93	25.8	13.33	20.52	14.45	98.93
+ 70 cm	5.71	1.39	21.85	22.3	13.81	23.29	13.18	101.53

We have described the more common pattern of soil; however other profiles can be found without one or several layers above the cangahua, or it may happen that only the cangahua appears.

This soil profile was interpreted as a type of soil derived from volcanic material. The volcanic origin of cangahua is well known in Ecuador and the black upper layer is thought to be made up of volcanic ashes which fossilize the cangahua. Besides between Cangahua and the black layer a line of gravels can be locally observed and regarded as the products of the unblocking which would have preceded a volcanic eruption. Taking into account the volcanic origin and the pedologic characteristics, this soil was classified as a "Duriudoll."

Although there is a lack of meteoroligical data, the available information gives the following characteristics:

- An average annual precipitation of 1300 mm, distributed in two rainy seasons extending from February to May and from October to November respectively.
- A daily rainfall of median frequency of 40 mm.
- A 30 minutes maximum rainfall intensity of median frequency of 40 mm, this value being one of the highest observed in the "interandina" region.
- An average temperature of 18° C.

The climate in the region can be denominated as "equatorial of altitude."

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[1] Analysis carried out in the ORSTOM "Bureau des sols" in Fort de France (Martinique).

Erosion process

The most widespread form of erosion in this region is the "erosion abrupt." The layout of these areas of "erosion abrupt" is either "subrectilinear" or semicircular; their areas vary between 50 and 100 m. Whatever their layout, the black layer above the cangahua can always be seen. The "subrectilinear erosion abrupt" present differences of level which vary from 1 to 3 m, whereas the semicircular ones have differences ranging from 0.40 to 0.80 m.

As a general rule, the walls of the "erosion abrupt" show a slightly concave profile due to the action of water flowing down. Their base is often partially occulted by black ash fallen from "micro-subsidences." From the base of the "erosion abrupt" downhill and according to the steepness of the slope, can be observed either greyish sandy deposits with a surface area of a few square meters or the development of a network of small gullies on the cangahua.

It can be put forward as an hypothesis, the formation in a first step of "mini-erosion abrupt" (of no more than 5 to 10 cm of differences of level) at the expense of the underlying black ash through both the action of the water flowing down around the tufts of grass and small mass movements due to either the gravity or the treading of the animals. Those "mini-erosion abrupts" are the starting point of the erosion process; then the active flow of water in this area will deepen the erosion abrupts till the cangahua be reached.

Undoubtedly the yer of black ash is all the more prone to water erosion through its susceptibility to small mass movements.

THE QUANTITATIVE STUDIES

To study the relationship between water erosion and the different agents which bring it about in the Alangasi zone, two experimental plots were set up in significant "morpho-pedological" conditions: the first one directly on cangahua with a slope of 28%; the second one on black soil subject to local agricultural practices with a slope of 26%.

Description of the plots

Most interesting studies dealing with the relationship between rainfall, water flow and erosion are available in the existing literature. However, these valuable pieces of work have not been used for the two following reasons:

- On the one hand their results have generally a fundamental character, whereas our concern is chiefly practical with the aim to recommend applicable methods for the conservation of soils.

- On the other hand to extrapolate the results found in a certain region in the world to other regions would be hazardous. For example, Wishmeier's work concerned the great plains of the U.S.A. with methods adapted to this region; obviously the parameters must be adjusted to the conditions prevailing in Ecuador.

The soil on which the two plots are set up is representative of the local physical conditions and is located on a little farming concern where the erosion problem is very acute.

Each plot has an area of 50 m^2 and a length of 10.6 m. The equipment consists of a rainfall recording gage (weekly rotation) and a settling basin of 2 m^3 to collect both sediment and runoff.

We are perfectly aware that the results obtained from a 50 m^2 plot are different from those obtained from a 1000 m^2 plot which in turn are different from those on a catchment area of a few square kilometers. In fact, specific erosion (in metric ton per km^2 for example) on an homogeneous region, from a physical and climatic point of view, generally decreases when the studied drainage area increases. Therefore, one must be very cautious when extrapolating. When very small plots are concerned, it is obvious that the "edge-effect" and the limited length bring about perturbations in both runoff and sediment measures.

For the sake of homogeneity in the results it was necessary to have identical parcels even if the representativity of so small parcels were questionable. Thus the two plots have the same area and the same design. It is worth mentioning that five other identical plots have been set up in the provinces of Pichincha and Cotopaxi for the same purpose.

A better way to deal with the problem would be to study experimental plots which would have the size of the average field in the zone. It is planned that this will be done in the framework of pilot projects which are to start this year.

RESULTS

General considerations

For 1982, the sediment yield observed on the two parcels near Alangasi is presented below.

Parcel on Cangahua. 1.050 kg for 50 m^2, that is to say a sediment production rate of 210 ton/ha/year or 21,000 ton/km^2/year which corresponds to a layer of 15 mm of soil lost per year with a ratio of runoff to rain of about 35%.

Parcel on black soil. 310 kg for 50 m^2, that is a sediment production rate of 62 ton/ha/year or 6,200 ton/km^2/year which corresponds to a layer of 5 mm of soil lost per year with a ratio of runoff to rain of more than 60%.

It is noteworthy that the annual rainfall in 1982 observed at the Quito observatorio station has a frequency of 0.03, that is a return period of 30 years, although no conclusion can be drawn since the sediment yield is more correlated with the rainfall intensity than with the annual rainfall. For example, during the period extending from January to May we obtained sediment yields on the parcel on Cangahua of 530 kg and 415 kg for 1982 and 1983 respectively, whereas the rainfall frequency for the same period is 0.22 (return period 4.6 years) for 1982 and 0.034 (return period 29 years) for 1983.

It was observed that erosion is generally higher during the first part of the rainy season. This phenomenon can be explained by changes in the consistency of the upper part of the soil or by rainfalls of higher intensities during the period, or better by a combination of both which are in fact not independent (see Fig. 1).

Parameters

As far as the parcel on Cangahua is concerned, the "parametric study" was easier since it remains under natural conditions all through the year.

The total weight of the dried sediment, Ws, is shown in Fig. 2 as a function of the maximum intensity during 30 m, I_{30}, of the rainfall which brought about the transportation of sediment.

Regarding the parcel on black soil, one was compelled to separate the results in several groups according to the various states of the soil.
In Fig. 3, the differences between the four following conditions can readily be seen:

a) plot with natural pasture : nearly no erosion;

b) plot with furrows and corn : light erosion without great effects from the rainfall intensities. Note: the protection is due mainly to the furrows;

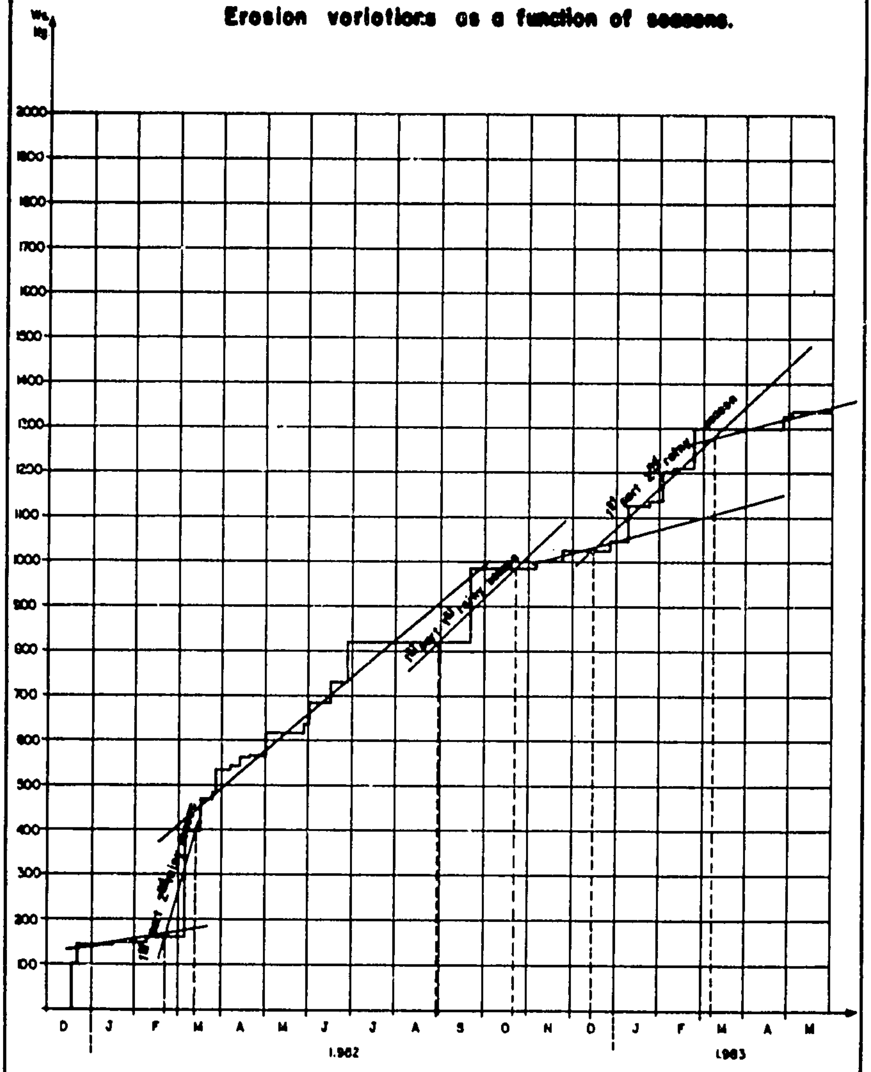
c) plot with discontinuous natural pasture : medium range erosion;

Grap. Nº 1

A LANGASI

Plot with CANGAHUA.

Erosion variations as a function of seasons.



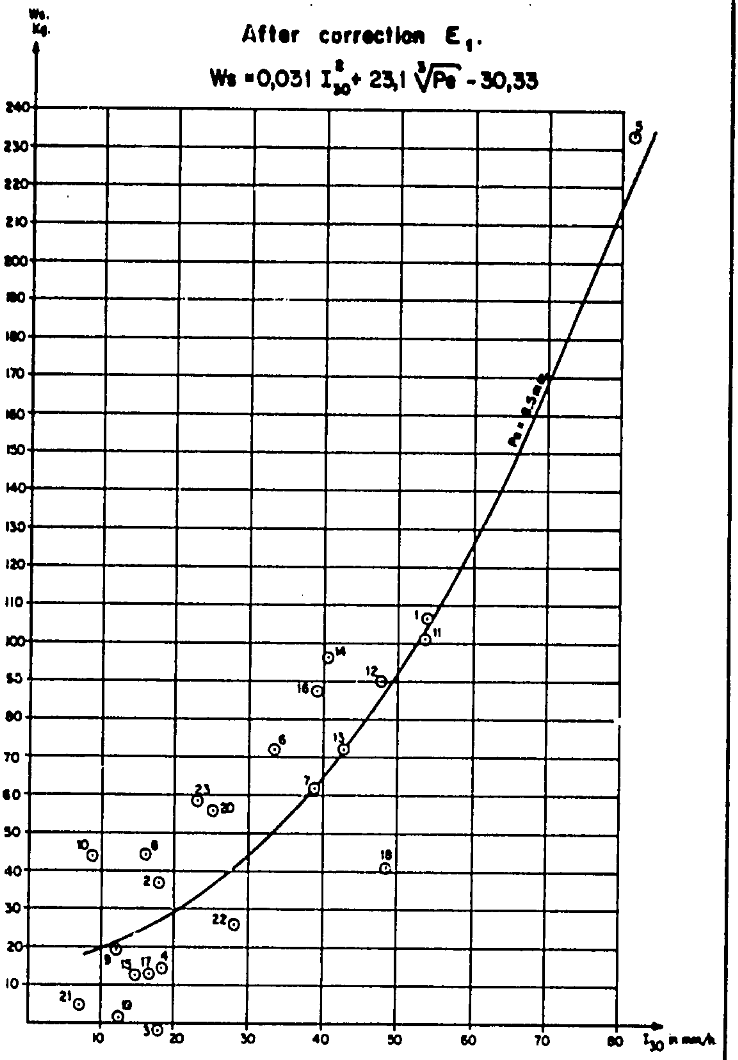
Grag. N°2

ALANGASI

Sediment weight as a function of the maximun intensity in 30 minutes.

After correction $\mathcal{E}_1$.

$$Ws = 0{,}031\ I_{30}^{2} + 23{,}1\ \sqrt[3]{Pe} - 30{,}33$$



d) plot with bare soil and without furrows : strong erosion.

To give an example and in order to compare the relative importance of the above conditions, let us choose the median intensity, that is 40 mm/hr, and let us see the dry weight of the transported sediment we get:

natural pasture: 0.5 kg
corn with furrows: 5 kg
discontinuous pasture: 15 kg
bare soil: 60-80 kg

Thus, natural pasture is undoubtedly the best soil protection when there are risks of erosion. Furthermore, comparison between results obtained on each parcel leads to the following conclusions (see Fig. 4):

- Sediment yield turns out to be twice as important on the black soil parcel as it is on the cangahua parcel, the former being in a state comparable with the latter, that is without either vegetation cover nor furrows.

- For the other states of the black soil plot, sediment yield is noticeably greater on the cangahua plot.

RECOMMENDATIONS

Although the results obtained so far are partial, a few recommendations can be put forward. The erosion process in the Alangasi zone is very quick, actually a farmer during his lifetime can see a soil layer from 0.30 m to 1 m disappear; therefore, the measure to take to prevent this washing away of the soil present a high degree of urgency. The following recommendations deal chiefly with cultural practices.

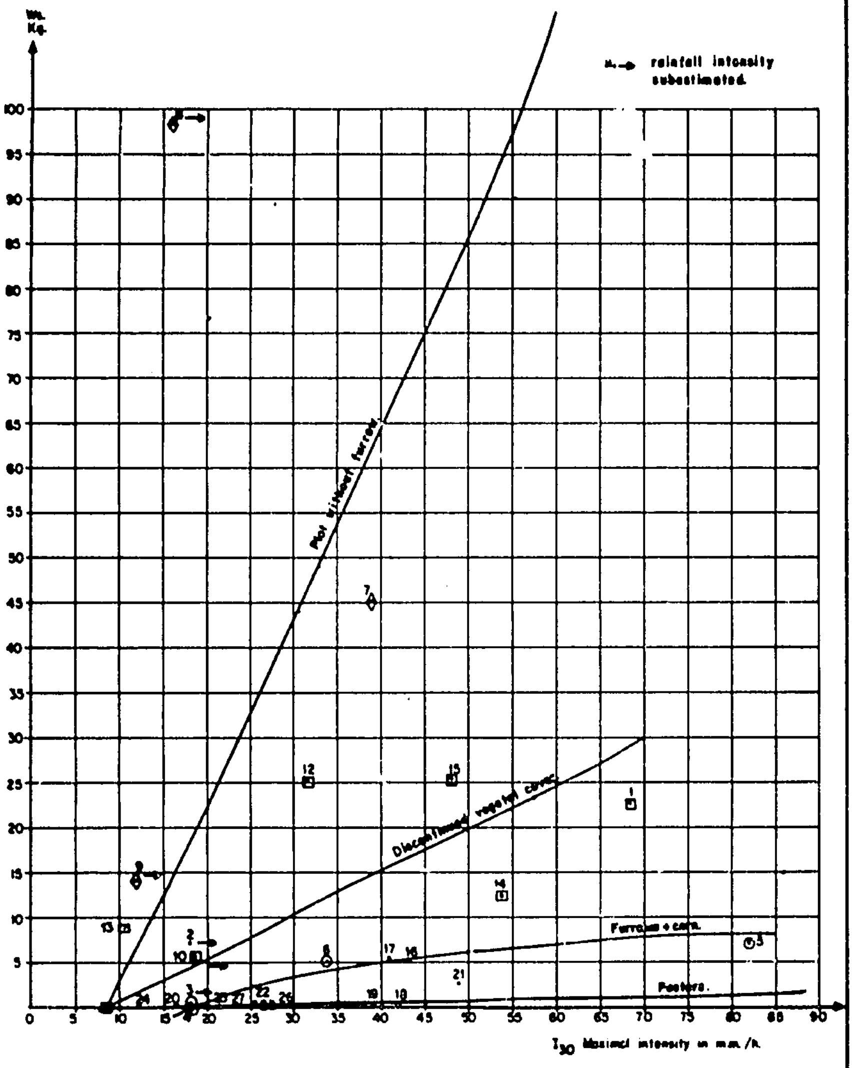
Peaks of intensities play the title role in the water erosion process, so it is paramount to find the best soil protection either through vegetation cover or adequate cultural practices, the latter being of importance since they can be modified according to the circumstances in order to assur the best protection. For example, the furrows must be drawn at right angles to the slope before the rainy season and maintained in good state not only until seedtime but beyond as well.

As far as corn is concerned, the plants are too distant from one another and leaves are cut during growth, thus decreasing soil protection. Furthermore, during harvest time stalks are cut leaving the soil once more without protection. Planting corn plants closer together and leaving vegetation remnants, at least partly, would be better practices.

Graf. Nº 5

ALANGASI

Plot with black soil. (DURIUDOLL)

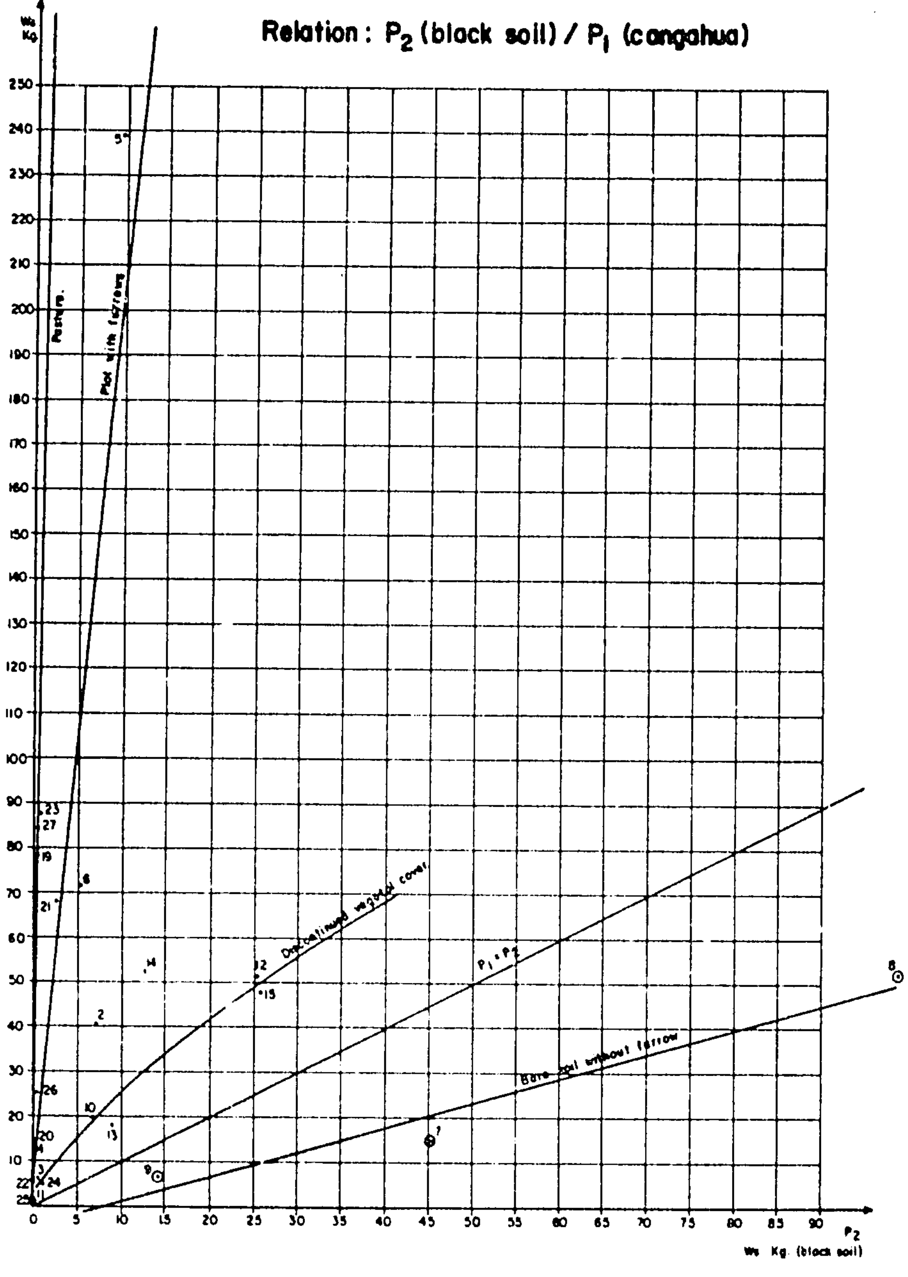


273'

Grap. Nº 4

ALANGASI

Relation: P_2 (black soil) / P_1 (cangahua)



CONCLUSIONS

The two Alangasi plots are only limited examples of a study at the national level with a practical aim. The first step is to analyse causes of the erosion process in order to put forward, then test, appropriate methods for the conservation of soils. Following this practical viewpoint a new program has already been started in the Sierra and the Costa.

LITERATURE CITED

De Noni, G., and J. F. Nouvelot. 1983. Los principales procesos erosivos en Ecuador. Seminario PRONACOS-UNESCO, Quito.

De Noni, G., J. F. Nouvelot, and G. Trujillo. 1983. Estudio cuantitativo de la erosion con fines de proteccion de los suelos : las parcelas de Alangasi e Ilalo. Seminario PRONACOS-UNESCO, Quito.

Fournier, F. 1[illegible] Climat et érosion. Les relations entre l'érosion [illegible] par l'eau et les précipitations atmosphériques. Paris, P.U.F.

Fournier, F. 1972. Conservation des sols. Conseil de l'Europe.

Roose, E. 1977. Erosion et ruissellment en Afrique de l'Ouest. Vingt années de mesures en petites parcelles expérimentales. ORSTOM, Paris.

Roose, E. 1981. Dynamique actuelle des sols ferrallitiques et ferrugineux tropicaux d'Afrique Occidentale. ORSTOM, Paris.

Wischmeier, W. H., and D. Smith. 1981. Predicting rainfall conservation planning. Washington, D.C.

EVALUATION OF THE ANDISOL PROPOSAL IN DIFFERENT ENVIRONMENTS

A CRITICAL EVALUATION OF THE PLACEMENT OF THE ANDEPTS OF HAWAII ACCORDING TO THE PROPOSED KEY FOR ANDISOLS

H. Ikawa, H. Eswaran, H. H. Sato, and G. Uehara

ABSTRACT

The latest definition of Andisols proposed by the International Committee on the Classification of Andisols (ICOMAND) was used to reclassify the Andepts of Hawaii as Andisols. Because some of the Eutrandepts had neither vitric nor andic properties, changes in the definition of the andic properties were proposed. The main change included the requirement of an acid oxalate extractable $SiO_2/(Al_2O_3 + Fe_2O_3)$ molar ratio of 0.7 or less. The existing requirements of low bulk density, high P retention, and acid oxalate Al or 4 M KOH extractable Al were used to classify the Placandepts, Hydrandepts, and Dystrandepts. Vitric soil properties were used to classify the Vitrandepts. The two suborders in Hawaii are the Ustands and the Udands. After eliminating the Tropudands, the great groups include the Vitrustands, Haplustands, Placudands, Hydrudands, and Hapludands. With further changes recommended for the Calcic and Typic subgroups of Haplustands, the Acric subgroup of Hydrudands and Hapludands, and the Hydric subgroup of the latter, the 63 soils derived from volcanic ash were classified in the soil family of Andisols.

INTRODUCTION

A proposal has been made to reclassify the Andepts of Soil Taxonomy into the new soil order of Andisols (Smith, 1978). Preliminary testing (Recel, 1980; Recel, et al., 1981) showed that the two suborders in Hawaii were the Ustands and the Tropands. With some modifications in the proposed definitions and taxa, the Vitrandepts, Eutrandepts, Placandepts, Hydrandepts, and Dystrandepts were reclassified as Vitrustands, Haplustands, Placotropands, Hydrotropands, and Haplotropands, respectively. The study, however, showed that for soils such as the Eutrandepts, the requirements of (1) a water retention of undried fine earth at 15-bar pressure of 40% or more and (2) a P retention of 90% or more were too high.

Further testing of the proposal by the International Committee on the Classification of Andisols (ICOMAND) has resulted in other modifications in the proposal (Leamy, 1983). The purpose of this paper is to examine and evaluate these modifications and to reclassify once again the Andepts of Hawaii on the latest revisions.

DEFINITION OF ANDISOLS

According to Leamy (1983), "Andisols are mineral soils that do not have an argillic, natric, spodic, or oxic horizon unless it is a buried horizon occurring at a depth of 50 cm or more, and which have soil material beginning at, or within 25 cm of the surface, in which all subhorizons have andic and/or vitric soil properties throughout a continuous thickness of 35 cm or more." The classification of Andisols, therefore, is governed by the presence of subhorizons having andic and/or vitric soil properties.

According to the latest proposal, Andepts now classified as Vitrandepts are likely to have vitric properties, while all others are likely to have andic properties. It appears, however, that problems arise when an Andept does not meet the definition of vitric or andic properties. Examples of such soils include some of the Eutrandepts which may have neither a high P retention value (more than 85%) nor a high acid oxalate extractable Al value (2.0% or more) or a 4 M KOH extractable Al value (1.5% or more).

The alternative in classification appears to be (1) to include these soils as Andic subgroups of Haplustolls or (2) to revise the definition of andic soil properties so as to accommodate the Eutrandepts. This paper suggests how the Eutrandepts of Hawaii can be retained and how all of the Andepts of Hawaii are placed in the new soil order of Andisols.

ANDIC SOIL PROPERTIES

Andepts are described as volcanic ash soils having a low bulk density and having appreciable amounts of allophane with a high cation exchange capacity or composed mostly of pyroclastic materials (USDA, 1975). The data show that all of the Andepts of Hawaii, including the Eutrandepts, have low bulk density (USDA, 1976). The data, however, show that when volcanic ash weathers, the vitric material transforms not only to allophane or related materials but also to other minerals (Hudnall, 1977). Consequently, although the Andepts of Hawaii have low bulk density, these soils have variable chemical and mineralogical properties. Selected properties of andic soil materials (Recel, 1980) are presented in Table 1, while the values of the acid oxalate extractable Si, Al, and Fe of six Eutrandepts (Hudnall, 1977) are presented in Table 2.

Based on the above data, the following definition of andic soil properties is proposed. Except for (3), the definition is essentially that proposed by Leamy (1983). The soil material with andic properties has:

(1) a bulk density of 1/3-bar water retention of the fine earth fraction of less than 0.9 g/cc <u>and has either</u>:

(2) appreciable amounts of amorphous or related materials <u>with</u>:

  (a) a phosphate retention value of more than 85% <u>and</u>
  (b) <u>either</u> an acid oxalate extractable Al value of 2.0% or more, <u>or</u> a 4 <u>M</u> KOH extractable Al value of 1.5% or more, <u>or</u>

(3) appreciable amounts of amorphous materials and minerals such as halloysite <u>with</u>:
  (a) a phosphate retention value of more than 85% <u>and/or</u>
  (b) the pH of 1 g of fine earth in 50 ml of 1 <u>N</u> Naf is 9.4 or more after two minutes, <u>and</u>
  (c) an acid oxalate extractable $SiO_2/(Al_2O_3 + Fe_2O_3)$ molar ratio of 0.7 or less.

It should be pointed out that Definition (3) is proposed to accommodate the Eutrandepts of Hawaii which are derived from ash associated with tholeiitic or alkalic basalt (Hassan, et al., 1975). The acid oxalate extractable $SiO_2/(Al_2O_3 + Fe_2O_3)$ molar ratio is used because the Hawaiian ash has a higher Fe_2O_3 content than the andesitic or rhyolitic ash from elsewhere. The acid oxalate ratio is further used because it can account for the amorphous or related materials in the Andepts. According to Parfitt (1983), acid oxalate extraction accounted for 100% of the Al and Si in allophane and imogolite as well as 100% of the "amorphous" Fe oxide.

In a study of six Eutrandepts of Hawaii (Hudnall, 1977), and as shown in Table 2, the acid oxalate extractable Al allowed only two of them to be classified as Ustands. The acid oxalate extractable $SiO_2/(Al_2O_3 + Fe_2O_3)$ molar ratio, on the other hand, allowed all six to be classified as Ustands with the ratio ranging from 0.32 to 0.69 in a continuous soil depth

Table 1. Selected properties of andic soil materials (Recel, 1980).

Depth	Horizon	pH_{NaF}	Phosphorus retention	15-bar water content	Bulk density
cm			%	% gravimetric	g/cc
Waimea series, Typic Eutrandepts, medial, isothermic					
0-18	A11	9.0	79	32	0.85
18-40	A12	9.5	80	36.4	0.76
40-71	B21	9.4	81	40.5	0.77
71-99	B22	9.4	73	38.7	0.77
99-127	C1	9.4	65	36.9	0.80
Akaka series, Typic Hydrandepts, thixotropic, isomesic					
0-25	Ap	10.4	99	55.6	0.35
25-60	B21	10.4	99	253.9	0.28
60-85	B22	10.1	99	237.5	0.28
85-95	IIApb	10.5	99	239.2	0.26
95-105	IIB21b	10.1	99	265.1	0.30
105-120	IIB22b	10.0	99	251.7	0.25
Hilo series, Typic Hydrandepts, thixotropic, isohyperthermic					
0-17	Ap	9.7	90	51.8	0.88
17-39	B21	8.7	97	126.7	0.39
39-65	B22	10.5	99	189.0	0.32
65-70	IIC	10.8	99	176.0	0.33
70-85	IIIAb1	10.7	99	190.9	0.34
85-110	IIIAb2	10.7	99	194.5	0.31
110-125	IIIAb21b	10.2	99	183.0	0.34
Kukaiau series, Hydric Dystrandepts, thixotropic, isothermic					
0-22	Ap	10.4	99	57.7	0.70
22-43	B21	10.8	99	116.7	0.47
43-66	B22	10.6	99	137.6	0.45
66-80	B23	10.5	99	130.1	0.46
80-97	B24	10.5	99	113.5	0.51
97-118	B25	10.3	99	113.9	0.47

Table 2. Acid oxalate extractable Si, Al, and Fe for six Eutrandepts (Hudnall, 1977).

Depth cm	Horizon	Si %	Al %	Fe %	$SiO_2/(Al_2O_3 + Fe_2O_3)$
Naalehu series, Typic Eutrandepts, medial, isohyperthermic					
0-25	A1	0.65	1.31	3.33	0.43
25-46	AB	1.15	1.70	3.94	0.61
46-76	B21	1.18	1.43	3.84	0.69
Waimea series, Typic Eutrandepts, medial, isothermic					
0-18	A11	0.52	2.17	2.03	0.32
18-40	A12	0.93	2.71	2.51	0.46
40-71	B21	1.36	4.40	1.68	0.50
71-99	B22	1.40	4.12	1.57	0.55
Kamaoa series, Typic Eutrandepts, medial, isothermic					
0-15	A11	0.54	1.36	2.24	0.43
15-28	A12	0.53	1.30	2.24	0.43
28-61	B2	0.48	1.23	1.93	0.43
61-74	C1	0.21	0.54	0.29	0.58
Waikaloa series, Ustollic Eutrandepts, medial, isothermic					
0-18	A11	1.31	4.57	2.62	0.43
18-40	A12	1.37	3.98	3.03	0.40
40-55	B1	1.48	2.67	3.80	0.63
55-81	B21	1.38	2.16	3.50	0.69
81-122	B22	0.47	0.87	0.56	0.79
Puu Pa series, Ustollic Eutrandepts, medial-skeletal, isothermic					
0-20	A1	1.19	3.91	1.09	0.52
20-56	B2	0.15	0.44	0.90	0.34
56-86	C1	0.19	0.26	0.85	0.54
Pakini series, Entic Eutrandepts, medial, isothermic					
0-18	A1	0.33	0.66	1.24	0.51
18-40	A3	0.53	0.76	2.19	0.56
40-91	B21	0.71	1.10	2.31	0.61
91-137	B22	0.12	0.48	0.07	0.38

of at least 35 cm. This ratio was less than 0.32 in a Dystrandept. Further studies are now underway to test the above definition of the andic soil properties with emphasis on the Eutrandepts.

KEY TO THE SUBORDERS

The suborders of Andisols in Hawaii are the Ustands and Udands. Udands are established in Hawaii with the elimination of the Tropands from an earlier proposal. There are 22 Ustands and 41 Udands in Hawaii (Table 3).

KEY TO THE GREAT GROUPS

Ustands

The great groups of Ustands are the Vitrustands and Haplustands. As shown in Table 3, of the 22 Ustands in Hawaii, five are Vitrustands and 17 are Haplustands. The Vitrustands include the Vitrandepts, while the Haplustands include the Eutradepts under the present classification. As mentioned earlier, studies are underway to obtain more information on the Eutrandepts (Haplustands).

Udands

Based on the proposal of Leamy (1983), Placudands, Hydrudands, Tropudands, and Hapludands are represented in Hawaii. Several modifications, however are proposed in this section. They are:

Hydrudands. Although the current proposal identified Hydrudands based on hydrous particle size/mineralogy class, it is felt that such a criterion should be reserved for the soil family.

If the hydrous property is to be retained, a 15-bar water retention value of over 150% (in some part of the subhorizon) and a SiO_2/Al_2O_3 molar ratio of less than 0.85 are proposed. The rationale is that Andisols occurring in areas of high rainfall and having such a high water content would also be highly desilicated. An alternate definition is either irreversible drying (currently used to distinguish the Hydrandepts and Hydric Dystrandepts from other Andepts) or a perudic moisture regime as the differentiating characteristics.

Table 3.--Continued

Suborder	Great Group	Subgroup	Family	Soil Series
		Acric Hapludands	hydrous, isohyperthermic	Paauhau
			hydrous, isomesic	Maile
			hydrous over fragmental, isothermic	Honuaulu
		Entic Hapludands	medial, isomesic	Umikoa
			medial over loamy-skeletal, mixed, isomesic	Olinda
		Hydric Hapludands	medial, isothermic	Manu
			hydrous, isohyperthermic	Ookala
			hydrous, isomesic	Manahaa Punohu Puu Oo
			hydrous, isothermic	Kukaiau Moaula Niulii
		Hydric Lithic Hapludands	medial, isothermic	Puhimau
			hydrous-skeletal, isomesic	Puukala
		Lithic Hapludands	medial, isothermic	Heake

Table 3. Placement of soil series of the Andepts of the state of Hawaii in the proposed soil order Andisols.

Suborder	Great Group	Subgroup	Family	Soil Series
USTANDS	<u>Vitrustands</u>	Typic Vitrustands	cindery, isomesic	Uma
			ashy over cindery, isomesic	Huikau
		Entic Vitrustands	medial, isomesic	Apakuie
		Mollic Vitrustands	ashy, isomesic	Kilohana
			medial over sandy or sandy-skeletal, isohyperthermic	Alae
	<u>Haplustands</u>	Typic Haplustands	medial, isothermic	Kamaoa Kikoni Kula Palapalai Waimea
			medial-skeletal, isohyperthermic	Kainaliu
			medial over cindery, isothermic	Io Ulupalakua
		Entic Haplustands	medial, isohyperthermic	Naalehu Pakini
		Lithic Haplustands	medial, isohyperthermic	Kalaupapa
			medial-skeletal, isohyperthermic	Waiawa
		Calcic Haplustands	medial, isohyperthermic	Koko Oanapuka
			medial, isothermic	Waikaloa
			medial-skeletal, isohyperthermic	Kaalualua
			medial-skeletal, isothermic	Puu Pa

--Continued

Table 3.--Continued

Suborder	Great Group	Subgroup	Family	Soil Series
UDANDS	Placudands	Typic Placudands	hydrous, isomesic	Kahua
	Hydrudands	Typic Hydrudands	medial over hydrous, isomesic	Puaulu
			hydrous, isohyperthermic	Hana
			hydrous, isomesic	Piihonua
			hydrous, isothermic	Alapai Honaunau Honokaa Kailua Kaiwiki Kealakekua Ohia
			hydrous over fragmental, isohyperthermic	Olaa
		Acric Hydrudands	hydrous, isohyperthermic	Hilo
			hydrous, isomesic	Akaka
		Lithic Hydrudands	hydrous, isothermic	Hilea
			hydrous-skeletal, isohyperthermic	Panaewa
	Hapludands	Typic Hapludands	medial, isomesic	Hanipoe Kaipoioi Laumaia
			medial, isothermic	Kapapala Oli Paaiki Pane
			medial over cindery, isothermic	Tantalus

--Continued

Tropudands. Again, the separation of the Udands based on a soil family criterion (soil temperature class) does not seem to be a good idea. This paper further proposes the elimination of the great group Tropudands. Although the Benchmark Soils Project of Hawaii has shown important differentiation in crop and related performance between isohyperthermic and isothermic soil temperature classes, problems may arise when the taxonomic units are related to soil map units. If the great group Tropudands were accepted, vast areas of Dystrandepts in Hawaii with nearly similar sugarcane performance may show map units associated with two different great groups--Tropudands and Hapludands. It is also likely that many of the soils that may key out as Tropudands may actually key out first as Hydrudands.

KEY TO SELECTED SUBGROUPS

Reference is made to an earlier classification of the Andepts of Hawaii according to the proposed key for Andisols (Recel, et al., 1981). Except for the change in the great group name from Tropands to Udands, the names for the present reclassification remain essentially the same.

Because certain subgroup names are preferred by Hawaii in the reclassification, the proposed modifications are repeated in this paper:

Calcic vs. Ustollic Haplustands

Soils such as the Waikaloa series have a subhorizon containing soft, powdery lime within 1.5 m of the surface. According to the present proposal, these soils would be classified as Ustollic Haplustands. It appears, however, that the presence of such a lime is best described by the Calcic subgroup. The use of Calcic also avoids redundancy of the formative element "ust." The Calcic, therefore, is proposed in place of the Ustollic in soils such as the Waikaloa series.

Typic vs. Mollic Haplustands

Soil with a lime horizon is presently classified as Mollic subgroup. Because the Typic subgroup, such as the Waimea series of the somewhat cool region with ustic moisture regime, has mollic epipedon, it is recommended that the use of the Mollic subgroup for Haplustands be discontinued.

Acric vs. Typic Hydrudands and Hapludands

The Akaka, Hilo, Honokas, and Kealakekua series are some of the soils representing the Hydrudands. Laboratory data (USDA, 1976) show that the Akaka and Hilo have positive delta-pH, while the Honokaa and Kealakekua have negative delta-pH. A proposal is made to classify the soils with positive delta-pH as Acric Hydrudands and those with negative delta-pH as Typic Hydrudands. It is further proposed that the Acric subgroup refer to soils with zero or positive delta-pH rather than the Altic subgroup proposed by Smith (1978). The term acric conotes extreme weathering and it is the extremely weathered soils that have zero or positive delta-pH.

Acric subgroup is similarly proposed for the appropriate Hapludands, for example, the Honuaulu, Maile, and Paauhau series.

Hydric vs. Typic Hapludands

Differences in sugarcane performance are noted in the Typic Hydrandepts, Hydric Hystrandepts, and Typic Dystrandepts in Hawaii. Hydrandepts and Dystrandepts are differentiated as Hydrudands and Hapludands, respectively. The Hydric subgroup is proposed to differentiate further the Dystrandepts or the Hapludands. Hydric subgroup are those having a weighted average ratio of percent 15-bar water retention of undried soil between 25 cm and 1 m or to a lithic or paralithic contact shallower than 1 m to percent organic carbon of the upper 18 cm that is over 10. The Typic subgroup, on the other hand, are those having a ratio less than 10.

LISTING OF THE ANDISOLS OF HAWAII

Based on the preliminary classification of selected soil series, the 63 series of Andepts of Hawaii were reclassified as Andisols. The soil moisture regime was tentatively established as ustic for those previously classified as Eutrandepts and Vitrandepts and as udic for those previously classified as Placandepts, Hydrandepts, and Dystrandepts. Table 3 shows 5 Vitrustands, 17 Haplustands, 1 Placudand, 16 Hydrudands, and 24 Hapludands. The reclassification is based on available data or correlated with the latest taxonomic names of the Andepts (USDA, 1980) to those of the Andisols.

SUMMARY

The latest modifications of the International Committee on the Classification of Andisols (ICOMAND) were examined, and after proposing still other changes, the Andepts of Hawaii

were reclassified as Andisols down to the family category. The two suborders, made up of 63 soil series, are the Ustands and the Udands. Because some of the Eutrandepts did not meet the requirements of andic soil properties, changes in the definition were proposed. These changes included the requirement of an acid oxalate extractable $SiO_2/(Al_2O_3 + Fe_2O_3)$ molar ratio of 0.7 or less. Thus, together with the low bulk density, the molar ratio was used to classify the Eutrandepts as Haplustands. Because the latest proposal used some of the soil family criteria in the key to the great groups, suggestions were made to use other differentiating characteristics. They included, for example, for the Hydrudands, a 15-bar water retention value of over 150% and a SiO_2/Al_2O_3 molar ratio of less than 0.85. Other recommended changes were the elimination of the great group Tropudands; the use of Calcic instead of Ustollic to denote soils having a soft, powdery lime subhorizon; and the use of Typic in place of Mollic in soils now classified as Typic Eutrandepts. Still other changes were use of the Acric subgroup in the Hydrudands and Hapludands with positive delta-pH and the differentiation of the Hydric and Typic Hapludands based on the 15-bar water/organic carbon ratio.

LITERATURE CITED

Hassan, T. S., H. Ikawa, and L. D. Swindale. 1975. The properties and genesis of four soils derived from basaltic ash, Mauna Loa, Hawaii. Pacific Sci. 29:301-308.

Hudnall, W. H. 1977. Genesis and morphology of secondary products in selected volcanic ash soils from the island of Hawaii. Ph.D. dissertation, University of Hawaii, Honolulu.

Leamy, M. L. 1983. International committee on the classification of Andisols (ICOMAND), Circular Letter No. 5. New Zealand Soil Bureau, DSIR, Lower Hutt.

Parfitt, R. L. 1983. Identification of allophane in Inceptisols and Spodosols. Soil Taxonomy News No. 5, pp. 11, 18. University of Hawaii, Honolulu.

Recel, M. R. 1980. Reclassification of Andepts of the state of Hawaii in the proposed order Andisols. M. S. thesis, University of Hawaii, Honolulu.

Recel, M. R., H. Ikawa, and G. Uehara. (in press). The classification of the Andepts of Hawaii according to the proposed key to Andisols. *In* Proceedings of the Fourth International Soil Classification Workshop, Rwanda, June 2-12, 1981.

Smith, G. D. 1978. A preliminary proposal for reclassification of Andepts and some andic subgroups. Unpublished paper.

Soil Survey Staff. 1975. Soil taxonomy. Agriculture Handbook No. 436. Soil Conservation Service, U. S. Dept. Agric., U. S. Govt. Printing Office, Washington, D. C.

USDA, SCS. 1980. Classification of soil series of the United States, Puerto Rico, and the Virgin Islands. U. S. Government Printing Office, Washington, D. C.

USDA, SCS. 1976. Soil survey laboratory data and descriptions for some soils of Hawaii. Soil Survey Investigation Report No. 29. U. S. Government Printing Office, Washington, D. C.

A CRITICAL EVALUATION OF THE PLACEMENT OF THE ANDEPTS OF KENYA ACCORDING TO THE PROPOSED KEY FOR ANDISOLS

F. N. Muchena and J. P. Mbuvi

ABSTRACT

The bulk of the Andepts in Kenya occur within close proximity of the Rift Valley where there has been a lot of volcanic activity. They are also found around Mount Kenya, the Aberdares, Nyambeni and the Chyulu range. They are found in a wide range of altitudes, from 1160 m in the Chyulu range to 3300 m in the Mount Kenya area. The parent materials are varied but are dominated by volcanic ash. Andepts in Kenya are found in udic and ustic moisture regimes and in soil temperature regimes ranging from cryic to isohyperthermic.

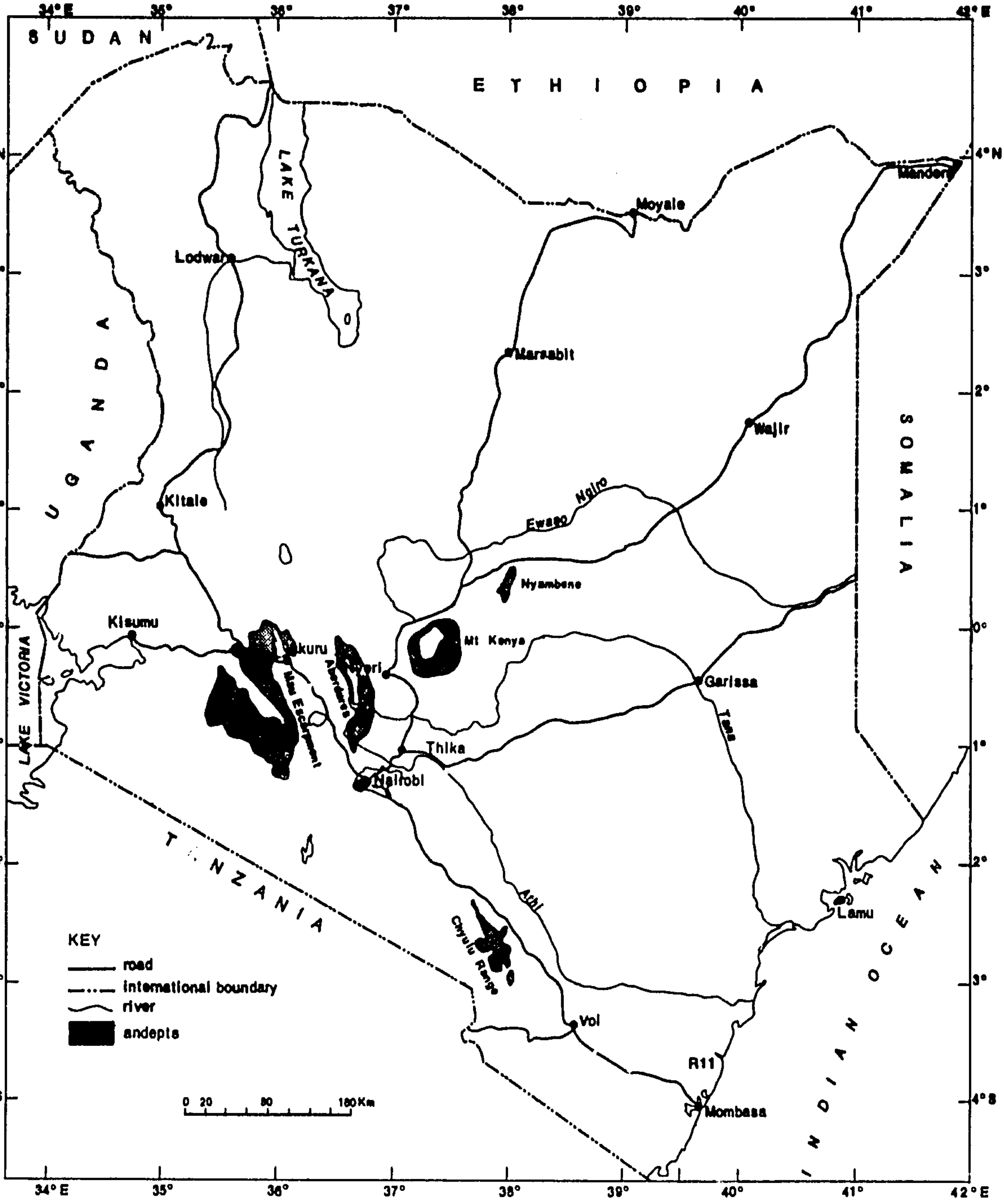
The structure of these soils is crumb to subangular blocky in the topsoil and subangular blocky to massive in the subsoil. The clay content is very variable and the organic carbon content ranges from 1.2 to 9.0% in the topsoil and decreases with depth. The bulk density of the top 30 cm is between 0.7 and 1.0 g/cm^3. The CEC-soil values (NH_4OAc at pH 7.0) are between 10 and 50 me/100 g soil. The clay mineralogy is dominated by amorphous material. The phosphate retention values for some of the soils are below the required values of 85% for Andisols.

According to the new Andisol proposal, very few soils in Kenya meet the requirements for Andisols mainly due to low phosphate retention and high bulk densities. Those Andepts that meet the criteria classify as Udands and Ustands.

INTRODUCTION

Andepts in Kenya cover only a minor part of the Kenyan land surface. They occupy approximately 10,600 sq. km which is about 1.8% of the total land area. Fig. 1 shows the distribution of the Andepts in Kenya. These soils are encountered at altitudes ranging from 1160 m in the Chyulu range to 3300 m

Fig. 1 Occurrance of Andepts in Kenya



in the Mount Kenya area. They are found on parent materials which are dominated by volcanic ash, pumice and tuff. The age of the ashes ranges from Pleistocene (Mt. Kenya, Aberdares and volcanoes in the Rift Valley) to Recent. At present, active volcanism occurs in the Chyulu range where ash soils of 100 years or younger are found (Wielemaker, 1981; Touber, et al., in preparation).

The soils occur in udic and ustic soil moisture regimes and cryic, isomesic, isothermic and isohyperthermic temperature regimes. They are found occurring in association with other soils which have a predominant influence of volcanic ash deposition.

The purpose of this paper is to examine the soils that have been classified as Andosols in Kenya (FAO, 1974; Mbuvi and Njeru, 1977; Kenya Soil Survey Staff, 1977; Siderius and Muchena, 1977; Wielemaker, 1981; Sombroek, et al., 1982; Speck, 1982; Wamicha, 1983; Touber, et al., in preparation) and to classify them according to the new key for Andisols with a view of determining the appropriateness of this key in the light of the situation in Kenya.

PHYSICAL AND CHEMICAL CHARACTERISTICS

The physical and chemical characteristics of some of the profiles classified as Andepts are given in Table 1. The color of the topsoils varies from very dark brown (7.5YR 2/2) to black (10YR 2/1) whereas that of the subsoils ranges from dark reddish-brown (5YR 3/2-3/4) to very dark greyish-brown (10YR 3/2). The clay content is variable in the different horizons within the profiles which indicates the stratified nature of the soils resulting from the repeated falls of volcanic ash and pumice. More than 60% of the soil is dominated by pumice, volcanic glass or pumice-like fragments. The structure of the topsoils is crumb to subangular blocky, whereas that of the subsoils is subangular blocky to porous massive. The bulk density of the topsoils ranges from 0.7 to 1.0 g/cm^3 and that of the subsoils ranges from 0.8 to 1.29 g/cm^3. A few of the soils classified as Andosols (Touber, et al., in prep.) have a bulk density of the topsoil slightly higher than 1.0 g/cm^3. Some of the Andosols are also calcareous in the lower horizons. The water retention at 15 bar varies from 18 to 30%.

The clay mineralogy is of noncrystalline type. The CEC-soil values (NH_4OAc at pH 7.0) are mainly between 10 and 50 me/100 g soil. The organic carbon content ranges from 1.2 to 9.0% in the topsoil and decreases with depth. The pH-H_2O varies from 4.6 to 8.6. The SiO_2/Al_2O_3 molar ratio ranges from 1.4 to 4.1. 4M KOH extractable aluminum values range from

Table 1: Physical and chemical properties of some selected Andepts of Kenya

Profile No.	133/3-11b					132/4-7b				147/1-3				
depth in cm	0/40	40/63	63/90	90/108	108/140	0/35	35/57	57/100	100/116	0/28	28/57	57/83	83/110	110/134
bulk density g/cm^3	0.83					1.0		0.97			0.9			
Organic C%	4.4	3.1	2.6	2.3	1.2	3.3	2.4	1.6	0.7	2.9	2.0	1.4	1.3	0.9
Colour A/B hor.	10YR2.5/1		2.5YR3/2			10YR3/1		10YR3/2		7.5YR3/2		5YR3/2		
15 bar water	28.8	18.3	21.2	20.7		21.1	22.2	20.7		23.9	21.9	17.7	18.8	
P-retention	91	90	79	94	73	84	81	83	81	59	62	58	63	68
pH-KCl	5.6	5.2	5.2	5.0	5.1	6.0	5.2	5.3	5.6	7.3	7.5	5.8	6.1	6.0
pH-H_2O	6.6	6.2	6.2	6.0	6.1	7.1	6.2	6.2	6.6	8.3	8.6	6.7	7.1	7.0
SiO_2/Al_2O_3		2.0		2.4			3.3	2.4	2.2			2.1	2.9	2.1
SiO_2/R_2O_3		1.1		1.2			1.8	1.3	1.2			1.3	1.6	1.3
Fe_2O_3 %		32.4		33.1			26.6	25.9	26.6			21.6	22.3	23.8
Clay %	14	16	24	24	28	18	28	40	34	24	22	18	34	32
CEC soil me/100g	30	24	20	31	22	24	21	20	21	24	23	15	22	20
Base saturation %	69	51	47	33	28	48	49	51	61	69	77	76	34	73
extr. Al_2O_3 (4M KOH) %	2.4	3.9	0.4	-	4.2	1.0	0.5	0.5	0.5	0.2	1.3	2.6	1.6	1.8
Classification														
FAO (1974)	mollic ANDOSOLS					mollic ANDOSOLS				mollic ANDOSOLS				
TAXONOMY (1975)	Typic EUTRANDEPTS					Typic EUTRANDEPTS				Typic EUTRANDEPTS				
ANDISOL PROPOSAL (1983)	USTANDS VITRUSTANDS					{USTANDS VITRUSTANDS} **				{USTANDS HAPLUSTANDS} **				

Table 1: Continued

Profile No.	146/2-4b			Exc.1					182/4-75				182/2-73			
depth in cm	$\frac{0}{20}$	$\frac{20}{44}$	$\frac{44}{85}$	$\frac{0}{17}$	$\frac{17}{45}$	$\frac{45}{75}$	$\frac{75}{105}$	$\frac{105}{160}$	$\frac{0}{25}$	$\frac{25}{50}$	$\frac{50}{110}$	$\frac{110}{150}$	$\frac{0}{30}$	$\frac{30}{55}$	$\frac{55}{80}$	$\frac{80}{114}$
bulk density g/cm^3				0.8	0.9	0.8	0.8	1.0								
Organic C%	1.2	0.3	0.3	9.0	2.5	2.9	3.2	2.4	4.7	2.7	0.7	1.6	2.8	2.9	3.0	tr
Colour A/B hor.	7.5YR3/2		7.5YR3/2	10YR2.5/1			7.5YR3/2		10YR2.5/1.5		7.5YR3/0		10YR2/1		7.5YR3/2	
15 bar water	20.0	22.8	22.5													
P-retention	71	71	66	86	79	93	61	98								
pH-KCl	5.2	5.0	5.3	6.0	6.0	4.9	4.4	4.4	6.0	6.4	7.6	7.2	5.6	5.8	6.0	6.0
pH-H_2O	6.5	6.4	6.5	7.0	7.0	6.2	5.4	5.5	7.1	7.9	8.6	8.3	6.7	7.1	7.2	7.6
SiO_2/Al_2O_3		3.2	3.3		1.5	-	1.9	1.6		1.4					1.4	
SiO_2/R_2O_3		2.0	1.8		1.4		1.7	1.2		1.1					1.4	
Fe_2O_3 %		17.3	21.6							0.04					0.043	
Clay %	28	22	14	27	23	30	33	44	16	12	6	14	20	28	33	7
CEC soil me/100g	18	32	55	72	32	36	54	50	32	41	9.9	64	32	32	36	35
Base saturation	86	51	95	83	70	32	10	7	84	100+	100+	100+	80	96	100+	100+
extr. Al_2O_3 (4M KOH) %	0.5	0.5	0.5	3.1	1.0	0.5	0.5	2.1								
Classification																
FAO (1974)	mollic ANDOSOLS			mollic ANDOSOLS					mollic ANDOSOLS				mollic ANDOSOLS			
TAXONOMY (1975)	Typic EUTRANDEPTS			Typic EUTRANDEPTS					Typic EUTRANDEPTS				Typic EUTRANDEPTS			
ANDISOL PROPOSAL (1983)	{USTANDS VITRUSTANDS} **			USTANDS VITRUSTANDS					USTANDS HAPLUSTANDS				USTANDS VITRUSTANDS			

Table 1: continued

Profile No.	174/1-172(1)		174/1-170(10)					132/2			52					
depth in cm	0/10	10/39	0/12	12/31	31/41	41/86	86/106	10/20	40/50	80/90	0/20	20/70	70/85	85/105	105/140	140/145
bulk density g/cm^3	0.81	0.80	0.81	0.80	0.83	0.82	0.82	0.73	0.87	1.10						
Organic C%	1.9	0.6	1.2	1.6	1.2	1.1	0.9	2.5	2.4	1.6	6.1	6.0	5.9	2.8	2.5	3.2
Colour A/B hor.	10YR3/2		5YR3/2		5YR3/4				5YR3/2		7.5YR2/2			7.5YR5/6		
15 bar water																
P-retention								70	77	77						
pH-KCl	5.9	6.1	5.4	5.7	5.8	6.2	6.3				4.2	4.5	4.8	4.5	4.6	4.7
pH-H_2O	6.5	6.8	6.5	6.8	6.6	6.9	7.1				4.6	4.9	5.1	5.3	5.2	4.9
SiO_2/Al_2O_3								1.7	1.7	1.7						
SiO_2/R_2O_3								1.2	1.2	1.2						
Fe_2O_3 %								15.7	15.5	16.5						
Clay %	33	20	44	48	50	52	42	40	42	44	22	24	36	28	28	36
CEC soil me/100g	43	50	21	20	20	25	17	29	29	24	33	32	27	20	14	23
Base saturation %	85	94	80	73	65	56	66	30	38	39	11	5	6	9	12	11
extr. Al_2O_3 (4M KOH) %																
Classification																
FAO (1974)	vitric ANDOSOLS		ochric ANDOSOLS					humic ANDOSOLS			humic ANDOSOLS					
TAXONOMY (1975)	Lithic VITRANDEPTS		Typic EUTRANDEPTS					Typic DYSTRANDEPTS			Typic DYSTRANDEPTS					
ANDISOL PROPOSAL (1983)	USTANDS HAPLUSTANDS		USTANDS HAPLUSTANDS					USTANDS }** VITRUSTANDS }			ALLANDS HAPLALLANDS					

Table 1: continued

Profile No.	75						134/4-2		
depth in cm	$\frac{0}{10}$	$\frac{10}{35}$	$\frac{35}{45}$	$\frac{45}{65}$	$\frac{65}{72}$	$\frac{72}{88}$	$\frac{0}{60}$	$\frac{60}{80}$	$\frac{80}{105}$
bulk density g/cm^3	0.72		0.86	1.29					
Organic C%	4.9	5.0	3.8	2.1	2.7	0.9	3.2		
Colour A/B hor.	7.5YR2/2			7.5YR5/8			5YR3/2		5YR4/4
15 bar water		21.9	20.3	29.9					
P-retention									
pH-KCl	5.0	4.9	5.1	5.0	5.0		4.2	4.5	4.5
$pH-H_2O$	5.7	6.1	6.0	6.1	5.9		5.1	5.1	4.9
SiO_2/Al_2O_3	4.1	3.4		3.5	3.9				
SiO_2/R_2O_3	2.9	2.4		2.6	2.3				
Fe_2O_3 %	9.5	13.3		12.2	20.1				
Clay %	10	14	18	16	12	9	40	52	56
CEC soil me/100g	31	27	14	14	10	10	42.6	25.0	22.0
Base saturation %	13	18	16	12	16	16	3	8	13
extr. Al_2O_3 (4M KOH) %									
Classification									
FAO (1974)	humic ANDOSOLS						humic ANDOSOLS		
TAXONOMY (1975)	dystric CRYANDEPTS						oxic DYSTRANDEPTS		
ANDISOL PROPOSAL (1983)	ALLANDS						ALLANDS		
	HAPLALLANDS						HAPLALLANDS		

** Does not fit in the classification because either the bulk density or the P-retention requirements are not met.

0.2 to 4.2%. The phosphate retention values range from 59 to 98%. Most of the phosphate retention figures are below the required values of 85%.

SOIL CLASSIFICATION

All major soil studies in Kenya are currently classified on the basis of the terminology of the FAO/UNESCO legend (1974) for the Soil Map of the World. Soil Taxonomy (Soil Survey Staff, 1975) is only used for international soil correlation purposes. According to the FAO legend, most of the Andepts in Kenya fall under mollic or humic Andosols. When classified according to Soil Taxonomy, the soils which occur at altitudes above 3000 m and have a cryic soil temperature regime classify as Cryandepts whereas those that occur in the udic moisture regime but at altitudes lower than 3000 m classify as Dystrandepts. Most of the Andepts are found in the ustic moisture regime. These classify predominantly as Eutrandepts.

When these soils are examined in the light of the new Andisol proposal (Leamy, 1983) the Cryandepts and Dystrandepts key out as Allands, at the suborder level and as Haplallands at the great group level. The bulk of the other soils, if they meet the requirements for Andisols according to the new criteria, key out as Ustands at the suborder level. At the great group level, they key out as Vitrustands or Haplustands.

A number of soils in Kenya which are currently classified as Andepts have phosphate retention values which are below the required value of 85%. This disqualifies them from being classified as Andisols although they have most of the other characteristics typical of Andisols (cf Table 1 profile Nos. 146/2-4b, 147/1-3, 132/2 and 132/4-7b). Other Andepts may be excluded from Andisols due to having a bulk density of up to 1.0 g/cm^3 within 35 cm from the surface, although the other requirements are met. Therefore, it may be useful to consider raising the bulk density requirements from 0.9 to 1.0 g/cm^3 in order to accommodate such soils.

The new definitions for Vitric and Andic soil properties rely mainly on chemical analysis. This implies that one cannot easily classify the soils in the field without waiting for the laboratory data. While emphasizing the importance of laboratory analysis, it may be worthwhile to note the difference that may arise in the different laboratories as has been demonstrated by van Reeuwijk (1982). Analytical errors may be critical in determining whether a soil is an Andisol or not. Some of the analyses are not carried out on a routine basis in some laboratories.

In Kenya there are soils with low bulk density (less than 0.9 g/cm^3) within 50 cm from the surface but they have argillic horizons below 50 cm. Hence, there is a need for intergrading andic and vitric subgroups in Alfisols and Ultisols.

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LITERATURE CITED

FAO/UNESCO. 1974. Soil Map of the World, Vol. I, Legend. UNESCO, Paris.

Kenya Soil Survey Staff. 1977. Guide to the "Standard" Soil Excursion in the Nairobi-Thika-Kindaruma area. Miscellaneous Paper No. M7, Kenya Soil Survey, Nairobi.

Leamy, M. L. 1983. Proposed Revision of the Andisol Proposal. ICOMAND Circular Letter No. 5.

Mbuvi, J. P., and E. B. Njeru. 1977. Soil Resources of the Mau-Narok area (Narok District), a preliminary investigation. Site Evaluation Report No. P29. Kenya Soil Survey, Nairobi.

Reeuwijk, van L. P. 1982. Laboratory methods and Data Exchange Programme for Soil Characterization, A report on the Pilot Round. Technical Paper No. 6. International Soil Museum, Wageningen. The Netherlands.

Siderius, W., and F. N. Muchena. 1977. Soils and Environmental Conditions of Agricultural Research Stations in Kenya. Miscellaneous Soil Paper No. M5. Kenya Soil Survey, Nairobi.

Soil Survey Staff. 1975. Soil Taxonomy. Agric. Handbook No. 436. Soil Conservation Service, U. S. Dept. Agric., U. S. Government Printing Office, Washington, D.C.

Sombroek, W. G., H. M. H. Braun, and B. J. A. van der Pouw. 1982. The Exploratory Soil Map and Agro-climatic Zone Map of Kenya 1980, scale 1.1 million. Exploratory Soil Survey Report No. E1, Kenya Soil Survey, Nairobi.

Speck, H. 1982. Soils of the Mount Kenya area, their formation, ecological and agricultural significance (with soil map, scale 1:125,000). Mountain Research and Development 2:201-221, IMS.

Touber, L., B. J. A. van der Pouw, and V. W. P. van Engelen (ed.) Soils and Vegetation of the Amboseli-Kibwezi area (quarter degree sheets 173, 174, 181, and 182). Reconnaissance Soil Survey Report No. R6, Kenya Soil Survey. (In press)

Wamicha, W. N. 1983. Soils influenced by Pyroclastics: In the Nguu Volcano Area (Wilaya ya Machakos, Kenya). MSc Thesis, University of Nairobi.

Wielemaker, W. G. 1981. Volcanic ash soils in Kenya. Paper presented at the Variable Charge Conference in New Zealand.

A CRITICAL EVALUATION OF THE PLACEMENT OF THE ANDEPTS OF NEW ZEALAND ACCORDING TO THE PROPOSED KEY FOR ANDISOLS

B. Clayden

ABSTRACT

Andepts and related soils occur widely in the North Island of New Zealand with a mesic or thermic temperature regime, and are developed in andesitic or rhyolitic tephras and derived deposits, and from laharic materials and basalts. They are represented by two distinct groups of mostly well-drained soils known as yellow-brown loams and yellow-brown pumice soils. Most yellow-brown loams are Dystrandepts, but the yellow-brown pumice soils are mainly excluded from Vitrandepts unless they have an umbric epipedon because the Bw horizons are too coarse to qualify as cambic.

In the Andisol proposals of 1978 and 1983, the N. Z. Andepts are renamed Hapludands and Vitrudands, and Andaquepts are included as Haplaquands or Vitraquands. The revised definition of the order dispenses with the requirement for diagnostic horizons and allows most yellow-brown pumice soils to be included as Vitrudands. The use of andic and vitric soil properties reflects the bimodal nature of N. Z. Andisols and is consistent with the original intent of the order.

Analytical data from representative pedons are presented for the limited range of N. Z. Andisols and placement in the proposed keys to suborders and great groups examined. The main problem arises with Hapludands in rhyolitic tephra that can be keyed out as Vitrudands because they contain as much glass as soils with vitric properties. In addition, the more restricted definition of Aquands excludes some soils in andesitic materials with an aquic moisture regime. Proposals are made for the amendment of the criteria for vitric soil properties and the morphological requirements of Aquands.

INTRODUCTION

Andepts and related soils occupy a large part of the central North Island of New Zealand. They are mainly developed in Holocene tephras (Gibbs, 1968) and derived deposits, but some are formed from laharic materials and others from basaltic rocks. Soil temperature regimes are mesic or thermic except on the upper slopes of the highest volcanic mountains, and most soils have a udic soil moisture regime with an annual rainfall of between 1100 and 2500 mm. The soils were mainly formed under forest or scrub which is now largely replaced by pasture or exotic production forest. Andepts have been broadly correlated with the two intrazonal soil groups of yellow-brown loams and yellow-brown pumice soils in the N. Z. Genetic Soil Classification (Taylor & Cox, 1956), though strictly most of the pumice soils are too coarse to be included as Inceptisols. They are also represented in the group of red and brown loams derived from basalts.

Yellow-brown loams are formed in medial andesitic or rhyolitic ash, in alluvium or loess containing a large proportion of tephric material, and in lahar deposits. They occur mainly in the regions of andesitic volcanism around Mt. Egmont and Mt. Ruapehu, and in areas peripheral to the centers of rhyolitic volcanism. They are relatively youthful soils and are mainly formed in materials that are between 5,000 and 20,000 years old (Cowie, 1982), though climate and the particle size and mineralogy of the parent material can strongly influence soil development.

Most yellow-brown loams are Dystrandepts (Neall & Orbell, 1982), and they usually fall in the Entic subgroup because the epipedons are too thin to qualify as Typic. Soils that meet the higher base status requirements of Eutrandepts are of only limited extent. Some of the coarser yellow-brown loams, particularly in the Bay of Plenty region, are Vitrandepts but Cryandepts, Durandepts, and Hydrandepts are not represented. Soils with discontinuous placic horizons have been described in upland environments, but no Placudand has been reported.

Yellow-brown pumice soils (Rijkse, 1974) are generally more youthful soils formed in coarser deposits of pumiceous rhyolitic tephra, including airfall tephra, flow tephra and water-sorted deposits. The tephras originate from the Taupo-Rotorua-Bay of Plenty volcanic zone and were erupted between about 900 and 5,000 years ago (Gibbs, 1980). In the N. Z. Classification, the soils are distinguished from "recent soils from volcanic ash" by the presence of a Bw horizon. Yellow-brown pumice soils have been loosely correlated with Vitrandepts which according to Soil Taxonomy (Soil Survey Staff, 1975) "...were mostly considered Regosols in the 1938 classification as modified in 1949." However, except for those with umbric epipedons, most fail to qualify as Vitrandepts because the color B horizons are too coarse for cambic horizons.

In the original Andisol proposal of 1978 (G. D. Smith, unpublished) New Zealand Andepts became Hapludands or Vitrudands, and most yellow-brown pumice soils were included by the provision for soils in which the upper 18 cm, after mixing, have a moist color value of 3 or less and have 3% or more organic carbon. In addition soils formerly classed as Andaquepts along with some Aquic Dystrandepts and Vitrandepts became Aquands. Soils on the upper slopes of Mts. Egmont, Ruapehu, Ngauruhoe, and Tongariro have a frigid temperature regime but there is unlikely to be sufficient soil development for Borands to be of more than local occurrence. Soils in tephric materials with an ustic moisture regime in Hawke's Bay are apparently too weakly weathered for the formation of Andisols.

CLASSIFICATION IN TERMS OF THE REVISED ANDISOL PROPOSAL

The soil order

An explanation for the proposed changes in the definition of Andisols is contained in the Circular Letter (Leamy, 1983) and Parfitt (n.d.)[1] has elaborated on the nature of andic and vitric materials. The aim here is to examine some of the implications to New Zealand of the revised definition before dealing with assignments at suborder and great group level.

In the original Andisol proposal, the central concept of an Andisol was perceived as:

> "... a soil developing in volcanic ash, pumice, cinders, and other volcanic ejecta and volcaniclastic materials, with an exchange complex that is dominated by X-ray amorphous compounds of Al, Si and humus, or a matrix dominated by glass, and having one or more diagnostic horizons other than an ochric epipedon."

In reality, it is difficult to conceive of a central concept, particularly from a New Zealand standpoint, if the order is intended to include both weakly weathered yellow-brown pumice soils (Vitrudands) containing much glass, and the more strongly weathered, allophanic yellow-brown loams (Hapludands). Thus, a definition in terms of requirements for a minimum thickness of material with either vitric or andic soil properties is consistent with the original intent and reflects the bimodal nature of Andisols. It is conceptually sound when applied to New Zealand soils, as is the proposal to have both andic and vitric intergrades to other orders.

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[1] Parfitt, R. L. (n.d.) The nature of andic and vitric materials.

The revised thickness criteria focus attention on the upper layers of soil material most critical to plant growth, as in the definition of Andepts, and have considerable advantages in operational simplicity. Andisols with lithic or paralithic contacts have not been described widely in New Zealand but the proposed treatment of such soils seems more logical than that of the earlier proposal in which soils with very thin layers meeting the bulk density and ECDAM requirements were included in the order.

It is proposed to exclude very weakly developed soils in volcaniclastic materials from Andisols by the requirements for vitric soil properties. Previously the minimum specifications were a diagnostic horizon, other than an ochric epipedon, and a pH in NaF of 9.2 or more, as evidence that some glass had weathered to "amorphous material."

Dispensing with the need for one of the specified diagnostic horizons, or the dark-colored soil material in the upper 18 cm, is welcome in New Zealand as it removes any doubt as to the correlation of yellow-brown pumice soils. Few such soils have a histic, mollic, or umbric epipedon, or a duripan or placic horizon and, as indicated above, in most cases the Bw horizon is too coarse to qualify as cambic.

The replacement of the requirement for pH in NaF by one based on acidoxalate extractable Al (Alo) has much support among New Zealand soil scientists. The value of 0.4% Alo, corresponding roughly to 1-2% allophane in the fine earth fraction, differentiates the B horizons of most yellow-brown pumice soils from their little-altered C horizons. More data is required from the less-developed soils grouped as recent soils from volcanic ash to assess how well it distinguishes Vitrudands from the proposed suborder of Andents and other Vitric intergrades.

The requirement in the definition of vitric soil properties for more than 40% volcanic glass in the sand fraction has proved unsatisfactory when applied in isolation from a textural parameter based on either a minimum sand content or an upper limit of 15-bar water. This shortcoming is discussed below when dealing with the proposed key to Udands where, as in other suborders, Vitric great groups are defined as those with vitric soil properties.

The parameters proposed to define andic soil properties are intended to distinguish soils in which the exchange complex is dominated by allophane, imogolite or humus-Al complexes. They represent a commendable simplification of earlier proposals relating to "amorphous materials" and apparently work well in differentiating the Hapludands of New Zealand, though some further testing is necessary as yellow-brown loam intergrades have been widely identified. The relaxation of the bulk density requirements from 0.85 to 0.90 g/cm^3 allows an extensive group of soils developed in "tephric loess," with a significant quartzo-feldspathic component, to be included as Andisols.

The most critical boundaries for soils with andic properties in New Zealand and probably elsewhere are those with Spodosols and Andic Dystrochrepts. Well-developed Spodosols in rhyolitic tephras, like the Mamaku and Tihoi series (N. Z. Soil Bureau, 1968; Pollok, et al., 1980), are clearly distinguished by well-defined spodic horizons below albic E horizons. Greater difficulties are likely to be experienced with some weakly weathered, strongly leached soils in materials derived from greywacke and schist in cool humid uplands of the South Island. These high country yellow-brown earths and podzolised yellow-brown earths (Leamy, 1971) are commonly intergrades between Dystrochrepts and Haplorthods, and have low bulk densities, high P retention and Alo values of 1% or more. At present there are no fully characterised profiles with andic soil properties through a continuous thickness of 35 cm but the available data is limited. These considerations lend support to the proposal that Andisols are placed before Spodosols in the Key to soil orders. They also suggest the desirability of developing revised concepts of the diagnostic features of Andisols in conjunction with any revision of the criteria for spodic horizons.

Suborders and great groups

Aquands. Aquands are not widely developed in New Zealand. They are mainly represented by Haplaquands in andesitic ash or laharic deposits of Taranaki, and are uncommon in rhyolitic materials.

Recent work in Taranaki lends support to the statement in Soil Taxonomy (p. 237) that soils "... developed entirely from ash rarely have the low chroma of Aquepts, no matter how wet they may ..." Thus, some soils in ash believed to have an aquic soil moisture regime have distinct mottles in subsurface horizons but do not meet the requirements for chromas of 2 or less. Experience suggests that a more realistic grouping of Andisols that are wet to near the surface at some time during each year could be made by retaining item b(3) of the earlier proposal which required only distinct, medium ferruginous mottles within or immediately below 18 cm of the surface of an Ap deeper than 18 cm. This provision could also facilitate the identification of Aeric subgroups.

Neall (1977), who has outlined stages in the development of the Taranaki Andisols from detailed studies of tephrochronology and lahar stratigraphy, has estimated that Andaquepts occupy 100 km^2 of the younger ringplain surfaces of Mt. Egmont. Wetness is associated with the lateral flow of groundwater moving radially outwards from Mt. Egmont, where the annual rainfall reaches up to 6500 mm, and the slow permeability of cemented laharic material at the base of ash layers.

A recent soil survey (Palmer, et al., 1981) found Haplaquands and related soils occupying depressions in laharic

Table 1. Analytical data for Aquands and a Vitric Aquept.

Horizon	Depth (cm)	Moist Color	Total C (%)	pH(NaF)	Al(KCl) (me/100g)	P retention (%)	Fe$_o$ (%)	Al$_o$ (%)	Si$_o$ (%)	15-bar Water Moist(%)	Dry	Bulk Density (g/cm^3)
Haplaquands												
Awatuna series in andesitic ash over laharic deposits (Rainfall 1500 mm)												
Ap	0-13	9YR 2.5/2	10.5	10.6	0.1	95	1.4	3.8	1.1	38	25	0.76
AB	13-24	7.5YR 4.5/2	5.4	10.8	0.0	98	1.4	5.0	1.7	48	22	0.78
Bg	24-41	10YR 5/3	3.6	10.2	0.0	98	1.0	5.0	2.0	51	18	0.78
2Bg	41-60	10YR 7/2	1.9		0.0	97	0.5	5.1	2.3	48		0.82
	60-80		1.5		0.0	97	0.7	4.7	2.1	44	19	0.89
Punehu series in laharic materials (Rainfall 1400 mm)												
Apg	0-18	10YR 3/1	10.8	10.2	0.3	95	2.0	3.6	1.0	44	24	0.70
Bg	18-35	10YR 5/3	5.9	10.9	0.0	98	1.6	4.6	1.7	49	19	0.75
Ccs	35-55	10YR 5/2	2.7	10.7	0.0	91	1.8	2.3	0.8		10	
Vitric Haplaquept												
Wharepaina series in silty lacustrine alluvium from rhyolitic tephra (Rainfall 1200 mm)												
Ap	0-20	10YR 3/2	4.6	9.1	0.4	41	0.4	0.5	0.2	19	13	0.76
Bg	20-32	2.5Y 7/2	0.5	8.6	0.5	17	0.1	0.2	0.1	11	7	1.02
BCg1	32-49	5Y 6/2	0.3	8.6	0.1	8	0.0	0.1	0.1	5	3	0.71
BCg2	49-100	5Y 7/2	0.2	8.5	0.1	8	0.1	0.2	0.1	8	5	0.81

plains mantled in part by andesitic ash. In the Glenn series the ash is more than 180 cm thick; similar soils with a thinner layer of ash over laharic deposits are distinguished as the Awatuna series. Puneha soils occur in laharic material with little or no ash cover and have medial upper horizons overlying gravelly sands containing boulders, often weakly or strongly cemented with iron oxides. As noted by Neall (1977) cemented ferruginous accumulations are also a characteristic feature of the interface between ash and an underlying lahar.

Representative pedons of the Awatuna and Punehu series (Table 1) have mottled subsurface horizons with chromas of 2 at a depth of less than 50 cm. The analytical data indicate that they have the low bulk densities, high P retention, high Alo, high pH in NaF, high organic C and low Al(KCl) values typical of soils with andic properties.

Hydromorphic soils with andic or vitric soil properties are much less extensively developed in association with Hapludands and Vitrudands in rhyolitic tephras, suggesting that poor drainage inhibits the weathering processes necessary for the formation of allophane in siliceous materials. In the Hamilton Basin the Waikato River has built a low-angled alluvial fan that includes much reworked rhyolitic tephra (McCraw, 1967; Orbell, 1982). Hapludands of the Horotiu series (Table 4) are developed on well-drained low ridges which intergrade to Aquic Hapludands (Bruntwood series) on the flanks. These soils contrast markedly with the halloysitic Aqualfs (Te Kowhai series) formed in the finer textured sediments of the fan toe and swales.

Wet soils occupy depressions and alluvial belts in the pumice country of the volcanic plateau. They may have sufficient glass in the sand fraction to meet the vitric criterion but no profile has been sampled that has 0.4% Alo over the required thickness. The data (Table 1) for a profile of the Wharepaina series (Vucetich & Wells, 1978) in a silty lacustrine deposit composed mainly of glass and derived from Taupo Pumice has low levels of Alo, pH in NaF and P retention below the Ap horizon. It provides further evidence that even in relatively fine-grained rhyolitic materials, little allophane is formed under an aquic moisture regime.

Allands

None has been recognized in New Zealand but it seems likely that some strongly leached soils on the flanks of Mts. Egmont, Ruapehu and Ngaurohoe may meet the specifications for Haplallands. A profile of the Patua series (Table 2) described in andesitic ash at 430 m with an annual rainfall of 4050 mm has > 1 me/100 g KCl extr. Al to a depth of 29 cm, and a pH in water that is slightly higher (c. 5.5) than the value of 5.1 proposed for Allic subgroups in the Andisol

Table 2. Analytical data for Patua and Takapau soils.

Horizon	Depth (cm)	Moist Color	Total C (%)	pH(NaF)	Al(KCl) (me/100g)	P retention (%)	Fe_o (%)	Al_o (%)	Si_o (%)	15-bar water		Bulk Density (g/cm^3)
										Moist (%)	Dry	
Hapludand												
Patua series in andesitic ash (Rainfall 4050 mm)												
Ap	0-14	5YR 2.5/2	18.0	11.3	2.1	91	1.3	2.3	0.2	58	25	
AB	14-29	7.5YR 3/2	11.5	11.6	1.2	97	1.6	3.2	0.4	55	20	
Bw1	29-54	10YR 4/3	7.1	11.5	0.2	99	1.8	5.9	1.9	63	19	
Bw2	54-87	10YR 5/4	4.7	11.3	0.1	99	1.2	7.1	2.8	67	19	0.53
Bw3	87-100	10YR 5/4	4.1	11.0	0.1	99	0.8	6.9	2.9	69	18	0.52
Andic Ustochrept												
Takapau series in loamy alluvium containing ash over gravelly alluvium (Rainfall 800 mm)												
Ap	0-14	10YR 3/4	6.3	10.4	0.3	65	0.6	1.8	0.6	17	14	0.86
AB	14-26	10YR 4/4	3.1	10.8	0.2	84	0.9	2.5	1.1	19	14	0.84
Bw	26-44	10YR 5/6	2.3	10.7	0.0	86	1.2	2.6	1.5	22	14	0.88
2Bw	44-62	10YR 5/6	1.6	10.3	0.1	68	1.1	1.4	0.7	12	12	1.09
3C	62-82	2.5Y 5/4	0.2	7.8	0.1	11	0.2	0.1	0.0	3	3	1.44

proposal of 1978. A noteworthy feature of subsurface horizons is the abundance of reddish-brown coatings on peds, which probably contain ferrihydrite and allophane.

Borands

As noted earlier, there is no data available to confirm the occurrence of Borands on the slopes of the volcanoes above about 1200 m. If any are present, they are likely to be Vitriborands rather than Haploborands.

Ustands

Thin deposits of rhyolitic and andesitic tephras occur in areas of Hawke's Bay with a ustic soil moisture regime. The absence of Ustands in occasional thicker deposits may be explained by the low rainfall and pronounced soil moisture deficit, conditions under which there appears to be insufficient leaching of Si for the formation of allophane (Parfitt, et al., 1983). Intergrades to Haplustands are represented by soils of the Takapau series (Table 2) developed in medial alluvium or loess with an appreciable tephra content overlying sandy gravels. The upper horizons meet the bulk density requirements but just fail to have the necessary values of Alo and P retention. They contain about 30% glass in the sand fraction but the clay fraction includes substantial amounts of vermiculite and halloysite.

Udands

A very large proportion of New Zealand Andisols are Udands of which nearly all are Vitrudands and Hapludands. Placudands, Hydrudands and Melanudands have not been described, and no part of the country has the isohyperthermic temperature regime required by Tropudands.

Vitrudands

These are now defined as the Udands which lack the requirements of Placic, Hydric, Tropic, or Melanic great groups, and have vitric soil properties beginning at or within 25 cm of the surface and extending through a continuous thickness of 35 cm or more. Thus, as in other Vitric great groups, the same properties are used to identify the soils at order and great group level.

The great group was previously defined by values of 15-bar water retention of dried and undried samples which, in the absence of a paralithic or lithic contact, were based on the weighted average of all horizons between 25 cm and 1 m. In the present proposal the amount of allophane, imogolite and Al-humus ("amorphous material") is assessed by acid-oxalate extractable Al rather than by the 15-bar water of

Table 3. Analytical data for Vitrudands and a Vitrandent in rhyolitic pumiceous tephra.

Horizon	Depth (cm)	Moist Color	Total C (%)	pH(NaF)	P retention (%)	Al_o (%)	Al_p (%)	15-bar Water Moist (%)	Dry	Glass in 0.05-2 mm (%)
Vitrudands										
Taupo series (Rainfall 1400 mm)										
Ap	0-12	10YR 2/1	4.2	10.6	58	0.6	0.5	17	8	>70
Bw	12-25	10YR 3/6	1.8	11.1	76	1.3	0.4	19	6	>70
C1	25-70	2.5Y 5/4	0.4	10.4	37	0.6	0.1	6	3	>70
C2	70-130	2.5Y 7/2	0.2	9.4	15	0.2	0.0	5	2	>90
Opotiki series (Rainfall 1600 mm)										
Ap	0-22	10YR 2/1	5.8	10.2	57	1.3	0.4	17	13	70
Bw1	22-43	10YR 4/6	1.7	10.9	80	2.1	0.3	18	8	70
Bw2	43-70	10YR 5/6	0.6	10.7	77	2.1	0.1	17	7	80
Bw3	70-100	10YR 5/6	0.4	10.5	68	1.7	0.1	16	9	70
2Bw	100-120	10YR 5/6	0.4	10.5	84	2.0	0.2	30	15	80
Te Puke series (Rainfall 1800 mm)										
Ap1	0-10	10YR 2/1	6.0	10.5	45	0.8	0.4		12	
Ap2	10-18	10YR 2/1	3.8	10.7	55	0.8	0.4		8	
Bw	18-27	10YR 4/4	2.1	11.1	70	1.4	0.5		6	70
2Bw	27-45	10YR 3/6	1.8	11.1	90	2.6	0.4		7	80
3Bw	45-60	10YR 4/6	1.1	11.1	88	2.5	0.3		7	80
4Bw	60-94	10YR 5/8	0.5	10.9	82	2.3	0.2		6	80
5Bw1	94-110	10YR 5/6	0.6	10.9	95	4.0	0.3		12	80
5Bw2	110-120	10YR 5/6	0.8	11.0	98	4.9	0.4		16	80
Vitrandent										
Ohinepanea series (Rainfall 1300 mm)										
Ap	0-21	10YR 2/1	3.2	9.7	26	0.4	0.2	8	8	70
Bw	21-43	10YR 5/4	0.6	10.2	18	0.3	0.1	4	3	60
C	43-53	10YR 6/3	0.2	9.7	11	0.2	0.1	3	2	60
2Bwb	53-81	10YR 3/4	0.7	10.5	70	1.7	0.3	19	8	80
3Bwb	81-100	10YR 4/6	0.5	10.2	60	1.5	0.2	16	9	70

dried samples, and the general relationship of these parameters in New Zealand soils has been discussed by Parfitt (n.d.). The revised criteria have considerable operational advantages and focus on the critical 35 cm layer rather than a control section between 25 cm and 1 m. However, the present definition does not exclude soils with andic properties that contain more than 40% glass in the sand fraction.

Vitrudands include most yellow-brown pumice soils except the podzolised soils with a spodic horizon occurring mainly above 550 m where the annual rainfall is more than 1500 mm. They also include some yellow-brown loams, particularly in the Bay of Plenty, and some recent soils from volcanic ash. They are developed in three main formations of rhyolitic pumiceous tephra (Kaharoa, Taupo and Waimihia) deposited between 900 and 3,500 years B.P. The soils are of coarse particle size and the fine earth feels coarse loamy or sandy. They have a weakly developed granular or crumb structure, a friable to loose consistence and a low bulk density.

Parfitt (n.d.) has quoted data from a Taupo sandy loam to illustrate the central concept of an Andisol with vitric soil properties. A yellow-brown loam profile cf the Opotiki series (Table 3) from the Bay of Plenty, developed mainly in an older rhyolitic tephra (Whakatane Ash, 5,000 years B.P.), is a more strongly developed soil with a thick yellowish-brown B horizon. It has sufficient allophanic material based on values of Alo to meet the requirements for andic soil properties but values for P retention are a little too low. Soils of this kind in Whakatane Ash have long been recognized to occupy the diffuse boundary zone between yellow-brown pumice soils and yellow-brown loams.

The Ohinepanea profile (Table 3) in Kaharoa Ash (900 years B.P.) has sufficient glass in the sand fraction but has less than 0.4% Alo in the upper 53 cm and is therefore a Vitrandent. Note that in the earlier proposal, it would have qualified as an Andisol on the basis of NaF pH and as a Vitrudand on values of 15-bar water.

In the New Zealand Soil classification "composite soils" are identified where a yellow-brown pumice soil is developed in young tephras less than 50 cm thick and the underlying soil material has the characteristics of a yellow-brown loam. This arrangement is exemplified by a profile of the Te Puke series (Table 3) which has vitric soil properties in the upper 27 cm developed in Kaharoa ash, but andic properties in the older tephras below. Such a profile would meet the proposal for a Thapto-andic subgroup of Vitrudands.

A more comprehensive examination of the New Zealand data is necessary before we can be sure that the proposed criteria make the most appropriate separations between Vitrudands and Hapludands, and between Vitrudands and Vitric Entisols. More

Table 4. Analytical data for Hapludands.

Horizon	Depth (cm)	Moist Color	Total C (%)	pH(NaF)	Al(KCl) (me/100g)	P retention (%)	Fe_o (%)	Al_o (%)	Si_o (%)	15-bar Water		Bulk Density (g/cm^3)
										Moist (%)	Dry	
Egmont series in andesitic ash (Rainfall 1000 mm)												
Ap	0-21	10YR 2/1	10.1	10.7	0.3	88	1.0	3.2	1.2	30	23	0.75
Bw1	21-38	10YR 3/6	3.8	11.0	0.2	98	1.4	4.7	2.0	36	18	0.73
Bw2	38-55	10YR 3/6	2.2	10.8	0.2	99	1.4	4.9	2.3	39	16	0.66
Bw3	55-89	10YR 4/6	1.7	10.9	0.1	99	1.8	5.0	2.5	42	17	0.75
Tirau series in rhyolitic ash (Rainfall 1400 mm)												
Ap	0-18	10YR 2/2	7.9	10.5	0.2	88	0.6	3.3	1.3	31	23	0.75
Bw1	18-30	9YR 4/4	2.0	10.7	0.0	98	0.7	4.1	2.2	34	16	0.71
Bw2	30-51	10YR 5/6	1.0	10.5	0.0	98	0.7	4.0	2.6	34	17	0.69
Bw3	51-74	10YR 5/6	0.5	10.2	0.0	91	0.4	2.8	1.7	35	22	0.79
2C	74-100	10YR 5/4	0.5	10.0	0.0	86	0.5	2.4	1.3	34	20	0.87
Opua series in laharic breccia (Rainfall 1450 mm)												
Ap	0-15	5YR 5/2	13.8	10.8	0.2	94	1.2	3.0	0.8	33	27	0.72
Bw1	15-25	5YR 3/3	7.6	11.1	0.0	99	1.7	6.0	2.2	32	20	
Bw2	25-48	7.5YR 4/6	5.5	11.2	0.0	99	1.3	6.6	2.6	23	12	
BC	48-74	2.5Y 4/2	1.4	10.8	0.0	99	0.9	3.1	1.5	8	5	
Horotiu series in rhyolitic alluvium (Rainfall 1300 mm)												
Ap	0-18	10YR 3/8	8.2	10.2	1.1	98	1.0	3.4	1.2	26	22	0.80
Bw1	18-34	10YR 4/6	3.3	10.2	0.0	99	1.3	4.5	2.0	44	21	0.62
Bw2	34-43	10YR 5/6	1.5	10.1	0.0	98	1.1	3.2	1.6	38	18	0.72
BC	43-55	10YR 5/8	0.6	9.6	0.0	81	0.6	1.2	0.6	23	15	0.96
	55-72		0.3	8.7	0.0	36	0.3	0.2	0.1	14	11	
2C	72-100		0.1	7.9	0.0	16	0.1	0.1	0.1	4	3	

studies are required of the soils in the younger tephras, particularly those from the andesitic sources. Thus, Ngauruhoe soils (N. Z. Soil Bureau, 1968) developed in andesitic sands erupted over the last 400 years have very limited horizon development but can include horizons with an appreciable glass content and sufficient Alo to qualify as having vitric soil properties.

Hapludands

As in the original Andisol proposal, Hapludands are the last great group to be keyed out in the suborder. Using the revised key to great groups, some New Zealand soils close to the central concept of Hapludands will key out as Vitrudands because they contain more than 40% glass in the sand fraction. This suggests that an additional requirement is needed to distinguish vitric from andic soil properties. Thus, it may be necessary to restrict vitric soil materials to those with less than 30% water retention at 15-bars on undried samples of the fine earth or introduce a lower limit for the sand fraction.

Hapludands include most of the yellow-brown loams of New Zealand except some in relatively young ash deposits like the Opotiki series cited above as a Vitrudand. The distinctive morphological, physical, and chemical properties of yellow-brown loams attributable to the allophanic clay fraction are documented by many authors, including the N. Z. Soil Bureau (1968); Gibbs (1980); Leamy, et al. (1981); and Cowie (1982). Hapludands also include some soils classed as red and brown loams in the New Zealand Soil Classification that occur in a thermic soil temperature regime in the Auckland region. Red loams are formed from scoriaceous basalt on the flanks of volcanic cones, and brown loams from massive basalt lavas.

Parfitt (n.d.) has quoted data from a New Zealand Hapludand--an Egmont soil in andesitic ash--to illustrate the central concept of an Andisol with andic soil properties. It can be matched by profiles in rhyolitic ash, peripheral to areas of rhyolitic volcanism, with essentially similar properties, as for example the Tirau series (Table 4). However, they may differ in that profiles like the Tirau can include substantial amounts of glass in the sand fraction (N. Z. Soil Bureau, 1968).

The Horotiu profile (Table 4) represents Hapludands found extensively in alluvium largely derived from rhyolitic tephras, and the Opua profile (Palmer, et al., 1981) is in laharic breccia occurring widely around Mt. Egmont. Both have gravelly horizons with low 15-bar water values at depth and were classified as Vitrudands in the original Andisol proposal.

Table 5. Analytical data for Hapludands associated with basalts.

Horizon	Depth (cm)	Moist Color	Total C (%)	pH(NaF)	Al(KCl) (me/100g)	P retention (%)	Fe_o (%)	Al_o (%)	Si_o (%)	15-bar Water		Bulk Density (g/cm^3)
										Moist (%)	Dry	
				Papakauri series in basalt colluvium (Rainfall 1650 mm)								
Ap	0-15	2.5YR 3/4	11.6	10.7	0.3	95	3.7	3.6	0.6	38	29	0.73
Bw1	15-32	2.5YR 3/6	6.2	11.2	0.3	97	3.7	4.2	0.7	48	24	0.65
Bw2	32-54	10R 3/6	3.9	11.1	0.2	99	3.7	5.2	1.1	55	24	0.79
Bw3	54-85	2.5YR 3/6	2.4	10.7	0.1	99	4.3	5.5	1.3	57	24	0.77
Bw4	85-111	4YR 3/6	1.5	10.5	0.2	99	5.2	3.9	0.6	54	26	0.93
BC	111-140	5YR 3/4	0.7	10.1	0.3	98	3.6	2.4	0.5	36	19	
				Ohaeawai series on basalt (Rainfall 1650 mm)								
Ap	0-16	7.5YR 3/2	12.9	11.2	0.3	97	2.4	7.0	2.2	45	34	
Bw1	16-46	10YR 3/3	6.3	11.3	0.1	99	2.6	7.9	4.2	91	34	
Bw2	46-76	2.5Y 3/3	4.6	11.1	0.1	99	2.7	7.8	4.3	101	34	

Other yellow-brown loams with evidence of **gleying** in subsurface horizons were classified as Aquic Hapludands according to the earlier Andisol proposal that included subgroup definitions. These include the Oeo series (Palmer, et al., 1981) in andesitic ash with distinct ferruginous mottles above 1 m, and the Te Puninga series (Wilson, 1980) in ash over rhyolitic alluvium of the Hauraki Plains with greyish horizons below 50 cm. Hapludands are also represented among composite soils, where andic soil properties are developed in ash deposits less than 50 cm thick, often above buried soils in older deposits with argillic horizons. Such soils with an argillic horizon with an upper boundary at a depth of more than 50 cm would be accommodated in Thapto-alfic or Thapto-ultic subgroups.

Hapludands from basalt in North Auckland are represented by profiles of the Papakauri and Ohaeawai series (Table 5). The Papakauri soil is a hematitic red loam in colluvium from a basalt cone that contains appreciable amounts of ferrihydrite (Parfitt and Childs, in press, 1984), consistent with the large values (3-5%) of acid-oxalate extractable Fe. The profile of the Ohaeawai series, a brown loam from basalt, has very high values of Alo (7-8%) and values of 15-bar water of undried samples amounting to 90-100% in subsurface horizons. Similar profiles with more than 35 cm of andic soil material, but with a lithic contact at less than 50 cm, are distinguished as Lithic Hapludands (Purdie, 1982a).

Two recent studies of soil sequences throw light on the relationship between Hapludands and Inceptisols in New Zealand. The first (Parfitt, et al., 1983) examined well-drained soils in rhyolitic tephras of similar stratigraphy under different leaching environments. The Mairoa profile at the wet end of the sequence with a mean annual rainfall of 2,600 mm was found to have a mainly allophanic clay fraction and has correspondingly large values of Alo (Table 6). The Ohaupo profile under a rainfall of 1,400 mm contains considerable amounts of both allophane and halloysite but also qualifies as a Hapludand. In sites with lower rainfall the soils as represented by the Kereone profile are predominantly halloysitic and are classified as Ochrepts. The sequence is explained by the formation of allophane where Si values in the soil solution are low as a result of strong leaching as at the Mairoa site, whereas Si-rich halloysite is formed at drier sites with pronounced seasonal moisture deficits and with significantly larger amounts of Si present in the soil solution.

The second study (Purdie, 1982b) involved soils developed on terraces in the Dannevirke region east of the central ranges in southern Hawke's Bay. The soils are developed in "tephric loess" consisting of andesitic and rhyolitic ash mixed with varying amounts of noncalcareous quartzo-feldspathic loess. Close to the ranges with an annual rainfall of more than 2000 mm Hapludands of the Dannevirke series (Table 7) are recognized.

Table 6. Analytical data for a soil sequence in rhyolitic ash (Parfitt, et al., 1983).

Horizon	Depth (cm)	Moist Color	Total C (%)	pH(NaF)	P retention (%)	Fe_o (%)	Al_o (%)	Si_o (%)	Bulk Density (g/cm^3)
Hapludands **Mairoa series (Rainfall 2600 mm)**									
Ap	0-18	7.5YR 3/2	13.6	11.5	88	2.8	3.4	0.7	0.58
AB	18-33	5YR 3/4		11.5	89	3.1	6.1	2.0	0.54
Bw	33-53	7.5YR 4/6	5.2	11.4	99	2.6	8.4	3.5	0.41
2Bw	53-60	10YR 5/6	4.2	11.3	99	2.0	7.9	3.5	0.54
3Bwb	60-81	7.5YR 4/4	3.3	11.2	99	2.4	7.4	3.4	0.57
4C	81-94	7.5YR 4/4	3.2	11.2	99	3.2	7.1	3.4	0.62
5C	94-104	7.5YR 4/6	3.8	11.0	99	4.7	9.9	4.7	0.48
Ohaupo series (Rainfall 1400 mm)									
Ap	0-15	10YR 3/2	6.6	10.0	99	0.8	3.0	1.4	
AB	15-36	7.5YR 4/4	2.0	10.5	99	1.1	4.4	2.4	0.66
Bw	36-50	7.5YR 3/4	2.2	10.5	97	1.0	4.1	2.2	0.59
2Bw	50-60	7.5YR 4/4	1.3	10.3	93	1.0	3.6	2.2	0.64
3Ab	60-74	7.5YR 3/4	0.9	10.1	88	0.8	1.9	1.1	0.73
3Bwb	74-90	7.5YR 4/4	0.4	9.8	78	0.7	0.9	0.6	0.76
4C	90-110	7.5YR 4/4	0.5	9.8	78	0.7	1.4	1.0	0.81
5C	110-116	5YR 3/4	0.4	9.4	62	0.8	0.5	0.4	0.86
Dystric Eutrochrept **Kereone series (Rainfall 1200 mm)**									
Ap	0-24	5YR 2.5/1	4.1	9.3	60	0.6	0.6	0.1	0.98
Bw	30-41	5YR 3/3	1.4	10.8	71	0.6	0.7	0.1	0.69
2Bw	41-53	7.5YR 4/4	0.7	10.0	54	0.4	0.5	0.4	0.82
3Ab	53-75	7.5YR 4/4		9.6	54	0.4	0.4	0.2	0.94
3Bwb	75-101	7.5YR 4/4	0.4	9.5	44	0.3	0.4	0.2	1.19
5C	108-114	5YR 3/4	0.4	8.8	39	0.3	0.2	0.1	1.34

Further east in areas of lower rainfall but similar parent material, the soils intergrade to Ochrepts or Umbrepts like the Dannevirke variant (Table 7) described where the annual rainfall is 1300 mm.

CONCLUSIONS

The revised definition of Andisols in terms of andic and vitric soil properties makes better provision for the two main groups of New Zealand soils embraced by the original intent of the order. In particular, it allows most yellow-brown pumice soils to be included unequivocally as Vitrudands.

The Andisols of New Zealand are predominantly Udands with relatively small areas occupied by Aquands, mainly in the andesitic tephras and laharic deposits of Taranaki. The revised definition of Aquands excludes some soils believed to have an aquic moisture regime in which gleying is expressed only by distinct ferruginous mottles in subsurface horizons within the upper 50 cm.

The Udands key out as Vitrudands and Hapludands, which closely parallel the New Zealand groups of yellow-brown pumice soils and yellow-brown loams. However, some soils with andic properties in rhyolitic tephra are keyed out as Vitrudands because they contain more than 40% glass in the sand fraction. For this reason, the definition of vitric soil properties needs an additional requirement in terms of 15-bar water or particle size.

Further studies are necessary to ensure that the proposed criteria make the most appropriate separations between Vitrudands and Hapludands, and between Vitrudands and Vitrandents.

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Table 7. Analytical data for a soil sequence in "tephric loess" (Purdie, 1982b).

Horizon	Depth (cm)	Moist Color	Total C (%)	pH(NaF)	Al(KCl) (me/100g)	P retention (%)	Fe_o (%)	Al_o (%)	Si_o (%)	15-bar Water Moist (%)	Dry	Bulk Density (g/cm^3)
Dannevirke series - Hapludand (Rainfall 2000 mm)												
Ap	0-20	10YR 3/3	11.0	10.7	0.2	96	1.3	4.1	1.3	38	28	0.63
Bw	20-51	10YR 5/6	2.4	10.4	0.0	99	1.5	4.1	1.5	53	15	0.55
BC	51-70		1.8	10.3	0.1	99	1.5	3.3	0.9			
C	70-100	10YR 5/4	1.4	10.6	0.1	97	1.0	2.3	0.8	33	15	1.02
Dannevirke variant - Haplumbrept (Rainfall 1300 mm)												
Ap	0-28	10YR 3/3	5.1	9.9	0.1	80	0.7	1.3	0.3	23	18	0.90
Bw1	28-47	10YR 5/6	1.3	10.0	0.0	70	0.6	0.7	0.2	22	12	0.89
Bw2	47-60	10YR 5/5	0.6	9.5	0.1	43	0.5	0.3	0.1	17	10	1.43
Bw3	60-81	10YR 5/4	0.4	9.2	0.1	37	0.3	0.2	0.0	20	11	1.50
Bw4	81-101	10YR 5/6	0.5	9.3	3.1	54	0.6	0.3	0.0	27	14	1.32

LITERATURE CITED

Cowie, J. D. 1982. Yellow-brown loams - definition and classification. p. 7-9. *In* V. E. Neall (ed.) Soil Groups of New Zealand. Part 6. Yellow-brown loams. N. Z. Soc. Soil Sci., Wellington, N. Z.

Gibbs, H. S. 1968. Volcanic-ash soils in New Zealand. N. Z., D.S.I.R. Inf. Ser. No. 65, Wellington, N. Z.

Gibbs, H. S. 1980. New Zealand Soils - An Introduction. Oxford University Press, Wellington, N. Z.

Leamy, M. L. 1971. Some characteristics of the upland and high country yellow-brown earths. N. Z. J. Sci. 14:1057-1081.

Leamy, M. L. 1983. ICOMAND Circular Letter No. 5. N. Z. Soil Bureau, Lower Hutt, N. Z.

Leamy, M. L., G. D. Smith, F. Colmet-Daage, and M. Otowa. 1980. The morphological characteristics of Andisols. p. 17-34. *In* B. K. G. Theng (ed.). Soils with Variable Charge. N. Z. Soc. Soil Sci., Soil Bureau, Lower Hutt, N. Z.

McCraw, J. D. 1967. The surface features and soil pattern of the Hamilton Basin. Earth Sci. J. 1:59-74.

Neall, V. E. 1977. Genesis and weathering of Andosols in Taranaki, N. Z. Soil Sci. 123:400-408.

Neall, V. E. and G. E. Orbell. 1982. Classification of yellow-brown loams, intergrades and composites according to U. S. Soil Taxonomy (1975) and the 1978 Andisol Proposals. p. 9-11. *In* V. E. Neall (ed.) Soil Groups of New Zealand. Part 6. Yellow-brown loams. N. Z. Soc. Soil. Sci., Wellington, N. Z.

N. Z. Soil Bureau. 1968. Soils of New Zealand. N. Z. Soil Bureau Bull. 26 (3 vols.).

Orbell, G. E. 1982. Yellow-brown loams of the Waikato region. p. 25-29. *In* V. E. Neall (ed.) Soil Groups of New Zealand. Part 6. Yellow-brown loams. N. Z. Soc. Soil Sci., Wellington, N. Z.

Palmer, R. W. P., V. E. Neall, and J. A. Pollok. 1981. Soils of Egmont County and part Taranaki County. N. Z. Soil Survey Report 64.

Parfitt, R. L., M. Russell, and G. E. Orbell. 1983. Weathering sequence of soils from volcanic ash involving allophane and halloysite, New Zealand. Geoderma 29:41-57.

Parfitt, R. L., and C. W. Childs. 1984. Comment on clay mineralogy of two Northland soils, N. Z. Soil Sci. Plant Nutr., Japan. (In press)

Pollok, J. A., R. L. Parfitt, and R. J. Furkert. 1980. Guide Book for Tour 4, North Island. Soils with Variable Charge Conference, Wellington, N. Z.

Purdie, B. R. 1982a. Yellow-brown loams in the South Auckland area. p. 29-32. *In* V. E. Neall (ed.) Soil Groups of New Zealand. Part 6. Yellow-brown loams. N. Z. Soc. Soil Sci., Wellington, N. Z.

Purdie, B. R. 1982b. The boundary between yellow-brown loams and yellow-brown earths; an example from the Dannevirke area, southern Hawke's Bay. p. 43-45. *In* V. E. Neall (ed.) Soil Groups of New Zealand. Part 6. Yellow-brown loams. N. Z. Soc. Soil Sci., Wellington, N. Z.

Rijkse, W. C. 1974. Definition: boundaries between yellow-brown pumice soils and related or associated soils. p. 22-27. *In* Read, N. E. (ed.) 1974. Soil Groups of New Zealand. Part 1. Yellow-brown pumice soils. N. Z. Soc. Soil Sci., Wellington, N. Z.

Soil Survey Staff. 1975. Soil Taxonomy. U. S. Agric. Handbook No. 436. Soil Conservation Service, U. S. Dept. Agric., U. S.. Govt. Printing Office., Washington, D. C.

Taylor, N. H. and J. E. Cox. 1956. The soil pattern of New Zealand. Institute Agric. Sci. Proc. 28-44.

Vucetich, C. C., and N. Wells. 1978. Soils, Agriculture and Forestry of Waiotapu Region, Central North Island, New Zealand. N. Z. Soil Bureau Bull. 31.

Wilson, A. D. 1980. Soils of Piako County, North Island, New Zealand. N. Z. Soil Survey Report 39.

ANDISOLS OF SYRIA

A. Osman, R. Tavernier, M. Ilaiwi, and B. Kabbara

The classification of soils formed on volcanic material has been discussed several times during the preparation of the Soil Map of Syria and Lebanon, and later on during the IV International Soil Classification Workshop that was held in Syria and Lebanon in 1980 and also in the circular letters of ICOMID. Recently these soils were studied at the University of Ghent by B. Kabbara.

A synthesis of all these studies is presented here.

ENVIRONMENTAL CONDITIONS

Parent Material

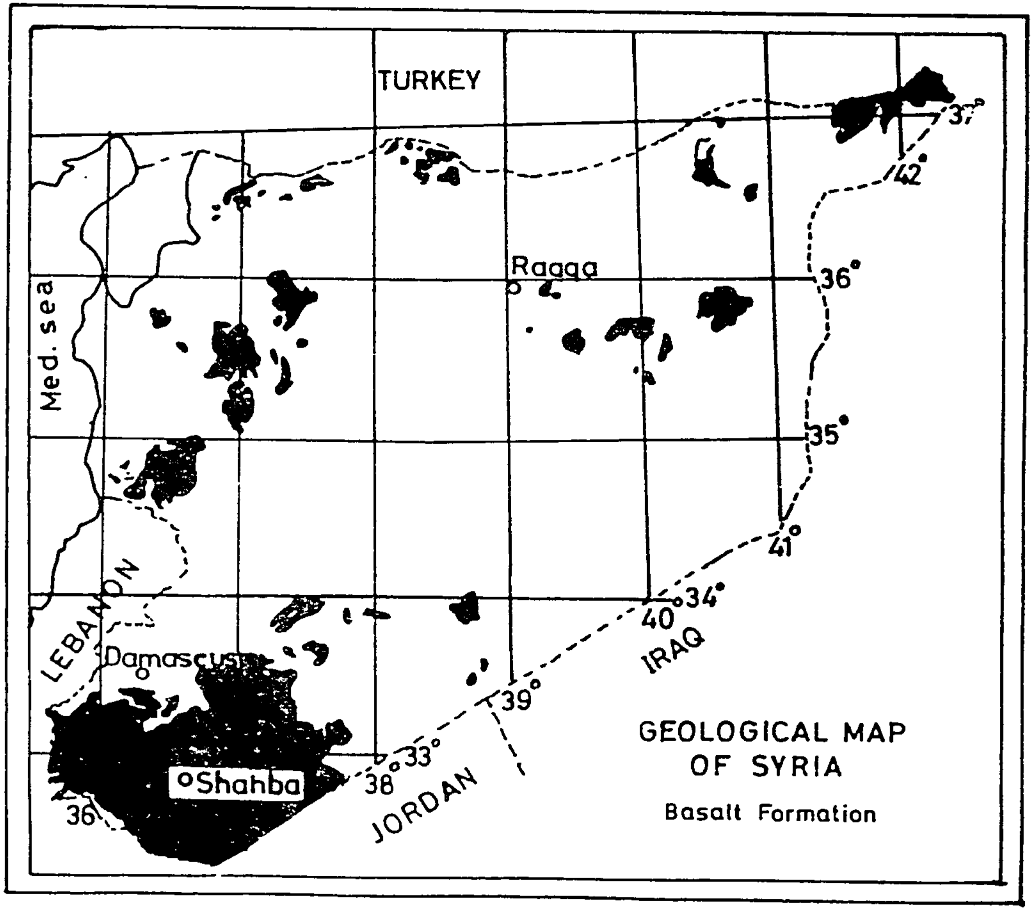
Volcanic material in Syria is well represented. They cover an important area mainly in the southwest, including the Hauran and Golan plateaus where lower quaternary basalts are weathered into vertisols. The rocky Leja and Harra were formed by Holocene basalt flows.

The mountain of Jebel El-Arab (1800 m) and the dissected reliefs of thick Miocene basalt flows border the plain of Damascus in the southwest. To the west of Homs, a Pliocene basalt flow forms a hilly area ending in the Akkar plain and the Mediterranean Sea. Relic plateaus of Neogene or Quaternary basalts, bordered by cliffs or steep slopes, are scattered in the Syrian territory.

Volcanic ashes, cinders, and lappilli are located on the slopes near the volcano craters.

Climate

Syria has two major climatic types representing the arid and the semi-arid areas. The rainfall, mainly concentrated in early spring, decreases from more than 1000 mm in the coastal mountains to less than 100 mm in the eastern desert. The precipitation is strongly influenced by the orographic conditions and the distance to the sea, although the influence



GEOLOGICAL MAP
OF SYRIA
Basalt Formation

of the Mediterranean Sea on the interior is limited due to the presence of the mountain range running north-south parallel to the coast. The mean monthly temperature in the Mediterranean zone in January ranges from 6°C to 15°C (in function of the elevation) and in July from 22°C to 28°C, while in central and eastern Syria these figures are respectively 4°C to 6°C and 26°C to 32°C.

The soil temperature and moisture regimes have been calculated for 76 climatic stations in Syria. Except for a few stations located at high elevations in the mountains where the soil temperature regime is mesic, the larger part of the area is characterized by a thermic soil temperature regime and even hyperthermic in the eastern part of Syria. The xeric moisture regime in Syria prevails in the extreme southwest (Hauran plateau and Jebel El-Arab), in a narrow strip along the Lebanese border, in the northwest part of Syria (Homs-Aleppo) and along the Turkish border (north of Ragga and Deir El-Zor). The central, eastern, and southern parts of Syria are dominated by an aridic (torric) moisture regime.

SOIL PROPERTIES

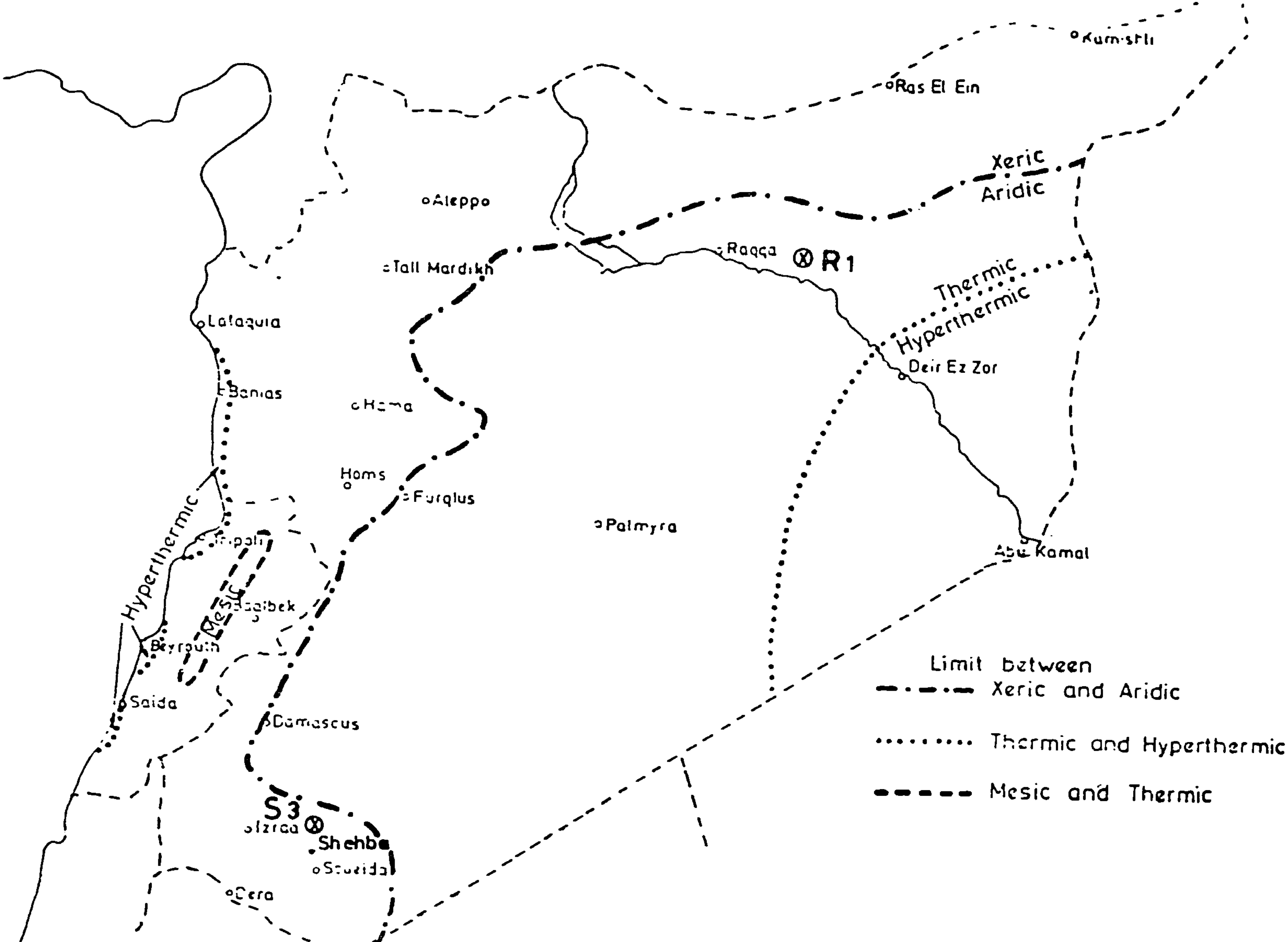
The soils formed on weathered volcanic material have different properties related to the degree of alteration of the parent material, the climatic conditions and the topographic position. Under arid conditions, the soils are impregnated with calcium-carbonate, gypsum, and sodium chloride. The nonvolcanic material is related mainly to eolian origin. The soils formed under xeric moisture regime are generally affected by water erosion, particularly on steep slopes.

Vitric properties

The soils are formed mainly on lappilli covered by cinders and volcanic ashes. The amount of lappilli increases with depth. The particles are coated by lime at variable depth. Acid-oxalate extracted aluminium ranges from 0.35 to 0.55.

Andic properties

The data available on the andic properties are not yet completed. The available information on the mineralogy C EC water retention and pH (NaF) show a good correlation with the requested andic properties, e.g. the bulk density, the phosphate retention and the extractable aluminium.



Soil temperature and moisture regimes of Syria and Libanon

PROFILE DEVELOPMENT

The profile development is mainly a function of the climatic conditions.

Torric (aridic) regime

The soil profile development under arid conditions is mainly of AC or ACca type. The typical profile has the following development:

A. A thin ochric epipedon, pale brown, weak structure, calcareous with little amount of organic matter.

B. Thick deposition of lappilli, coated by calcium carbonate at a certain depth, forming a C ca horizon.

Profile No. R1 is representative of this soil.

Xeric regime

Under xeric moisture regime, the soil profile is much more developed. The typical profile has the following development:

A. (or Ap when cultivated): An ochric epipedon, relatively thick, pale brown, low organic matter, calcareous, weakly structured.

B. Cambic horizon, brown, weakly structured, calcareous, low organic matter.

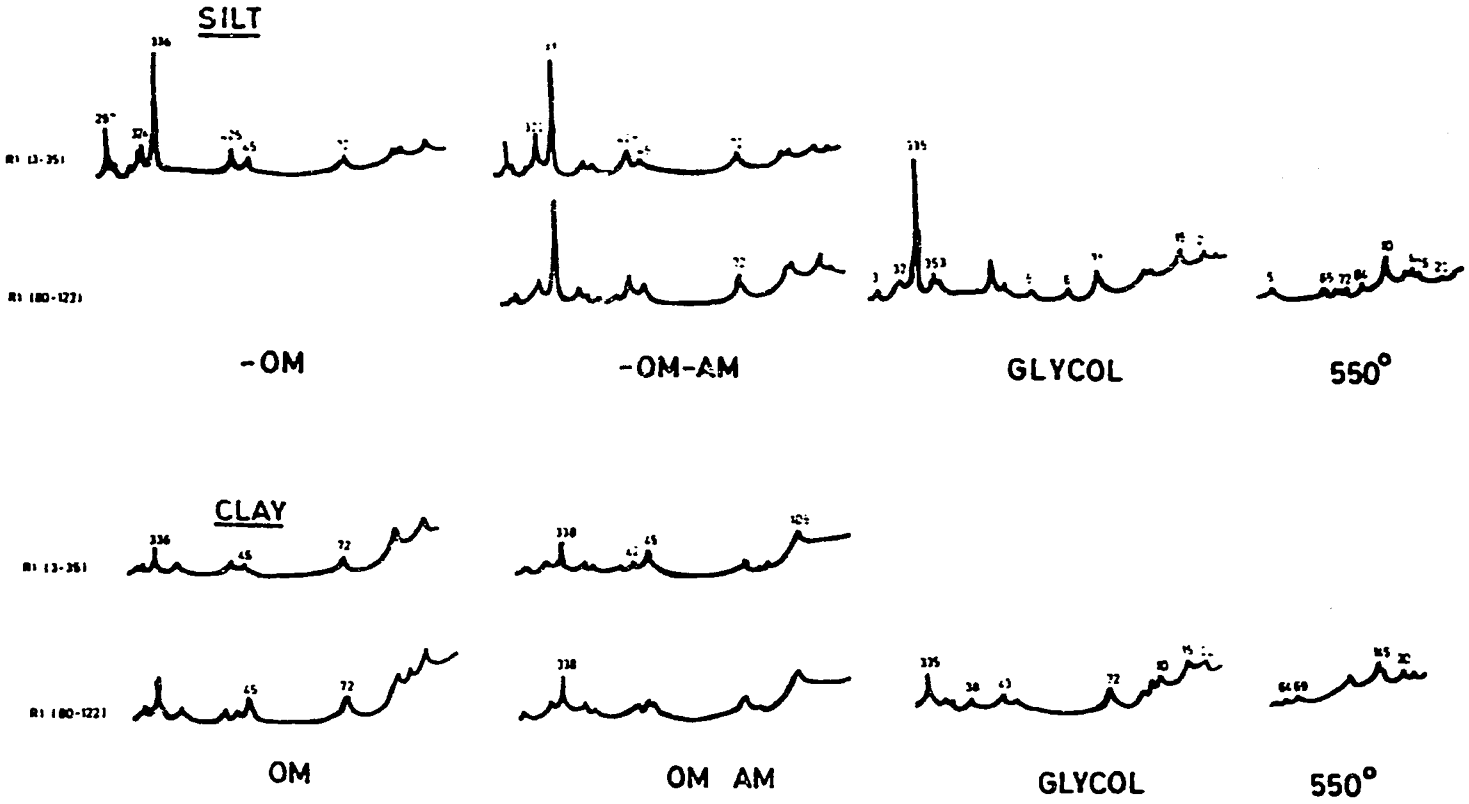
C. Deposition of a thick layer of lappilli.

Profile No. S3 is representative of this soil.

Pedon R-1

Mapping unit: 67 (group 50)
Tentative classification : Calcic-Gypsic Vitritorrands
Date of description : 16.08.1982
Location : Raqqa, 1.5 km southeast of Minkher Gharbi
Physiography : undulated plain
Topography : almost flat
Elevation : 290 m
Rainfall : 209 mm
Vegetation : sparse winter grass
Parent Material : volcanic ash and lapilli
Sampled by : N. Khatib
General description : soil formed on volcanic material, under arid conditions

PROFILE R-1



X-ray diffraction patterns of the silt and the clay fractions after removal of organic matter and oxalate-oxalic acid extraction and other treatments.
(After B. KABARA RUG)

Chemical Analysis of the profile R1 (after B. Kabbara, RUG)

Horizon	Depth	pH			$CaCO_3$	Al_2O_3 %	
	cm	H_2O	Kcl	NaF	%	Clay	Silt
A1	0 - 3	8.3	8.1	10.6	10.0	-	-
C1	3 - 35	9.4	8.4	10.8	13.0	0.34	0.53
C2	35 - 80	9.0	8.3	10.8	14.3	-	-
C3	80 - 123	8.5	8.0	10.7	13.7	0.50	0.61
C4	123 - 144	8.3	8.0	10.7	14.2	-	-
C5	144 - 160	9.2	8.6	10.4	4.0	-	-

0 - 3 cm : Very pale brown (10 YR 7/3) dry, dark yellowish-brown (10 YR 4/4) moist, loamy, weakly developed, fine platy, slightly hard dry, friable moist, slightly sticky, slightly plastic, calcareous, ± lapilli (1-3 cm diameter) 15% by volume, common very fine roots, abrupt boundary.

3 - 35 cm : Very pale brown (10 YR 7/3) dry, dark yellowish-brown (10 YR 4/4) moist, loamy, weakly developed, fine subangular blocky, slightly hard dry, very friable moist, nonsticky, nonplastic, calcareous, lapilli partly coated by lime (1-4 mm diameter) and 35% by volume, very thin layer (2 cm) of lapilli, slightly cemented by lime at the bottom of the horizon.

35 - 123 cm : Very pale brown (10 YR 7/3) dry, yellowish-brown (10 YR 5/4) moist loam, weakly developed, fine subangular blocky, slightly hard dry, very friable moist, nonsticky, nonplastic, calcareous, lapilli (75%) coated by lime.

123 - 144 cm : Very pale brown (10 YR 7/3) dry, yellowish-brown (10 YR 5/4) moist, very weakly developed, structureless, nonsticky, nonplastic, calcareous, 95% of lapilli.

144 - 160 cm : Lapilli as single grains partly coated by lime, locally cemented by lime and gypsum.

DISCUSSIONS

These soils are formed under xeric or aridic (torric) moisture regimes. They might be classified as Xerands and Torrands respectively. A tentative classification at the great group level showed that the profile S3 could be classified as Vitrixerands with regards to the water retention property and profile R1 could be classified as calcic-gypsic Vitritorrands with regards to the profile development.

Table 1. Physico-chemical analysis : Profile R-1.

		-- Total --			------------------- Sand (microns)							---------------	Sand fractions 354-50 microns	
Horizons	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	354-500	250-354	177-250	125-177	88-125	63- 88	50- 63	20- 50	Heavy Minerals (%)	Light Minerals (%)
A1	0- 3	12.6	34.9	52.5	26.8	2.47	2.28	2.66	2.23	2.23	4.00	3.23	34.15	15.85
C1	3- 35	12.5	37.2	49.4	25.5	2.02	2.63	2.83	3.24	3.04	4.05	2.63	70.40	29.60
C2	35- 80	6.5	63.6	29.9	30.3	1.88	1.88	1.85	1.82	2.04	1.72	2.35	67.25	32.75
C3	80-123	14.4	34.9	50.6	32.3	1.37	1.17	1.57	1.47	2.16	2.35	2.55	49.70	50.30
C4	123-144	1.9	29.9	68.2	29.9	2.34	2.34	2.34	2.05	1.61	1.90	1.46	65.42	34.58
C5	144-160	2.4	11.2	86.4	41.4	2.43	1.27	1.27	1.04	1.15	0.57	0.81	48.92	51.08

Table 2. Physico-chemical analysis : Profile R-1.

										Oxalate-oxalic acid extractions					
					PH					Clay			Silt		
Horizons	Depth (cm)	Gypsum (%)	Lime (%)	Organic Matter (%)	H_2O	Kcl	NaF	CEC	Base Saturation	Fe_2O_3 (%)	Al_2O_3 (%)	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	SiO_2 (%)
A1	0- 3	0.44	10.0	0.45	8.3	8.11	10.68	18.6	100	-	-	-	-	-	-
C1	3- 35	0.11	13.5	0.94	9.4	8.45	10.83	19.5	100	0.03	0.34	0.18	0.62	0.53	0.21
C2	35- 80	0.03	14.3	1.63	9.0	8.37	10.85	24.1	100	-	-	-	-	-	-
C3	80-123	0.33	13.7	0.34	8.5	8.03	10.74	24.7	100	0.01	0.50	0.18	1.73	0.61	0.23
C4	123-144	2.50	14.2	0.33	8.3	8.00	10.76	26.1	100	-	-	-	-	-	-
C5	144-160	0.22	4.0	0.31	9.2	6.63	10.47	13.4	100	-	-	-	-	-	-

Pedon S-3

Tentative classification : Calcic Vitrandept
Date of description : 15.08.1982
Location : 1 km north of Shehba (Syria)
Elevatoin : 500 m
Physiography : piedmont
Topography : hilly (volcano piedmont)
Rainfall : 300 mm
Vegetation : shrubs
Parent material : lapilli

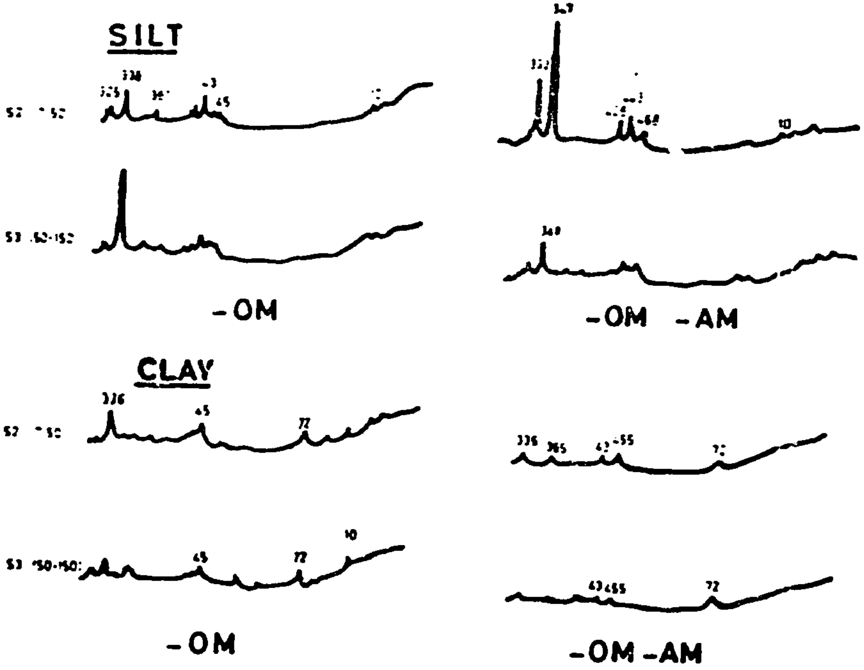
0 - 2 cm : Volcanic material (2-5 mm of diameter)

2 - 7 cm : Light yellowish brown (10 YR 6/4) dry, dark yellowish brown (10 YR 3/6) moist, sandy loam, platy fine at the top, fine subangular blocky underneath, slightly hard dry, very friable moist, nonsticky, nonplastic, noncalcareous, very fine lapilli (20%), common very fine roots, abrupt irregular boundary.

7 - 50 cm : Soil pockets from the upper horizon (15 cm diameter) at the top.
Lapilli (95%) of 2 - 10 mm diameter, cemented by lime with increase in the depth. 5% of soil, same as above.

50 - 150 cm: Lapilli cemented by lime.

PROFILE S-3

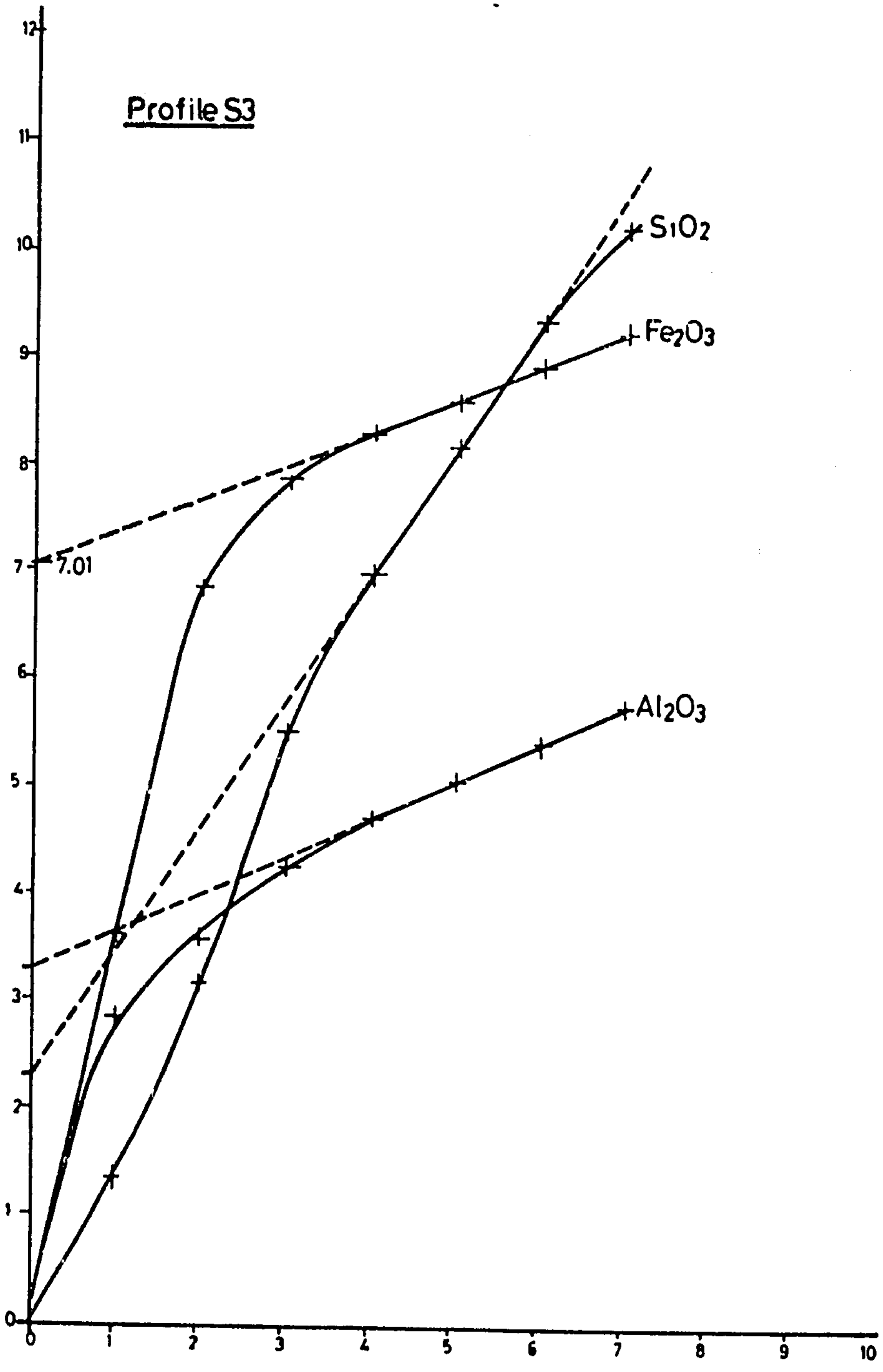


X-ray diffraction patterns of the silt and clay fractions after removal of organic matter and oxalate-oxalic acid extraction.
(After B. Kabbara Rug)

Chemical Analysis of the profile S3 (after B. Kabbara, RUG)

Horizon	Depth	pH			$CaCO_3$	Al_2O_3 %	
	cm	H_2O	Kcl	NaF	%	Clay	Silt
A1	0 - 7	8.4	7.8	10.3	1.3	-	-
C1	7 - 50	8.6	7.9	10.3	0.6	0.57	0.99
C2	50 - 150	8.8	8.8	10.9	13.7	0.36	1.10

334 -



Profile S3
SiO_2
Fe_2O_3
Al_2O_3
7.01
0
1
2
3
4
5
6
7
8
9
10
11
12
0
1
2
3
4
5
6
7
8
9
10

Table 3. Physico-chemical analysis : Profile S-3.

		Total			Sand (microns)								Sand fractions 345-50 microns	
Horizons	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	354-500	250-354	177-250	125-177	88-125	63- 88	50- 63	20- 50	Heavy Minerals (%)	Light Minerals (%)
A	0- 7	12.8	21.0	66.1	31.1	3.32	4.38	3.62	3.93	3.47	2.42	1.66	37.62	62.38
C1	7- 50	4.9	16.5	78.6	51.5	0.90	0.63	0.70	0.70	0.50	0.51	0.51	18.57	81.57
C2	50-150	1.7	7.1	91.2	38.2	2.30	1.64	1.75	1.97	0.98	0.98	0.43	10.11	89.89

Table 4. Physico-chemical analysis : Profile S-3.

					PH					Oxalate-oxalic acid extractions					
										Clay			Silt		
Horizons	Depth (cm)	Gypsum (%)	Lime (%)	Organic Matter (%)	H_2O	Kcl	NaF	CEC	Base Saturation	Fe_2O_3 (%)	Al_2O_3 (%)	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	SiO_2 (%)
A1	0- 7	0.40	1.32	-	8.4	7.81	10.35	30.5	100	-	-	-	-	-	-
C1	7- 50	0.05	0.67	0.55	8.6	7.94	10.36	30.4	100	0.94	0.57	0.20	2.47	0.99	0.30
C2	50-150	0.03	13.7	-	8.8	8.85	10.90	13.0	100	0.09	0.36	0.53	4.18	1.10	0.70

COMMENDATIONS AND RECOMMENDATIONS

COMMENDATIONS AND RECOMMENDATIONS

The following commendations and recommendations were submitted, discussed, and approved during the closing session of the workshop on January 20, 1984.

COMMENDATIONS

1. The participants of the workshop . . .

   ... note with great satisfaction that the meeting has provided an excellent forum for the advancement of the understanding of soils derived from volcaniclastic materials,

   ... are convinced that such meetings are extremely useful for the testing of Soil Taxonomy and the proposed revisions, and

   ... record their warm appreciation and deep gratitude to:

   - the Chilean Society of Soil Science and the Ecuadorian Society of Soil Science and their respective governments for hosting and organizing the workshop,

   - the Soil Management Support Services, the United States Agency for International Development and the University of Puerto Rico for taking the initiative to organize this workshop and for their important contributions,

   - the Chairman of ICOMAND for providing the participants with the necessary background documents and for his leadership during the workshop,

   - the Organizing Committees in Chile and Ecuador for providing excellent facilities both during the conference sessions and during the field trips and, last but not least, a wonderful hospitality, and

- all those, often unknown to most participants, who in some way or another have contributed to the success of the workshop.

Proposed by R. Tavernier
Seconded by A. Osman
Motion carried unanimously

2. The workshop participants highly commend Dr. Michael L. Leamy for his outstanding performance as Chairman of ICOMAND, both before and during the workshop, and express their appreciation for his continuing efforts and leadership.

Proposed by M. Mendoza
Seconded by A. Alvarado
Motion carried unanimously

3. The workshop participants convey a special commendation and recognition to Dr. F. H. Beinroth of the University of Puerto Rico for his instrumental role in this and the five previous workshops and his excellent organizational contributions.

Proposed by F. N. Muchena
Seconded by M. L. Leamy
Motion carried unanimously

4. The workshop participants commend the United States Agency for International Development for providing continuing support for the Soil Management Support Services of the USDA Soil Conservation Service. The program of SMSS is considered highly effective.

Proposed by A. Osman
Seconded by F. N. Muchena
Motion carried unanimously

RECOMMENDATIONS

As indicated below, various recommendations were proposed by a Drafting Committee and represent a consensus opinion of the committee which consisted of N. Ahmad, A. Cortes, B. Clayden, W. Luzio, M. Mendoza, F. N. Muchena, and W. G. Sombroek and was chaired by F. H. Beinroth.

1. It is recommended that ICOMAND establish an international data base of pedons in volcaniclastic materials. The data base should be set up in New Zealand with provisions for user-friendly access by organizations in other countries, some of which do not have sophisticated computer facilities.

Proposed by Drafting Committee
Seconded by H. Ikawa
Motion carried unanimously

2. It is recommended that SMSS prepare and circulate a manual for the field and laboratory characterization of Andisols. This manual should include soil sampling, sample preparation and the various physical, chemical, mineralogical, and micromorphological methods. The manual should be published in English, French, and Spanish. SMSS is also encouraged to develop simple field tests for the identification of Andisols.

Proposed by Drafting Committee
Amended by W. G. Sombroek
Seconded by K. Stahr
Motion carried unanimously

3. It is recommended that SMSS assist countries lacking adequate laboratory facilities in obtaining reliable characterization data. For the Andean countries, it is recommended that SMSS assist the Geographic Institute "Agustin Codazzi" of Columbia so that it can serve as a Regional Laboratory and provide training in analytical soil characterization.

Proposed by Drafting Committee
Seconded by G. Uehara
Motion carried unanimously

4. It is recommended that SMSS, in cooperation with regional centers in the Third World, explore the possibility of developing a program for the training of soil surveyors from the less developed countries and that SMSS expand its in-country training and assistance for soil surveys and the application of Soil Taxonomy.

Proposed by Drafting Committee
Amended by R. Tavernier
Seconded by B. Meurisse
Motion carried unanimously

5. It is recommended that SMSS provide assistance in compiling, publishing and distributing suitable methods of field descriptions of soils, field chemical tests, and the interpretation of this information for the use and management of the described soils.

Such assistance would preferably be in cooperation with Commission V of the International Society of Soil Science. It is felt that such activities would further international cooperation and assist in agrotechnology transfer.

Proposed by W. G. Sombroek and R. W. Arnold
Seconded by S. Alcayaga
Motion carried unanimously

6. It is recommended that ISM/ISRIC continue and, if possible, expand its LABEX program with adequate attention to Andisols in order to achieve a comparison of methods and results from a wider range of laboratories.

Proposed by R. Grez
Seconded by R. L. Parfitt
Motion carried unanimously

7. It is recommended that SCS prepare a defined strategy for testing final proposals from all ICOMs and particularly ICOMAND. Such a strategy could include the submission of a soil map carrying two legends--one showing the existing classification and one reflecting the new proposal. It would be helpful to ICOM chairmen to know the requirements of the final testing prior to submitting their final proposal.

Proposed by M. L. Leamy
Seconded by A. Osman
Motion carried unanimously

APPENDIX

SIXTH INTERNATIONAL SOIL CLASSIFICATION WORKSHOP

- Taxonomy and Management of Andisols -

CHILE AND ECUADOR

9 to 20 January 1984

PROGRAM FOR CHILE

Saturday, 7 January 1984

Participants arrive in Santiago
Night in Santiago, Hotel Carrera

Sunday, 8 January 1984

0630 Dep. Hotel Carrera
0710 Arr. Santiago airport
0810 Dep. Santiago, LAN Chile flight 085
0930 Arr. Valdivia, transfer to hotel
1030 Registration of participants
Free afternoon and evening in Valdivia
Night in Valdivia, Hotel Isla Teja

Monday, 9 January 1984

0800 Registration of local participants

OPENING CEREMONY
Chairman: R. Grez
Venue: Universidad Austral de Chile

0900 Welcome -- J. Ferrer, Chancellor, Universidad Austral de Chile

Introductory remarks by:

- W. Luzio, Professor of Soil Science and Chairman, Host Organizing Committee
- R.W. Arnold, Director of Soils, USDA Soil Conservation Service and Principal Investigator, Soil Management Support Services
- M.L. Leamy, Director, New Zealand Soil Bureau and Chairman, ICOMAND

1000 Refreshments

Technical Session I: PERSPECTIVES
Chairman: S. Alcayaga

1030 R.W. Arnold: The rationale for an order of Andisols in Soil Taxonomy

1115 V.E. Neall: Parent materials of Andisols

1200 Lunch

Technical Session II: PROPERTIES OF ANDISOLS
Chairman: E. Besoain
Rapporteur: G. Galindo

1330 R. Parfitt: The nature of andic and vitric materials

1415 G. Uehara: Physico-chemical characteristics of Andisols

1445 Discussion

1500 Refreshments

Technical Session III: TAXONOMIC FRAMEWORK FOR ANDISOLS
Chairman: R.W. Arnold
Rapporteur: B. Clayden

1530 M.L. Leamy: Proposed taxa and diagnostic features of Andisols

Technical Session IV: FIELD TRIP BACKGROUND
Chairman: A. Van Wambeke

1700 H. Moreno: Physiography of south-central Chile

1715 W. Luzio: Soils of south-central Chile

1730 P. Baherle: Land use in south-central Chile

1745 Panel Discussion

Topic: The soils of field trips
Panelists: P. Baherle, E. Besoain, A. Carrasco, A. Ellies, R. Honorato, W. Luzio, A. Mella, H. Moreno, F. Santibañez

1830 Adjourn

Night in Valdivia, Hotel Isla Teja

Tuesday, 10 January 1984

Field Trip I: VALDIVIA - LANCO - VALDIVIA

0730 Dep. Valdivia

0815 Arr. Pedon CHI-01 (Pelchuquín)
Discussion leader: M.L. Leamy
Rapporteur: B. Clayden

1015 Dep. Pedon CHI-01

1100 Arr. Pedon CHI-02 (Lanco)
Discussion leader: F.N. Muchena
Rapporteur: N. Ahmad

1300 Box lunch, Universidad Austral forest

1400 Dep. Lunch site

1500 Arr. Pedon CHI-03 (Los Olmos)
Discussion leader: H. Ikawa
Rapporteur: J.M. Kimble

1700 Dep. Pedon CHI-03

1745 Arr. Valdivia

Night in Valdivia, Hotel Isla Teja

Wednesday, 11 January 1984

Field Trip II: VALDIVIA - ANTILLANCA

0730 Dep. Valdivia

0930 Arr. Pedon CHI-08 (Puerto Fonck)
Discussion leader: R.W. Arnold
Rapporteur: R.W. Fenwick

1130 Dep. Pedon CHI-08

1300 Arr. Aguas Calientes, box lunch

1400 Dep. Aguas Calientes

Wednesday, 11 January 1984 (cont'd)

1445 Arr. Pedon CHI-06 (Chanleufú)
Discussion leader: W.G. Sombroek
Rapporteur: F.N. Muchena

1645 Dep. Pedon CHI-06

1715 Arr. Pedon CHI-05 (Antillanca)
Discussion leader: K. Wada
Rapporteur: T.D. Cook

1915 Dep. Pedon CHI-05

1930 Arr. Antillanca

Night in Antillanca, Hotel Antillanca

Thursday, 12 January 1984

Field Trip III: ANTILLANCA - PUERTO VARAS

0730 Dep. Antillanca

0815 Arr. Pedon CHI-07 (Puyehue)
Discussion leader: R.L. Parfitt
Rapportuer: V.E. Neall

1015 Dep. Pedon CHI-07

1245 Arr. Frutillar, box lunch

1345 Dep. Frutillar

1400 Arr. Pedon CHI-09 (Frutillar)
Discussion leader: S. Alcayaga
Rapportuer: G. Galindo

1600 Dep. Pedon CHI-09

1630 Arr. Pedon CHI-10 (Puerto Octay)
Discussion leader: C.O. Scoppa
Rapporteur: R.T. Meurisse

1830 Dep. Pedon CHI-10

1900 Arr. Puerto Varas, hotel check-in

Thursday, 12 January 1984 (cont'd)

1945 Dep. hotels for Club Aleman

2000 Dinner, Club Aleman

2100 Review of Field Trips in Chile
Discussion leader: M.L. Leamy
Rapporteur: B. Clayden

2200 Dep. Club Aleman for hotels

Night in Puerto Varas

Friday, 13 January 1984

0730 Dep. hotels for meeting room

Technical Session V: PROPERTIES OF ANDISOLS CRITICAL TO VARIOUS LAND USES (1)
Chairman: R. Dudal

0800 R. Meurisse: Properties of Andisols important to forestry

0830 A. Alvarado and E. Bornemisza: Properties of Andisols important to crop production

0900 K. Wada: Properties of Andisols important to paddy rice

0930 Refreshments

Technical Session VI: PROPERTIES OF ANDISOLS CRITICAL TO VARIOUS LAND USES (2)
Chairman: G. Uehara
Rapporteur: H. Ikawa

1000 V.E. Neall: Properties of Andisols important to pasture and horticulture

1030 B.P. Warkentin: Properties of Andisols important to engineering

1100 Discussion

1130 Dep. for hotels, check-out

1200 Dep. hotels for Club Aleman

1215 Lunch at Club Aleman, Puerto Varas

Friday, 13 January 1984 (cont'd)

1330 Dep. Puerto Varas

1400 Arr. Tepual airport

1500 Dep. Tepual airport, LAN Chile, flight 084

1635 Arr. Santiago

Night in Santiago, Hotel Carrera

Saturday, 14 January 1984

0715 Dep. Hotel Carrera

0800 Arr. Santiago airport

0930 Dep. Santiago, flight EU 042

1300 Arr. Quito, Ecuador

Night in Quito, Hotel Inter-Continental Quito

SIXTH INTERNATIONAL SOIL CLASSIFICATION WORKSHOP

- Taxonomy and Management of Andisols -

CHILE AND ECUADOR

9 to 20 January 1984

PROGRAM FOR ECUADOR

Saturday, 14 January 1984

1315 Participants arrive at Quito airport; transfer to and check-in at Hotel Inter-Continental Quito

1500 Registration
Free afternoon and evening in Quito; night in Quito

Sunday, 15 January 1984

Free day or optional sightseeing in Quito; night in Quito

Monday, 16 January 1984

0800 Registration of Ecuadorian participants, Hotel Inter-Continental Quito

OPENING CEREMONY
Chairman: J. Delgado
Venue: Pichincha Room, Hotel Inter-Continental Quito

0900 National anthem of Ecuador

Welcome -- F. Maldonado

Official inauguration -- H. Ortiz, Undersecretary of Agriculture

Introductory remarks by: J. Goodwin, USAID/Quito
R.W. Arnold, SCS/SMSS
M.L. Leamy, ICOMAND

Monday, 16 January 1984 (cont'd)

1000 Refreshments

Technical Session VII: RATIONALES FOR TAXONOMIC CRITERIA FOR ANDISOLS: SUBORDERS
Chairman: R. Tavernier
Rapporteur: R. W. Fenwick

1030 S. W. Buol: Use of soil temperature regimes in Soil Taxonomy

1100 A. Van Wambeke: Soil climatic regimes as criteria for establishing sub-order of Andisols.

1120 S. Shoji: The case for recognizing a sub-order of non-allophanic Andisols

1140 Discussion

1200 Lunch

Technical Session VIII: RATIONALES FOR TAXONOMIC CRITERIA FOR ANDISOLS: GREAT GROUPS AND SUBGROUPS
Chairman: S. W. Buol
Rapporteur: A. Alvarado

1330 M. Otawa: Criteria for great groups of Andisols

1400 F. Colmet-Daage: Criteria for subgroups of Andisols

1430 Discussion

1500 Refreshments

Technical Session IX: PROBLEMS OF ANDISOLS
Chairman: R. L. Parfitt
Rapporteur: V. Neall

1530 J. M. Kimble and W. D. Nettleton: Analytical characterization of Andisols

1550 T. D. Cook: Field of identification and mapping of Andisols

1610 R. W. Arnold: Criteria for intergrades between Andisols and other orders

1630 Discussion

Monday, 16 January 1984 (cont'd)

Technical Session X: FIELD TRIP BACKGROUND
Chairman: C. O. Scoppa

1700 E. Maldonado and F. Maldonado: Distribution of volcanic ash soils in Ecuador

1730 G. Yanchapaxi and H. Serrano: The Machachi soil sequence

1800 G. del Posso and C. Luzuriaga: The Santo Domingo soil sequence

1830 Announcements

1845 Adjourn

Night in Quito

Tuesday, 17 January 1984

Field Trip I: QUITO-MACHACHI-SANTO DOMINGO-QUITO

0730 Dep. Hotel Inter-Continental Quito
0900 Arr. Pedon ECU 01

Discussion Leader: F. Maldonado
Rapporteur: A. Cortes
Refreshments

1030 Dep. Pedon ECU 01
1100 Arr. Pedon ECU 09

Discussion Leader: G. del Posso
Rapporteur: F. Maldonado

1215 Dep. Pedon ECU 09
1300 Arr. INIAP Experiment Station Santa Catalina for lunch
1345 Dep. Cafeteria
1400 Arr. Pedon ECU 06

Discussion Leader: W. Luzio
Rapporteur: M. Mendoza

1530 Dep. Pedon ECU 06

1545 Arr. auditorium of Santa Catalina station, refreshments

Tuesday, 17 January 1984 (cont'd)

Technical Session XI: EROSION, CONSERVATION AND MANAGEMENT OF ANDISOLS
Chairman: F. Maldonado
Rapporteur: W. Luzio

1600 G. de Noni and J. F. Nouvelot: Erosion and conservation of volcanic ash soils in the highlands of Ecuador: A. case study

1630 Discussion with INIAP staff about soil management

Review of pedons ECU 01, 09 and 06

1730 Dep. Santa Catalina station

1900 Arr. Quito

Night in Quito

Wednesday, 18 January 1984

Field trip V: QUITO-SANTO DOMINGO

0730 Dep. Hotel Inter-Continental Quito
0930 Arr. Pedon ECU 04

Discussion Leader: A. Alvarado
Rapporteur: C. O. Scoppa
Refreshments

1045 Dep. Pedon ECU 04
1330 Arr. INIAP Experiment Station Santo Domingo for lunch
1430 Dep. Cafeteria
1445 Arr. Pedon ECU 05

Disucssion Leader: F. Colmet-Daage
Rapporteur: G. del Posso

1615 Dep. PedonECU 05
1630 Arr. meeting room of Santo Domingo station
Refreshments
Discussion with INIAP staff about soil management
Review of pedons ECU 04 and 05
1730 Dep. Santo Domingo station
1900 Arr. Santo Domingo

Night in Santo Domingo, Hotel Zaracay

Thursday, 19 January 1984

Field Trip VI: SANTO DOMINGO-QUEVEDO-SANTO DOMINGO-QUITO

0730 Dep. Hotel Zaracay
0900 Arr. Pedon ECU 12

Discussion Leader: A. Cortes
Rapporteur: C. Zebrowski
Refreshments
1015 Dep. Pedon ECU 12
1115 Arr. Pedon ECU 13

Discussion Leader: A. Van Wambeke
Rapporteur: A. Alvarado

1230 Dep. Pedon ECU 13
1300 Arr. INIAP Experiment Station Pichilingue for lunch
1400 Discussion with INIAP staff about soil management
Review of pedons ECU 12 and 13 and field trips in Ecuador
1500 Dep. Pichilingue station
1630 Arr. Santo Domingo, refreshments
1700 Dep. Santo Domingo
2000 Arr. Quito

Night in Quito, Hotel Inter-Continental Quito

Friday, 20 January 1984

Technical Session XII: EVALUATION OF THE ANDISOL PROPOSAL IN DIFFERENT ENVIRONMENTS
Chairman: W. G. Sombroek
Rapporteur: J. M. Kimble

0800 H. Ikawa: A critical evaluation of the placements of the Andepts of Hawaii according to the proposed key for Andisols

0830 F. N. Muchena: A critical evaluation of the placements of the Andepts of Kenya according to the proposed key for Andisols

0900 B. Clayden: A critical evaluation of the placements of the Adnepts of New Zealand according to the proposed key for Andisols.

0930 Discussion

Friday, 20 January 1984 (cont'd)

1000	Refreshments
	Technical Session XIII: ICOMAND SUMMARY DISCUSSION Chairman: M. L. Leamy Rapporteur: B. Clayden
1030	Discussion
1230	Lunch
	Technical Session XIV: RECOMMENDATIONS OF THE WORKSHOP Chairman: F. H. Beinroth Rapporteur: T. D. Cook
1400	Discussion and adoption of commendations and recommendations
	CLOSING SESSION Chairman: R. Tavernier
1530	The workshop in retrospect -- W. G. Sombroek
1545	Workshop impact in Chile -- W. Luzio
1600	Workshop impact in Ecuador -- F. Maldonado
1615	Workshop impact on ICOMAND -- M. L. Leamy
1630	Vote of thanks -- A. Van Wambeke
1645	Adjourn
	Refreshments
2000	Closing Dinner, Hotel Inter-Continental Quito

Saturday, 21 January 1984

Participants depart Quito

Optional pedologic or touristic programs

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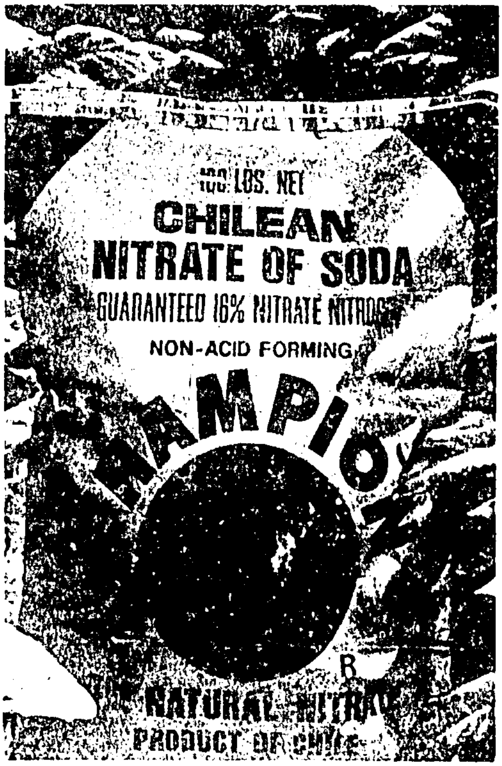
CHILEAN NITRATES FERTILIZERS

Produced by Sociedad Química y Minera de Chile S.A. — S.Q.M.

- * 16–0–0 : Nitrate of Soda (natural sodium nitrate)
- * 15–0–14 : Nitrate of Soda-Potash (potassium sodium nitrate)

Outstanding Properties

- Quick action, because all its nitrogen is in nitrate form, being highly soluble and having rapid access and availability to plant roots.
- Chilean Nitrates are optimum for timely nutrition of plants, and for supplemental applications to promptly replenish nitrogen, or nitrogen and potassium, leached by heavy rains especially in sandy soils.
- Nitrate nitrogen is a requisite to produce maximum yields and optimum quality flue - cured and burley types of tobacco.
- They supply sodium, an essential element for maximum yields in sugarbeets and some vegetable crops. In addition, sodium replaces part of the potassium requirements of these and several other crops, thus reducing fertilization costs.
- Chilean Nitrates do not acidity. They help to prevent a decrease in soil pH and loss of fertility. They save important amounts of lime.
- Nitrate of Soda-Potash (15–0–14) is virtually free of chloride. Excess chloride is harmful particularly to crops such as tobacco, orchards, vineyards, vegetables and potatoes.
- They are not subject to volatilization losses as ammonia. Even remaining on the soil surface they keep 100 o/o efficiency.
- They supply small quantities of boron, an essential micronutrient for plants



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Beside these two traditional nitrate fertilizers, S.Q.M. will start producing a third one in 1986

* 13–0–45: Potassium Nitrate.

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