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PROCEEDINGS OF

SECOND INTERNATIONAL SOIL CLASSIFICATION WORKSHOP

PART I : MALAYSIA
28 August to 1 September 1978

SOIL SURVEY DIVISION
LAND DEVELOPMENT DEPARTMENT
BANGKOK, THAILAND
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from 28 August to 1 September 1978

Co-sponsored by

National Soil Survey
Department of Agriculture
Kuala Lumpur, Malaysia

University of Puerto Rico
Mayaguez Campus
College of Agricultural Sciences
Mayaguez, Puerto Rico

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Editors: F. H. Beinroth and S. Paramananthan

Managing Editors: Sheila and Tom Ferrari

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FOREWORD

Since 1976 the University of Puerto Rico has been concerned with the improvement of the taxa established in the U.S. system of soil classification, Soil Taxonomy, for soils of the lower latitudes. The strategy in these activities, which were supported through grants from the Agency for International Development, has been to collaborate with international committees created to re-examine relevant aspects of Soil Taxonomy and to hold workshops with field tours in countries where the soils under scrutiny can be studied in situ. National institutions have been centrally involved in these endeavors. The first such workshop was held in Brazil in 1977 in cooperation with the Servico de Levantamento e Conservacao de Solos and future workshops are contemplated for the Near East and Africa.

The second International Soil Classification Workshop held in Malaysia and Thailand in 1978 thus formed part of a comprehensive international effort to adapt Soil Taxonomy to the edaphic conditions of the tropics and subtropics. It addressed mainly the respective mandates of the International Committee on the Classification of Alfisols and Ultisols with Low Activity Clays (ICOMLAC) and the International Committee on the Classification of Oxisols (ICOMOX).

The workshop was initiated by the University of Puerto Rico, and organized and conducted by the National Soil Survey of the Department of Agriculture in Malaysia and by the Land Development Department in Thailand. Financial support of the workshop by the U.S. Agency for International Development under grant AID/DSAN-G-0003 to the University of Puerto Rico and by the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA) is gratefully acknowledged.

The duties of host in Malaysia were assumed by the Department of Agriculture which, in cooperation with the University of Puerto Rico and the University of Ghent, developed the program, organized the workshop,

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prepared a tour guide and conducted the field trips. The University of Puerto Rico arranged the travel for invited participants. The preparation of Part I of the Proceedings was the joint responsibility of the University of Puerto Rico and the Department of Agriculture.

In addition to the authors of papers and reports, many persons have contributed to the workshop and to the contents of the Proceedings. Staff of the Malaysian National Soil Survey provided site and profile descriptions and analytical data for all pedons studied in the field. Dr. H. Eswaran of the University of Ghent contributed the micromorphological information. The Organizing Committee flawlessly arranged the logistics of the conference sessions and the field tour and provided a multitude of helpful services and courtesies. Sincere appreciation is expressed for all of these individual and institutional efforts.

The Editors further wish to thank the Managing Editors, Sheila and Tom Ferrari of Editorial Services, who performed the complex task of editing the technical papers with diligence and competence.

Part I of the Proceedings contains the papers presented at the Kuala Lumpur conference sessions and the descriptive and analytical data for the soils studied during the field trips in Malaysia. Part II contains similar materials for the Thailand portion of the workshop. The Proceedings constitute a reference publication on the taxonomy of tropical Alfisols, Ultisols and Oxisols in general, and key soils of Southeast Asia in particular. It is hoped that the Proceedings will also be of value to international soil correlation work.

S. PARAMANANTHAN

F. H. BEINROTH

KEYNOTE ADDRESS

RATIONALE, INTENT AND PERSPECTIVE OF THE WORKSHOP

F.H. Beinroth

Honorable Deputy Director General of Agriculture, Encik Ahmad bin Yunus, distinguished guests, ladies and gentlemen:

I am pleased and privileged to present the organizers' view of the rationales underlying this workshop and to attempt to place it into perspective in the general context of agricultural development.

It is distressing indeed to realize that many of you have seen the world population double in your own lifetime. And all of us must confront the fact that fossil energy shortages are no longer vague predictions, but realities; moreover, marked increases in the production of agricultural commodities will be restricted in many areas by the high cost of chemical inputs and by limitations in the environment.

In view of this dilemma, and in the wake of the World Population Conference held in Bucharest in 1973 and the World Food Conference held in Rome in 1974, a great number of Malthusian doomsday scenarios have been publicized in the popular media. If nothing else, they have brought the world food and population problem into sharper focus and new prominence. By and large, however, the rhetoric has produced more food for thought than for the starving millions.

Although I hate to bore you with statistics, it seems appropriate to briefly comment on the state of food and agriculture in the world.

A recent analysis by the International Food Policy Research In-

stitute (IFPRI) indicates that food production levels must be increased by some 180 million tons above the projected 1990 output, to meet market demand and to bring undernourished populations to a satisfactory dietary level. Translating the projected food gap into growth rates, the food production growth rate for the developing market economies must increase to 3.4 percent just to meet present per capita consumption levels; and must be increased to more than 4.5 percent to meet added demand and dietary energy needs. This is a monumental task that requires massive and concerted efforts on a wide front.

So, one may ask, what can we as soil scientists in general, and this soil classification workshop in particular, do to fight the famines of the future? Maybe not as much as we would wish, but maybe more than some might think. Let me elaborate.

To begin with, when talking about soil classification one must immediately qualify which system is being referred to, because many different systems of soil classification are used in different parts of the world. Whereas there is, in general, international agreement on botanical, zoological, mineralogical and other classifications, there exist several kinds of soil classification. This is because the study of soils is a comparatively new science, and a polyglot science at that. I must refrain here from examining the historical, geographic, cultural, academic, and chauvinistic reasons for this predicament. It may suffice to say that this has, at least in the past, resulted in the seemingly insoluble problem of comparing one soil with another and of naming it in such a way that people in other countries can recognize it. Fortunately, there are now two systems of soil classification that supply a common denominator for the correlation of research and experience, and allow international communication. I refer, of course, to the Legend for the FAO-UNESCO Soil Map of the World and Soil Taxonomy.

The former was developed to provide a uniform legend for the Soil Map of the World which is at a scale of 1:5,000,000. This purpose clearly controls the level of generalization at which the 104 soil units are defined and results in necessarily broad groupings. Soil Taxonomy, on the

other hand, with which we are mainly concerned at this workshop, is as the title implies, "a basic system for making and interpreting soil surveys" including, I may add, detailed soil surveys. Although basically an American system, Soil Taxonomy is gradually becoming the internationally accepted classification for scientific communication. More and more pedologists, particularly in the Third World, are talking to each other in terms of this system. It is also used, either in lieu of or parallel with national systems of soil classification, notably in Southeast Asia and Latin America. Coming back to the original question of the role of soil classification in the process of agricultural development, it may be pertinent to note that the main financial sponsor of this workshop is the U.S. Agency for International Development (AID). This agency obviously has no direct interest in soil classification; but it is, among other things, concerned with agricultural development in the less developed countries (LDC's) and recognizes that soils and soil classification are of central importance and consequence to this concern.

For AID, as for others, soil classification is not an end in itself but a means to expedite agricultural development and increase food production in the LDC's. There are good reasons for this viewpoint. Many statements can be found in the literature that allude to the fact that soil classification facilitates knowledge transfers. Cline, for example (1949, Soil Sci. 67:81-91), points out that "classification performs the extremely important function of organizing, naming and defining the classes that are the basic units used...to formulate generalizations...and to apply these generalizations to specific cases that have not been studied directly" -- a clear reference to knowledge transfers. Another example is found in the FAO-UNESCO Soil Map of The World (1974, V.1:legend, UNESCO, Paris), one objective of which is "to supply a scientific basis for the transfer of experience between areas with similar environments..[for]..with the tremendous amount of knowledge and experience gained in the management and development of different soils throughout the world, the hardship perpetuated in some areas by methods of trial and error is no longer justified." However, notwithstanding the confidence and authority with which such statements have been made, it is not beyond reason to wonder if and how soil classification can perform

the task of knowledge transfers, particularly in the agricultural sector. True, we now have general soil maps covering the whole world and detailed soil surveys of many areas. But most of the soil classification systems used for soil surveys are essentially genetic systems, and as a consequence the information on the soil maps is mostly pedogenetic. And it is not at all self-evident that soil genetic data *per se* are the best criteria to effectuate this process. More often than not, the users of soil surveys are faced with the very real challenge of translating genetic information into agronomic data.

This also seems to reflect the dichotomy that traditionally existed between the disciplines of soil survey and fertility. As Dr. Buol stated "Pedologists and agronomists really see two different soils while examining the same pedon."

Nonetheless, some systems of soil classification are better suited for making interpretations than others. And Soil Taxonomy should be particularly useful in this respect since it was conceived with this practical end in mind. As it is stated in the foreword of that book "...at each step the all-important question was asked, 'Do these groupings permit us to make predictions of soil behavior?'" Is the answer to this question affirmative in all instances? With respect to agricultural predictions, the answer should be "Yes," at least at the level of the soil family. Families, it will be recalled, have been contrived with the intent to group soils of similar physical and chemical properties that affect their response to management and which are important to plant growth.

I may mention here that the Universities of Hawaii and Puerto Rico are currently engaged in an ambitious research project to test the transferability of agrotechnology on the basis of Soil Taxonomy families. Under this so-called Benchmark Soils Project, highly controlled experiments are being performed for three soil families at twenty-three sites in six tropical countries. Although preliminary at this time, results are very encouraging and indicate that soils of the same families have indeed a common response to identical

management practices and are, therefore, useful entities for transferring agricultural experience.

Thus, Soil Taxonomy holds great potential for practical applications of far-ranging consequence, and has attractive attributes that can facilitate the conversion of soil survey data into meaningful agronomic information. However, it should be remembered in this context that the differentiae of Soil Taxonomy are applied mainly in the control section that starts below the plowed layer. Consequently, less precise statements can be made about the surface soil than about the subsoil for most taxa. These inherent limitations notwithstanding, Soil Taxonomy may well serve as the basic system for more technical schemes and interpretations. This is so because soil productivity is ultimately controlled by chemical and physical subsoil characteristics that influence root development, and moisture and nutrient utilization. Useful fertility appraisals require additional knowledge of the chemical fertility status of the surface soil. Relevant parameters defining this condition could, therefore, be used as modifiers of Soil Taxonomy classes. Thus, I am not suggesting that Soil Taxonomy be changed drastically to conform to the particular needs of agronomists. Rather, I am advocating the development or refinement of interpretative methodologies that, on the basis of Soil Taxonomy, will allow reliable and specific interpretations and predictions of land potential and crop performance.

The Framework for Land Evaluation recently published by FAO (1977, FAO, Rome) constitutes a milestone event in this regard. And the Fertility Capability Classification developed by Dr. Buol and his colleagues may also prove useful. Again, I feel that these and other technical systems should complement, but not be substituted for, Soil Taxonomy, in order to meet the practical purposes that a taxonomic system, by intent and design, cannot satisfy. Soil classification is only one but essential component of more encompassing systems of land evaluation. We may want to keep this in mind when discussing necessary changes in Soil Taxonomy later in the workshop.

Another more immediate concern of this workshop is a critical

analysis of Soil Taxonomy with respect to certain taxa of tropical soils. We all realize that Soil Taxonomy is not a perfect system for the very simple reason that, at this point in time, the knowledge of soils is still incomplete. Not only is our knowledge incomplete, it is also unequally distributed. Upon examining Soil Taxonomy, we find 51 pages dedicated to Mollisols; by contrast, a mere 10 pages deal with Oxisols. This points to the fact that, as a group, tropical soils are comparatively less well known than temperate region soils. Their classification is therefore less complete and more subject to change. As indicated by the authors of Soil Taxonomy, the classification of Oxisols in particular "needs to be tested more widely... for it is far from completion and is certain to have many shortcomings."

What is meant here by testing? It is essentially the comparison of statements that can be made about the soils included in taxa if they are formed by one set of definitions, versus the statement that can be made if the taxa are formed by another set of definitions. With this in mind, two international committees were constituted to re-examine the definitions of select tropical soils -- the International Committee on the Classification of Alfisols and Ultisols with Low Activity Clays (ICOMLAC), and the International Committee on the Classification of Oxisols (ICOMOX).

The primary objective of this workshop is to provide an opportunity for key members of both committes to pursue their mandates. Thirty papers will be presented on the mentioned subjects during the conference sessions, and thirty critical pedons will be inspected in the field to test the validity of theoretical concepts in light of the real world of soils. Although somewhat less tangible, another objective of the workshop is to demonstrate to the world that the U. S. -- the guardian of Soil Taxonomy as it were -- is not only interested in improving the system, but is also concerned with the problems soil scientists in the tropics have in using it.

The organizers have succeeded in convening at this workshop an exceptional group of pedologists. It is no exaggeration to state

that some of the best talent in the field of classification of tropical soils are present here today. And there is sufficient justification to call this workshop international: in attendance are participants representing multinational institutions, universities and various government agencies from fourteen countries and from all the continents. Appropriately enough, we meet in the International Hall of this beautiful hotel.

If I may digress for a minute, let me emphasize that for those of us belonging to the transitional "second generation" of pedologists, it is a distinct honor to be here in the presence of the great leaders of soil classification like Guy Smith (who will join us in Thailand), Rene Tavernier, Jakob Bennema, Rudy Dudal, and Frank Moormann. For some of them this may be the last international meeting, so even more we should cherish this opportunity to exchange ideas, learn more about how and why certain decisions were made in the past, and gain a proper perspective for the future. But not only is the attendance international, the whole workshop is a fine example of international collaboration: Malaysia and Thailand have graciously assumed the role of hosts and co-sponsors; the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA) was an early and enthusiastic supporter of the event; the Soil Conservation Service of the USDA and the University of Hawaii provided analytical data; the University of Ghent in Belgium released Dr. Hari Eswaran who, with support from Cornell University and in cooperation with the host countries, developed much of the program; the University of Puerto Rico deserves credit for originating and administrating the workshop; and last but not least, financial support from the U.S. Agency for International Development (AID) made it all possible.

Thus there are all the ingredients and a very promising scenario for another outstanding workshop which is actually the second of its kind. The first one, it will be remembered, was held last year in Brazil. It was really on the strength of the success of the previous workshop that we could convince AID to provide funds for a similar event here in Southeast Asia.

In the two weeks ahead there will surely arise heated arguments about how soils should best be classified. In all likelihood, there will be no easy solutions, but there should be intelligent choices. In reference to the latter, allow me to make an appeal for relevance: Soil science has made remarkable strides in the past decades and as a consequence the tools of our trade have changed markedly. Pedologists no longer have to rely only on a perceptive eye, hand-lens, auger and spade; but they can now make use of more sophisticated techniques, such as electron microscopy, x-ray diffraction, Mössbauer spectroscopy and the like. Therefore, we now have the technology to measure all kinds of parameters that could conceivably be used in soil classification. However, let us not forget the men in the field who map the soils.

While we certainly need a system of reasonable scientific standards that results in a suitable stratification of the population of soils, the taxa must also be susceptible to mapping and interpretation. If not, soil classification may end up in the ivory tower of academia and become an exercise in futility for the practical-minded. We must insure that soil classification and soil survey permit the application of knowledge and experience to solving the practical problems of land development and food production. When all is said and done, the pragmatic value of soil classification and soil surveys will, in the words of Dr. Dudal, depend on whether they can answer the decisive questions: if a given tract of land is arable, what crop should be grown for how long, at which level of technology, and at what cost?

If this workshop makes a contribution to this end, it will have succeeded.

ADEQUACY OF SOIL SURVEYS AND SOIL CLASSIFICATION FOR PRACTICAL APPLICATIONS IN DEVELOPING COUNTRIES

R. Dudal

The objectives of soil surveys are to study soil properties, to describe soils and classify them, and to map their distribution so that predictions can be made about their use and their response to various management practices (USDA 1951).

Since soil is the medium for plant growth, information derived from soil surveys should be basic for land use planning. The application of soil surveys should be particularly important for opening up of new lands and the intensification of agriculture in the developing world. Comparison and correlation should allow transfer of experience and technology between soils with similar characteristics even in areas far apart.

While there is general agreement about the stated objectives of soil surveys, the question arises whether sufficient use is being made of survey work, especially in developing countries. Though many feasibility studies include soil survey information, often it is not taken into account in the subsequent layout of development plans. In other instances, where soils information is sought as a basis for decision making, the data supplied by surveys are difficult to interpret for specific requirements. This has been ascribed to various reasons: poor presentation of results, lack of communication between soil scientists and agriculturists, difficulties arising from specialized terminology, inadequate interpretation by the surveyor, or a lack of interest of the planners. One may wonder, however, if some more fundamental issues are not at stake and if soil surveys and soil classification, as presently conceived, are adequate to serve the needs of potential users.

Recently a Workshop on Soil Resource Inventories (Soil Resource Inventory Group, Cornell University, 1977) dealt with numerous factors which have a bearing on the effectiveness of soil surveys. Reference is made to the proceedings of this workshop for a comprehensive review of problems related to quality, methodology, presentation, and use of soil surveys. This paper focuses on some technical aspects which, while not usually questioned, may be the cause of the insufficiencies in the application of soil surveys.

ARE UNITS OF A SOIL CLASSIFICATION SUITABLE FOR MAPPING?

Soils described and mapped in a soil survey are normally named and separated on the basis of a soil classification. Since soils form a continuum, and can hardly be classified as such, a break of the continuum into segments or classes, which have a limited and defined range of properties, becomes necessary. Such a conceptual framework makes it possible to organize our knowledge of soils and to visualize relationships with the environment.

Soil classes are characterized by the description and analysis of sampling units called pedons, and are represented in nature by polypedons (Soil Survey Staff, 1975). It is then assumed that the soil cover can be represented in terms of one class in homogeneous areas, or of two or more classes in areas where contrasting kinds of soils occur. In the latter case, the various classes are grouped into soil associations with an indication as to which soils are dominant. Soil associations, however, do not normally bring out relationships between the different components nor provide information on where the different taxa occur.

Alternative approaches have been developed recently which advocate a more comprehensive representation of the soil pattern. Soils are characterized not only through sampling of a vertical succession of horizons but also through the study of lateral variations of properties. These variations, which stretch over distances that

exceed the few meters of a pedon, are related essentially to lateral water movements both at the surface and within the soil. Under a given climate, landform and slope determine to a great extent the moisture regime of the soil, lateral flow of nutrients and weathering products, runoff and erosion hazards, occurrence of salinity, and waterlogging. The dynamics of these phenomena can not easily be observed or measured in pedons but can be appraised from the sequence in which they occur in the landscape. An understanding of these features is essential for reliable land use interpretation.

It is felt that mapping units should not be defined in terms of "dominant soils" in the same way that a soil class is not necessarily defined in terms of the thickest soil horizon. A narrow strip of hydromorphic soils - that cannot be mapped - showing lateral seepage along a slope is probably more indicative of the moisture regime of a soil sequence than is the dominant soil after which the association is named. Generalizations through which "minor inclusions" are left out, often mean the loss of precious information for interpretive purposes. From a taxonomic point of view, soil associations which may be "heterogeneous" are in fact often functional systems in which the formation and behavior of different components are clearly linked.

Soil-sociology (Schlichting, 1970) rather than soil-systematics is proposed by a number of authors as a basis for mapping and land use planning. The nomenclature differs - soilscapes (Buol et al, 1973), soil cover (Fridland, 1976), genons (Boulaine, 1978) - but the tendency which prevails is a dynamic rather than a static approach to the characterization of soils as they occur in nature. In French Guyana (Boulet et al, 1978) and in Indonesia (Soil Research Institute, 1976), surveys have actually been conducted using "soil systems" as mapping units. The map boundaries separate different soil sequences or soil transects related to hydrodynamic characteristics in recurring segments of the landscape. The authors report a considerably improved prediction value of the soil information which has been gathered. These new approaches, which seem to have sprung up as a result of requirements for practical land use planning, may merit

further study for possible applications in development work.

DO SOIL TAXA CARRY THE NECESSARY INFORMATION TO MAKE PREDICTIONS?

The units in a soil classification system are concepts designed to enable an orderly organization of knowledge, and the study of relationships between different soils and the factors causing their formation. Classification may differ to serve different purposes, but in order to meet the objectives of soil survey one needs classes that can be grouped, or subdivided and regrouped to permit the largest number and the most precise predictions possible about responses to management (Soil Survey Staff, 1975).

Over the last three decades soil classifications have shifted from a qualitative genetic approach to a quantitative expression of properties of the soil itself. This shift has led to considerable progress towards an objective assessment of soil-plant relationships. It should be realized, however, that the selection of differentiae is still very much inspired by the factors of soil formation. Characteristics which have accessory properties and mark important processes in soil genesis are considered to be most suitable to define the higher categories. Furthermore, it is felt that the inclusion of genesis in the construction of soil classification enhances the value of soil survey since it facilitates the placement of more accurate boundaries. Properties important to plant growth but unrelated to genesis, are normally considered in the lower categories. The usefulness of a classification applied for soil surveys must be tested by the nature of the interpretations that can be made. Such tests in developing countries have not always been conclusive.

It is essential that prior to making interpretations, a relationship be established between the soil properties about which data are available and the requirements of the land use which is being envisaged. There is a major difference in this respect be-

tween developed and developing countries. In the former, predictions can be derived by inference from existing land use on similar soils. In developing countries there often are no points of comparison, and predictions have to be made from an interpretation of the soil properties themselves. Although some generally accepted principles of plant growth requirements can be used, it appears that little precise information is available about how soil properties, used as differentiae in a soil classification system, affect the growth of specific crops. Since requirements differ for various types of land use, the hierarchy of properties recognized at different levels of generalization may not be equally suitable for different purposes.

From a number of studies it appears that factors considered to be significant differ according to the crop. It is also noticeable that among these properties few are differentiae of soil classification units. The majority are "phases" which, though important for soil management, do not determine the separation of taxa. In a number of cases the first separations made with regard to land use choices are determined by "phases": in Tunisia the selection of lands for pasture and forestry was in the first instance made on the basis of differences in slope, stoniness, soil depth, and lime content in the surface layers (Loyer, 1974); in the alluvial plains of Bangladesh the major characteristic to determine type of land use and production potential was the time and depth of flooding (Brammer, 1978); in Tanzania, lands for wheat production require an elevation of over 1,300 meters, a rainfall of 500-700 mm, a level topography and the absence of stones in view of mechanization (CIDA, 1977); in computing productivity ratings for wheat, cotton, and sorghum in Oklahoma (USA), it was found that the most significant factor was slope on account of moisture effectivity (Allgood and Gray, 1978).

Special attention is called to the properties of the surface layer which in many cases is of paramount importance to plant growth. Soil surface layers influence germination, support the most biological activity, contain a major portion of the roots of annual crops,

store a large part of plant nutrients applied as fertilizers, and may show fluctuating degrees of salinity. Yet these properties are not reflected in the definition of taxa, not even in the lowest categories. This shortcoming may be the main cause of many frustrated attempts to establish a relationship between soil taxa at various levels and response to fertilizers. On the other hand, soil classification units seem to carry a number of characteristics - for instance color, thickness of certain horizons, mottling, base saturation at considerable depth - the significance of which has not been clearly determined in terms of plant growth.

It has been emphatically stated that map units identified as appropriate phases for taxa of high categories may be more useful for some interpretations than others identified only as taxa of categories low in the same system (Cline, 1977). Indeed, certain groupings, which may be fully justified on logical grounds, seem too broad for reliable interpretation and transfer. A systematic testing of diagnostic criteria in terms of their significance for plant growth should lead to making necessary adjustments.

IS THE USEFULNESS OF SOILS SURVEYS DETERMINED BY THE LEVEL OF DETAIL?

The quality of soil surveys is often appraised on the "purity" of mapping units and accuracy of boundaries between different taxa. To obtain this degree of precision a considerable density of observations is needed. Precise maps can be very complex and intricate, and the time and cost involved are not necessarily proportional to the use which can be made of the data collected.

The practical significance of the separations made depends on the level of generalization at which interpretations have to be made (Smyth, 1978). In low intensity studies carried out at regional level, the controlling environmental factors influencing decision making will be climate and landform, in which case the precision of boundaries between soil taxa is not of primary importance. In medium intensity studies, landform and slope are often more deter-

mining for land use alternatives than actual soil characteristics. While in more detailed studies soil data are coming more to the foreground, the usefulness of precise boundaries is limited by the smallest area that can be managed separately in accordance with its specific suitability. Very seldom, except possibly for experimental work or for tree planting, it is possible to lay out a land use plan that takes full account of soil variations occurring within short distances. More often land use planning has to be based on "average" conditions of a manageable tract of land, not just for one crop but for a crop rotation, with input levels which can be applied uniformly over a sizeable area. In practice, interpretations have to be made for farming systems, watersheds, and conservation areas, for which precise and detailed delimitation of soil taxa might not be fully justified. The detail and precision required for soil surveys might be seen in this perspective.

A screening of the information required at various levels of decision making is needed. Where broad subdivisions are needed, landform and agro-ecological conditions may have to be the first entry in the survey legend rather than taxa, even in the higher categories. Land systems comparable to soil associations but including elements of physiography, water regime and vegetation, may in certain instances provide a better view of regional potential than a more conventional soil survey. Use of aerial photographs and remote sensing techniques have favored the distinction of landscape patterns which lend themselves to land use recommendations, taking into account the characteristics of component soils but not on the basis of soils information only. A landscape analysis with emphasis on soils (Hole, 1978) may be more revealing than study of various soil taxa subsequently grouped into associations.

ARE THE ANALYTICAL DATA REQUIRED FOR SEPARATING SOIL CLASSES SUFFICIENT TO MAKE INTERPRETATIONS?

In soil classification, considerable importance is attached to chemical soil characteristics such as cation exchange capacity (CEC), base saturation, pH, carbon content, etc. Difficulties have arisen in obtaining comparable data for different soils. Variations in CEC depend on reagents used and on the nature of surface charge of the clay. Variations in base saturation are caused by the different dispersibility of the colloidal fraction. Since these characteristics are used for separating classes, even at the highest categorical level, considerable efforts are being devoted to improving their determination, to finding alternative ways of expressing the properties which are involved, and to determining precise values which can be used as differentiae. It may also be necessary to assess more explicitly the significance which these properties have for plant growth.

One wonders if these chemical characteristics are, in fact, of primary importance as such, or whether they are important because they correlate with some major physical properties. Special reference is made to the correlation between CEC and the clay activity (Uehara, 1978) - in the physical sense of the term - which in turn strongly influences moisture retention and permeability. It is striking that while some physical characteristics can be inferred from properties which are currently required for placing soils into a classification system, few of them are directly measured. However, when making an interpretation, physical characteristics often appear to be the most important. Efforts are being made to upgrade soils with low activity clays in soil classification systems (Moormann, 1978), in order to improve the interpretation value of the taxa involved. While Alfisols and Ultisols are separated on base saturation values, it may well be that the differences in rooting depth and moisture volume available to plants, resulting from differences in calcium saturation, are more important

than the nutrient status itself.

One observes that many of the data used for estimating productivity ratings are measured or collected in addition to those needed as class differentiae. This applies especially to physical soil parameters. One could ask if more use could be made of such physical characteristics to sharpen class definitions and facilitate interpretation. The same applies to certain chemical characteristics which are not normally measured to determine soil classes, but can be of major importance for management, such as aluminum saturation, specific surface area, phosphate and silica sorption characteristics of iron oxides (Juo, 1977), trace element deficiencies, and composition of the organic matter.

ARE CLIMATIC FACTORS APPROPRIATELY TAKEN INTO ACCOUNT?

The degree to which upper limits of crop production can be reached is closely related to prevailing climatic conditions. Since soils with similar morphology and chemical characteristics can occur under different climates, most soil classification systems have introduced climatic data at various levels of generalization. In the French classification, e.g., the "sols brun" are subdivided into humid temperate and tropical groups (CPCS, 1967). In the USSR (Rozov and Ivanova, 1967) thermal belts - boreal, subboreal, subtropical and tropical - are used at the highest level of classification and thermal parameters are also recognized at the facies level. Soil Taxonomy (Soil Survey Staff, 1975) applies soil temperature and moisture regimes for the definition of certain taxa from a suborder to family level.

The justification given for introducing climatic data into soil classification is that temperature and moisture are essential soil characteristics, that they are related to soil development and are important for interpretation in terms of suitability for plant growth. However, one may ask if the range of criteria currently used is not too wide and if their application reaches beyond the separation of

broad regional subdivisions. In the USSR the usefulness of thermal classes and facies is seriously being questioned (Glazovskaya, 1966; Liverovskiy, 1977). For Soil Taxonomy, a refinement of soil moisture regimes has been advocated. With special reference to the ustic category, which for the inter-tropical areas shows a wide range of length of the dry period, a further separation of "udi-ustic" and "aridi-ustic" moisture regimes has been proposed (Tavernier and Van Wambeke, 1978).

With regard to soil temperature, use of the "trop" concept in Soil Taxonomy - which groups soils that are isothermic and have an annual soil temperature which is mesic or warmer - offers some difficulties for classification of soils in the tropics. Since the "trop" attribute has been recognized at various levels of generalization (e.g. at suborder level in the Inceptisols, at group level in the Alfisols and Ultisols, at family level in the Mollisols and Vertisols), its bearing on interpretation and correlation varies with the category used in the mapping legend.

While refinements such as those proposed above for the soil moisture regime could bring about improvements, it is felt that the requirements of a soil taxonomy would of necessity limit the number of "climatic subdivisions" that can be made. Therefore, a soil taxonomy may not provide for a sufficient number of classes as required for the transfer of site-specific experience and know-how.

The introduction of soil temperature and moisture phases independent of soil taxonomy may have to be given consideration. An overlay of climatic and soils data would allow for a more detailed and precise breakdown of climatic crop requirements, taking into account not only temperature and moisture but also radiation to cater to the different photosynthetic pathways. An attempt in this direction was made in a study of the land use potential of major agroecological zones (FAO, 1978) in which the climatic inventory was expressed in terms of the length of growing period. Isolines at intervals of 30 days (e.g. 90-119 days, 120-149 days, etc.) were plotted on soil maps, thus combining climatic and soil

requirements into suitability ratings for a specific type of land use. The adoption of a more flexible characterization of soil- and air-climate phases, rather than the use of "broad" soil and moisture regimes, may facilitate application of soil surveys for development purposes, and may improve the reliability of technology transfer between comparable soils in different parts of the world.

WHAT IS THE CONTRIBUTION OF SOIL SURVEYS TO LAND APPRAISALS?

This topic has been dealt with extensively in a seminar dealing with soil resource data for agricultural development (Swindale, 1978). Soil is an environmental factor that is stable enough to form a base for land classification and, at the same time, is sufficiently flexible to be influenced by man by way of improvement or degradation (Vink, 1975). Soil survey information can therefore contribute considerably to the evaluation of land suitability, but it is only one of the important elements. The great complexity of land is now recognized in terms of geology, hydrology, climate, vegetation, animal population, disease hazards, and the results of past and present human activities, to the extent that they influence present future use (FAO, 1977).

Soil survey interpretations, although being important, are often still one-sided and have sometimes failed because other important land factors were not systematically considered: while powdery gypsum at depth is not impeding plant growth it might be a major obstacle to laying out irrigation systems as a result of the formation of sinkholes and subsequent canal ruptures; the success of irrigation is as dependent on water quality and depth of groundwater as on soil properties; transfer of technology on similar soils might prove difficult as a result of disease hazards, e.g. livestock or draught animals in tsetse-infested areas; the cost of clearing in heavily forested areas is an element in land evaluation even though soils may be the same as in already cultivated areas; certain soils may have favorable properties for growth of coffee but occasional

frosts would make the land unsuitable for this type of use.

It seems insufficient to interpret soil surveys as a source of planning in their own right. A conscious effort is required towards a multi-disciplinary approach which uses various elements of the physical environment in a social and economic context and in terms of a clearly defined use (Smyth, 1978).

CONCLUSIONS

A major application of soil survey and soil classification is to supply basic information for making optimum use of available land resources. A number of steps could be taken to improve their application in developing countries:

A. The relationships between soil characteristics and the requirements of different types of land use must be systematically established. Special reference should be given to testing the diagnostic criteria used for differentiating soil classes in terms of their significance for plant growth in general, and for specific crops in particular. As a result of these investigations it may become necessary to adjust class separations or even to introduce new criteria which have not, to date, been given sufficient weight.

B. It will need to be ascertained whether predictions can best be made from sets of properties considered collectively in terms of soil bodies; or if better interpretation can be obtained from a limited number of soil properties specifically selected for different types of land use. In any case, a clear definition of the purpose of a soil survey should be made so that data needed for a certain type of land use could be collected even if they are not part of soil class deferentiae.

C. Since soil information is only one element in the evaluation of land, due attention must be given to other important factors related to landform, slope surface water, ground water, climate, and vegetation. The detail of the soil information required should be assessed in this overall perspective. In this connection the "land" survey or soilscape approach - versus the soil survey approach - may merit further consideration, especially with regard to elucidating spatial relationships, which are of importance to the development of manageable tracts of land.

It is realized that many questions have been raised and few answers given. Since different methods of soil resource appraisals are being developed and important adjustments to soil classifications are being proposed, it may well be that some disillusionment has occurred over conventional soil surveys. The points brought up here are merely meant to promote a hard look at some traditional techniques which may have to be integrated into new approaches.

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CONCEPTS OF OXISOLS - REPORT ON RESULTS OF QUESTIONNAIRE

A. Van Wambeke

Soil classification systems are intended to organize the knowledge of a group of people in such a way that soils can be easily remembered and identified. Definitions of classes in the system are usually related to the objectives that the group has in mind, which may vary considerably, i.e. naming of mapping units, diagnosis of constraints to crop production, grouping of genetically similar soils, or highlighting relationships between different kinds of soils.

In the preceding statements some points have been stressed: a *group* of people are involved. The system should insure identical classification of soils when it is applied by different members of a group. The criteria should be unambiguous and precisely described so that different people within the group arrive at identical results.

The second point to emphasize is that classifications are called *satisfactory* when they achieve groupings of soils in such a way that they correspond with the *purposes* the individuals have in mind. Testing a classification is, in fact, measuring the extent to which the system responds to the objectives for which it was developed. Evaluating the adequacy of the definitions used in systems, therefore, consists of comparing groupings obtained by the classification with groupings which people think best serve the original intents. Classifications cannot be tested, or the needs for improvements in parts of it cannot be assessed, unless the original intents or concepts which have to be served have been clearly defined.

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The principles discussed above were considered sufficient to justify use of a questionnaire at a soil classification workshop. It was addressed to a group of pedologists having considerable experience in the classification of tropical soils. The purpose of the consultation was to identify concepts that specialists may have in mind when referring to the class of Oxisols. At the same time an attempt was made to evaluate the effectiveness of the criteria which are used to reflect these concepts.

An interpretation of the answers obtained from the questionnaire follows. Subjectivity could not be avoided completely; questions may have been formulated in a way which may have influenced answers; and the participants only had 30 minutes to react to questions. Therefore, the survey probably explored more the subconscious than the conscious.

The questionnaire was divided into two parts; the first is a series of questions; the second is a record of reactions of people to visual displays of classified profiles following different sets of criteria.

The use of a questionnaire approved at the workshop does not mean that this method is necessarily considered appropriate for making decisions in soil classification. Science would probably not make such progress if every decision had to be voted upon. However, in the case of classifications, which do not have to discover truth, a periodic inquiry of what people want may be useful.

PART ONE

REPLIES TO QUESTIONNAIRE

Questions related to the definition of Oxisols

1. We now have ten orders (or eleven, if Andisols are accepted). Do you think that the order of Oxisols as presently defined or modified, should be maintained if we were to remodel Soil Taxonomy?

Replies:

27 out of 31 participants wanted to maintain the order of Oxisols.

2. If the order of Oxisols were eliminated and the ex-Oxisols were incorporated in the remaining orders, do you think the homogeneity of taxa down to great group would be disturbed enough to seriously detract from their usefulness?

Replies:

20 participants thought that the usefulness of the remaining orders would be seriously disturbed when incorporating the ex-Oxisols. There were four "noes" and seven blanks. Except for one participant, the negative replies were not consistent with the reply given to the first question.

3. Having no Oxisol order, would it be satisfactory in your opinion to handle the "oxic" properties: (select one or more:)

Alternatives	Number of times option was selected
(a) as "Oxi" great groups	15
(b) as inclusion in "Kandi" great groups	10
(c) as extragrades at the subgroup level?	3
(d) as mineralogy classes at the family level?	6

4. If Oxisols are maintained as an order do you think that the soils with plinthite at less than 30 cm depth should be classified at the order level with well-drained Oxisols even if they don't have an oxic horizon?

Replies:

24 preferred not to include soils in the Oxisol order only on the basis of plinthite being present at less than 30 cm depth. Four participants wanted to keep

them in the same order. There were seven blanks.

Question related to the purposes of recognizing an order of Oxisols

1. If Oxisols are maintained as an order, the soils in the order of Oxisols should have properties which (select one or more of a, b, c):

Alternatives	Number of times options were selected
(a) reflect evidence of common soil-forming processes (genesis)	21
What do you consider to be the dominant forces that shaped the characteristics of Oxisols at the order level (select one or more of 1, 2, 3):	
(1) soil climate	15
(2) duration of soil formation	16
(3) other genetic forces, describe:	3
(b) require similar soil management practices (land use)	8
(c) combine as much as possible the objectives a and b above	13
However, if the use of two criteria result in conflicting groupings (genesis versus land use) you would give the priority, at the order level, to the criterion related to (mark only one):	
(1) genesis	14
(2) land use	12

Questions related to usefulness of climatic regimes

1. Do you consider that the soil moisture regimes (excluding aquic or hydromorphic soils in other classifications) is a soil property suitable for use in a soil classification system?

	Replies		
	Yes	No	Blank
	24	6	1

2. Do you similarly consider the soil temperature regime (excluding perma-frost) to be suitable for soil classification purposes?

	22	7	2

3. If yes, at what level?

Soil Regime	Order	Suborder	Great Group	Subgroup	Family
			Number of Replies		
Moisture	1	10	7	5	4
Temperature	0	3	4	2	14

4. If climate, either past or present, was considered an important pedogenetic factor in the formation of soils which now belong to Oxisols, what regimes, past or present, do you associate with an Oxisol-forming environment? (Circle one or more of the following):

Results:

Regime	No. of times regime was marked
Mesic	1
Thermic	12
Hyperthermic	19
Isomesic	2
Isothermic	15
Isohyperthermic	27

5. In the same perspective, how do you associate Oxisol information, as defined now, with the following soil moisture regimes (mark one or more):

Results:

Regime	No. of times regime was marked
Perudic	24
Udic	25
Ustic	17
Xeric	1
Acquic	4

Questions related to diagnostic properties

1. If soil properties were selected to distinguish Oxisols (as presently defined) because they were important for management, what properties would you use at the order level? Rank them by numbers from 1 to 7 starting with 1 for the most important.

2. If the same list of properties were used to reflect the dominant soil-forming processes responsible for the genesis of Oxisols, what would be your priority sequence?

	Ranking based on dominant response	
	management	genesis
kaolinite as dominant clay mineral	1	1
high amount of free sesquioxides	2	2
similar soil moisture regime	5	4
similar soil temperature regime	6	5
absence of argillic horizon	4	5
no weatherable minerals in non-clay fraction	3	3
plinthite at less than 30 cm depth	7	7

3. At present, well-drained Oxisols are required to have an oxic horizon, and no argillic horizon. According to your understanding and experience, what would be the rationale for excluding soils with argillic horizons?

Replies:

(a) There were six participants out of 19 who did not see any reason why soils with an argillic horizon were excluded from Oxisols.

(b) Three invoked management properties: essentially, the increased erodibility of soils and the difference in water availability were the main reasons for exclusion.

(c) Eight thought that clay migration and strong weathering were not compatible from a genetic point of view, because of the low mobility of colloids in materials which have reached the ultimate stage of weathering.

(d) Two additional answers placed the argillic and the oxic horizon in an evolutionary time sequence, and stressed the need to separate these stages at a high level in the classification.

PART TWO

REACTIONS TO CLASSIFICATIONS

Soil workshop participants were shown a series of slides in which 24 profiles were represented by drawings. Each profile had attributes which were marked by symbols which related to five soil-forming factors or processes: formation of a thick epipedon under grasslands (G), formation of an argillic horizon (illuviation) (I), strong weathering (W), strong leaching of cations (L), and the tropical climate (T).

The 24 profiles were arranged in different sets according to keys which followed different priority sequences. In one sequence clay illuviation (I) was used first to identify a first order of soils, followed by leaching (L) and weathering (W), to give an ILW sequence (Fig. 1). The other priority rankings for criteria which were used to key out the profiles were: WIL (Fig. 2), TWI and GWI.

The arrangement of profiles for each particular sequence was shown to the participants for a short period, and they were asked to score the mini-classifications by a scale from 1 (absolutely unacceptable) to 5 (definitely best), 3 being good.

The results were as follows:

Criteria Sequence	Average Score
WIL	3.67
ILW	2.35
TWI	2.31
GWI	2.14

When the profile representations were shown in an arrangement which indicated they were organized according to Soil Taxonomy, the score was 3.67.

SUMMARY AND CONCLUSIONS

A strong majority of the soil workshop participants would maintain an order of Oxisols in a new system. If they were forced not to consider a separate order for soils with oxic or "kandic" properties 25 out of 34 participants would use one of these properties at the great group level. Most of them disagree with the present inclusion of profiles in the Oxisol order only on the basis of the presence of shallow plinthite.

There was a preference for recognizing the order of Oxisols based on selecting soil properties which reflect common soil-forming processes. The genetic forces that were thought to be responsible for

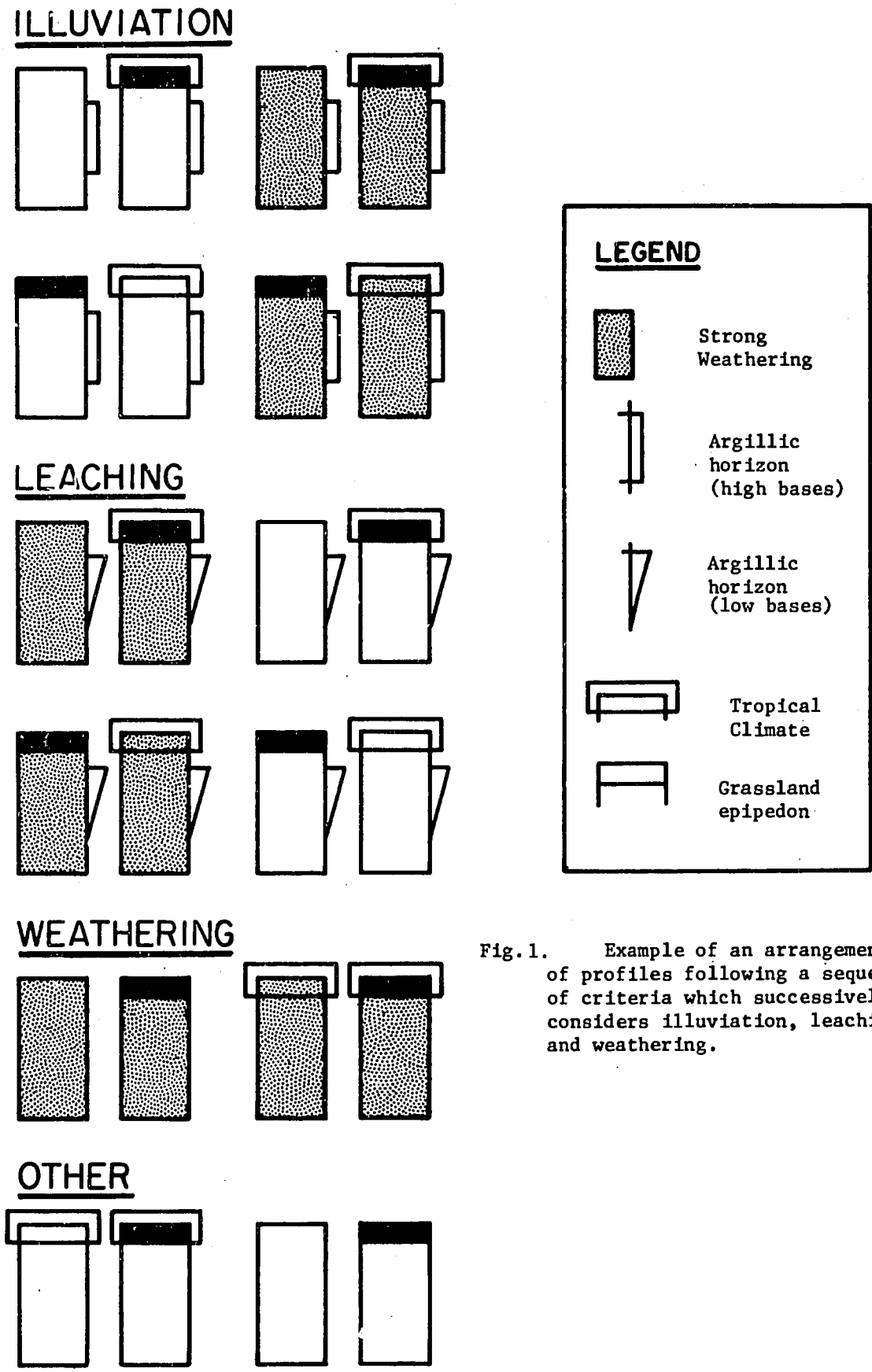

Fig. 1. Example of an arrangement of profiles following a sequence of criteria which successively considers illuviation, leaching and weathering.

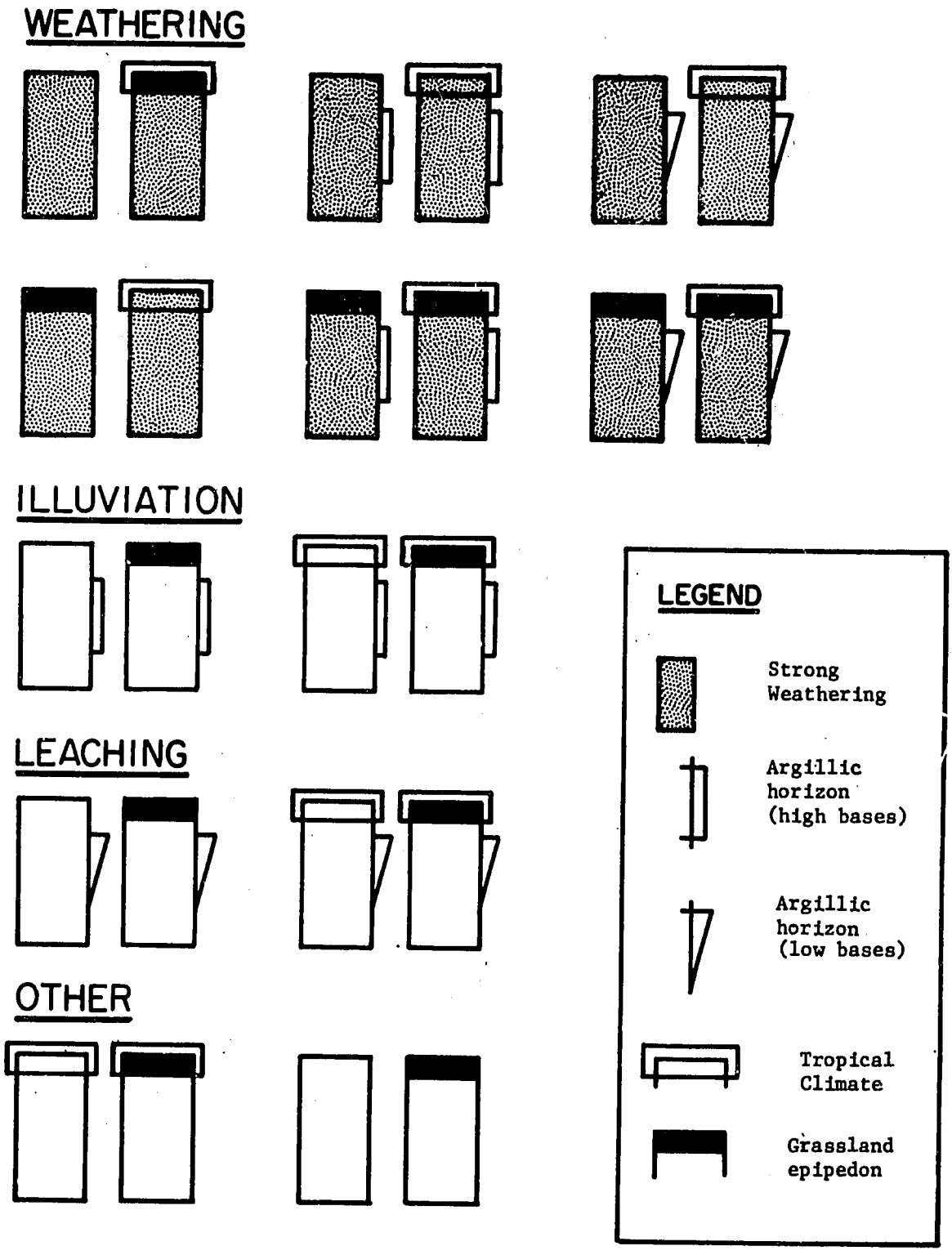

Fig. 2. Example of an arrangement of profiles following a sequence of criteria which successively considers weathering, clay illuviation and leaching.

shaping the characteristics of Oxisols were duration of soil formation and soil climate. The votes for writing a definition for Oxisols on a genetic bias versus land use considerations was 21 against 8, respectively. When conflicting groupings would be obtained by using a given property as a criterion, a small majority (14 vs. 12) would maintain the selected diagnostic feature for reasons of common genesis, even if for land use purposes the class would be heterogeneous.

The participants definitely associated the formation of Oxisols with well-drained soils and humid moisture regimes. It is surprising that there were 32 opinions that Oxisols can form in non-iso temperature regimes, even if the majority opted for tropical climates (44).

There is complete agreement on selecting the dominance of kaolinitic clay, the high amount of free sesquioxides, and the absence of weatherable minerals to reflect the major soil-forming processes responsible for the formation of Oxisols. Absence of an argillic horizon is only fifth, after the soil moisture regime, in the ranking of genetically important properties. When management is the major concern, the argillic horizon receives higher priority but only after the properties which are essentially related to weathering.

The mini-classification exercise gave preference to the weathering-illuviation-leaching priority sequence, when no reference to Soil Taxonomy was made. In fact, the sequence of decisions to be made when classifying a profile in Soil Taxonomy is, for the criteria considered here, a clay illuviation-weathering-leaching-grassland (mollic epipedon) sequence.

If a revision of Soil Taxonomy were needed, and would accept the reactions of the workshop as a consensus related to the expressed intent for Oxisols, the definition would have to be changed for that order and neighboring order. It would have to reverse the importance given in the key to the argillic horizon and the oxic horizon.

ACKNOWLEDGMENTS

The author wishes to thank all the workshop participants for answering the questionnaire. He wants to stress the point made before that this methodology is not necessarily the best one to arrive at decisions in soil classification.

GEOMORPHOLOGY OF SOME OXISOLS

S.W. Buol

"Oxisols commonly occupy old land surfaces, but they may occur on young surfaces if the parent materials were very strongly weathered before they were deposited." (Soil Survey Staff, 1960)

"Geomorphic evidence shows that the oxic horizons are generally found in soils of very stable land surfaces...If quartz gravels are present, stone lines in or under the oxic horizon are almost normal... Their (stone line) occurrence is so common that one must consider the possibility that oxic horizons are found mainly in transported sediments of ancient age." (Smith, 1965)

"Because Oxisols are on stable surfaces, weathering has commonly proceeded to great depths, producing a thick regolith...They have a relatively high permeability that, combined with gentle slopes, makes them, as a group, highly resistant to erosion when cultivated." (Soil Survey Staff, 1970, 1975)

From these quotes we can see some shift in concept regarding the geomorphic factors in Oxisol formation. Old land surfaces and stable surfaces have continued to remain the dominant theme. However, the 1960 concept that parent materials were strongly weathered before they were deposited on young surfaces, has not persisted in later versions of Soil Taxonomy. Instead the impression given by the Oxisol chapter of Soil Taxonomy is that weathering, presumably *in situ*, has taken place to great depths producing a thick regolith. However, the 1960 concept is retained in the oxic horizon discussion as follows: "Most of the soils that have an oxic horizon are nearly level or have relatively

gentle slopes; relief commonly is only a few tens of meters." They occur mostly on old high-level surfaces, high terraces, and pediments. *The geomorphic position is one in which weathered sediments could have been deposited.* It is not one in which recent unweathered sediments could accumulate, nor is it one that would receive groundwater that has moved laterally from an area where fresh rock is weathering (Soil Survey Staff, 1975, p. 37).

I believe it is a bit premature to presume that soil scientists have established firm geomorphic associations for Oxisols. Certainly it would be presumptuous of me to attempt to set forward a universal Oxisol-geomorphic relationship. In the following discussion, highly biased toward experience in Brazil, examples will be cited as will published studies from some other areas.

RECOGNITION OF OXISOLS

A major portion of this workshop addresses the problems of recognizing Oxisols. Since opinions on the definition of Oxisols vary it is necessary for the purposes of this presentation that I define the properties in question that I embrace when the term Oxisol is used: the presence of an apparent clay activity of less than 16me/100 g clay at pH 7; limits of weatherable minerals; clay contents greater than 15 percent; and absence of an argillic or natric horizon. Presence or absence of clayskins is not considered. However, the class limit with argillic horizons is based upon an increase in clay content of 50 percent, relative, within a vertical distance of 30 cm, and no clear evidence is presented to indicate that the clay content increase is due to a lithologic discontinuity. These conditions are clearly met in the Ustox-dominated area of the central Brazilian plateau.

CHARACTERISTICS OF AREAS WITH PREWEATHERED (OXIC) DEPOSITS

On the continental divide of the Brazilian shield near Brazilia, complete associations of Acrustox, Haplustox, and Ochraquox are present. The Acrustox tend to be associated with the highest surfaces, and the Haplustox on lower surfaces. Ochraquox are present on both surfaces; they are apparently more prevalent along drainageways on and in depressions of lower surfaces. Frequently geomorphic surfaces are rimmed with indurated ironstone, and ironstone gravels compose a high percentage of friable soil material on lower escarpment surfaces. Frequently the only soil on steeper escarpments between surfaces is less than 1 m of clayey- or loamy-skeletal oxic material over saprolite of the basement complex.

Stone lines extend from the divide and other old remnant surfaces, throughout the central Brazilian shield area. The stone lines are frequently composed only of ironstone gravels; however, where basement complex is eroding near the area, quartz gravels are prevalent in the stone line, and may be the only gravels present. As a general observation, the further one travels from the base of higher surfaces the less numerous are stone lines.

The conclusion one reaches from studies in this area is that Oxisols are simple soils composed of inert minerals. Although there may have been weatherable minerals present at one time, these have been reduced to inert secondary minerals, not in the present soil, but in the numerous soils within which they were components and/or during the many cycles of transportation they have been subjected to since their original exposure. One has no sense of intense or unique weathering or soil formation processes. This lack of any uniqueness is further substantiated by the frequent presence of Mollisols, Alfisols, and Inceptisols on areas where rock is being exposed for the first time (Lepsch et al, 1977 a, b).

In brief, one cannot escape the feeling that the Oxisols are fluvial deposits of inert (oxic) materials presently being dissected by modern drainages. This is further substantiated when Entisols are encoun-

tered in positions similar to Oxisols. Such areas are Quartzimpsamment (red-yellow sands by virtue of the fact that they contain less than the 15 percent clay needed to qualify them as Oxisols.

Odell et al (1974) report (Table 1) on some areas in Sierra Leone and make the following statement: "Oxic horizons, which occur in Gbehan, Makundu and Moa soils, contain few weatherable minerals and have a low cation exchange capacity. The presence of oxic horizons in young alluvial floodplain soils is a good example of the importance of preweathering of the parent material." (p. 18)

Table 1. Oxisol profiles in Sierra Leone (after Odell et al, 1974).

Soil	Physiography and Parent Material
"Plinthic Tropeptic" Ochraquox	Basin in the floodplain of Sewa river: clayey alluvium
Plinthic "Tropeptic" Umbriorthox	Nearly level river terrace: alluvium from Mabole river
Tropeptic Hapliorthox	Bottomland (river terrace): a thick layer of clayey river alluvium
Plinthic "Tropeptic" Umbriorthox	Sewa river natural levee: clayey alluvium
Typic Umbriorthox (Ult ?)	Dissected erosion surface, 6% slope: gravelly weathering products of Precambrian granite and acid gneiss

INFLUENCE OF GEOMORPHIC FACTORS IN AREAS OF THICK OXIC MATERIALS

Two geomorphic features seem to be associated with the occurrence of Oxisols in areas of thick oxic composition sediments. First and most obvious is that on stable and level areas, the sediments are deeper than on side slopes. Thus many side slopes have soils formed in residual rock on shallow colluvial sediments (Bennema et al, 1970; Lepsch and Buol, 1974). Frequently the colluvial sediments are coarse-textured with many ironstone or other gravels.

An apparently consistent but less obvious feature seems to be development of an argillic horizon within the oxic material as slope gradients reach about 8-10 percent. This feature has been attributed to "activation" of the clays, thus freeing them for lessivage upon removal of an iron coating either by shear (Beinroth et al, 1974) or by reduction of iron by laterally moving water (Lepsch et al, 1977 a, b).

OXISOLS ON RESIDUAL PARENT MATERIAL

Although there are some exceptions, clearly the majority of the reported Oxisols on residual material is from mafic (basic) parent material. Also, in reports that were reviewed in preparing this report, there is some indication of a clay content increase in the B horizon of such soils (Paramananthan, 1977; Schargel, 1977; SSIR, 1967; SSIR, 1976). Exceptions are the Nipe soil from serpentine rock in Puerto Rico and several profiles described as being from "chloritized greenish-black basaltic andesite flow breccia" (SSIR, 1967). In perhaps most of these cases the clay content increase is great enough to meet the 1.2x and/or the 1.4x rule for the argillic horizon (Schargel, 1977). No consistent pattern with respect to geomorphic position appears to apply in these kinds of soils. Angular and subangular blocky structure of weak or moderate grade is commonly cited in profile descriptions of the B horizon. It is in these profiles that placement as Oxisols is most frequently questioned.

CONCLUSIONS

The low clay activity defined as criteria for the Oxisol order can develop either from *in situ* weathering or from some preweathering of soil-forming material. Thus, where soil material has been preweathered, Oxisols can occupy geomorphic positions of almost any age from ancient stable to young floodplain. In these situations it appears that Oxisol profiles are confined to slopes less than 8-10 percent.

In residual soils where weathering *in situ* produces the required low clay activity, parent rocks of mafic (basic) composition appear to be most prevalent and no distinct geomorphic position appears more favorable. From the limited data available, it appears to this author that many Oxisols formed from residual material must be examined for the possibility of argillic horizons, albeit with oxic horizon mineralogy, and are better placed with "Kandi" great groups of soil orders.

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MINERALO-CHEMICAL PROPERTIES OF OXISOLS

G. Uehara

Two general types of minerals are found in the clay fraction of soils. They are: (a) the constant surface charge and (b) the constant surface potential clay minerals.

Montmorillonite, a member of the clay mineral group called smectite, is a typical example of a constant surface charge mineral. For the most part, the surface charge on montmorillonite arises from isomorphous substitution of an ion of lower valence in a position normally occupied by an ion of higher valence. Since ion substitution occurs in the interior of the crystal, the defect and therefore the corresponding charge is permanent and constant. Montmorillonite, like all constant surface charge minerals, is commonly called a permanent charge mineral.

In highly weathered soils of the tropics minerals with permanent charge have been either severely altered or completely weathered out. The surface charge now largely arises from adsorption of potential determining ions. The most important potential determining ions are the hydrogen and hydroxyl ions. Their adsorption on a mineral surface depends on the soil solution pH and minerals which behave in this manner are often called pH-dependent charge minerals. Hematite, the oxide of iron which imparts a red color to many tropical soils, is a typical example of a constant surface potential or pH-dependent charge mineral.

While it is now known that virtually all soils consist of a mixture of permanent and pH-dependent charge minerals, the origin of surface charges on soil mineral surfaces was not generally known until about 1940. In the 1930's Sante Mattson published a series of papers (1931, 1932, 1940) on the "Laws of Colloidal Behavior" in which he assumed that soil clays were of the pH-dependent charge type. Many of Mattson's ideas are valid today, but Kelley (1944) published a critical and devastating review of Mattson's work.

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When Kelley published his review, soil scientists were just beginning to appreciate the significance of crystallographic analysis of silicate minerals. Overwhelming evidence was accumulating to indicate that the colloidal soil fraction was largely crystalline and that the ion exchange properties of clays could be explained by isomorphous ion substitution in the crystal interior. When World War II ended, clay mineralogical research attained unprecedented popularity. New techniques for identifying clay mineral species, in particular x-ray diffraction methods, became readily available and added to Kelley's assessment of Mattson's work.

At least two factors contributed to the swing towards the permanent charge concept. First, virtually all soil mineralogical research was conducted in Europe and North America. Researchers found ample evidence to show that the dominant soil minerals in the colloidal fractions were of the permanent charge type. Second, in order to identify and examine individual mineral species, organic matter, x-amorphous coatings, free carbonates, and iron, aluminum, and hydrous oxides were systematically removed from the clay fraction. The pH-dependent charge components were treated as contaminants and largely ignored. It is only fair to state that their existence was never denied, but they did not receive the intense scrutiny of the permanent charge minerals.

Mattson's work would have received greater acclaim had soil scientists given equal time to soils of the equatorial regions of Africa, South and Central America, Southeast Asia, and Oceania. Mattson's work was relevant to soils of the tropics, but the permanent charge concept was so appealing and the information emanating from the tropics so sparse, that Kelley's assessment of the situation was assured.

What was lacking in soil science was a means to organize soils knowledge on a global scale. Soon after World War II, the Soil Conservation Service of the United States Department of Agriculture embarked on an ambitious plan to develop a new and comprehensive system of soil classification. The product of that effort--a handbook entitled Soil Taxonomy--was released in 1975. It is probably the most significant soil science document to be published in the last 25 years.

An attempt was made in Soil Taxonomy to select criteria to separate and stratify the highly weathered soils of the tropics. The name Oxisol was coined and the term "low activity clay" was used to reflect the properties of the clay fraction. By definition all Oxisols have low activity clays, but the reverse is not true for there are many non-Oxisols which contain as much low activity clays. This problem may or may not have been anticipated, but it is one of the principal reasons for holding this workshop.

In Soil Taxonomy, the Oxisols are defined as mineral soils that (1) meet one of these two requirements: (a) have an oxic horizon at some depth within 2 m of the soil surface; or (b) have plinthite that forms a continuous phase within 30 cm of the soil surface and that the soil is saturated with water within this depth at some time of year in most years; and (2) do not have a spodic horizon or an argillic horizon that overlies the oxic horizon.

The oxic horizon is in turn defined as a subsurface horizon, exclusive of the argillic or natric horizon, that (1) is at least 30 cm thick; (2) has a fine earth fraction that retains 10 me or less ammonium ions per 100 g clay from an unbuffered 1N NH_4 Cl solution (me of NH_4^+ retained per 100 g soil x 100 ÷ clay percentage $\leq$ 10) or has < 10 me of bases extractable with NH_4OAc plus aluminum extractable with 1N KCl per 100 g clay; (3) has an apparent cation exchange capacity (CEC) of the fine earth fraction of 16 me or less per 100 g clay by NH_4OAc unless there is an appreciable content of aluminum-interlayered chlorite (me CEC per 100 g soil x 100 ÷ clay percentage $\leq$ 16); (4) does not have more than traces of primary alumino silicates such as feldspar, micas, glass, and ferromagnesium minerals; (5) has a texture of sandy loam or finer in the fine earth fraction and has > 15 percent clay; (6) has mostly gradual or diffuse boundaries between its horizons; and (7) has <5 percent by volume that shows rock structure.

THE CHEMISTRY OF OXISOLS

The definition of the oxic horizon ensures that its mineral-chemical properties correspond to those of low activity clays. Four key properties are implied in, or required by, the definitions. These are: (1) low CEC of the clay fraction, (2) pH-dependent charge, (3) high degree of weathering and (4) clay which is difficult to disperse. All of the above properties are interrelated and can be described by the single expression

$$CEC = S\sigma \qquad (1)$$

where CEC is the cation exchange capacity in me/g, S is the specific surface in cm^2/ gm and σ is the surface charge density in me/cm^2. The complex part of equation 1 is the surface charge density, which is related to pH through the expression

$$\sigma = \left(\frac{2n\varepsilon kT}{\pi}\right)^{1/2} \sinh z(1.15) \ (pHo - pH) \qquad (2)$$

where n = salt concentration, ε is the dielectric constant of water, k is the Boltzmann constant, T is the absolute temperature, z is the counter ion valence and pHo is the pH of the zero point of charge. A more complete set of equations is required (Van Raij and Peech, 1972; Wann and Uehara, 1978) to fully describe the surface charge characteristics of Oxisols.

By treating $(2\varepsilon kT/\pi)^{1/2}$ as a constant, equation 2 can be simplified to read

$$\sigma = K\sqrt{n} \ \sinh z(1.15) \ (pHo - pH) \qquad (3)$$

Equation 1 tells us what we already know, namely that a low CEC arises from a low specific surface, a low surface charge density or a combination of both. In Oxisols, the low CEC is primarily due to low specific surface of the clay fraction. At pH 7, the surface charge density of most materials from oxic horizons is generally higher than that of montmorillonite. For soil materials to meet the 16 me/100 g CEC requirement, their specific surface must be less than about 100 x 10^4 cm^2/g. Montmorillonite has a specific surface six to eight times and allophane ten times that value. Examples of CEC, specific surface and surface charge density of montmorillonite, allophane, kaolinite and clay from three Oxisols are provided in Table 1.

Table 1. Cation exchange capacity, specific surface, and surface change density of montmorillonite, allophane, kaolinite, and clay from three Oxisols.

Mineral or soil	cation exchange capacity or cation retention capacity me/100 g	me/g	specific surface $cm^2/g(x10^4)$	Surface charge density $\mu C/cm^2$	$me/cm^2(x10^{-8})$
Montmorillonite	90	0.90	750	11.5	12.0
Allophane	143	1.43	1000	13.7	14.3
Kaolinite	5	0.05	35	13.7	14.3
Torrox (koalinitic)	< 16	<0.16	60[a]	13.7	14.3
Eutrustox (kaolinitic)	< 16	<0.16	96[a]	13.7	14.3
Acrustox (oxidic)	< 1.5[b]	<0.015[b]	[illegible]	< 1.44	< 1.5

[a]From Sharma et al. (1976)

[b]Cation retention capacity.

The 16 me/100 g CEC requirement excludes large quantities of high specific surface, permanent charge and amorphous minerals from the oxic horizon. The effective CEC (ECEC, sum of bases plus KCl-extractable aluminum) is even lower than the NH_4OAc, pH 7, CEC because in the field soil pH is normally lower than 7. To avoid the pH problem the use of unbuffered salt solution has been offered as an alternative to measure CEC.

If we examine equation 2, it becomes clear that the unbuffered salt solution has many of the hidden faults of the NH_4OAc, pH 7 method. Five parameters of equation 2 are altered by the NH_4OAc method. These are the dielectric constant (alcohol washing), salt concentration (varies from 1 N to near zero during washing), counter ion valence (use of monovalent NH_4^+ when dominant soil counter ions are divalent), zero point of charge (affected by acetate ion) and pH (buffered at pH 7). When unbuffered NH_4Cl is substituted for buffered NH_4OAc, problems with salt concentration, dielectric constant and counter ion valence still remain.

If the NH_4OAc method has all of these faults, why does it so effectively stratify soil materials according to clay activity? It does so by virtue of its reproducibility and its ability to integrate specific surface and surface charge density into a single number. This number has little theoretical value owing to the deficiencies outlined earlier; but, it can serve as a practical index to stratify soils into groups which differ in clay activity.

There are indications that this method will be used to differentiate soil materials according to clay activity. If this is so, it might be useful to examine how other soil properties relate to the NH_4OAc CEC.

Equation 1 suggests that the magnitude of S and σ determines whether a soil material will meet the chemical criteria of an Oxisol. The specific surface (S) is a simple and straightforward parameter. Although it is not routinely measured for soil characterization and classification, other routinely measured properties relate to it. The two properties which come to mind are texture and the 15 bar water content. In <u>Soil Taxonomy</u> clay content of the oxic horizon may be estimated by

multiplying the 15 bar water content by a factor of 2.5. For Oxisols this factor ranges from a low of about 2.0 to a high of about 3.0, so the average value of 2.5 is not unreasonable.

The fact that this factor varies indicates that the 15 bar water content is related to a more fundamental property than texture, namely specific surface. Based on very limited data (Sharma et al., 1967) the relationship between specific surface and the 15 bar water content is

$$S = 3 \times 10^4 (15\ BW) \tag{4}$$

where S is specific surface in cm^2/g and 15 BW is the percent gravimetric water content at 15 bar tension. The first parameter of equation 1 can thus be quantitatively estimated from data normally acquired for soil characterization.

Obtaining an estimate of the surface charge density from routine soil characterization data is more difficult. For clays with identical specific surface (15 bar water content), the parameter which most influences the magnitude of CEC is the zero point of charge. The zero point of charge, when it exists, may be estimated from the relationship

$$pHo = pH_{KCl} + \Delta pH$$

$$\text{or} \tag{5}$$

$$pHo = 2pH_{KCl} - pH_{H_2O}$$

where pHo is the zero point of charge and ΔpH is the difference between pH measured in 1N KCl (pH_{KCl}) and water (pH_{H_2O}). Equation 4 only applied to pH-dependent charge materials. A comparison of measured and calculated pHo is shown in Figure 1.

It should now be possible to relate CEC of Oxisols to the 15 bar water content and pH data normally acquired in soil characterization work. The relationship is

$$CEC \simeq K\ (15\ BW)\ \sqrt{n}\ \sinh z(1.15)\ (pHo - pH) \tag{6}$$

where $K = 3 \times 10^4 (2\varepsilon kT/\pi)^{1/2}$.

At least four methods are used to measure CEC in Oxisols. They are: (1) the sum of bases plus KCl-extractable Al or effective CEC

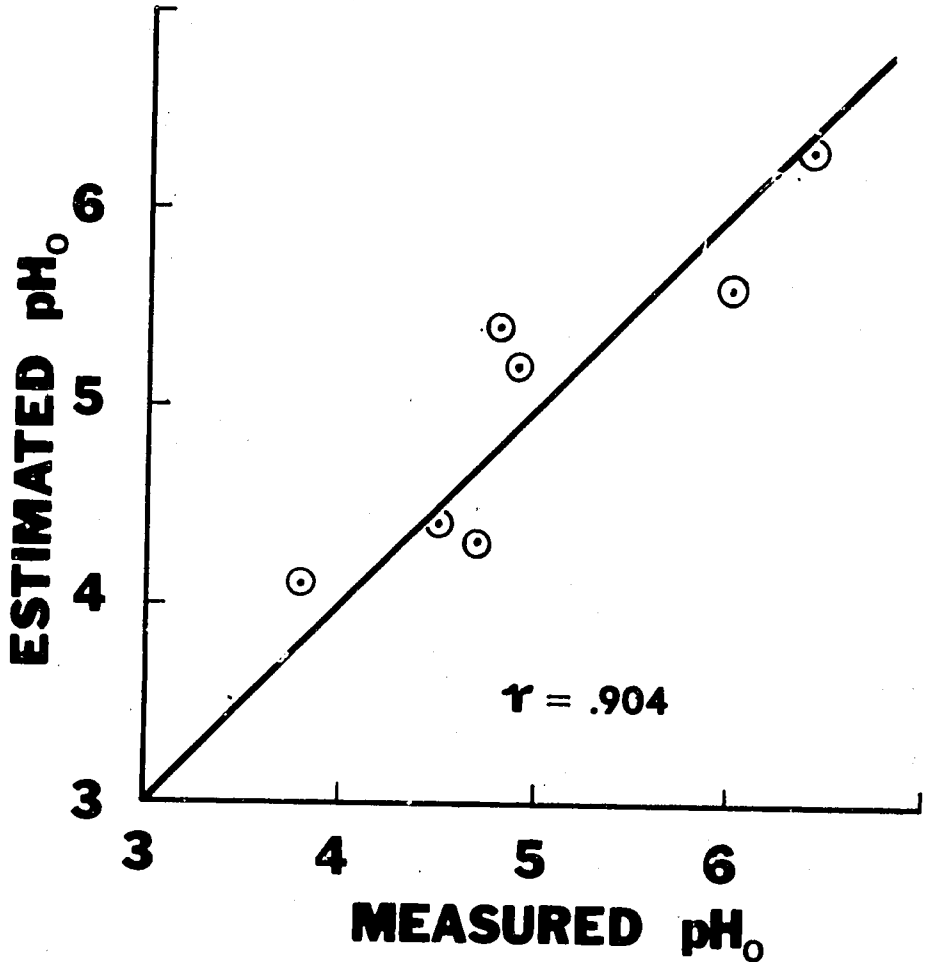

Fig. 1. Comparison between estimated and measured zero points of charge (pHo). pHo was estimated from the relations, pHo = $2pH_{KCl}-pH_{H_2O}$. (Data obtained from Keng, J.C.W. 1974. Surface chemistry of some constant potential soil colloids. M.S. Thesis. University of Hawaii, Honolulu, Hawaii.)

(ECEC); (2) the buffered, NH_4OAc, pH 7, CEC; (3) the unbuffered NH_4Cl CEC; and (4) the sum of cations. The last quantity is obtained by adding the sum of bases to the extractable acidity. Of these, the effective CEC is most amenable to analysis by equation 6. If the formula for estimating pHo is substituted into equation 6, and one further assumes that the principal exchangeable bases are divalent (z = 2), equation 6 reduces to

$$ECEC \simeq K\ (15\ BW)\ \sqrt{n}\ \sinh\ (2.3\ \Delta pH) \qquad (7)$$

If equation 7 corresponds to reality, plotting the measured sum of bases versus ΔpH should result in a scatter of points which conform to a hyperbolic sine (sinh) function. Such a plot is provided in Figure 2. The adherance of data to trends predicted by theory is remarkable.

It might be appropriate to mention at this point that the sum of bases and not ECEC was used in Figure 2. In pH-dependent charge materials, KCl-extractable Al should not be treated as exchangeable cations, but rather as potential determining ions. In this instance, addition of extractable Al to the sum of bases would have made little difference in Figure 2, since aluminum values were low.

An interesting deviation from equation 2 is the presence of extractable bases even when ΔpH is zero or positive. This is not unexpected if it is realized that ΔpH relates to net charge. When ΔpH is zero, extractable bases must be counter-balanced by an equivalent quantity of anions. This statement can be expressed as

$$\sigma = e(z_+\Gamma_+ + z_-\Gamma_-) \qquad (8)$$

where e is the electron charge, z_+ and z_- are the valences and signs of the potential determining ions, and Γ_+ and Γ_- are the densities of these ions. When ΔpH is zero, σ is zero, but finite and equal quantities of cations and anions may be adsorbed on the clay surface.

In Table 2 the specific surface and surface charge densities have been calculated for the Nipe Series of Puerto Rico. The specific surface was computed from equation 4, and the surface charge density was computed from equation 1, equation 4 and the NH_4OAc CEC data.

The reason for the decrease in CEC and surface charge density with depth of soil is organic matter. Organic matter in turn affects the

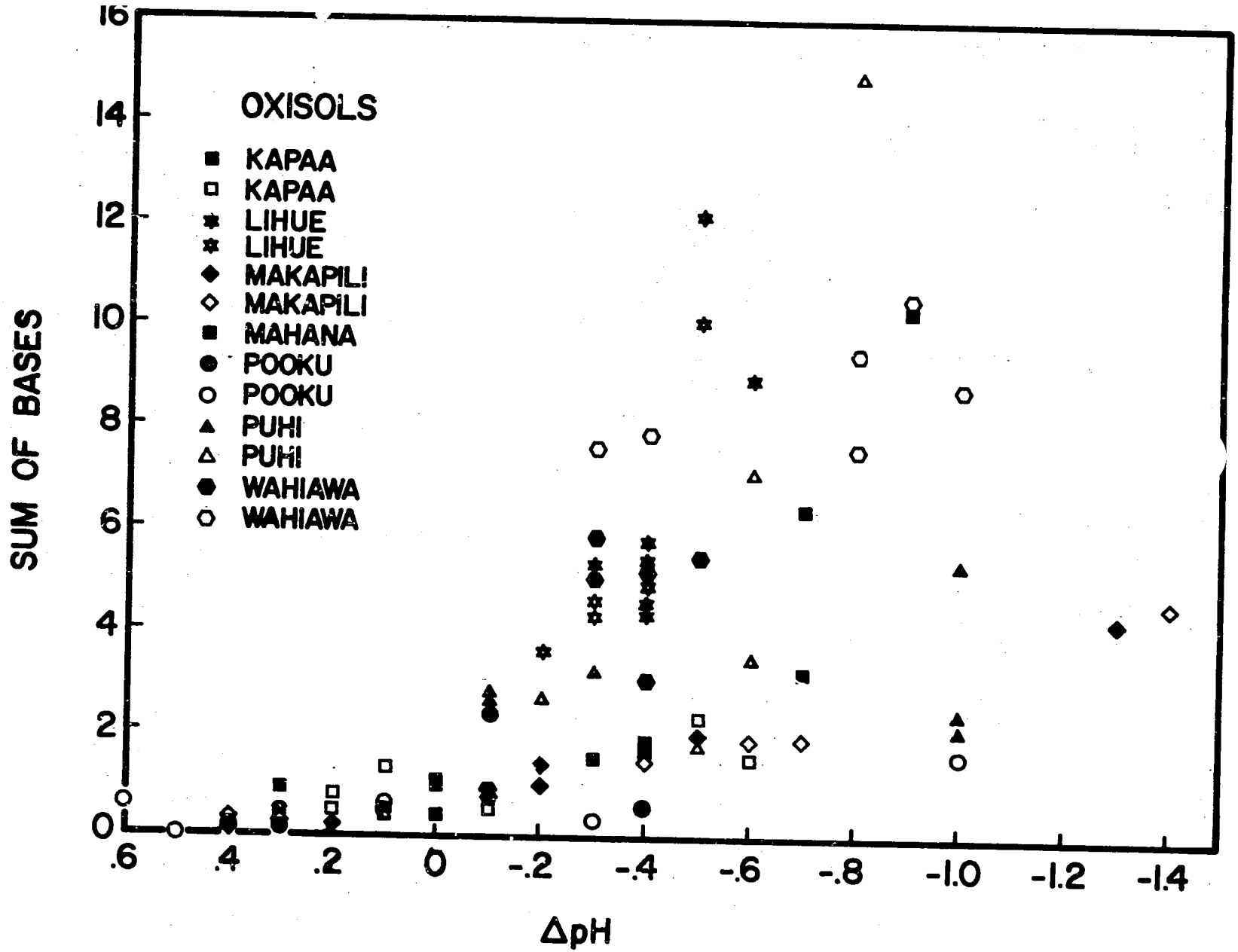

Fig. 2. Relationship between sum of bases and delta pH (ΔpH).

Table 2. Surface charge density of the Nipe Series (Typic Acrorothox. clayey, oxidic, isohyperthermic) calculated from CEC and 15 bar water content.

depth cm	clay content %	15 bar water content %	NH_4OAc CEC me/100g	% clay / 15 bar water	CEC / % clay	CEC / 15 bar water	specific surface $3x10^4$x15 bar water content $cm^2/g(x10^4)$	surface charge density $me/cm^2(x10^{-8})$
0-11	54.5	26.5	25.4	2.60	0.47	0.96	79.5	32
11-18	57.7	22.8	12.1	2.53	0.21	0.53	68.4	18
18-28	59.6	24.8	8.2	2.40	0.14	0.33	74.4	11
28-38	55.7	25.9	6.4	2.15	0.11	0.25	77.7	8.2
38-48	59.7	26.4	5.3	2.26	0.09	0.20	79.2	6.7
48-62	53.6	24.5	3.8	2.19	0.07	0.16	73.5	5.2
62-70+	37.6	18.0	1.4	2.09	0.04	0.08	54.0	2.6

Source: Soil Survey Investigation Report No. 12, Puerto Rico and Virgin Islands.

position of the zero point of charge. As predicted by theory, CEC and surface charge density decrease as (pHo - pH) becomes increasingly positive.

WEATHERING AND THE ZERO POINT OF CHARGE

While it is true that the chemistry of Oxisols is pH-dependent, it is pHo that ultimately controls soil pH and the overall behavior of Oxisols. In Oxisols and virtually all soils dominated by pH-dependent charge materials, soil pH is highly correlated to pHo. This is due to a natural tendency of soil pH to follow pHo. This is simply the tendency of natural systems to achieve stability and equilibrium. The surface potential of a pH-dependent charge material is related to pHo and pH by the Nernst-type equation

$$\Phi_o = \frac{RT}{F} \ln \frac{H^+}{H_o^+}$$

or at 25°C

$$\Phi_o = 0.059 \text{ (pHo - pH)}$$

where Φ_o is the surface potential, R is the universal gas constant, T is the absolute temperature, and F is the Faraday constant. So long as H^+ or pH is very different from H_o^+ or pHo, the surface potential will be large. Under natural conditions of weathering and leaching, H^+ and pH will shift towards H_o^+ and pHo. Stability and equilibrium are attained when pH equals pHo.

Thus highly leached organic and siliceous soils with low pHo's tend to be acid, but highly leached ferruginous soils low in organic matter and with high pHo's tend to have higher pH's. The silica-sesquioxide ratio was commonly used to explain the cation exchange properties of gels. High silica in the clay fraction is generally associated with low pHo's and therefore with high cation exchange capacity. Silica, like organic matter, lowers pHo and therefore increases surface charge by enlarging (pHo - pH). Phosphorus has the same effect as silica and organic matter, and when applied in heavy doses will increase CEC by lowering pHo.

WATER DISPERSIBLE CLAY

The water dispersible clay decreases as the absolute value of (pHo - pH) decreases. In many Oxisols this value is a large negative value in the surface horizon (∿-1.0) but tends to decrease with depth. Less frequently the value attains zero values in the oxic horizon and in some cases turns to large positive values at greater depths of the oxic horizons. As illustrated by the trend in Table 3, water dispersible clay is low when the absolute value of (pHo - pH) is low. For soil materials with high pho's, it is sometimes easier to achieve dispersion by adding acid to the suspension because acid will make (pHo - pH) a large positive value.

Sodium hexametaphosphate is an effective dispersing agent because the phosphate ion lowers pHo and the salt raises pH. Problems with clay dispersion occur in samples with large surface area and high pHo's. These materials possess high phosphorus adsorption capacities and high buffering capacities so that standard laboratory procedures are insufficient to disperse the clay. Complete dispersion can be achieved by adding more sodium hexametaphosphate.

DEFINITION OF LOW ACTIVITY CLAY

All low activity clays possess a pH-dependent surface charge but the reverse is not true for there are many pH-dependent charge minerals which would not normally be considered low activity clays. Allophane is an example of a pH-dependent charge mineral which would not fit the general description of low activity clays. Low activity implies low specific surface or low surface charge, or both. A necessary and sufficient condition for, and therefore a useful definition of, low activity clay is -- "any clay having a CEC of less than 16 me/100 g by the buffered, NH_4OAc method." As in Soil Taxonomy it is permissable to estimate clay content by multiplying the 15 bar water content by 2.5.

Since medium and high activity clays also exist, it is useful to define medium activity clay as those having CEC between 16 and 24 me/g, and high activity clays as those having CEC greater than 24 me/100 g. It may be necessary to raise the 24 me/100 g limit.

Table 3. Relationship between water dispersible clay and soil properties which affect surface charge characteristics of clay.

depth (in.)	organic carbon %	Free Fe %	pHo (estimated)	pH 1:1 (H_2O)	(pho - pH)	Δ pH	Water dispersible clay
0-11	6.04	13.0	3.5	5.1	-1.6	-0.8	22
11-18	2.04	12.9	3.8	5.0	-1.2	-0.6	33
18-28	1.33	16.5	4.4	5.0	-0.6	-0.3	37
28-38	0.86	19.2	6.2	5.2	+1.0	+0.5	2
38-48	0.72	23.1	6.7	5.5	+1.2	+0.6	42
48-62	0.52	25.7	7.1	5.7	+1.4	+0.7	32
62-70+	0.19	27.3	7.6	5.8	+1.8	+0.9	34

Source: Soil Survey Investigation Report No. 12, Puerto Rico and Virgin Islands.

Table 4. Relationship of clay activity to surface charge characteristics, specific surface and mineralogy.

Specific surface	Surface Charge Characteristics: Constant surface potential (pH-dependent charge)	Mixture of constant surface potential and constant surface charge	Constant surface charge (permanent charge)
High >200 M^2/g	High Activity Clay • Dominantly x-amorphous • Imogolite • Halloysite	High Activity Clay • Smectite-vermiculite • Kaolin • Chlorites • Some x-amorphous material • Mica (illite)	High Activity Clay • Smectite • Vermiculite • Swelling chlorites • Attapulgite-poly-gorskite • Sepiolite
Medium 100-200 M^2/g	Medium Activity Clay • Kaolin • High specific surface oxide • Al-interstratified chlorite • Some x-amorphous material	Medium Activity Clay • Kaolin • Smectite • Chlorite • Mica • Some x-amorphous • Al-Interstratified chlorites	
Low <100 M^2/g	Low Activity Clay • Kaolin • Oxides, hydrous oxides • Al-interstratified chlorites		

In Table 4 clay activity is categorized into low, medium and high activity on the basis of surface charge characteristics, specific surface and mineral type. From the table and the definition of the oxic horizon, one may say that all Oxisols have low activity clays. But it can also be said that all soils with low activity clays are not Oxisols. This in itself does not present a taxonomic problem. The problem arises when soils with low, medium and high activity clays are permitted to fall in the same taxon at the subgroup and great group categories. This is not a problem in Oxisols, but it is for Alfisols and Ultisols and to a minor extent in Mollisols.

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MICROMORPHOLOGY OF OXISOLS

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ABSTRACT

This contribution summarizes observations on the micromorphology of Oxisols from Brazil, Malaysia, and Thailand and of a few other profiles in the collection of the author. The mineralogy of the soils gives them specific optical properties and in addition, also affects the physico-chemical properties which in turn determine several micromorphological characteristics. Consequently, Oxisols or other soils with oxic properties have certain specific characteristics which are collectively termed the "oxic syndrome."

Oxisols also have other subordinate properties which, though shared with other soils, are generally best expressed in Oxisols. A brief discussion is included on plinthite, petroplinthite, petroferric contact and the lithoplinthic horizon. Gibbsite accumulations are also considered. Some Oxisols also have pseudonodules of soil material, called chicken pox or varioles in the field. The occurrence and morphology of these are discussed.

INTRODUCTION

The definition of the oxic horizon in Soil Taxonomy (Soil Survey Staff, 1975) is essentially mineralo-chemical in nature. The concept is centered around soil material weathered to such an extent that the clay fraction is reduced to kaolinite and iron and aluminum minerals

such as goethite, haematite, and gibbsite. The sand and silt fractions have little or no weatherable minerals and are composed largely of quartz and opaques such as ilmenite and magnetite. Occasionally other resistent minerals such as zircon and rutile may also be present in these fractions. If large amounts of gibbsite are present, these occur as nodules (Eswaran et al, 1977a, 1977b). Other aspects in the definition of the oxic horizon are designed to separate it from other diagnostic horizons or kinds of soils.

The specific mineralogy gives the oxic horizon characteristic optical properties. In addition, the specific mineralogy also imparts specific physico-chemical properties to the horizon which are also reflected in many micromorphological characteristics. A preliminary appraisal of the micromorphology of Oxisols is given by Buol et al (1977) and the reader is referred to it for a review of literature on the subject. Buol et al (1977) introduced the concept of the "oxic syndrome" and this subject is elaborated in this paper with the use of soils from Brazil, Malaysia, Thailand and a few observations from other countries.

The main objective of this contribution is to provide guidelines for the identification of oxic horizons in thin sections. As this is the diagnostic horizon of Oxisols, properties of the order may be extrapolated. Soils will have in addition subordinate properties of other horizons or soils and these are elaborated.

NATURE OF THE S-MATRIX

Related distribution patterns

The normal packing of sand, silt and clay particles, as observed in thin sections and without any modifications through pedogenesis, has been termed the normal related distribution pattern (NRDP) by Eswaran et al (1976). This may be considered as the initial state of the system, and several terms are available to describe the nature of the s-matrix due to different proportions of sand, silt, and clay. All NRDPs except granic are possible in oxic horizons by definition.

Plate Ia is an example of a grani-plasmic NRDP. The grains are composed of silt-sized ilmenite and magnetite with small amounts of fine sand-sized quartz. In Plate Ib, a plasmic NRDP is shown where grains are almost insignificant. These NRDPs are not exclusive to Oxisols but are generally frequent in soils at advanced stages of weathering especially on basic and ultrabasic rocks.

With pedogenesis, however, the NRDP is modified and the kind of modification varies with the soil. In Oxisols, weathering results in the production of sesquioxides which have several roles. The sesquioxides tend to aggregate the soil material into microgranules and this kind of RDP is called a specific related distribution pattern (SRDP) and is termed 'agglutinic' (Eswaran et al, 1976). Plate Ic, which is the B horizon of a Terra Roxa Legitima or an Acrustox from Brazil (profile samples by Dr. S. W. Buol), illustrates this morphology. The granules may be up to 5 mm in diameter though more frequently they are 1 to 2mm. This kind of SRDP has now been seen by the author in Oxisols from Brazil, Malaysia, Thailand, Zaire, and Madagascar. They have also been reported by Verheye and Stoops (1975) in Ivory Coast and in other Brazilian soils by Lepsch and Buol (1974) and Moura and Buol (1976). The granules are very homogeneous and show no domains of oriented plasma as in Plate Ic. A modified form has some orientation of the plasma just below the surface of the granule as in Plate Id. Verheye and Stoops (1975) have observed similar forms in the soil from Ivory Coast and they term them ooidal pellets and relate their origin to faecal material. This explanation is untenable as this morphology is retained to a depth of more than 6 m in some Acrustox. Buol et al (1977) attribute the subcutanic orientation of the plasma, which is now considerable as a specific kind of plasmic fabric-ooidesepic, to orientations resulting from the packing of the granules.

The significant point is that the agglutinic SRDP, with or without the ooidsepic plasmic fabric, is unique to some kind of Oxisols. It seems to be best expressed in Acrustox. In other Acri great groups, it seems to be confined to the surface horizons. The amount of sesquioxides and the soil moisture regime appear to be the two

determinants of this morphology.

The agglutinic SRDP is not just a micromorphological curiosity. In the field, the consistence of such horizons is very friable and the soil flows like flour between the fingers. There is indirect evidence that the granules are water stable. In addition, fine roots do not penetrate the granules; thus the effective volume exploited by the roots is reduced. In addition, Moura and Buol (1976) have shown that a higher amount of bases trapped within the granules are not easily available to plants. Tests of wetting angles with water of such materials indicate that they are also hydrophobic. Consequently this SRDP has immense management implications.

Plasmic fabrics

Weathering and soil formation induce other changes in the soil material. In Oxisols, kaolinite is the only or dominant aluminosilicate mineral. Small flakes of muscovite may be present, and in soils with muscovite in the saprolite, aluminous chlorite may be present in the solum. The latter are clay size and cannot be detected in thin sections. Gibbsite and to a lesser extent boehmite and nordstrandite may be present. Their contribution to the oxic syndrome is discussed later.

A more important feature is the accumulation of iron. Under well-drained conditions, iron settles on the clays (Follett, 1965) or aggregates as discrete particles between clay platelets. Iron which settles on the clays does so by a physical precipitation process. The effect is to mask optical properties of the clay domains. Consequently, the plasmic fabric types observed in Oxisols are different from those in younger soils. Apart from the masking effect, oxic horizons have a low coefficient of linear extensibility (COLE) and so the soil does not experience considerable stresses (Eswaran, 1972). Large domains of oriented plasma are not readily formed and so there is a poor expression of the plasmic fabrics as seen in the micrographs of Plate I. The masking effect has been shown by Stoops and Eswaran (1975) by a microphotometric procedure.

The characteristic feature of Oxisols is thus that the plasmic fabric is asepic or even isotic (Bennema et al, 1970; Stoops, 1968; Eswaran, 1972; and Buol and Eswaran, 1977). Unfortunately, this is not a mutually exclusive character of Oxisols as other soils with a kaolinitic-sesquioxidic mineralogy show this feature. In the latter it illustrates the oxic nature of the material.

PEDOLOGICAL FEATURES

Gibbsitic forms

Accumulations of iron and aluminum reach a maximum in Oxisols. These are not exclusive to Oxisols as similar forms may be present in other soils, especially LAC soils. The most frequent aluminum mineral is gibbsite; boehmite and nordstrandite have been reported but are not common. Gibbsite is frequently in the silt size and occurs as nodules ranging from a millimeter to more than tens of centimeters (Sooryanarayanan and Eswaran, 1973; Eswaran, Stoops, and Sys, 1977). Gibbsite may form directly from feldspars (Eswaran and Wong Chaw Bin, 1978) or other minerals. Gibbsitic nodules may also form by precipitation from the soil solution. These nodules are frequently spherical and sometimes incorporate unaltered weatherable minerals (Sooryanarayanan and Eswaran, 1977). As a result, if the nodules are disintegrated during mineralogical studies, it may not be uncommon to find weatherable minerals in oxic horizons. At an extreme case, sheets or gravels of gibbsite may characterize the soil as in a Gibbsiorthox. Plate IIa shows a micrograph of such a soil (Ghent Series, Malaysia) where the matrix is composed almost completely of silt-sized gibbsite; only small amounts of plasma are left behind. The crystallization of gibbsite in soils takes the most unique forms. In Plate IIb, gibbsite is present around quartz grains. A detailed study of these and other forms is given by Eswaran, Stoops, and Sys, 1977.

Ferruginous forms

Accumulation of iron in soils has been considered before. Under well-drained conditions, there is no segregation of iron, i.e. there is no concentration of iron in specific parts of the s-matrix. If the soil material is subject to hydromorphism, segregation of iron results. This may result in specific accumulations of iron which in the field have been identified and differentiated. These include plinthite, petroplinthite, petroferric contact, and the lithoplinthic horizon; the last was recently defined by Smith et al (1977). The mineralogy and some aspects of the micromorphology of some of these forms have been considered by Comerma et al (1977).

Basically, plinthite, petroplinthite, petroferric contact, or the lithoplinthic material are features which are distinct expressions of different stages of a single process - the absolute accumulation of iron in soils. All require an external supply of iron which accumulates in specific parts of the soil matrix. All are invariably associated with a present or past groundwater table or laterally (downslope) moving water.

Plinthite

Segregation of iron in the soil by a fluctuating water table may result in a variegated horizon composed of interconnected domains of iron-rich and iron-deficient parts of the soil matrix. The term "plinthite" is employed to refer to the iron-rich parts. Plinthite is generally not a discrete entity in the sense that it can be picked out of the soil material. But, when it is compared with the iron-poor parts of the matrix, it is contrasting enough to be considered as a distinct material. The plinthic material is present as interconnected streaks on the pedon wall, the streaks being generally vertical. The volume occupied by the plinthite generally decreases with depth until a layer is reached which is almost completely pale. In some soils, the latter may be saprolite

There is generally at least two units of hue difference between the plinthite and enclosing soil material, and the chroma value is 4 or more. The matrix of the horizon in which plinthite occurs is homogeneous in all respects except for color and free iron. Plinthite is soft--it can be scratched by a fingernail.

Generally, plinthite forms in materials with low activity clay but this need not be so. Its presence indicates a relatively stable, and sometimes old, surface.

In thin sections, plinthite has a specific morphology. As shown in Plate IIc, diffuse neo-ferrans penetrate the kaolinitic s-matrix which is white in color. No interconnected streaks of goethite or haematite are present. Much of the iron is generally amorphous in XRD. Diffuse amorphous iron forms a network which gives the patterns observed in the field. The absence of detectable crystalline iron explains the lack of turgidity of plinthic material.

Petroplinthite

Unlike plinthite, the petroplinthite is hard--it does not break under pressure between the fingers and is not scratched readily with a fingernail. All transitions between the two are possible and it is necessary to draw a limit. Micromorphologically, hardening of plinthite appears to take place in a centripetal manner--from the core outwards. In the hardening process, there is a tendency to form discrete entities. Initially, hardened core is surrounded by softer material. For purposes of taxonomy this is still considered as plinthite. Petroplinthite only forms when an outer crust of about 0.2 to 2 mm develops. The crust may enclose one or more hardened cores with or without the enveloping soft material. The resulting petroplinthite is irregular in shape. Crust formation implies a secondary supply of iron.

Plinthite need not be a precursor to petroplinthite. Mottles, sesquioxidic concretions, nodules and thick argillans may also act as centers for iron accumulation. The secondary supply of iron engulfs all these features. Successive supplies of iron cause

banding of the outer crust as shown in Plate IId. Cementing can also cause primary petroplinthite to be built into larger blocks. As in the gibbsitic nodules, petroplinthite may also incorporate weatherable minerals.

In thin sections, petroplinthite has characteristic forms and is easily differentiated from plinthite. The classical morphology of petroplinthite in thin sections is illustrated by Hamilton (1964), Eswaran and Raghumohan (1972), and Comerma et al (1977). Scanning electron micrographs show the network of goethite or haematite which provides the rigidity of the material (Eswaran et al, 1977b). The outer crust is frequently made up of acicular goethite. Veins of manganese may sometimes be present in petroplinthite and gibbsite (Eswaran et al, 1977b).

Petroferric contact

This may form after the plinthic or petroplinthic stage or may form directly in the soil material. A plate-like layer of cemented material characterizes this contact. The cement is frequently laminated, indicating several fluxes of iron. The laminated layer is frequently made up of acicular goethite or by a very fine packing of haematite discoids. In thin sections the lamina are homogeneous and frequently no differentiation of the matrix is seen. If quartz was present in the original material, this is embedded in the matrix.

Lithoplinthic horizon

No micromorphological studies have been done on this material. The only difference with petroplinthite is that the material is vesicular. The vesicles are former kaolinite parts of the matrix which were not enriched with iron and which have since been washed out.

Plasma infusion

Plasma infusion (Eswaran et al, 1975) is a pedological process of some significance in the tropics. Results of this process are only observed at a microscopic scale, but the features formed are very helpful in the genetic interpretation of the soil.

At the oxic stage of soil formation (Tavernier and Eswaran, 1972), disintegration of the quartz, which is the main resistent mineral retained in the soil, is an important phenomena. Disintegration is both physical and chemical (Eswaran and Stoops, 1979). One stage is the formation of hairline cracks or fissures. Sesquioxidic plasma appears to have been sucked up into the fissures by capillary forces. The quartz grain then has iron-rich plasma crisscrossing it, similar to runic script, and in thin sections it is termed "runiquartz."

Once sesquioxidic infiltration has taken place, the quartz is very stable and does not seem to disintegrate further. If soil material is eroded and transported, the runiquartz moves as an entity. In the resulting soil, after deposition, runiquartz has bright red plasma while the enclosing s-matrix may be pale yellow or other colors. This is conclusive evidence that the soil material is reworked and transported and could be used for studies on old geomorphic surfaces. Presence of runiquartz seems to characterize some Oxisols formed on old surfaces.

The plasma in the cracks need not be iron alone. Sometimes alumina-rich soil solution penetrates the cracks, and gibbsite precipitates. A modified form is seen in Plate IIb where the gibbsite completely coats the quartz and in some cases penetrates it.

Pseudonodules

Some Acri great groups have soil nodules of 1 to 2 mm diameter in the oxic horizon. Apart from being a discrete entity, they do not differ in color or texture from the rest of the soil material. They have bulk densities of more than 2 in comparison to the soil material which is about 0.8. These have been called 'variole' or chicken pox in the Zaire soil survey and are termed pseudonodules

here. Even in thin sections, they are difficult to differentiate. Apart from a very compact s-matrix, they have few other differences in micromorphological properties. The field observations in Malaysia indicate that they are frequent in Oxisols and only in those which belong to the Acric great group. Their genesis is unknown and requires more study.

CONCLUSION

Some oxic horizons, especially those of the acric great groups, have specific micromorphological properties which are perhaps exclusive to them. The remaining Oxisols have properties, some of which are also shared by other soils with low activity clays.

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Fig. 3

CAPTIONS FOR FIGURES

Plate I. (All at magnification X 80).

a. S-matrix of Kuantan series, Malaysia. The large nodule is composed of gibbsite. The black spots in the nodule (indicating it is formed *in situ*) and the matrix, are opaque crystals of ilmenite. The NRDP is porphyri-plasmic.

b. S-matrix of Segamat series, Malaysia. Quartz is only present as fine silt-sized grains. Voids are few and the matrix is compact. The NRDP is plasmic.

c. S-matrix of Terra Roxa Legitima, Brazil. The best expressed agglutinic SRDP.

d. S-matrix of Chok Chai series, Thailand. An agglutinic SRDP with some ooidsepic plasmic fabric.

a
b
c
d

Plate II. (All at magnification X 80).

a. Part of a large gibbsitic nodule in Ghent series, Malaysia--a Gibbsiorthox. The fine white crystals are gibbsite and the reddish linear vein is haematitic.

b. Fabric of a petroplinthite from Zaire. The white coating on the quartz grains is gibbsite. The matrix is goethic.

c. Plinthite from Paka series, Malaysia, showing retulic SRDP.

d. Part of a petroplinthite block showing that it is composed of recemented nodules and concretions. The laminations indicate several fluxes of iron.

THE CLASSIFICATION OF HIGHLY WEATHERED SOILS IN THE FRENCH CLASSIFICATION

P. Segalen

French soil scientists have been concerned for many years with tropical soils. Studies of genesis, geography, and classification were carried out by some distinguished soil scientists working in Africa and in other tropical countries. Among these, A. Lacroix is one of the most prominent. In the homeland, studies started rather slowly and pedology as an independent science was introduced by V. Agafonoff in the early twenties.

The first tropical soil studies were done by a mineralogist, who studied soils from the standpoint of mineral constituents. As optical studies were not possible at the beginning of the century, at least on loose soil materials, he relied almost entirely on chemical centesimal analyses which, performed with utmost care, provided very reliable results. Kaolinite and the main hydroxides and oxides of iron, aluminum, and titanium were identified, and percentages given. But, of course, clay minerals other than kaolinite could not be identified. At Lacroix's time, very scanty information was given on profiles but the difference between the often very thick "zone d'alteration" and the rest of the profile was fully appreciated and was clearly pointed out. Lacroix's views on soil genesis in the tropics and part of his nomenclature prevailed for a long time among French pedologists working in the tropics. After the end of World War II, when systematic soil surveying was initiated in Madagascar, Lacroix's works were long bedside books for beginners and still offer a large amount of reliable information.

Meanwhile, at home, Agafonoff introduced the Russian approach to soils. He studied soils all over the country and set up the first

draft of the pedological map. At the same time, the concepts of soil zonality and genetic classification appeared. He arrived in France with the framework for the soils of the world already laid out by his friend Glinka, and he endeavoured to adapt it to French soils. For the first time, zonal and azonal soils were spoken of. As usually favored by Russian soil scientists, morphological characteristics were the most important, and among them color was determinant. Chemical values were scant and hardly anything was said about soil constituents.

Therefore, before World War II, two different approaches were making their own separate way. The first, from tropical areas, depended on the mineral constituents. The second, from the temperate zone, laid emphasis on morphology and especially soil colors. This latter trend was that of Demolon and his pupils. He presented a classification of French soils in his treatise "Dynamique du Sol" which was in widespread use after the war.

Soil studies then received a new and important impulse, both in the homeland and overseas. A small-scale soil map was prepared for France. Many young soil scientists were set to work in all the overseas French-speaking countries. Many of them were from ORSTOM and worked under the leadership of G. Aubert. Their main objective was to undertake medium-scale soil surveys in many countries located in Africa, Madagascar, Guyana, and various islands in the West Indies and the Pacific area. As the soil survey progressed, many problems arose that had to be handled almost at the same time. The first problem was to compose a list of all soils that were studied and arrange them in a coherent classification. In addition, various studies dealing with soil genesis, soil geography, and soil fertility were initiated.

G. Aubert, alone or with the joint authorship of Ph. Duchaufour, prepared, between 1956 and 1966, various drafts of a French soil classification. In 1967, a team of French pedologists working either in France or overseas, gathered and wrote down a classification system derived from, and very close to, the Aubert-Duchaufour draft. This was

elaborated by the "Commission de Pedologie at de Cartographie des Sols" (CPCS). It was issued provisionally in 1967 and, as a whole, has remained as it was until now. Duchaufour in each issue of his Pedology textbook introduced some minor modifications, but the whole system was not significantly altered. Let us see how highly weathered soils were accommodated in the successive systems.

First, the general frame of the classification seems very much inspired by that proposed by Kubiena in 1953. He chose as the very first criterion the differentiation of the profile, starting from raw mineral soils with (A)C, rankers and calcimorphic soils with AC, to well-evolved soils with A (B) C and A B C profiles. The highly weathered soils belong to both latter categories.

Second, criteria used to differentiate the classes concerned the weathering conditions, the type of humus and the chemical status of the absorbing complex.

Third, the subclasses were defined after an ecologic factor responsible for the evolution of the soil (climate, parent rock and local conditions).

Fourth, at the group and subgroup level, appear morphological characteristics related to the above-mentioned general evolution conditions. Therefore, two main levels provide for the main evolutionary trends and for the resulting morphology. Later on, soil series were provided, as well as associations, for soils genetically related or set side by side.

It is not possible in a few minutes to discuss too many details about the whole system and especially about the succession of the different classes. But, it can be roughly considered that the first differentiating criteria are the following: morphology for Vertisols; calcium ions for calcimagnesic soils; distribution of organic matter for isohumic soils; soft organic matter for brunified soils; raw acid organic matter and morphology for Podzols; excess water for hydromorphic soils; and excess soluble salts for halomorphic soils. Of course, all

these soils contain mineral constituents, but no provision was made for them in the definition and none is specific.

On the other hand, mineral constituents are considered of prime importance in the remaining classes. The first one is that of Andosols, where organic matter is equally important, and where allophane (plus imogolite) is the main mineral constituent.

But, these products cannot really be considered as highly weathered, since as time goes by, they are replaced by other minerals (mostly clay minerals belonging to the halloysite family and gibbsite). The following units have been associated differently in the various classification schemes. The last one provides for two main divisions: The sesquioxidic class and the ferrallitic class. They can both be considered as more or less highly weathered. The primary minerals are destroyed by hydrolysis; oxides and hydroxides of aluminum, iron and titanium are formed giving the soil yellow or red colors; 1:1 and/or 2:1 lattice clay minerals are synthesized.

The main subdivision is due to the degree of hydrolysis. In both cases, iron sesquioxides are synthesized. But, in the first case the hydrolysis of primary minerals does not go very far; the profiles remain rather shallow; the clay minerals are a mixture of 1:1 and 2:1 clay minerals, with some iron occupying octahedral positions, and generally without aluminum hydroxides. In the second case, hydrolysis is strong with very thick profiles and the clay minerals are only 1:1 and 2:1 clay minerals, with the possibility of high amounts of aluminum hydroxides.

The first class, "soils with sesquioxides," is subdivided into two subclasses: the "ferruginous tropical" and the "fersiallitic." The main difference is related to forms of iron compounds.

- In the first subclass, soil-forming conditions are responsible for the separation of iron oxides from clay particles. These oxides can therefore migrate, concentrate, and accumulate as various forms, such as mottles, nodules, or crusts. In most occurrences, these

soils present the following other characteristics: a rather pale yellow color, a massive structure in the solum, a rather high degree of saturation (50-65%), the presence of a prominent clay accumulation in the B horizon.

- In the second subclass, iron oxides appear closely linked to clay minerals. When clay size particles move in the profile, clay minerals and iron oxides move together.

These soils, studied by French pedologists, occur mostly in the mediterranean area where they are often associated with limestone rocks. So, clay minerals are often illitic and the saturation degree is always high (65-100%). Two main groups are known: one is not leached and presents no clay accumulation; the other is leached and shows a conspicuous clay bulge.

The second class, "ferrallitic," concerns soils where 1:1 clay minerals, iron, and aluminum oxides are the staple minerals associated with very resistant primary ones, such as quartz and magnetite. Profiles are usually very thick and bright colored with very gradual transitions between horizons.

Since the soils are considered to be formed under warm and rainy weather conditions, rather low base exchange capacities, exchangeable bases and pHs are to be expected. The class has been subdivided into three subclasses depending on their saturation complex characteristics that are liable to be related with climatic conditions.

Groups are related with morphological characteristics, such as impoverishment, leaching, penevolution, and reworking, along with the accumulation of organic matter.

Therefore, the French classification system considers that various soil-forming processes are especially important in a classification scheme. Formation and accumulation of sesquioxides and various clay minerals is one of these, and it is used for sesquioxidic and ferrallitic soil classes. Several remarks can be made about them as follows:

- The subdivisions are based on the nature of mineral constituents. Organic matter is always present, but this constituent appears at a lower level (group).

- The leaching and accumulation of clay always appear at a group level as they do for the whole system, and never at a higher level. Therefore, in the two classes concerned, weathering (more accurately the products of this weathering) occupies the highest rank, whereas other proccesses such as clay illuviation, occupy a subordinate one.

- French soil scientists make a sharp distinction between at least two types of clay enrichment in the profile: the first is covered by the term "lessivage" (leaching) and deals with illuviation that can be identified by a conspicuous clay bulge and by clayskins; the second is called "appauvrissement" (impoverishment) and corresponds to any kind of clay increase in the profile (with no clay bulge and no clayskins).

- French soil scientists are of the opinion that the process of "remaniement" (reworking) is important and is worth mentioning at group level. Accumulation of quartz and lateritic rubble is widespread on planated surfaces of the tropical zone.

- The link between ferrallitic and fersiallitic soils can be realized through "penevolue" soils, which means that ferrallitic soils contain some weatherable minerals but not enough to fall into the fersiallitic class.

Of course the system is not perfect and many flaws have been detected. The most prominant flaws are the lack of accuracy for most of the definitions of the different categories, and the boundaries of the various categories are especially ill defined. By the way, this can be observed in any genetic classification system where concepts are more important than criteria. I know of no system based on soil-forming factors or processes that has been able to overcome this difficulty.

Soils belonging to two above-mentioned classes were classified more than ten years ago using information available to French pedolo-

gists at that time. Fersiallitic soils were known mostly as soils related with limestone. The result was a high amount of 2:1 clay minerals (not only illite) and a high base saturation. Now, it is known that these soils can be found both inside and outside the mediterranean area and that they are derived from many other parent rocks, with any saturation degree.

Ferrallitic soils were known mostly on acidic rocks and countries with warm temperature and heavy rainfall. Such soils are also known to be associated with basic sedimentary rocks. So, in some instances pHs can be very near 7.0 and degree of saturation can rise to 100.

Therefore, it can be considered that there is a continuum between 2:1 clay mineral-rich fersiallitic soils which grade into 1:1 clay mineral-rich ferrallitic soils. General and local situations can influence the pH and the degree of saturation. Such soils may or may not be leached. None of these characteristics is considered sufficient to move a soil from one class into another.

The division between the two classes has always caused problems. The method that seemed most reliable ten years ago was the determination of the silica/alumina ratio. The procedure was time and money consuming, but seemed rather safe even if not entirely flawless. It can always be corrected and strengthened by direct mineral determination such as, for instance, X-ray diffraction or thermal analysis. It was never considered that base exchange capacities could be used at a high level to separate classes; an attempt was made to use it at subclass level within the ferrallitic class. Most users agree it was a failure.

Even if the classification remains as it was in 1967, knowledge and ideas about soils have been changing steadily. Currently, various trends seem to be making way among French pedologists.

One group of pedologists still favors the classical genetic way of classifying soils. Among them, some prefer soil-forming processes, while others prefer ecology and soil-forming factors. In neither case is it apparent how the separation will be made between processes or

factors. In none of the proposed systems is it apparent how the daily discovery of countless exceptions to the general rules will be dealt with. And as far as language is concerned, it does not appear that any effort has been made to get away from the usual general statements, and to acquire the accurate definitions that are urgently needed.

A second group of pedologists does not believe that classification can be satisfactorily established only through a genetic approach. Soils are indeed the product of various soil-forming factors and processes. But as the link cannot be correctly established, it is considered safer to base the classification on soils themselves and not on factors nor processes. Soil characteristics that can be observed and/or measured--such as mineral and organic constituents, morphology, physical and chemical properties--seem the safest way to a sound classification system. No individual position, sometimes very close to guessing, is possible any more. To begin with an accurate definition of all soil criteria is therefore necessary. Once this problem receives a proper solution, one needs to think about what type of classification one wishes to build: a highly scientific one, a highly pragmatic one, an ascending one, a descending one...etc. In any case, unending discussions lie ahead.

So, the French soil classification system can be considered as influenced both by the Russian genetic shcool and by the mineralogists who studied soil constituents in the tropics early this century. The latter influence prevailed as far as the highly weathered soils are concerned. It is not yet possible to foresee what will come of the work initiated on a new soil classification system. It seems likely that, at least in this case, soil-forming processes will remain subordinate to constituents.

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REPORT OF THE INTERNATIONAL COMMITTEE ON CLASSIFICATION OF OXISOLS

Hari Eswaran

A new committee on the classification of Oxisols (ICOMOX) was established in January, 1978. The committee is still operating in an informal manner, as it has no official mandate from USDA. This will perhaps be forthcoming after the workshop in Malaysia and Thailand.

CIRCULARS

Two circulars were sent out: the first in January and the second in May, 1978. The response from the members was encouraging and copies of some letters received were included in the second circular.

MEETING AT EDMONTON, CANADA

USDA organized two meetings during the XIth ISSS Congress at Edmonton. Your chairman informed the people present of the existence of ICOMOX but since it was organized only recently, there was nothing much to report.

The first meeting, chaired by Jack McClelland, was essentially on the question of developing "machinery" to handle the proposals for modifications to Soil Taxonomy. Jack informed the participants that USDA did not have the funds nor the possibilities to consider suggestions and comments from outside the United States. To handle this aspect, USDA is now strongly considering establishing the post of an International Soil Correlator. And USAID support is being

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sought for this project. A formal resolution at the Malaysia-Thailand Workshop will give considerable momentum to this endeavor.

The second meeting, chaired by Dick Rust, was mainly concerned with a monograph on "History of Soil Taxonomy." Many people want to know the "whys" in Soil Taxonomy and this book is intended for that purpose. Mike Leamy has already taken the initiative and has recorded on tape discussions with Guy Smith on the mollic epipedon A part of this discussion appears in the New Zealand Soils Newsletter and the tapes have been forwarded to USDA. USDA hopes to contact all the fathers of Soil Taxonomy including the godfather - Guy - to produce this monograph.

MEETING AT GHENT

A meeting was arranged at Ghent on July 25, 1978 to discuss some proposals of ICOMOX. The suggestions of the other members who had written to the chairman were also taken into consideration. The minutes of the meeting are included in Appendix I and the proposals in Appendix II.

MALAYSIA-THAILAND WORKSHOP

Thanks to Fredaid and the work already put in by Param and Panichapong and their respective committees, we are assured of another successful meeting in Malaysia and Thailand. The meeting in Malaysia will be devoted mainly to matters of ICOMOX while that in Thailand to ICOMLAC.

Proposals for classification are developed only up to the great group level (Appendix II). However, discussions need not be confined to this level, and suggestions for subgroups are also solicited.

Welcome to Malaysia and Thailand!

APPENDIX I

Minutes of the meeting held at the Geological Institute, University of Ghent, Belgium

Date:	Monday, July 25, 1978. 10:00 a.m. to 5:30 p.m.
Members:	Drs. Guy Smith, Rene Tavernier, Carl Sys, Willie Verheye, and Hari Eswaran.
Subject:	Discussion on report of ICOMOX.
Acknowledgement:	The members wish to thank Mrs. Smith for the sumptuous lunch she provided. This and the cigars and cigarettes kept the group going.

Report

The report of the meeting is presented in two parts. In Appendix II, the suggestions of the group on the classification of Oxisols is presented for discussion at the Workshop.

The major points raised at the meeting at Ghent are given below. No agreement was reached on a few questions and these are also included for further discussion. As the group is heavily biased on Afro-Asian countries, we expect considerable inputs from the people of South America and Oceania. I have taken the liberty of making a few additional changes after the meeting and these are indicated.

Definition of the oxic horizon

1. Thickness criterion is changed to 50 cm. Work done in Malaysia indicates that there is an exponential decrease of feeder roots with soil depth, and it is at about 60 to 70 cm where they become negligible in amount. This is the main reason for increasing the thickness requirement.

2,3. The CEC criteria takes out allophanic soils and those with significant amounts of 2:1 minerals. Note that oxic horizons need to meet both criteria. CEC NH_4Cl is dropped.

4. The pH in NaF is used for eliminating again the allophanic

materials and, more specifically in this context, soils high in halloysite and meta-halloysite.

5. The weatherable mineral stipulation in Soil Taxonomy is reverted to with some modifications. The main argument is that a check on mineralogy can be made with a simple petrographic microscope.

6. The lower texture limit of the oxic is made to correspond to the upper limit of the Psamments.

7. The rock fragments requirement is retained, with an additional clause stating that fragments coated with gibbsite or iron are permitted to occur in higher amounts.

Definition of Oxisols

The concept of the Oxisol is centered around the soil where the oxic horizon extends to more than two meters from the soil surface. The soil may have an ochric or umbric epipedon or a sombric horizon. Plinthite, petroplinthite, a petroferric contact, or a lithoplinthic horizon may be present. In addition, the soil may have segregated gibbsite present as sheets or gravels. In every case the soil has an oxic horizon.

Two intergrades and one extragrade are defined to allow them in the Oxisols. In either, there must be an oxic horizon meeting all the requirements. Conceptually, the intergrades are those which are grading from or to an Oxisol. The first situation is where an oxic horizon overlies an argillic. In this case, apart from meeting the thickness requirement, the oxic must extend to at least 1.25 m from the soil surface. In the second case, an argillic develops in an oxic material. These soils have a subsurface horizon, overlying the oxic, that shows either the clay increment requirement of an argillic or has clayskins identifiable in the field (cutans in thin sections) or both. In Zaire, (Sys and Tavernier, personal communications) this horizon is identified as the "Consistence B" and experience shows that it does not exceed 40 cm in thickness. To be an

Oxisol, this horizon must be underlain by an oxic horizon which extends to at least 1.25 m from the soil surface. The oxic may or may not be underlain by another argillic or a saprolite, neither of which is important for taxonomic purposes. However, if the overlying argillic meets the requirements of an abrupt textural change with the surface horizon, the soil is classified as an Ultisol despite the fact that the argillic is underlain by an oxic. In Central Africa, there is usually a stone line at the limit between the argillic and the underlying oxic horizons.

The extragrade is the case where the oxic rests on rock with or without a thin intervening saprolite. This situation may arise if the rock is limestone or ultrabasic rock or if transported oxic materials sit on rock. To be an Oxisol, the soil must have an oxic horizon and the lithic or paralithic contact appears at depths greater than 75 cm. Shallower soils will go into the Kandepts. Interalia, it may be mentioned that in Oxisols, since a lithic contact at less than 50 cm is rare, a "batholithic" subgroup is proposed for soils where the lithic or paralithic contact appears at a depth of less than 1.25 m.

Finally, plinthite as a defining criteria in Oxisols is eliminated. It now defines one kind of Aquox. It may be necessary to make modifications in the Aquults and Aquepts.

Suborders in Oxisols

Guy explained that the suborders, as they now stand, incorporate two important principles:

1. They can be used in small-scale maps.
2. They attempt to retain the previous zonal, azonal and intrazonal concept. For this reason, climatic factors are brought in at this level.

Consequently, the proposed suborder of Acrox has to be eliminated. The old suborders are obtained with some modifications.

In the Aquox, soils with mottles and pale colors are admitted, even if the mottles do not meet the low chroma requirement. The temperature restriction is brought back into the Humox to keep all the mountain Oxisols together. Humus rich soils in isohyperthermic areas will now belong to the Umbri Great Groups.

Great Groups in Oxisols

Time only permitted discussion of the Orthox. Since the Acrox is dropped from the suborder, it is brought back into the great groups. Its definition is now changed. Some of the soils currently classified as being Acric have to be re-examined.

There was no agreement on the Paleorthox. Everybody disliked the "pale" prefix and there was no agreement (though no serious objection) to bring petroplinthite etc, at the great group level. Since I was asked to think of an alternative prefix, I propose "Lat," e.g. Latorthox.

Subdivisions based on color were received with mixed feelings. Color is significant especially in Oxisols for two reasons: (a) Much of the chemistry of Oxisols is related to iron, and color is a reasonably good parameter related to iron content in Oxisols. In other soils, the relationship is less meaningful. (b) There are not too many field criteria for the differentiation of Oxisols and in this respect, color is helpful. It was proposed that the Xanth- and Hapl- could be combined together as Haplorthox. I have retained this for further discussion.

The position of great groups in the key is tentative and requires modification. The relevance of great group in other suborders of Oxisols needs to be examined.

APPENDIX II

Summary of properties of the oxic horizon

The oxic horizon is a subsurface horizon, exclusive of the argillic or natric, that has the following properties:

1. Is at least 50 cm thick.
2. Has an effective CEC (me bases extractable with NH_4OAc plus aluminum extractable with 1N KCl) of 12 me or less per 100 g clay.
3. Has a CEC by NH_4OAc at pH 7 of 16 me or less per 100 g clay.
4. Has a pH in 1N NaF (ratio 1:50) of less than 9.4.
5. Has no more than traces (5%) of weatherable minerals in the 20 to 200 micron fraction. Muscovite, if present, constitutes less than 10% of this fraction.
6. Has textures of loamy fine sand or finer in the fine earth fraction.
7. Has less than 5% by volume that shows rock structure, unless the rock relicts are coated with gibbsite, iron or both.

Key to Soil Orders

A. .....Histosols

B. .....Spodosols

C. Other soils that have an oxic horizon within 2 m of the soil surface, but not a plaggen epipedon or argillic or natric horizon above or below the oxic; or meet one of the following requirements:

a) If underlain by an argillic or natric horizon, the oxic horizon extends to a depth of more than 1.25 m from the soil surface.

b) If the oxic horizon is overlain by another subsurface horizon having all properties of an oxic, except that it either meets the clay increment requirement of an argillic (apart from an abrupt textural change), or has clayskins, or both, then the underlying oxic

horizon extends to a depth of more than 1.25 m from the soil surface.

c) If underlain by a lithic or paralithic contact within 75 cm of the soil surface, the oxic horizon extends to this contact.

Key to Suborders

CA. Oxisols that have one or both of the following characteristics:

(1) Plinthite that forms a continuous phase within 50 cm of the soils mineral surface, and is saturated with water within this depth at some time during the year; or

(2) Either are saturated with water at some time during the year or are artificially drained, and also have one or both of the following characteristics associated with wetness:

a) A histic epipedon; or

b) If free of mottles, immediately below any epipedon that has moist color value of less than 3.5 there is dominant chroma of 2 or less; or if there are distinct or prominent mottles within 50 cm of the soil surface, either the dominant chroma is 2 or less, or the hue is 2.5 or yellower.

----------AQUOX

CB. Other Oxisols that have either an umbric epipedon or an ochric epipedon that has more than 1% carbon in all subhorizons to a depth of 75 cm or more below the mineral soil surface; and have an isothermic, thermic or cooler soil temperature regime.

----------HUMOX

CC. Other Oxisols that have a torric moisture regime.

----------TORROX

CD. Other Oxisols that have an ustic soil moisture regime.

----------USTOX

CE. Other Oxisols.

----------ORTHOX

Key to the Great Groups of the Orthox

CEA. Orthox that have a sombric horizon.

----------SOMBRIORTHOX

CEB. Other Orthox that have within 1.5 m of the surface, sheets that contain 30% or more gibbsite or a subhorizon that has 20% or more by volume of gravel-size aggregates that contain 30% or more of gibbsite.

----------GIBBSIORTHOX

CEC. Other Orthox that have a zero or positive delta pH in some subsurface horizon of the oxic within 1.5 m of the soil surface.

----------ACRORTHOX

CED. Other Orthox that have within 1.5 m of the soil surface more than 20% by volume of petroplinthite, or a litho-plinthic horizon or a pertroferric contact.

----------LATORTHOX

CEE. Other Orthox that have either an umbric epipedon or an ochric epipedon that has more than 1% carbon in all sub-horizons to a depth of 75 cm or more below the mineral soil surface.

----------UMBRIORTHOX

CEF. Other Orthox that do not have an anthropic epipedon and have a base saturation of 35% or more (by NH_4OAc) in the epipedon and in all subhorizons of the oxic to a depth of 1.5 m from the soil surface.

---------- EUTRORTHOX

CEG. Other Orthox that have a value and chroma (moist) of 4 or less in all subhorizons of the oxic to a depth of 1.5 m from the soil surface.

----------MELANORTHOX

CEH. Other Orthox that have a hue of 5YR or redder in all subhorizons of the oxic to a depth of 1.5 m of the soil surface.

----------RHODORTHOX

CEI. Other Orthox that have a hue of 10YR or redder in all sub-horizons of the oxic to a depth of 1.5 m of the soil surface.

----------XANTHORTHOX

CEJ. Other Orthox.

----------HAPLORTHOX

OXISOLS OF MALAYSIA

S. Paramananthan and C. P. Lim

ABSTRACT

Oxisols occupy about 50,000 sq km or 15% of Malaysia and are one of the more important soil orders mapped in Malaysia. They are particularly important in Peninsular Malaysia where they have been extensively utilized for perennial crop cultivation. The distribution of Oxisols in Malaysia appears dependent largely on two factors - the parent material and the climate. Oxisols are commonly developed over highly weatherable parent material such as ultra-basic, basic and metamorphic rocks. On more siliceous rocks they are only found on granite where the moisture regime is perudic.

Physical, chemical, mineralogical, and micromorphological properties of the Oxisols found in Malaysia appear to be largely dependent on the nature of the parent material from which they are developed. The slope position and the nature of the topography also determine some properties of these soils.

Oxisols have been utilized mainly for the cultivation of rubber, oil palm, cocoa, and pepper. They represent some of the more productive soils in the country. However, early establishement of the crop is difficult and heavy doses of fertilizers are required. Soils with a skeletal textural class require special management.

Some problems in the classification of these soils using Soil Taxonomy (Soil Survey Staff, 1975) have been encountered, and some proposals for changes are discussed and included in the text.

INTRODUCTION

Malaysia lies between 1° and 7°N latitude and 100° and 119°E longitude. Peninsular Malaysia on the Asian mainland is comprised of 11 states; the states of Sabah and Sarawak are on the island of Borneo. The total land area of Malaysia is 336,700 sq km.

Malaysia has a hot, humid, tropical climate. The climate of the lowlands belongs to Koppen's tropical rainforest climate (Af), with no distinct dry season. The rainfall ranges from about 1500-4000 mm/year and the average daily temperature is about 27°C with little seasonal variation. The temperature regime in the lowlands is isohyperthermic. In the northwest of Peninsular Malaysia, the climate qualifies for Koppen's tropical monsoon climate (Am) as it experiences a dry spell from December to February. This area has a soil moisture regime which is udic marginal to ustic (Paramananthan et al, 1975; Eswaran and Van Wambeke, 1975). The southeast of Peninsular Malaysia and part of Sarawak around Kuching has a perudic moisture regime while the rest of the lowlands in the country experience a udic moisture regime. With an increase in elevation the moisture regime becomes perudic and the temperature regime isothermic and isomesic.

SOIL SURVEYS IN MALAYSIA

Systematic soil surveys have been carried out by the National Soil Survey Sections of the Departments of Agriculture of Peninsular Malaysia, Sabah and Sarawak. Basically three scales of mapping are carried out and these are outlined in Table 1.

In Peninsular Malaysia, soil surveys were initiated in the latter part of the last century. However, systematic soil surveys were not initiated until 1955 and the survey of Peninsular Malaysia was completed in 1967. Since then semi-detailed and detailed soil surveys have been completed. In Sabah the reconnaissance soil survey was completed in 1975 while in Sarawak this survey is expected to be

Table 1. Scales of mapping.

Scale of Mapping	Intensity of Examination	Mapping Units	Scale of Map	
			Field	Final
Reconnaissance	Traverses 1-2 miles apart, auger boring every 10 to 20 chains	Soil association complexes	1:63,360	1:50,000 1:136,000
Semi-detailed	Traverses every 1/2 mile, auger boring every 10 chains, and pits every half mile	Soil series, associations	1:63,360 1:25,000	1:63,360
Detailed	10 x 10 chains	Soil series, phases, variants	1:400	1:12,500

complete by the end of this year. However, in both these states semi-detailed and detailed surveys of selected areas have also been performed.

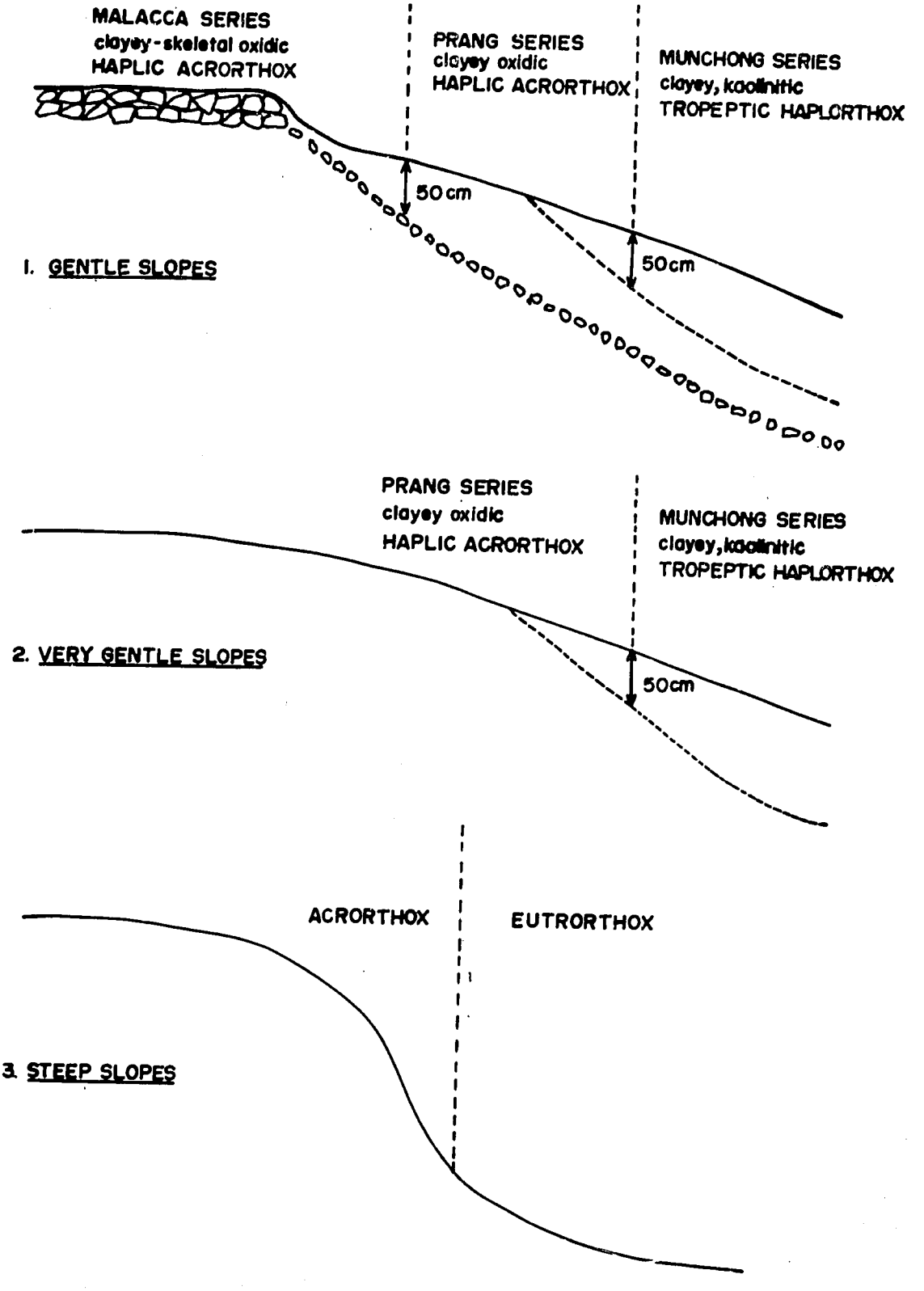
With soil surveys done in the past, very little emphasis was placed on chemical, mineralogical, and micromorphological data. The classification of soils during field mapping -- particularly during the reconnaissance soil survey -- has been based mainly on parent material, color, texture, and soil depth. Little emphasis was placed on genetic and micromorphological studies for soils of the country (Noordin, 1975; Eswaran and Sys, 1976; Wong, 1976; Lim, 1977; Paramananthan, 1977). The discussions presented have been based mainly on these studies.

OXISOLS OF MALAYSIA

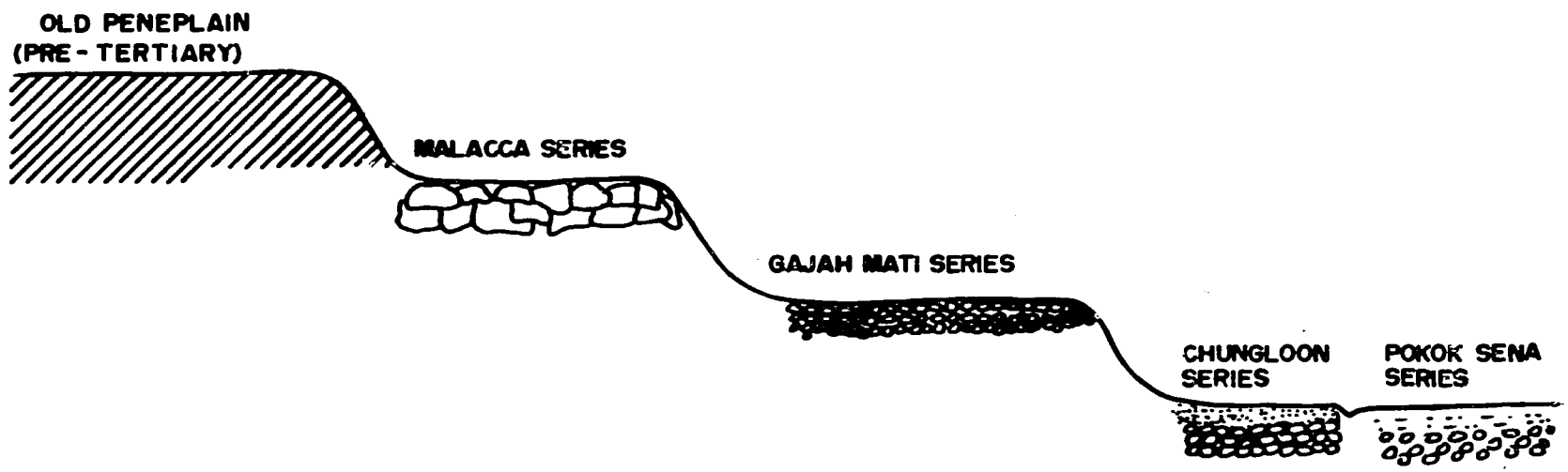
Distribution

Oxisols are of restricted occurrence in Sabah and Sarawak but are an important group of soils in Peninsular Malaysia. These soils occur primarily on basic parent material such as serpentinite, gabbros, basalts, and andesites. In Sabah, these soils are found mainly in the Tawau and

SLOPE RELATIONSHIP BETWEEN OXISOLS OF PENINSULAR MALAYSIA



GEOMORPHIC RELATIONSHIP BETWEEN "LATERITIC SOILS" IN PENINSULAR MALAYSIA



Semporna areas where basic and ultrabasic parent material occur (Acres et al, 1975). In Sarawak most Oxisols are restricted to West Sarawak where basalts, andesites, and gabbros occur (Andriesse, 1975). Oxisols have been mapped fairly extensively throughout Peninsular Malaysia. They have been mapped in isolated areas in the northern states of Kedah and Kelantan, but they become more extensive towards the south. They occur mainly over intermediate and basic igneous rocks and metamorphic rocks such as schists, amphibolites, and hornfels. The distribution of Oxisols in Peninsular Malaysia appears to be governed by parent material and soil moisture regime.

Oxisols are found on parent material which is rich in ferromagnesian minerals, e.g. intermediate and basic igneous rocks and high grade metamorphic rocks, and on more siliceous parent material, such as granites and dacites. Oxisols are only formed where the climate is perudic or tending towards perudic. In areas around Kuantan and in Johore, where precipitation exceeds evapotranspiration, the extent of Oxisols is greater. Thus gibbsite gravel (a gibbsiorthox) is found only in one soil on rhyo-dacite parent material in an area with a distinct perudic soil moisture regime (Paramananthan, 1977).

Field characteristics

The Oxisols mapped in Malaysia generally occur on gently undulating, relatively stable terrain. However, in some areas these soils have been mapped on steep slopes, and there the parent material is invariably highly weatherable, e.g. serpentinites and basalts. The position on the slope also appears to have some effect on soil properties. The relationship between the slope and the nature of some soils is shown in Figs. 1 and 2. Oxisols have only been mapped on steep slopes over highly weatherable parent materials, such as serpentinites. The upper part of such slopes have soils classified as Acrorthox and the lower slopes have soils classified as Eutrorthox. On gentler slopes deep, red autochthonous profiles have been classified and mapped as Acrorthox, while on lower slopes yellow, sandier Haplorthox occur. On old surfaces the presence of petroplinthite has been observed, but a complete understanding of its geomorphic relationship is still to be studied.

Physical properties of the Oxisols mapped in Malaysia appear to be very strongly correlated to amounts of weatherable minerals found in the parent material. With increased amounts of weatherable minerals the hues become redder because of the amount of free iron present in these soils. In some soils however, although the free iron content is high, the hue becomes yellow. then they have a chroma value of 4/4 or 3/3.

With an increase in the amount of weatherable minerals in the parent material, there is a general weakening of the macrostructure and an increase in the friability of the soil. As a rule of thumb, the redder the soil the weaker the structure and the more friable it is. However, they often have very stable fine granular or crumb structure. Such aggregates are often difficult to disperse and consequently routine mechanical analysis gives low values for clay content.

Almost all the Oxisols mapped in Malaysia have almost indistinct horizonation and good internal drainage. The rate of internal drainage increases with the weathering potential of the rock.

Physical characteristics

Clay content of soils is largely dependent on the nature of the parent material. All Oxisols mapped to date in Malaysia have more than 40 percent clay, thus falling into the clayey textural family class. Some soils which have either petroplinthite or gibbsite gravels fall into the clayey-skeletal class. The silt/clay ratios for the soils are generally low and decrease with the degree of soil weathering.

Oxisols in Malaysia have a lower bulk density than Ultisols. More than 80 percent of the soils with an oxic horizon mapped in Peninsular Malaysia have a bulk density between 1.0 and 1.5 g/cc, with a mean of 1.19 g/cc. Among these, soils with a higher clay content have a lower bulk density and are hence more porous. The mean is 1.55 g/cc for soils in Peninsular Malaysia with an argillic and cambic horizon, and having over 50 percent clay (Paramananthan, 1977).

About 80 percent of the soils with oxic horizons in Peninsular Malaysia have between 50 mm and 100 mm/m moisture content between 1/3 bar and 15 bar. These have a mean of 78.4 mm/m. If the 1/10 bar and 15 bar tensions are used to estimate available moisture, about 45 percent of the soils have a moisture content between 50 and 100 mm/m, while another 45 percent have between 100 and 150 mm/m, with a mean of 105.4 mm/m. The Ultisols, on the other hand, generally have the capacity to store more moisture than Oxisols.

Chemical characteristics

As with the field and physical characteristics, the chemical characteristics of Oxisols are strongly related to the type of parent material. The pH for most soils is less than 5.0, but on more basic materials such as basalts and serpentinites, pH 5.0 is exceeded. This increase in pH appears to be correlated with the free iron content of the soils. To date only one soil -- the Pinanakan Series on ultrabasic rocks -- has a ΔpH which is positive. The free iron content of Oxisols is high and often strongly related to the mineralogy of the parent material. The free iron content of Oxisols ranges from about 5 percent to over 30 percent. The hue of the soil is also related to the free iron content, being redder with an increase in free iron content. The cation exchange capacity (CEC) of most Oxisols is low, indicating an advanced stage of weathering. The permanent charge (PC) in most soils is less than 1.5 me/100 g clay, indicating that they are in the "acric" stage of soil formation. The PC and the PDC/PC ratio appear to be strongly correlated to the degree of weathering.

Mineralogy

Kaolinite, gibbsite and iron oxides are by far the commonest minerals in these soils. Kaolinite is predominant in soils developed over parent materials rich in silica, while gibbsite and iron oxides predominate in soils over material rich in weatherable minerals. Gibbsite, while present in many Oxisols, is present as gravels only in one soil over rhyo-dacite parent material in the perudic region. The mineralogy class of all soils is either kaolinitic or oxidic, depending on the de-

gree of weathering.

Micromorphology

The micromorphology of soils in Malaysia reflect to some extent their weathering stage. Most Oxisols studied show a distinct micromorphology compared to Ultisols and Inceptisols. The grains found on Oxisols are mainly a reflection of the parent material, i.e. quartz in the more silica-rich parent material, and ilmenite and magnetite in soils on basic and ultrabasic rocks. The plasma in these soils consists essentially of clay with varying amounts of iron-oxyhydrates. Soils with a high iron content lose their plasma color transparency and tend to be isotic. The related distribution pattern in Oxisols is also largely dependent on the degree of soil weathering and the nature of the parent material. Oxisols on granite have a prophyroskelic (Brewer, 1964) or porphyric-related (Eswaran and Banos, 1976) distribution. For soils in a more advanced stage of weathering the plasma tends to form aggregates, giving rise to large amounts of pores. Such a related distribution has been termed porphyroskelic (Brewer, 1964) or agglutinic (Eswaran and Banos, 1976). Most Oxisols for which micromorphological studies have been made do not show the presence of argillans even at depths greater than one meter In soils at a more advanced stage of weathering, gibbsite glaebules initially appear as fine nodules, and they increase in size with intensity of weathering.

Productivity and management

The Oxisols represent an important group of soils in Malaysia, including some of the more productive areas in the country where perennial crops have been planted. In Sabah most of these soils have been planted with cocoa, oil palm, and rubber, while in Sarawak they have mainly been planted with pepper and rubber. In Peninsular Malaysia these soils have been mainly planted with rubber, oil palm and some cacao. Most Oxisols (except those with petroplinthite at shallow depths) are considered to be highly productive soils (Class 1) for oil palm, rubber, and pepper cultivation (Table 2). In the case of oil palm, even though these soils are

Table 2. Productivity potential of some soils from Peninsular Malaysia.

Soil Series	Subgroup	Family	Rubber		Oil Palm	
			Productivity Class	Yield Level (kg/ha/annum)	Productivity Class	Yield Level (tons/FFB/a/yr)
Kuantan	Haplic Acrorthox	clayey, oxidic.	I	1250-1350	I	8 - 10
Malacca	Haplic Acrorthox	clayey-skeletal, oxidic	IV	800- 900	IV	4 - 6
Munchong	Tropeptic Haplorthox	clayey, kaolinitic	I	1250-1350	I	8 - 10
Bungor	Typic Paleudult	clayey, kaolinitic	I	1250-1350	I	8 - 10
Rengam	Typic Paleudult	clayey, kaolinitic	I	1250-1350	I	8 - 10
Durian	Orthoxic Tropudult	clayey, mixed	III	1000-1150	II	8 - 9
Batu Anam	Aquoxic Dystropept	clayey, mixed	IV	750-1000	III	6 - 8
Selangor	Aeric Tropaquept	clayey, mixed	V	800-1000	I	10 - 12
Briah	Aeric Tropaquept	clayey, mixed	V	800-1000	I	10 - 12
Parit Botak	Typic Sulfaquept	clayey, mixed	V	800- 850	IV	3 - 5

considered to be suitable and give fairly high yields, they are prone to yield fluctuations depending on rainfall. Discussions with agronomists indicate that the biggest problem with these Oxisols is early establishment of the crop. The success or failure of the crop during this period is largely dependent on rainfall. Once the crop is established and the canopy closes, the fluctuation in yield is less pronounced.

The low fertility status of these soils has long been recognized and heavy doses of fertilizers are added in order to ensure good yield. Magnesium deficiences and micronutrient toxicities have also been reported on these soils.

Special management practices are used in areas where soils with clayey skeletal families dominate. In these areas, particularly for oil palm, planting holes are often made larger and deeper to loosen the petroplinthite layer, thereby ensuring good root penetration and minimizing wind damage.

In addition to this, an extra heavy dose of fertilizers are added in the form of split applications. In spite of these practices the yield of oil palm is often delayed by a year or two, and it is much lower than that for other Oxisols.

Classification

The classification systems used in Sabah, Sarawak, and Peninsular Malaysia are different. In Sabah the FAO/UNESCO Legend for the Soil Map of the World was used and the soils fall into the Rhodic Ferralsols, Zanthic Ferralsols, Orthic Ferralsols, and Acric Ferralsols. In Sarawak, soils are Lateritic and probably Tropeptic Haplorthox. In Peninsular Malaysia most soils have been classified recently (Eswaran et al, 1977) according to Soil Taxonomy (Soil Survey Staff, 1975), and they fall into four great groups: Gibbsiorthox, Dutrorthox, Acrorthox, and Haplorthox. By far the Haplic Acrorthox and Tropeptic Haplorthox are the commonest. When attempting to classify the soils mapped in Malaysia according to Soil Taxonomy, problems were encountered. Some of these difficulties will be discussed in the following sections.

Limits between Acrorthox and Haplorthox. The definition of Acrorthox is based on a permanent charge of 1.5 me and the lack of discernible structure. Structure is a very subjective criterion to be used at such a high level of classification. At the subgroup level the Acrorthox is subdivided on the basis of Δ pH into the typic and haplic subgroups. It is our opinion that Δ pH is a more important and significant criterion and should hence be used at the great group level while permanent charge (PC) should be used at the subgroup level. The determination of PC in these highly weathered soils is wrought with many errors, and hence differences in lab techniques could also change the great group. Therefore, it is proposed that Δ pH be used to define the great group of Acrorthox while the PC be used to define the acric subgroup in both Haplorthox and Acrorthox. Using this modified distinction, most Oxisols in Malaysia would be Acric Haplorthox or Tropeptic Haplorthox. It seems odd that such productive soils as are found in Malaysia are placed in the Acrorthox, which should rightly be soils having low productivity. Only one soil in Malaysia in the Pinanakan series, found on ultrabasics in Sabah, woild be an Acrorthox with the new definition.

Tropeptic subgroup of Haplorthox. The tropeptic subgroup of Haplorthox is defined as soils having strong structures and/or in which the oxic horizon does not extend to a depth of 1.25 m. Structure is a very subjective criterion.

It is therefore proposed here that the tropeptic subgroup of Haplorthox be subdivided into two subgroups, namely leptic and tropeptic; and the new tropeptic subgroup be defined using PC rather than the grade of structure. If the Acrorthox as proposed earlier is defined using Δ pH, then the subgroups of the Haplorthox could be redefined as follows:

PC (me/100 g clay)	Criterion in Taxonomy
> 10	Oxic horizon
6 - 10	Tropeptic Subgroup of Haplorthox
1.5 - 6	Typic Subgroup of Haplorthox
< 1.5	Acric Subgroup of Haplorthox

The leptic subgroup would then be soils in which the oxic horizon does not extend to more than 1.25 m from the mineral soil surface.

The key for the great groups of the Orthox and Soil Taxonomy (Soil Survey Staff, 1975) can thus be modified according to the suggestions made here. The revised key is as follows:

KEY TO GREAT GROUPS OF ORTHOX

Orthox that have a sombric horizon.

SOMBRIORTHOX

Other Orthox that have within 1.25 m of the soil surface, sheets that contain 30% or more gibbsite or a subhorizon that has 20% or more by volume gravel-size aggregates that contain 30% or more gibbsite.

GIBBSIORTHOX

Other Orthox that have a positive Δ pH in some subhorizon of the oxic horizon within 1.25 m of the soil surface.

ACRORTHOX

Other Orthox that do not have an anthropic epipedon and have base saturation of 35% or more (by NH_4OAc) in the epipedon and all subhorizons of the oxic horizon to a depth of at least 1.25 m.

EUTRORTHOX

Other Orthox that have an umbric epipedon or an ochric epipedon that has 1% carbon in all subhorizons to a depth of 75 cm or more below the mineral soil surface.

UMBRIORTHOX

Other Orthox.

HAPLORTHOX

Acrorthox. These are Orthox that are deep, freely-drained soils having a net positive charge in some subhorizon of the oxic horizon within 1.25 m of the soil surface. They have virtually lost all ability to retain bases in their mineral fraction. No subgroups for these soils are proposed at this stage as they are not common in Malaysia.

Haplorthox. These are Orthox of tropical evergreen forests. They may be yellow or red and have a net negative charge. These soils are quite productive and are the commonest of the Oxisols mapped in Malaysia.

Haplorthox are Orthox that:

1. Do not have a sombric horizon.
2. Do not have sheets of gibbsite or gravel-sized aggregates cemented by gibbsite within 1.25 m of the soil surface.
3. Have Δ pH which is negative or zero in all subhorizons of the oxic horizon.
4. Have a base saturation (by NH_4OAc) that is <35% in some subhorizon of the oxic horizon within 1.25 m of the mineral soil surface.

Distinctions between Typic Haplorthox and other subgroups. The subgroups defined and described have been only partly developed. Typic Haplorthox are Haplorthox that:

1. Do not have mottles with chroma of 2 or less accompanied by red or dark red mottles within 1.25 m of the soil surface.
2. Have less than 5% by volume plinthite in all subhorizons within 1.25 m of the soil surface.
3. Have texture that is sandy clay loam or finer in all parts of the oxic horizon within 1.25 m of the mineral soil surface.
4. Have an oxic horizon which extends to more than 1.25 m of the soil surface.
5. Have in all subhorizons of the oxic horizon a cation retention capacity of 1.5 me or more (from NH_4Cl) per 100 g clay (or 1.5 me or more extractable aluminum plus exchangeable bases per 100 g clay).

6. Have in all subhorizons of the oxic horizon a permanent charge of 6 me/100 g clay or less.
7. Have a hue redder than 10YR in all parts of the upper 75 cm that have a color value (moist) of 4 or more if the hue becomes redder with depth by more than 2.5 Munsell units within the upper 1.5 m, and if there are mottles due to segregation of iron within the upper 75 cm.
8. Do not have a subhorizon of the oxic horizon that has as much as 4% more clay (relative) and as much as 15% more clay (absolute) than an overlying subhorizon that has a coarse-loamy or coarser particle size class and is 60 cm or less above the horizon having the greater percentage of clay.

Acric Haplorthox are like Typic Haplorthox except for 5.
Aquic Haplorthox are like Typic Haplorthox except for 1.
Epiaquic Haplorthox are like Typic Haplorthox except for 7.
Plinthic Haplorthox are like Typic Haplorthox except for 2.
Quartzipsammentic Haplorthox are like Typic Haplorthox except for 3.
Leptic Haplorthox are like Typic Haplorthox except for 4.
Tropeptic Haplorthox are like Typic Haplorthox except for 6.
Ultic Haplorthox are like Typic Haplorthox except for 8.

In the discussion above no attempt was made to suggest changes in the classification of soils with petroplinthite. It is our opinion that these soils should be separated at least at the great group level. They form an important group of soils in Peninsular Malaysia and their management involves special techniques. As such we feel that they should be separated at a higher level than the present family level.

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OXISOLS OF THAILAND

S. Rojanasoonthon and S. Panichapong

ABSTRACT

Oxisols have become virtually non-existent in Thailand through the application of the definitions for Oxisols and the oxic horizon in Soil Taxonomy (Soil Survey Staff, 1975). Red soils in Thailand, which were classified as Latosols and Reddish-brown Lateritic soils, occur in spots and patches either on old landscapes or on basic rock outcrops throughout the northeast plateau, and the southeast and southern regions of the Kingdom.

Four of the so-called Latosols were studied in 1972. Only one with a very limited occurrence on basalt outcrop, the Tha Mai series, appeared to fit the oxic horizon concept and is the sole remaining Latosol in the order of Oxisols. The remaining three series, all from old landscapes, fail to have less than 5% water-dispersible clay and less than 1% clay-skins. The Siracha series was classified as an Alfisol on the strength of an argillic horizon and high base saturation. The Yasothon series occurs throughout the northeast and has an argillic horizon and low base saturation; therefore, it was classified as a Paleustult. The Sadao series, which occurs only in a few spots in the south, was placed in the Rhodudult great group.

In the highland of the north, patchy occurrences of red soils derived from basic rocks and some yellow and grayish-brown soils, presently grouped in Paleustults with low activity clays, may fit the Oxisol concept. Detailed checking and repeated analyses may reveal more meaningful

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solutions. Under the present situations, unless some amendments are made, Oxisols are virtually non-existent in Thailand.

INTRODUCTION

In Thailand, isolated patches of red soils on old stable landscapes and on basic rock outcrops have been classified as Reddish-brown Latosols and Red Yellow Latosols (Dudal and Moormann, 1964). They were also mapped as such in the general soil map of the Kingdom of Thailand (Moormann and Rojanasoonthon, 1972). Other red and reddish-brown soils on various landscapes with less pronounced age and stabilities are widespread throughout Thailand. They have been mapped as Reddish-brown Lateritic and Red Yellow Podzolic soils with or without low activity clays (LACs). In Soil Taxonomy (Soil Survey Staff, 1975) only a few soil series of the Reddish-brown Latosols and Red Yellow Latosols can be classified directly as Oxisols. Most of the other red and reddish-brown soils which have been called Reddish-brown Lateritic soils, Red Yellow Pedzolic soils, and Red Brown Earths were grouped as either Alfisols, Ultisols, or Inceptisols. A few of the "Oxisol" soil series will be described in this paper according to their occurrence, distribution, formation, and classification. Questionable groups of soils will be discussed as to their placing in Soil Taxonomy and the difficulties encountered in their measurement and analyses, particularly where LACs are concerned.

GENERAL INFORMATION ABOUT THAILAND

Thailand lies in the tropical monsoon zone of Southeast Asia between about 5° and 21° north latitude; its total land area is 513,982 sq. km. Thailand has a monsoonal climate and the dry season is from November through February, which coincides with the prevailing northeast monsoon. Hot weather and variable winds prevail during March, April, and May. The rainy season from May through October coincides with the

southwest monsoon. On the southeast coast of Peninsular Thailand, the rainy season lasts until December.

Most of Thailand has an average rainfall of 1100 to 1500 mm. High rainfall zones (1000 mm and above) are found in Peninsular Thailand, particularly in its southeastern tip. A major trough of low rainfall is found in the rainshadow of the Tenessarim Range (less than 1100 mm). A large part of Thailand has a pronounced dry season of 3 months or more during which soils dry to a considerable depth for a period of more than 60 consecutive days (ustic moisture regime). An exception occurs in the south and southeast where soils remain moist at relatively shallow depths throughout the year (udic moisture regime).

Temperatures in Thailand show slight variations with the seasons. At lower elevations, the minimum temperature occurs during the dry season; the mean monthly temperature for January ranges from 22° - 26° C for most of the country. The average hot season temperature in April is from 28° - 32° C, and during the rainy season the values are intermediate. The mean monthly temperature in the south remains at 26° - 30° C throughout the year. Most of Thailand can be classified as AW Tropical Savanna. Limited parts of the mountain ranges in the north are sufficiently cool to be classified as having CW Humid Subtropical Climate. The lower tip of the Southeast Coast and most of Peninsular Thailand have a Tropical Monsoon Climate AM.

Thailand can be divided into two distinct geographical regions: the northeast and the rest of the country, including Peninsular Thailand. The rocks in the northeast are mainly arenaceous, i.e. sandstone, shale, conglomerate etc., and are flat or gently folded. The rest of the country has clastic sediments from shale, sandstone, and limestone. Some of these rocks are metamorphosed and show evidence of intense foldings. Igneous rocks are relatively rare in the northeast but are common in the folded regions.

OCCURRENCE AND DISTRIBUTION OF OXISOLS IN THAILAND

Oxisols as they have been classified in Thailand occur sporadically and in patches throughout the Kingdom. Significantly large areas are, however, in the lower part of the Northeast Plateau and the Southeast Coast. The study and mapping of Ultisols, Alfisols, and Oxisols in Thailand was done by Moncharoen and Vijarnson (this workshop, Vol. II). Ultisols and Alfisols occupy approximately 276,223 sq. km., or 53.7% of the total land area of the Kingdom, with Ultisols dominating (43.03% of the land area). Limited occurrences of Oxisols are indicated in the map (Fig. 1). As it now stands, occurrence of Oxisols is almost negligible in the Kingdom (Table 1).

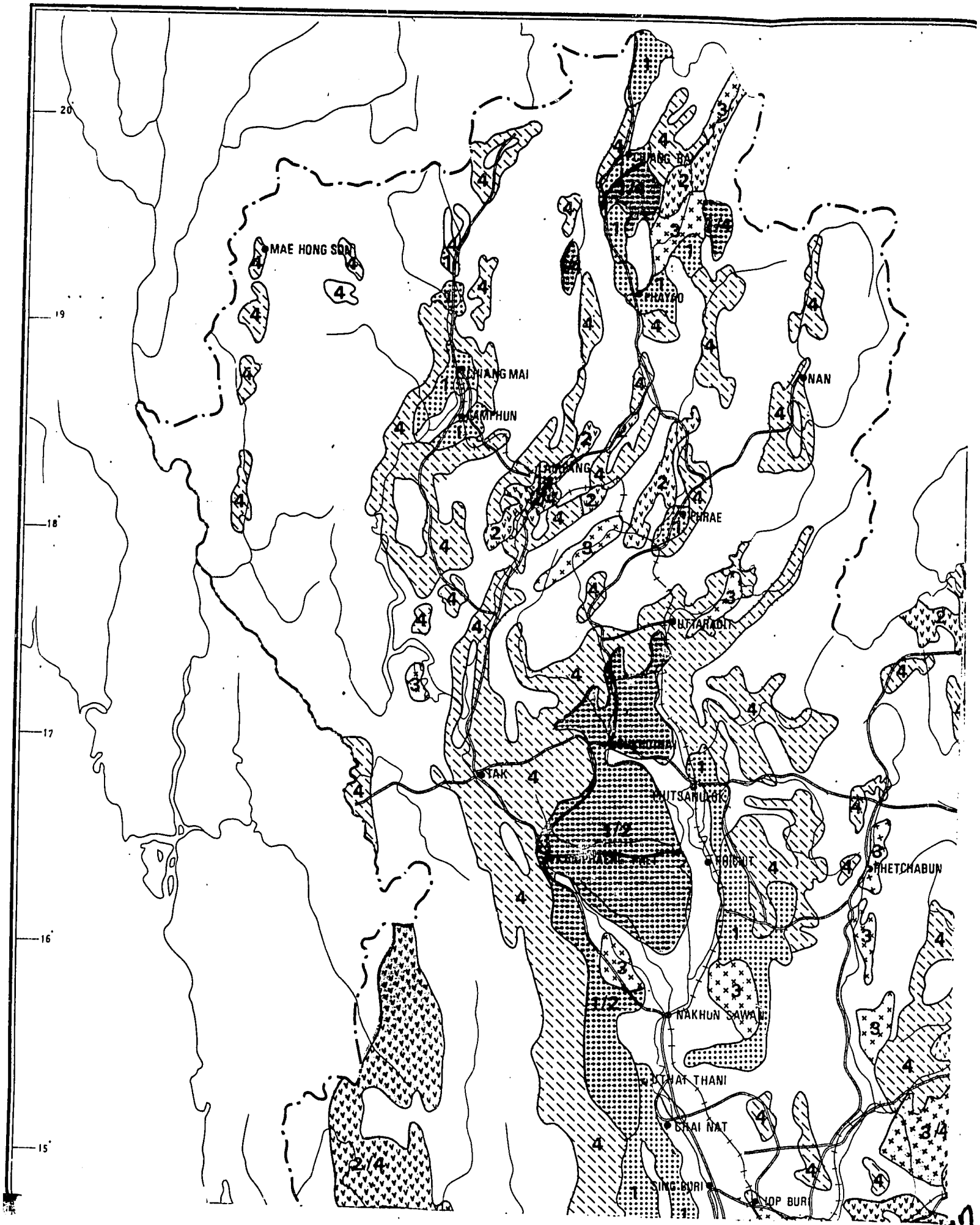
Table 1. Distribution of Oxisols in Thailand.

Subgroup	Southeast Coast		Northeast Plateau		Total	
	(km)	(%)	(km)	(%)	(km)	(%)
Ustox	200.5	0.04	742.6	0.14	943.1	0.18
Orthox	237.6	0.05	-	-	237.6	0.05
				Total	1180.7	0.23

After Moncharoen and Vijarnsorn, 1979, this publication, Vol. II: Thailand.

FORMATION AND CHARACTERISTICS OF OXISOLS IN THAILAND

The study of Oxisols in Thailand indicates that there are two distinctly different groups of parent materials--basalt and old alluvium. Various small outcrops of basalt in the form of plugs, cones, and lava flow occur in the north (as sporadic occurrences throughout the Pasak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MAE HONG SON
CHIANG MAI
LAMPHUN
LAMPANG
PHAYAO
NAN
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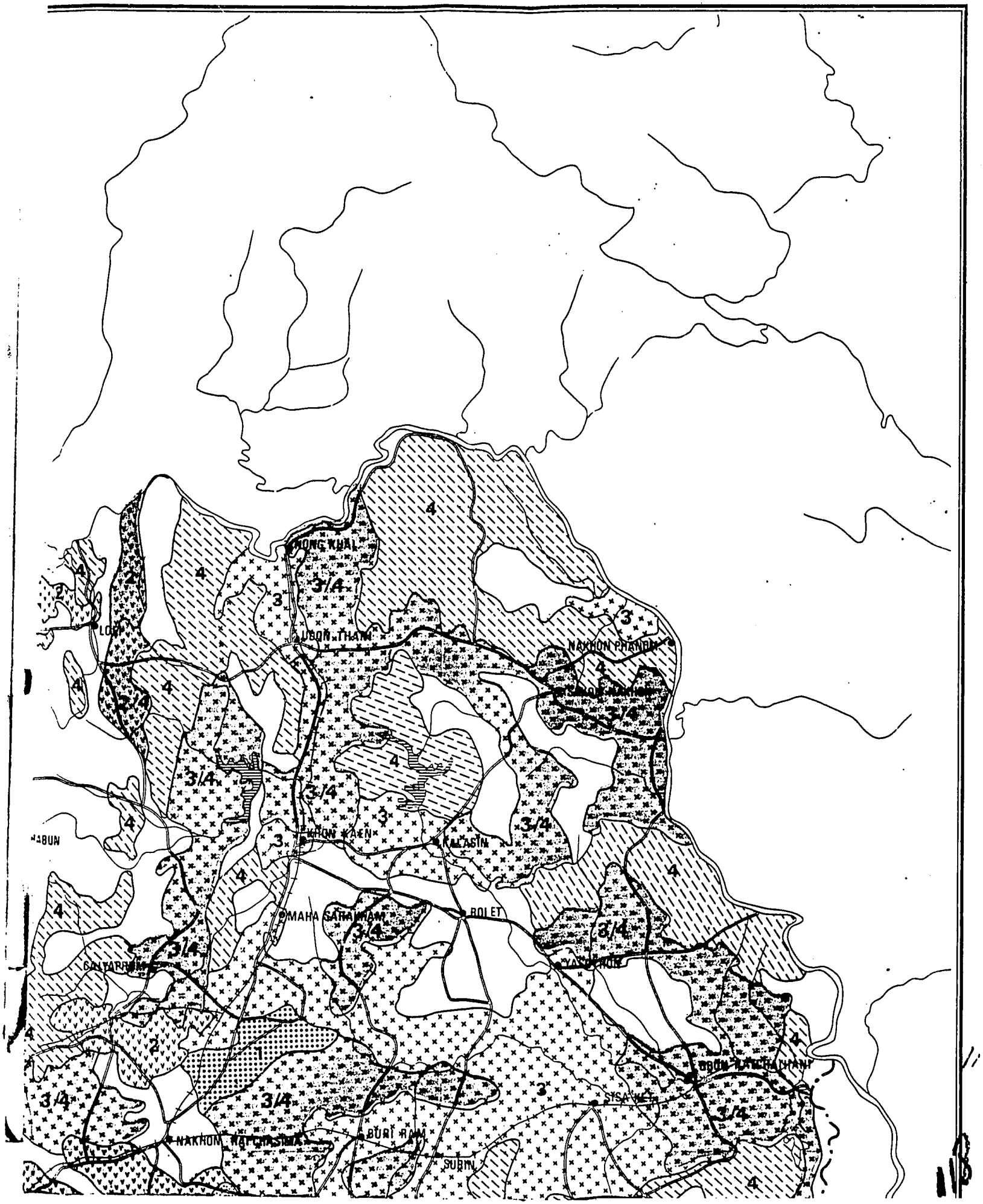
TAK
PHITSANULOK
PHETCHABUN
NAKHON SAWAN
CHAI NAT
SING BURI
LOP BURI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LOEI
UBON THANI
NAKHON PHANOM
KHON KAEN
KALASIN
ROI ET
MAHA SARAKHAM
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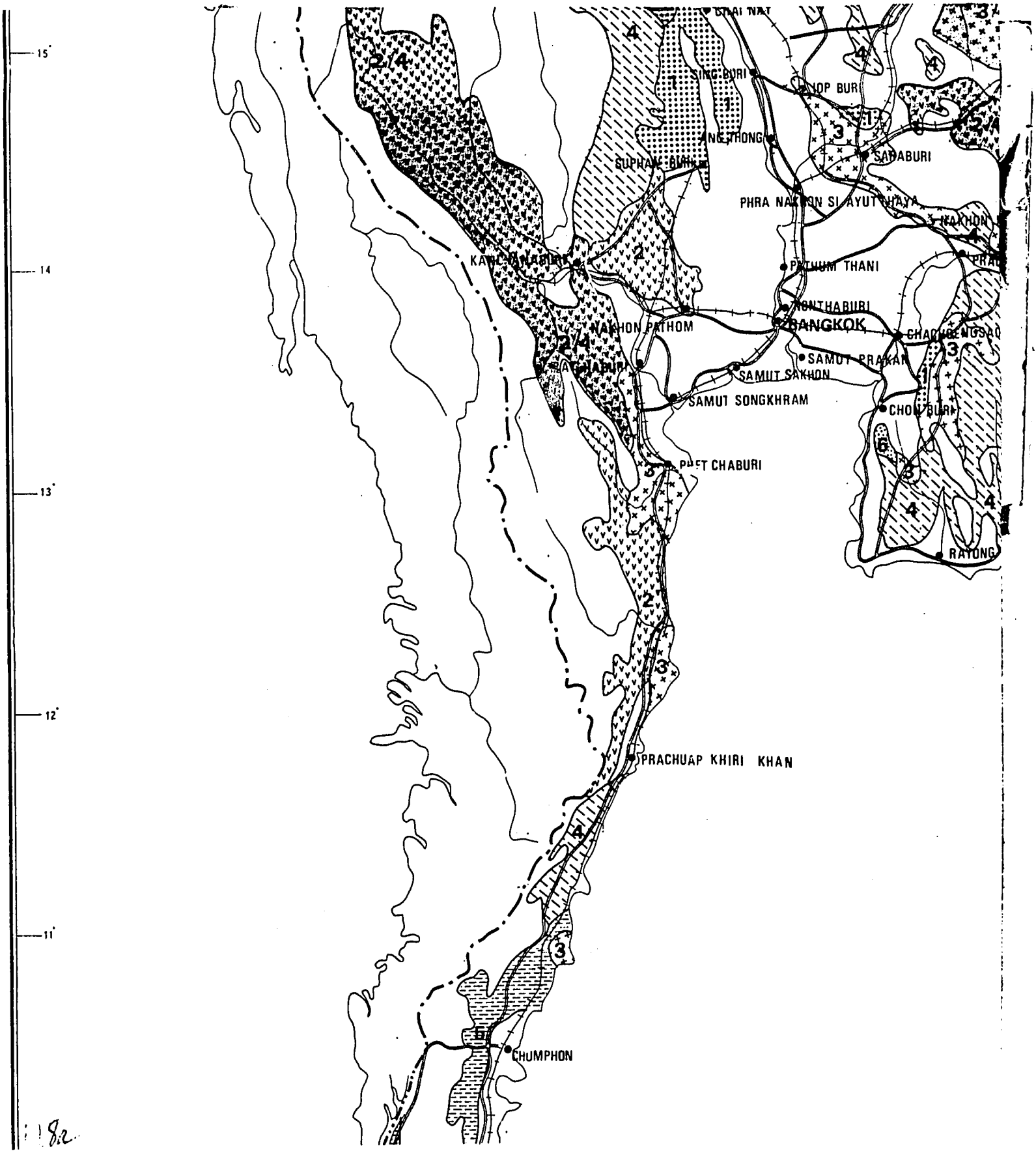
SISAKET
BURI RAM
SURIN
NAKHON RATCHASIMA
CHAIYAPHUM
NABUN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SUPHAN BURI
PHRA NAKHON SI AYUTTHAYA
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KANCHANABURI
PATHUM THANI
NONTHABURI
BANGKOK
NAKHON PATHOM
SAMUT PRAKAN
SAMUT SAKHON
SAMUT SONGKHRAM
CHONBURI
PHET CHABURI
RAYONG
PRACHUAP KHIRI KHAN
CHUMPHON

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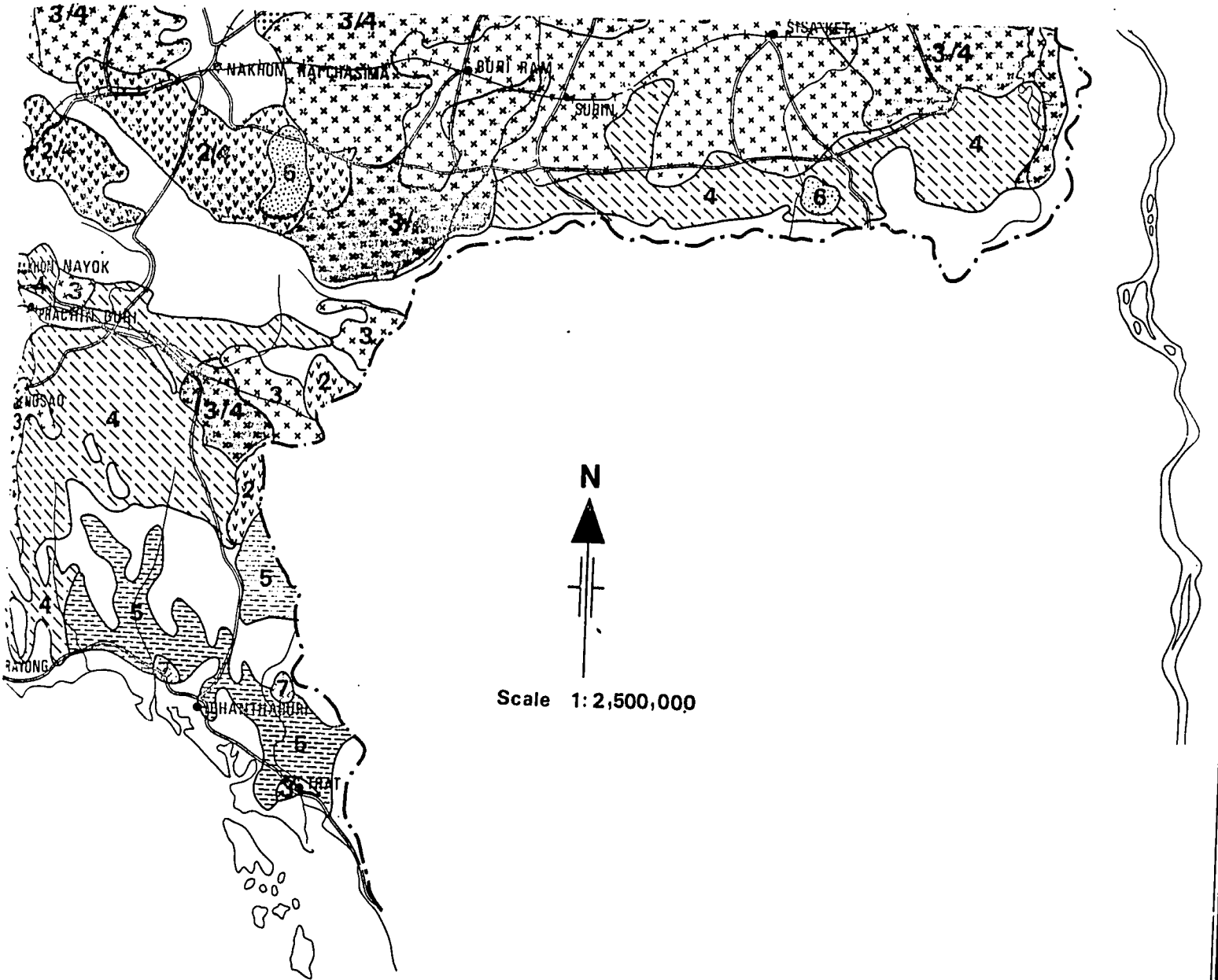
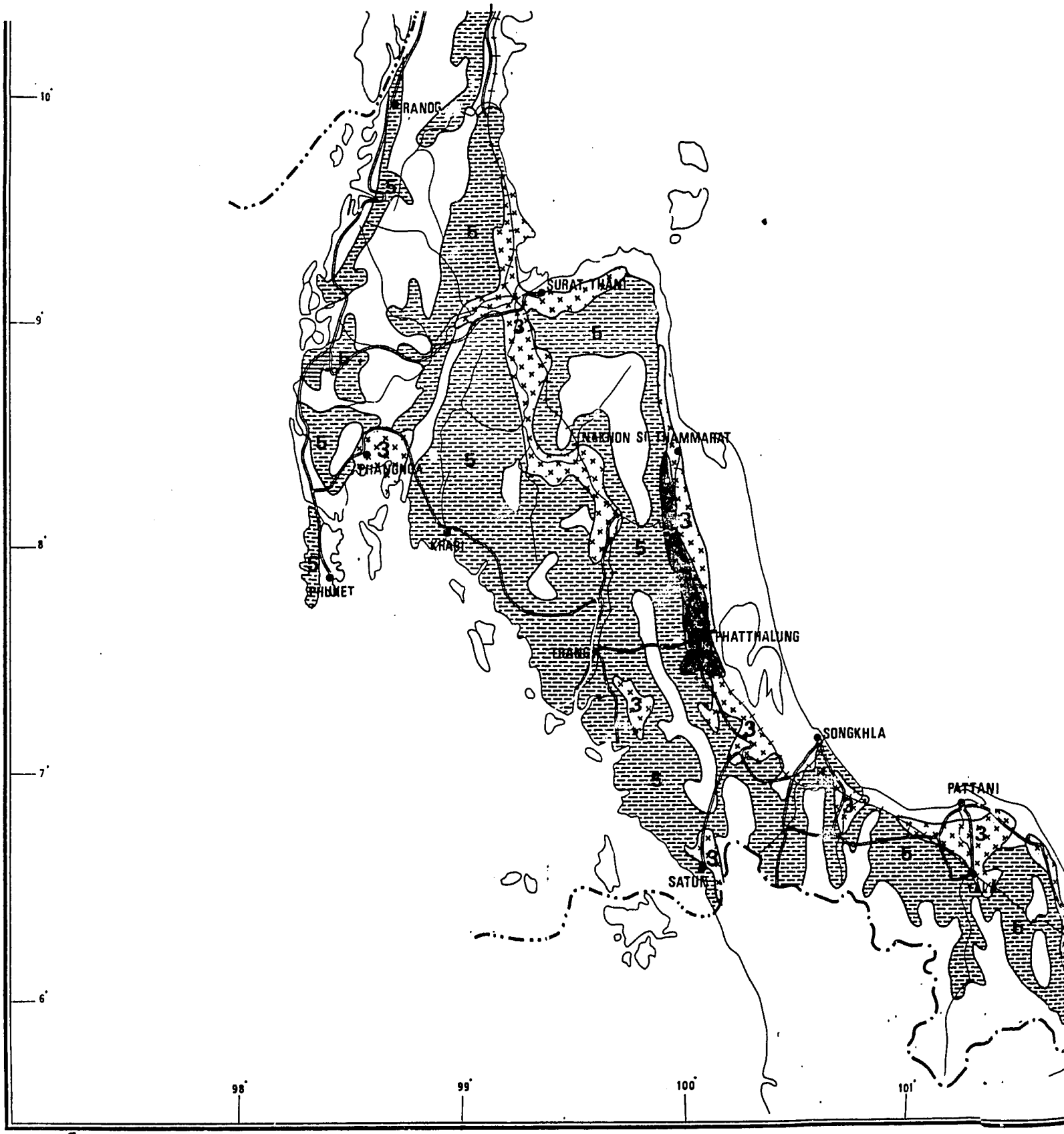


MAP SHOWING THE DISTRIBUTION OF ULTISOLS, ALFISOLS AND OXISOLS IN THAILAND

Mapping Unit No	Suborder
1	Aqualfs

118a

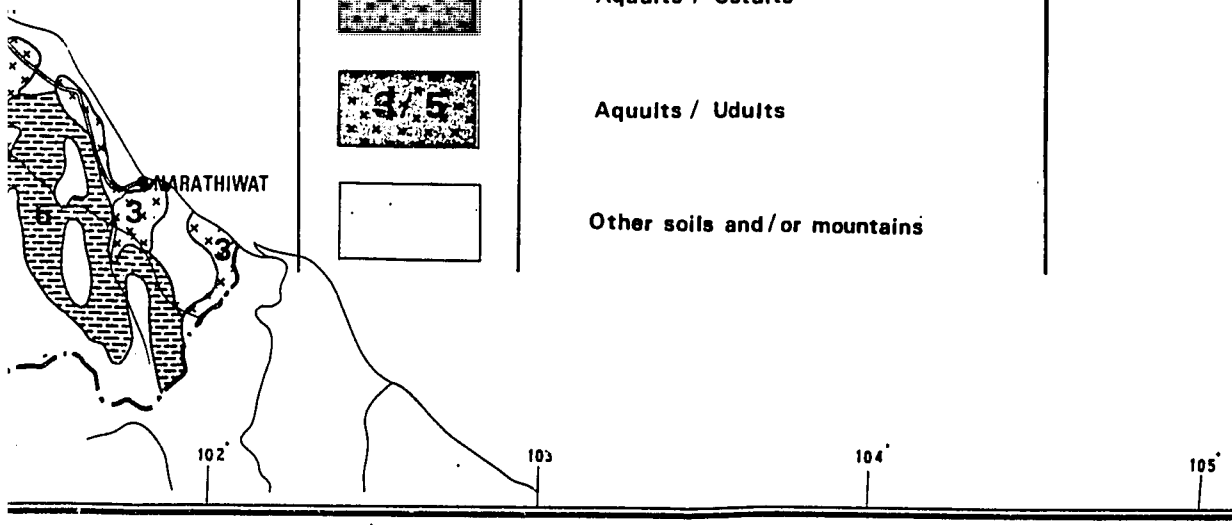
118b


RANOG
SURAT THANI
NAKHON SI THAMMARAT
PHANGNGA
KHABI
PHUKET
PHATTHALUNG
TRANG
SONGKHLA
PATTANI
SATUN
10°
9°
8°
7°
6°
98°
99°
100°
101°

118C

118C

1	Aqualfs
2	Ustalfs
3	Aquults
4	Ustults
5	Udults
6	Ustox
7	Orthox
1/2	Aqualfs / Ustalfs
1/4	Aqualfs / Ustults
2/4	Ustalfs / Ustults
3/4	Aquults / Ustults
3/5	Aquults / Udults
	Other soils and/or mountains



118d

Valley), the Northeast Plateau, and the Southeast Coast. Not all basalt-derived soils however are Oxisols.

The only two soils qualified for the Orthox and Ustox suborder of Oxisols are the Tha Mai and Chokchai series, respectively. Important morphologic descriptions and analyses pertinent to the definition of some Oxisols in Thailand are given in Table 2. The Tha Mai soils used to be the only series which qualified as Oxisols. Chokchai series was only recently identified as having no argillans which can qualify for an argillic horizon. The Nong Bon soil is another series with limited occurrence that fits the Oxisol concept. Si Racha series is probably the only soil on old alluvium which may fit the Oxisol definition, provided that the problem of the percentage of argillans can be positively identified. The Phuket series appears to have a thin oxic horizon and may fit the Oxisol classification. Yasothon series in the northeast and Sadao series in the south have been positively identified as having an argillic horizon and, therefore, were grouped accordingly.

Where water is available, these soils are used for orchards and rubber plantations. The Ustox member has been used mainly for field crops like cassava. The low fertility status has long been recognized and fertilizers are needed accordingly.

PROBLEMS IN CLASSIFICATION

In order to classify soils according to Soil Taxonomy the following discrepancies need to be examined in view of the comprehensive nature of the system:

1. The oxic horizon definition has been relied upon too heavily in certain analytical procedures, particularly when the soil has low clay content. The important demarcation of 16 me/100 g clay may be amplified with only small discrepancies in determinations. Red soils from old alluvium usually contain low clay content and they often reflect

Table 2. Important morphologic descriptions and analyses pertinent to the definition of some Oxisols and Oxisol-like soils in Thailand.

Profile	Depth	Texture	% Clay	CEC Soil me/100 g	CEC Clay me/100 g	Note
Tha Mai on basalt			(Haplorthox)			CEC NH_4CL
A_1	0 - 20	Clay	61.6	17.5	29	9.9
B_{21}	20 - 50	"	53.2	11.2	21	6.5
B_{22}	50 - 95	"	57.2	10.5	18	5.0
B_{23}	95 - 180	"	66.0	9.5	14	4.9
Chokchai on basalt			(Haplusthox)			CEC NH_4Cl
A_1	0 - 10/14	"	57.3	8.2	16	5.3
B_{21t}	10/14 - 36	"	61.7	5.8	10	3.6
B_{22t}	36 - 86	"	59.6	5.73	10	3.6
B_{23t}	86 - 156	"	61.6	4.6	8	3.5
B_{24t}	156 - 220	"	58.8	5.0	8	3.3
Nong Bon on basalt			(Haplorthox?)			
A_1	0 - 16	SiC	16.0	17.8	11.2	
B_{21}	16 - 65	SiCL	34.5	9.4	27.2	
B_{22}	65 - 100	Clay	52.5	7.5	14.3	limited
B_{23}	100 - 150	Clay	66.0	6.1	9.2	occurrence
Si Racha on old alluvium			(Haplusthox?)			
A_1	0 - 28	SL	8.4	3.7	46.3	
B_1	28 - 55	SL	16.5	3.2	19.4	Argillic
B_{21}	55 - 75	SCL	23.0	2.7	12.3	horizon?
B_{22}	75 - 120+	SCL	27.0	3.9	14.4	
Phuket on Granodiorite			(Haplorthox?)			
A_1	0 - 16	SL	21.9	4.7	21	
B_{21}	16 - 35	SC	39.0	3.5	9	
B_{22t}	35 - 68	SC	45.1	3.2	7	Argillic
B_{23t}	68 - 117	SC	49.2	3.0	6	horizon in
B_{24t}	117 - 144	SC	44.6	3.3	7	lower B
B_{25t}	144 - 180	Gravelly C	43.7	3.0	7	

such a problem.

2. Positive identification and separation of an Oxisol in the field and laboratory, in the presence or absence of oriented clay at 1 or 2%, is often difficult to ascertain. Discrepancies may be amplified manyfold when thin sections are made without observing the proper randomization of the soil sample as it was collected in the field. Another factor to be considered is the competency of personnel who determine such characteristics both in the laboratory and in the field.

3. In view of the 30 cm thickness required for an oxic horizon, a thin oxic horizon may overly a well-developed argillic horizon without much consistency. A thicker oxic horizon which may extend down the profile to 75 or 100 cm depth may be a more appropriate requisite. A thin horizon usually will not require different land use management of the soils, and therefore they do not warrant separation at this level, particularly if the area is used for plantation or tree crops.

EPILOGUE

In view of the outcome of the soil classification system review by many specialists from various world areas, the rift in identification and interpretation is even greater than expected. Differences may be due to the individuals, their background and a real specialization coupled with past experiences. Amendments dealing with classification of Oxisols and related soil groups will be most welcome in order to eliminate the identification and interpretation discrepancies as stated earlier.

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LOW ACTIVITY CLAY ALFISOLS, ULTISOLS, AND OXISOLS IN TROPICAL AUSTRALIA AND NEW GUINEA

R.F. Isbell

ABSTRACT

The low activity clay (LAC) soils in tropical Australia, in order of decreasing areal extent, are Oxic Alfisols, Ultisols, and Oxisols. Most of the Oxisols and Ultisols occur in high-rainfall areas, though some (most Oxic Alfisols are relict) occur where present rainfall is low. These soils have few consistent morphological features and possess wide ranges in structure, consistence, nature of cutans, horizonation, and color--though shades of red and yellow predominate in the latter. Particle size distribution is not a definitive characteristic and the presence or absence of argillans in thin sections does not consistently separate classes of LAC soils.

The soil clays are dominated by kaolin, with associated iron oxides, gibbsite (high-rainfall areas), and small amounts of 2:1 or interstratified minerals (low-rainfall areas). Soil pH values are generally above pH 4.8, and KCl-extractable Al is prominent only in some high-rainfall soils where levels of Ca and Mg can be very low. Base saturation varies between wide limits. Plant-available P is nearly always very low, and P sorption can be very high.

The problem of identifying argillic horizons, and the use of soil moisture and temperature criteria in certain class definitions, make it difficult to classify LAC soils in Soil Taxonomy terms. The extent and nature of LAC soils in New Guinea are uncertain because of the insufficiency of laboratory data. They are less extensive than their high-rainfall regimes indicate. Ultisols are the most common, with very restricted occurrence of Oxisols.

INTRODUCTION

This paper deals with the occurrence, properties, and classification of low activity clay (LAC) soils in tropical Australia which have been classified as Alfisols and Ultisols, or Oxisols according to Soil Taxonomy (Soil Survey Staff, 1975). Brief comments concerning similar soils in New Guinea are given in Appendix II. Low activity clay is considered to have a cation exchange capacity of less than 24 me/100 g using the ammonium acetate method, or its approximate equivalent using other methods. Therefore, LAC Alfisols and Ultisols largely correspond to present oxic subgroups of these two orders.

SOIL CLASSIFICATION IN AUSTRALIA

Two systems of soil identification are currently being used in Australia, usually in a complementary fashion. The older of the two (recently revised by Stace et al., 1968) had its origin in the early Russian (Dokuchaev) system and thus bears considerable resemblance to the earlier United States Department of Agriculture system (Baldwin et al., 1938). This 1938 scheme was largely modified in an attempt to suit Australian conditions (Stephens, 1962). The most recent version is nominally a many-level hierarchical system, but in practice it is only used at the great soil group level. The classes are non-exclusive and the central concepts have not been explicitly defined; no key has been constructed and hence identification of any soil is highly subjective. Class differentiation at the great soil group level is essentially based on morphology, with lesser attention paid to chemical aspects, such as soil reaction and base saturation, as shown by some relevant examples in Table 1.

The second scheme widely used in Australia is the Factual Key (Northcote, 1971). This is a strictly exclusive, bifurcating hierarchical scheme which is almost entirely based on field-observable attributes, although soil reaction trends are also used in the lower levels of some classes. Classes are designated by an alpha-numeric code, e.g. Dr2.21, and although an English-word nomenclature has also been devised (Northcote et al., 1975), many names are cumbersome, particularly at the lower

level (e.g. Dr2.21 - hard, pedal red duplex soil, unbleached A2 horizon, acid reaction trend).

In current Australian usage a combination of both schemes is commonly found (e.g. red podzolic soil, Dr2.21) although there is no close or consistent correspondence between many classes in the two schemes.

ENVIRONMENT AND DISTRIBUTION OF LOW ACTIVITY CLAY SOILS

It is not possible to state explicitly the extent of LAC soils in tropical Australia because of insufficient chemical data and lack of correlation between LAC soils and many classes in the two Australian schemes. However, sufficient data are available for some estimates to be made. One source is the FAO-UNESCO (1976) soil map of Australasia, essentially based on a correlation of the units shown on the soil map of Australia by Northcote et al (1975). More recently Sanchez and Isbell (in press) have prepared a small-scale map showing the probable distribution of Soil Taxonomy orders in tropical Australia, along with their approximate areas. Table 1 shows the major Australian great soil groups of Stace et al (1968) (with approximate Soil Taxonomy equivalents), which in tropical Australia are likely to contain LAC soils.

Large areas of tropical Australia are arid: about 56% has a mean annual rainfall of less than 500 mm; only 12% receives more than 1000 mm. Areas with greater than 1500 mm rainfall are confined to far northern Cape York Peninsula and a narrow zone fringing the northeast coast, where a few small areas receive an excess of 4000 mm. Vast areas of tropical Australia, therefore, have aridic or ustic soil moisture regimes. Although northern near-coastal soil temperature regimes are isohyperthermic (estimated from the difference between mean summer and winter air temperature), most inland areas, though in the geographic tropics, have a non-iso regime.

Although the climate might be expected to give a broad indication of the distribution of LAC soils in tropical Australia, the situation is greatly complicated by the widespread presence of relict soils. Some of these are at least as old as mid-Tertiary, and obviously were formed under greatly different environmental conditions than those of today.

Table 1. Major tropical Australian soils which may contain low activity clays.

Australian great soil groups	Distinguishing features	Most common equivalent great groups in Soil Taxonomy[a]
Kraznozems	Red, generally deep, very strongly structured kaolin-sesquioxide soils with high iron contents. Usually high clay content (60-80%) and weak horizon differentiation. Mildly to strongly acid and usually base unsaturated (<50% at pH 7.0). Almost invariably formed from basic rocks.	Acrohumox Acrorthox Eutrorthox Eutrustox
Xanthozems	Yellowish, moderate to strongly structured kaolin-sesquioxide soils. Clay content may be uniform or increase gradually with depth; horizon differentiation is moderate. Normally moderately acid throughout and often strongly base unsaturated. Tending to intergrade to yellow podzolic soils.	Haplorthox Acrohumox Palehumult
Red podzolic soils	Soils with dominantly red, moderate to strongly structured red clay B horizons (> 30-40% clay) and a gradual to clear textural boundary to the overlying sandy to loamy A horizons. A pale A2 is present. The soils are acid thoughout and usually but not always base unsaturated. B horizon color commonly intergrades to that of the yellow podzolics. Varying clay mineralogy, commonly kaolin-dominant.	Hapludult Paleudult Haplustult Paleustult Paleustalf
Yellow podzolic soils	Very similar to the red podzolic soils in almost all properties except the B horizon color which ranges from yellowish red to yellow to yellowish brown and is commonly mottled with red and yellow-grey.	Haplustalf Haplustult Paleustalf

Table 1 continued on next page.

Australian great soil groups	Distinguishing features	Most common equivalent great groups in Soil Taxonomy[a]
Gleyed podzolic soils	The poorly drained equivalent of the red and yellow podzolics and characterized by coarse ochreous, grey and some reddish mottles and grey ped coatings in the B horizon which tends to a macro prismatic structure separating to angular blocky. Rusty fleckings and root tracings commonly occur in the A horizons.	Albaquult Paleaquult
Lateritic podzolic soils	Usually deep acid soils of podzolic form with thick A3 and B1 horizons containing prominent accumulations of ironstone nodules or nodular laterite, and thick coarsely mottled white, red and yellow-brown B3 horizons. The B2 horizons are massive to moderate blocky, strongly mottled yellow-brown and red, medium or heavy clay and are usually base unsaturated.	Paleustult Plinthustult Paleustalf
Red earths	Deep to very deep, kaolin-sesquioxide soils which are massive throughout and have a characteristic porous (earthy) fabric. Clay content commonly increases gradually with depth in the upper part of the profile. The soils are freely drained and horizonation is usually only weakly developed, although layers of ironstone nodules commonly occur at depth. Soil reaction ranges from neutral to strongly acid but normally changes little with depth. Base saturation varies widely.	Paleustalf Paleustult Haplustalf Torrox Haplargid Paleudult
Yellow earths	Yellowish kaolin-sesquioxide soils similar to red earths but usually shallower and with more pronounced horizon differentiation. Drainage is slower than in the red earths and red mottling is common in the B horizons. Prominent horizons of ironstone nodules are also more common. Soil reaction and base saturation vary as widely as in the red earths.	Haplustalf Paleustalf Paleustult Plinthustalf Haplargid

[a]The presence of an argillic horizon is determined solely on the basis of the specified clay increase.

The most striking examples are deep Oxic Paleustalfs (Red earths) commonly present in current rainfall regimes of 700 mm or less. These are also often associated with Torrox (Red earths). Soil distribution in tropical Australia is largely determined by three variables - present climate, geomorphic and climatic history, and soil parent material.

Oxisols

Sanchez and Isbell (in press) have estimated that less than 1% of tropical Australia contains Oxisols. This estimate is only approximate because laboratory data and micromorphology are lacking for many arid areas where Torrox are thought to occur. However, in more humid areas Oxisols are essentially confined to the wetter (above approximately 1500 mm), northeast coastal region. The largest occurrences are those derived from basalt (Kraznozems), with some also present on acid rocks and sediments (Xanthozems).

Ultisols

Ultisols are almost entirely confined to the higher rainfall (greater than 1000 mm) near-coastal regions of the north and northeast, but they account for only about 4% of the Australian tropics. Most of the soils examined to date presumed to be Ultisols are LAC soils, and they formed on a wide range of acid rocks. They also cover a range of Australian great soil groups (Table 1).

Alfisols

Alfisols occupy about 15% of the Australian tropics (Sanchez and Isbell, in press) but insufficient data are available to estimate the proportion dominated by low activity clays. They are widespread in many parts of northeastern Queensland and the northern part of the Northern Territory. There they formed on a variety of parent materials and occur over a wide range of present-day rainfall. Many of them, particularly the Paleustalfs, Haplustalfs, and Plinthustalfs (Red earths, Yellow earths, Lateritic podzolic soils) are relict soils.

SOIL PROPERTIES OF RELEVANCE TO CLASSIFICATION

Field morphology

Australian soil classification has relied heavily on field morphological properties, and in particular on texture, as assessed by field manipulation of moist soil, which may not be a good measure of clay content. In contrast, Soil Taxonomy makes greater use of laboratory-determined attributes in conjunction with water and temperature regimes. It appears that there are few general relationships between readily-determined field properties and the presence of low activity clays. The Australian Kraznozems, with their characteristic morphology are usually dominated by low activity clays, while groups such as the Red and Yellow earths are commonly, but by no means universally, LAC soils. Other groups are usually of low activity, such as the Podzolics, which contain plinthite-like material or have strong red and yellow-grey mottling in their lower B horizons.

In terms of Soil Taxonomy it appears that at the great group level (the Alfisols in particular) few classes can be expected to be consistently dominated by LAC soils.

Nine representative LAC soils from the Australian tropics (see Fig. 1) illustrate the range of some field morphological features encountered. Horizonation may be weakly or strongly expressed; structure and dry consistency may vary between wide limits. The presence of cutans--both thicker, well-defined "illuvation" clay-skins and shiny surfaces that may be the results of pressure--also show no consistent relationships within and between the various LAC soils. Color is variable, although hues of red and yellow predominate. The presence of ironstone nodules is not necessarily indicative of LAC soils, particularly since these may be inherited.

Physical properties

Particle-size distribution within a profile is certainly not a definitive characteristic of LAC soils, as shown by the clay profiles

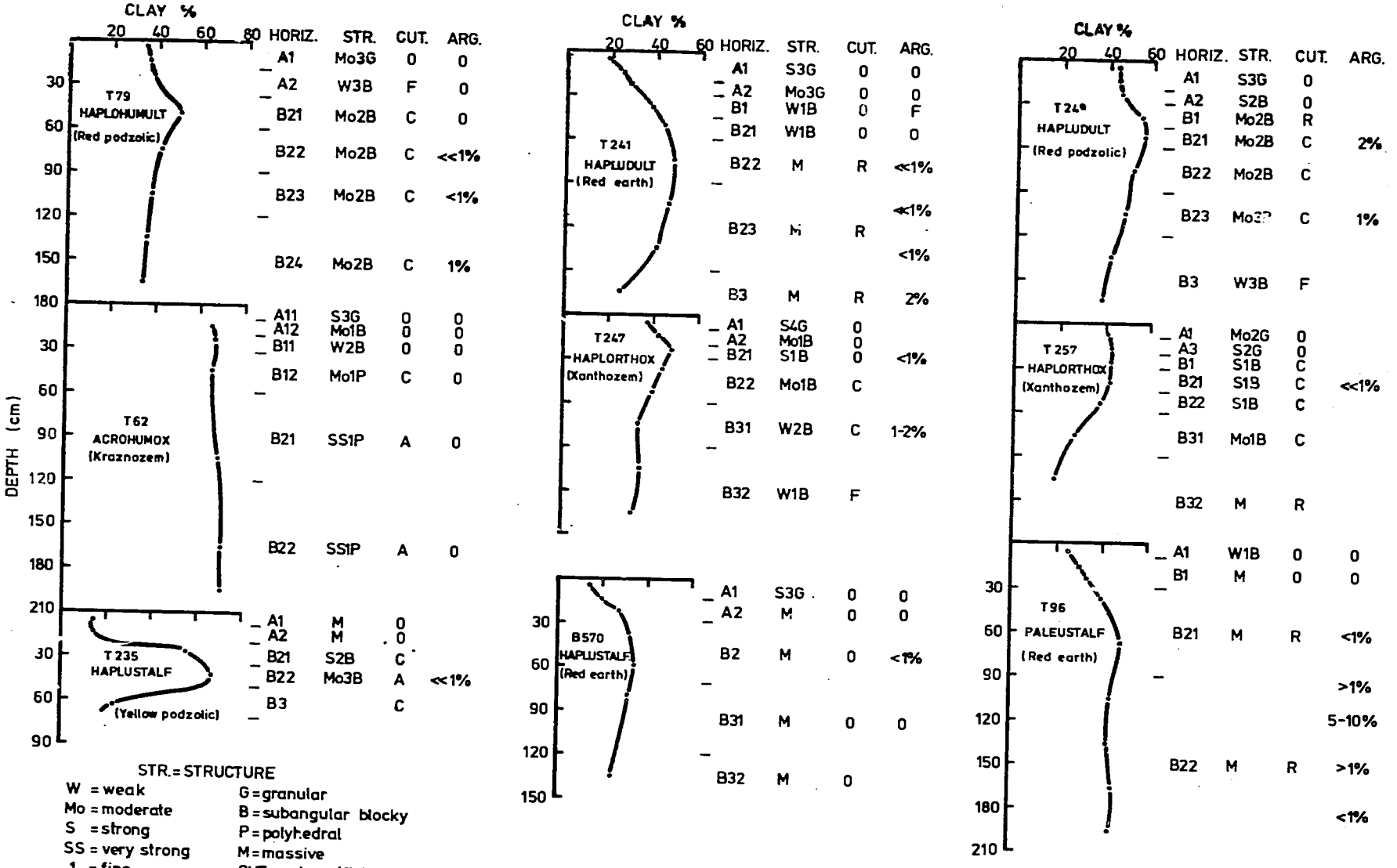

FIG.1 Clay distribution and some major morphological attributes of selected low activity clay soils from tropical Australia. (Identification of an argillic horizon is solely on the basis of the specified clay increase.)

illustrated in Fig. 1. Forty characteristic LAC soils with an apparent argillic horizon were examined from tropical Queensland (mainly Paleustalfs, Haplustalfs, and Paleustults, with lesser Udults). Twenty-four would remain as Alfisols or Ultisols if the argillic horizon specification were widened to a ratio of 1.4 or greater when clay content was <40% and the absolute increase raised to 16% or more if clay content was >40%. The majority of the soils examined were Red earths and Yellow earths--characterized by a gradual rather than a clear clay increase with depth--but again about two-thirds showed an increase of >1.4 or 16%.

Limited available data suggest that the presence of an apparent argillic horizon in LAC soils may not impede water penetration. Fig. 2 (based on data from Day, 1977) shows the clay profiles and infiltration rates for two Oxic Alfisols from the Northern Territory. There is no indication that the clay increase in the sandier Blain soil impedes water movement. The infiltration curve for this soil follows the classic pattern (Philip, 1957) for a rigid homogeneous profile. If the clay increase at 50-80 cm was behaving as a constraint to infiltration, the curve should show a marked decline during the steady state infiltration period (Miller and Gardner, 1962), by which time the wetting front will have entered the high clay horizon. There is no evidence at this time of a change in water entry rate during infiltration. In fact the water entry into Blain soil is superior to Tindall soil which has a lesser texture contrast in all except the near-surface horizons.

These data suggest that it is not just the change in clay content, but also the absolute amount and the pore size distribution, which determine the hydraulic conductivity of the respective horizons in weak blocky to massive but porous Oxic Alfisols.

The term "activity" has also been used in relation to engineering properties of soils. Thus Skempton (1953) used the term "inactive" for kaolin-dominant clays which had an "activity" of <0.75, where activity = Atterberg plasticity index/clay %. Of 18 Lac soils examined from tropical Queensland, all except three had activities <0.75.

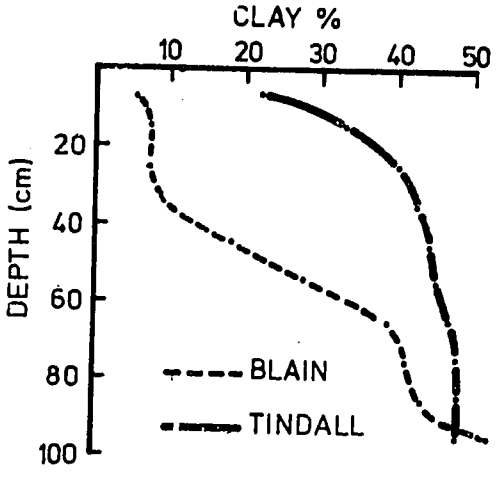

FIG. 2a

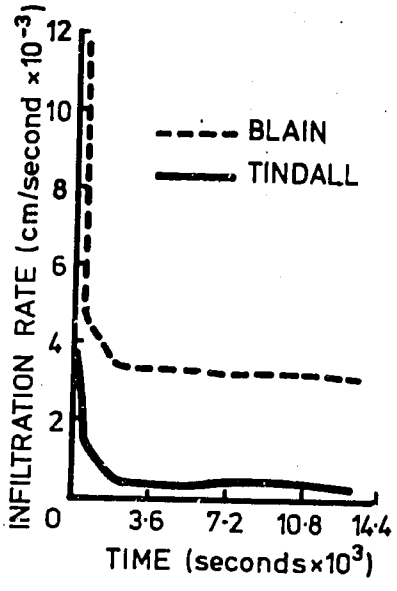

FIG. 2b

FIG. 2 Clay profiles and infiltration curves for two oxic Alfisols

from California and Hawaii. In the Hawaiian soils, he found a direct relationship between the ammonium acetate cation exchange capacity (CEC) and the plasticity index, with both being expressed on a unit clay basis. No such relationship was revealed with the LAC soils from tropical Queensland, using both ammonium acetate CEC and "effective" CEC, although a significant regression between plasticity index and percent clay was obtained (plasticity index = 0.47 clay % + 4.25; r = 0.75; n = 18). However, the CEC per unit clay values were all much lower than those shown by Uehara (in press) for the Hawaiian soils. Further studies on the LAC soils in relation to engineering properties would seem desirable.

Micromorphology

Data for key horizons are available for a number of LAC soils in tropical Australia, mostly from north Queensland. If Oxisols are regarded as such, because of insufficient clay increase to satisfy the argillic horizon requirement, four out of ten profiles contained 1-5% of oriented clay in the form of argillans or papules. Soils derived from basalt were consistently without oriented clay. In the case of seven presumed Ultisols, three contained less than 1%, and another marginally 1%. Ten presumed Alfisols examined were much more consistent in that only two had less than 1% oriented clay, although one of these (T235 in Fig. 1) possessed the most dramatic total clay increase with depth. In terms of the Australian classification, only the Kraznozems were a consistent group, with no oriented clay.

If we compare the thin-section results with field morphology (Fig. 1) there is little consistency. The most strongly structured soils - the basaltic Oxisols (Kraznozems) - with their smooth, shiny ped surfaces, appear to even have few stress cutans. In contrast, the massive, porous Ultisols and Alfisols (Red and Yellow earths) tend to have relatively high amounts (up to 5%) of oriented clay. However, in the Red and Yellow earths without oriented clay (both Ultisols and Alfisols in terms of total clay increase) there is no discernible difference in field morphology. Of the three very similar, moderately structured Ultisols (Red podzolics) derived from acid

igneous rocks, two contained considerable amounts of oriented clay while the third contained very much less.

This lack of consistency between field morphology and micromorphology has been noted elsewhere in oxic soils of the tropics (see Isbell in press). Recent evidence from non-oxic temperate soils in Canada (McKeague et al., 1978) has also shown similar discrepancies.

Clay mineralogy (< 2 μm)

Most of the LAC soils examined to date in tropical Australia have a relatively simple clay mineralogy that is only partly related to present rainfall. All are kaolin-dominant (usually > 60%, often > 80%) with iron oxides the most commonly associated mineral. Whereas both hematite and goethite (up to 20%) occur in many red soils, in the yellow soils only the latter has been found. Gibbsite is common above about 1700 mm mean annual rainfall, but amounts seldom exceed 10-20%, except in some highly weathered Oxisols derived from basalt (Isbell et al., 1976) and in a very high rainfall (7000 mm) Ultisol derived from granite. Small amounts of illite, vermiculite, and randomly interstratified material are found in Oxisols and Ultisols derived from metamorphic and some granitic rocks.

The Oxic Alfisols (mostly Red and Yellow earths) which generally occur under rainfalls of more than 1000 mm usually have small amounts of illite or randomly interstratified minerals (Isbell and Smith, 1976; Day and van Cuylenburg, in press).

Amorphous material appears to be absent in the LAC soils examined to date, and there are no consistent differences in clay mineralogy between the high-rainfall Oxisols and Ultisols. Although the data may not be fully representative of tropical Australia, there seems to be a clear contrast with many Ultisols (Red and Yellow podzolics) of sub-tropical eastern Queensland, which tend to have lower kaolin contents and much higher amounts of interstratified minerals (CSIRO Division of Soils, unpublished data).

Chemical properties

All data discussed below have been obtained from the analysis of soil samples from virgin sites. Results for two horizons of representative soils are shown in Table 2, and methods of analysis are given in Appendix 1.

Iron. There is virtually no relationship between soil color and iron content, nor between the three orders of Soil Taxonomy and iron content. However, one strong correlation with parent soil material is that the basaltic Oxisols invariably have high contents of total iron (20-30% Fe_2O_3), of which 80-90% is dithionite-extractable (Gillman, 1976). In contrast, red soils on more acidic parent materials seldom have > 5% total, or > 3% dithionite-extractable Fe_2O_3. Many have < 3% total Fe_2O_3, and at these levels a red or yellow soil color may not give a reliable indication of iron content (Isbell and Smith, 1976).

Organic carbon. A_1 horizon contents vary widely and, at least for some soils, are correlated with rainfall and vegetation (Gillman, 1976; Isbell and Smith, 1976). The highest % organic carbon values occur under rain forests (up to 9%) but in more arid areas values are commonly only 1% or less. The decline in organic carbon with depth is usually rapid in soils with low surface contents. The decline is less in many high-rainfall soils where there may still be 0.5% at about a meter depth, as in some basaltic Oxisols.

Clearing the rain forests leads to a rapid decline in surface soil carbon. This may lead to the situation where some virgin soils are classified as Humox, whereas their cleared and cultivated neighbors will not meet the organic carbon requirement. It would seem more appropriate to define Humox in a manner similar to the Humults, requiring a certain amount of organic carbon at a specified depth in the B horizon rather than being biased to the high A horizon contents of virgin soils.

Soil reaction. A feature of tropical Australian LAC soils compared to those in the more humid world tropics, is the relative absence of very strong acidity. Values (1:5 soil:water suspension)

Table 2. Analytical data for A_1 and B_2 horizons of some low activity clay soils from tropical Queensland.

Soil	Depth	Classification	Clay	Org.C	pH (H_2O)	pH (KCl)	Ex.bas. cat.[b]	KCl H+Al	KCl Al	CEC[c]	CEC[d]	ECEC[e]	AEC[f]	Al.[g] Sat.	Base[h] Sat	Base[i] Sat.	Dith. Fe_2O_3
	(cm)		← (%) →				← meq/100 g soil →			← meq/100 g clay →				← (%) →			
62.1	0-10	Acrohumox (K)[a]	66	8.0	5.1	4.5	3.50	1.62	0.78	38.2	7.6	7.8	0.6	15	14	68	20.0
.6	90-120	"	68	0.3	4.9	4.9	0.78	0.31	0.11	6.9	2.5	1.6	3.4	10	17	72	20.6
101.1	0-10	Acrorthox (K)	66	3.5	5.9	6.0	6.30	0.26	0	20.0	10.1	9.9	0.4	0	48	96	24.0
.8	150-180	"	58	0.5	5.5	5.9	0.60	0.18	0	6.4	2.1	1.3	3.1	0	16	77	24.1
247.1	0-10	Haplorthox (X)	38	5.1	4.8	3.9	3.70	2.80	1.95	51.1	11.6	17.1	0.8	29	19	57	0.66
.4b	45-60	"	40	0.2	4.7	4.0	0.47	2.68	2.44	11.2	7.0	7.9	0.8	77	10	15	1.34
66.1	0-10	Haplorthox (RP?)	47	4.3	4.8	4.1	1.50	2.40	2.30	33.6	8.5	8.3	0.6	59	9	38	1.40
.5	40-60	"	39	0.4	4.9	4.0	0.59	2.72	2.40	17.1	7.2	8.5	1.0	73	9	18	1.60
249.1	0-10	Hapludult (RP)	44	4.8	4.6	3.9	2.16	3.65	2.80	44.1	10.0	13.2	0.7	48	11	37	--
.4b	45-60	"	56	0.7	5.5	4.3	2.05	1.36	1.00	14.6	5.9	6.1	0.7	29	25	60	2.20
137.1a	0-5	Paleustult (YE)	10	1.3	5.4	4.2	1.14	1.00	0.80	33.0	14.0	21.4	2.0	37	35	53	0.52
.6b	105-120	"	29	0.1	5.0	4.4	0.51	0.62	0.30	4.1	5.2	3.9	1.7	27	42	45	0.96
79.1	0-10	Haplohumult (RP)	34	4.5	4.5	4.1	3.79	3.68	2.50	50.0	10.6	22.0	0.9	33	22	51	--
.6	60-90	"	42	-	4.7	4.1	0.74	2.30	1.90	--	7.4	7.2	1.4	63	--	24	--
241.1	0-10	Hapludult (RE)	19	3.6	4.5	3.9	1.23	2.04	1.37	52.6	13.2	17.2	1.6	42	12	38	1.28
.6	90-1[illegible]	"	46	0.1	4.7	4.3	0.29	1.31	0.95	7.8	4.1	3.5	2.2	59	8	18	3.07

Table 2 continued on next page.

Soil	Depth	Classification	Clay	Org.C	pH (H_2O)	pH (KCl)	Ex.bas. cat.[b]	KCl H+Al	KCl Al	CEC[c]	CEC[d]	ECEC[e]	AEC[f]	Al.[g] Sat.	Base Sat.[h]	Base Sat.[i]	Dith. Fe_2O_3
	(cm)		←(%)→				←meq/100 g soil→			←meq/100 g clay→				←(%)→			
115.1	0-10	Haplustalf (YE)	9	0.6	5.9	5.1	2.54	0.16	0.03	24.4	23.3	21.4	1.1	1	80	94	0.94
.4b	45-60	"	33	0.2	5.9	4.4	2.88	0.48	0.20	11.5	10.3	10.2	0.6	6	76	86	2.10
96.1a	0-5	Paleustalf (RE)	26	2.4	6.1	5.5	8.34	0.26	0	41.5	30.4	33.1	0.8	0	77	97	2.17
.11	150-180	"	48	0.1	6.0	5.8	3.45	0.14	0	8.7	7.1	7.5	0.4	0	82	96	3.43

[a] Australian classification: K = kraznozem, X = xanthozem, RP = red podzolic, RE = red earth, YE = yellow earth.

[b] Extracted by 1M NH_4Cl. [c] 1M NH_4OAc [d] Compulsive exchange method. [e] Sum of 1M NH_4Cl basic cations and 1M KCl (H+Al).

[f] Compulsive exchange method. [g] 1M KCl Al as a percentage of ECEC. [h] 1M NH_4Cl basic cations as a percentage of 1M NH_4O Ac CEC.

[i] Lm NH_4Cl basic cations as a percentage of ECEC.

Soil nos. 62 and 101 are derived from basalt, nos. 247, 249, and 241 from acid igneous rocks, no. 66 from mica schist, nos. 137, 115 and 96 from sandstone.

Mean annual rainfall: no. 62-1680 mm, 101-3050 mm, 247-1800 mm, 66-3200 mm, 249-1325 mm, 137-1680 mm, 79-2000 mm, 241-4300 mm, 115-910 mm, 96-635 mm.

seldom fall below pH 4.7. The great majority of Oxisols and Ultisols have values between pH 4.7 and pH 5.5. There is normally little change throughout the profile. In 0.1M KCl pH is usually 0.5-1 pH unit lower than in water, although near-zero or positive Δ pH values have been recorded in the basaltic Oxisols (e.g. Gillman and Bell, 1976).

Although it has often been noted that oven drying will cause an appreciable decrease in pH (White, 1969), there seems to be little evidence on the effect of long-term storage of air-dried samples. Gillman and Bakker (this workshop, Vol. II) have discussed this problem and their results are worth emphasizing here. Thus, after eight years' storage, six out of 21 B_2 horizon samples of LAC Alfisols, Ultisols, and Oxisols from tropical Queensland decreased in pH (1:5 soil:water) by more than 0.3 pH units (two by 0.6 units). A similar decrease was more common in A_1 horizons. A range of non-Oxic Alfisols also showed a similar magnitude of decrease in some samples, but in contrast, neutral to alkaline Vertisols showed a slight increase on storage. It has not been possible to make a similar comparison with pH measured in KCl.

Exchangeable basic cations. Data for most Australian soils has been obtained by extracting them with 1M NH_4Cl at pH 7.0. Unpublished data by G.P. Gillman indicates that this gives comparable results to extraction with 1M NH_4OAc. The high rainfall Oxisols and Ultisols are characterized by low levels of calcium and magnesium. Values are normally < 1 me in B_2 horizons - often <0.2 me - with Mg usually predominant in the Ultisols. A_1 horizon values in virgin soils are generally somewhat higher. Most Alfisols have slightly higher Ca and Mg levels, although in the B_2 horizon, values seldom exceed 2 me of either cation.

Although exchangeable potassium is moderate in the virgin A_1 horizons of the basaltic Oxisols (mean of 0.34 me - Gillman, 1976), values decrease with depth to < 0.1 me. Similar but more variable contents are found in most Oxisols and Ultisols derived from acid igneous rocks, but in contrast the Ultisols derived from sandstone are very low throughout in exchangeable K. The lower-rainfall Oxic Alfisols have variable contents, but again values are often very low

(i.e. < 0.1-0.2 me).

Extractable aluminum. Aluminum extracted by 1M KCl is relatively high in many of the high-rainfall Ultisols and non-basaltic Oxisols (Table 2.). Values range up to 3 me and they are almost always higher in the B_2 than the A_1 horizons. The virtual absence of appreciable aluminum in the basaltic Oxisols has been noted earlier by Gillman (1976). Aluminum saturation expressed as a percentage of the "effective" cation exchange capacity (1M NH_4Cl-exchangeable basic cations plus 1M KCl-extractable acidity, i.e. H + Al) ranges between 50% and 80% in the B_2 horizons of many high-rainfall Ultisols and non-basaltic Oxisols; but A_1 horizon values rarely exceed 50%. Few Oxic Alfisols contain extractable aluminum, and when they do it is only in low amounts.

The available data showed that for B_2 horizon samples, virtually no extractable aluminum was present above pH (KCl) 4.5, which is consistent with the results of Juo (1977) and Gillman and Bakker (this workshop). The same result was also generally true for surface soils. However, the relation between pH (H_2O) and aluminum was not well defined.

Finally, it should be noted that the fall in pH found for some stored samples may lead to higher extractable aluminum values. This needs to be further investigated.

Cation exchange capacity (CEC) and base saturation. CEC has been determined by three methods. "Effective" CEC (ECEC) was obtained by summation of 1M NH_4Cl basic cations and 1M KCl-extractable acidity (H + Al). Available B_2 horizon data (11 Oxisols, 10 Ultisols, and 7 Alfisols) showed, with one exception, ECEC values < 14 me/100 g clay. There were few consistent differences between the three orders, although values were usually much lower for the basaltic Oxisols (e.g. Table 2). In all orders the A_1 horizon values were almost always higher, and although the higher ECEC of surface soils would be partly due to organic carbon, there was no significant correlation.

CEC was also determined by a compulsive exchange method (Gillman, in press; Gillman and Bakker, this workshop). The advantages of this method have been discussed in the latter paper. For the LAC soils studied in tropical Queensland, the following regressions were obtained (100 g clay basis):

B_2 horizons: compulsive exchange CEC = 0.77 ECEC + 0.71 (r=0.97, n=28).

A_1 horizons: compulsive exchange CEC = 0.72 ECEC + 0.68 (r=0.94, n=25).

All soils: compulsive exchange CEC = 0.71 ECEC + 0.79 (r=0.79 (r=0.95, n=53).

The subsoil correlations are consistent with results obtained by Gillman and Bakker (this workshop) for a wider range of tropical and subtropical Australian and overseas subsoils.

CEC was measured by a slightly modified ammonium acetate method on a number of B_2 horizon samples, and regressions with the other two methods were obtained (100 g clay basis) as follows:

NH_4OAc CEC = 1.29 ECEC + 2.95 (r=0.87, n=23).

NH_4OAc CEC = 1.38 compulsive exchange CEC + 1.93 (r=0.81, n=23)

A_1 horizon values were nearly always much higher than those obtained by the other two methods, and there was a close relationship with organic carbon content (NH_4OAc CEC = 3.35 Org. C + 0.90; r=0.97, n=10).

NH_4OAc base saturation (see Table 2) in B_2 horizons was significantly related to ECEC base saturation (NH_4OAc B. Sat. = 0.70 ECEC B. Sat. - 5.52; r=0.87, n=23), but the former was usually much lower in the Oxisols and Ultisols than the ECEC base saturation.

Anion exchange capacity (AEC). This was determined by a compulsive exchange method (Gillman, in press; Gillman and Bakker, this workshop). A number of Oxisols and Ultisols showed an appreciable AEC in the B_2 horizon. Basaltic Oxisols are again noteworthy in that AEC/100 g clay exceeded the ECEC/100 g clay in most instances. The

high AEC of these basaltic subsoils probably explains their high sorbed sulphate contents (Gillman, 1974; Probert, 1977). The increase in sorbed sulphate with depth in some other Oxisols and Ultisols is also probably related to their having an appreciable AEC. Similarly the retention of nitrate has been shown to be dependent upon positive charges (Black and Waring, 1976; Balasubramanian and Kanehiro, 1978).

Phosphorus. The non-basaltic soils almost invariably contain low amounts (usually < 200 ppm) of total phosphorus in their B_2 horizons, although A_1 horizons may occasionally range up to 400 ppm. In contrast, the basaltic soils normally contain from 1,000 to 3,000 ppm in both surface and subsoils. However, nearly all soils contain low to very low amounts of extractable ("plant available") phosphorus; the only exceptions are the A_1 horizons of some virgin basaltic Oxisols.

Phosphate sorption characteristics (M.E. Probert, unpublished data) for a range of LAC soils in tropical Queensland that were determined under standardized conditions (1:10 soil:solution, 10^{-2}M $CaCl_2$, 24 hours equilibration) are described in Table 3. The data show that P sorbed at 0.2 ppm was invariably higher in the subsoils. The Oxic Alfisols sorbed little P, basaltic Oxisols (Kraznozems) high amounts; non-basaltic Oxisols and Ultisols sorbed varying amounts, but values were always much higher than those for Alfisols.

To investigate any relationships between P sorption and certain other soil properties - namely pH, organic carbon, clay content, dithionite-extractable iron and KCl-extractable aluminum - the phosphate buffering capacity (PBC, expressed as the increase in P sorbed when raising the final solution concentration from 0.2 to 0.3 ppm) was chosen in preference to P sorbed because it ought to be less dependent on native P present in original soil samples. When all samples were used, high correlations were found with dithionite-extracted iron, but this largely resulted from comparing two dissimilar subgroups of soils. No significant relationship existed between PBC and dithionite when the basaltic Oxisols with their high dithionite-extractable iron contents were excluded. The next best relationship was found with % clay and KCl-extractable aluminum (72.7% of the variance in PBC being accounted for).

Table 3. Phosphate sorption characteristics for some low activity clay soils from tropical Queensland. (M. E. Probert, unpublished data)

A_1 horizons			B_2 horizons			
Soil	P sorbed[a] (µg/g soil)	PBC[b] (µg/g/ 0.1 ppm)	Soil	P sorbed[a] (µg/g soil)	PBC[b] (µg/g/ 0.1 ppm)	Classification
T62.1	225	63.6	T62.6	667	87.9	Acrohumox (K)[c]
T84.1	239	53.1	T84.4	742	118.6	Acrorthox (K)
T101.1	237	48.8	T101.8	964	129.5	Acrorthox (K)
T88.1	133	43.2	T88.8	445	51.7	Eutrorthox (K)
T247.1	54	23.7	T247.4b	122	24.4	Haplorthox (X)
T257.1	100	27.1	T257.4a	287	45.3	Haplorthox (X)
T66.1	110	42.2	T66.5	219	35.7	Haplorthox (RP?)
T249.1	155	55.1	T249.4b	314	42.5	Hapludult (RP)
T49.1	26	11.3	T49.4	113	19.5	Haplustult (RP)
T241.1	40	14.3	T241.6	484	45.8	Hapludult (RE)
T128.1	101	14.1	T128.4a	128	15.2	Paleustult (RE)
T137.1a	66	12.1	T137.6b	163	19.2	Paleustult (YE)

Table 3 continued on next page.

A_1 horizons			B_2 horizons			
Soil	P sorbed[a] (µg/g soil)	PBC[b] (µg/g/ 0.1 ppm)	Soil	P sorbed[a] (µg/g soil)	PBC[b] (µg/g/ 0.1 ppm)	Classification
T115.1	9	2.0	T115.4b	93	12.1	Haplustalf (YE)
T255.1a	14	3.0	T255.4b	91	11.1	Haplustalf (YE)
T256.1a	14	3.5	T256.4b	58	10.1	Paleustalf (RE)
T96.1	10	4.1	T96.5	58	9.6	Paleustalf (RE)

[a] P sorbed at final concentration of 0.2 ppm.

[b] P sorbed in increasing final concentration from 0.2 to 0.3 ppm.

[c] Australian classification (see Table 2).

If non-basaltic surface soils are considered, the best predictor of PBC is % clay^2 + KCl-extractable aluminum, which accounted for 87.9% of the variance in PBC. However, virgin A_1 horizons are unlikely to be encountered in most field situations in which fertilizer phosphorus is required. In fact most long-cultivated sites, particularly on slopes, now have B horizons exposed at the soil surface because of erosion. Unfortunately, for the non-basaltic B horizons there was no soil property examined - or any combination - which accounted for more than 50% of the variance in PBC.

LAND USE ASPECTS

Because of existing land use patterns in tropical Australia, it is not possible to reach any definite conclusions as to whether particular LAC soils behave differently under various forms of land use. Almost all LAC Alfisols remain under native pasture, although some have been upgraded by growing improved legumes, such as *Stylosanthes* spp. There is evidence (J. Williams, unpublished data) that in some soils (e.g. Red and Yellow earths - Paleustalfs and Haplustalfs) the red and yellow forms have very different soil water regimes. More information is needed on the relevance of color to land use for these soils.

The high-rainfall Oxisols and Ultisols of tropical Queensland are extensively used for sugarcane and improved pastures, and much less so for horticulture and cropping. In the case of growing sugar, very high fertilizer inputs and lack of yield data for specific sites have generally obscured soil differences. For pastures, once nutrient differences have been overcome, there seem to be few differences between Oxisols and Ultisols, other than those that might be attributable to lower clay contents in upper horizons. In general, few valid comparisons can be made because of the very limited extent of improved pastures on non-basaltic Oxisols and Ultisols, many of which remain under rain forests. Cropping, other than sugarcane and limited horticulture, is almost entirely confined to the basaltic Oxisols.

DISCUSSION

From the foregoing it is obvious that the LAC Alfisols, Ultisols, and Oxisols of tropical Australia have a number of common features which are obscured at relatively high levels, in both Soil Taxonomy and existing Australian soil classifications. In the former scheme the present distinction between Oxisols and the other two orders often seems unrealistic, with the exception of the basaltic Oxisols. However, even in this instance there are very similar soils (in terms of genesis, general properties, and behavior under land use) that in subtropical Australia have been classified as Paleustalfs rather than Eutrustox on the basis of their clay increase with depth. At present it would seem desirable that these basaltic soils be more closely grouped in Soil Taxonomy.

Several other comments regarding the tropical Australian Oxisols may be made. Attention has been drawn to the fact that present criteria regarding clay skins and oriented clay in thin section do not provide a sufficiently consistent distinction between Oxisols and the other two orders. It is also evident from the examples given in Fig. 1 that any decision as to which limit is to be regarded as a sufficient clay increase to qualify for an argillic horizon, is likely to be very arbitrary. At the moment this cannot be based on any documented evidence of land use difference. Since LAC soils in general are permeable, and often highly so, it may be questioned if the presence of a clay increase with depth is of any special relevance for most uses except the more extreme cases. In terms of water entry and transmission, it seems likely that absolute clay content at various levels in a profile may be more relevant than its rate of increase, again with the possible exception of abrupt changes of considerable magnitude.

There is also a problem concerning the classification of some acric Oxisols derived from basalt. At present there is no provision for strongly structured acric great groups of Orthox. Such soils are relatively common in tropical Queensland, and in this paper they have been classed as Acrorthox.

In terms of differences between Oxic Ultisols and Oxic Alfisols, the present distinction is based essentially on base saturation. This does appear to reflect important differences in other properties, such as levels of exchangeable calcium and magnesium. The question remains, however, if there are any real land use differences between Oxic Alfisols, in which clay content increases gradually with depth, and "Eutric' Oxisols--particularly if the differences are important enough to warrant distinction at the order level.

There are also several questions regarding the use of soil temperature and moisture criteria in relation to LAC soils. For Oxisols a case could be made for not using moisture regimes at the suborder level (as in the Inceptisols and Entisols). In these soils inherent properties are of overriding importance, and in instances where they are relict the use of present soil moisture regimes tends to give misleading impressions of both their properties and genesis. Additionally, the exclusion of moisture regimes at the suborder level would give greater freedom for making a high-level distinction using other important properties, such as base saturation, high organic matter content, etc.

The use of soil temperature regimes is at present illogical. For example, Humults have no temperature restrictions other than being mesic, isomesic or warmer, whereas Humox cannot be hyperthermic or isohyperthermic. In addition, it seems difficult to justify a distinction at the great group level between iso and non-iso temperature regimes, as in the Tropudults and Hapludults, where we are dealing with essentially the same soils.

Several other points may be noted in relation to the classification of LAC soils in the Australian tropics. Because many of the Oxic Alfisols are relict soils, they occur widely in aridic soil moisture regimes. Thus whether such soils are classed as Alfisols or Aridisols may depend merely on whether they have a massive and hard epipedon. Australian experience suggests this can frequently be simply a matter of the clay content in the epipedon. Finally, many Australian Oxic Alfisols in the tropics presently "key out" as Paleustalfs (those in

either a lack of clay decrease with depth, or of a sharp increase in clay content at the upper boundary of the argillic horizon, leads to some very different soils being placed together in these great groups. It may also be noted that in the "pale" great groups, the uneven treatment given to color leads to somewhat diverse soils being placed together. As an example, many of the tropical Australian Red and Yellow earths, which are now known to have very different soil water regimes, are classed as Paleustalfs or Paleustults. In the former case the presence of red mottles may permit the inclusion of imperfectly drained Yellow earths as well as freely drained Red earths; in the latter case, no color criteria are involved.

In terms of the Australian soil classification of Stace et al. (1968), LAC soils of tropical Australia may occur to varying extent in any of the eight groups listed in Table 1, although non-oxic soils would be rare in the Kraznozems and Xanthozems. In the Northcote (1971) system, with its greater emphasis on morphology, their spread is probably even wider.

Although this review has only dealt with tropical Australia, it needs to be emphasized that LAC soils also occur widely in temperate Australia, both in humid and arid regions.

CONCLUSION

If it is thought desirable to more closely group the LAC soils than is presently done in Soil Taxonomy - and there seems to be increasing evidence in favor of this, a number of possible options are available. On the basis of evidence from tropical Australia, one approach would be to redefine and expand the present Oxisol order to embrace all the oxic soils (defined on the basis of a mutually acceptable CEC and low weatherable minerals) and remove the argillic horizon constraint.

At the suborder level there are a number of alternatives. Removal of the existing moisture and temperature criteria would give more flexibility in class differentiation. In particular, it would enable important properties, such as base saturation and "rhodic" properties based on high iron content, to be used at a higher level than at present. It seems the presence of a clay increase with depth - perhaps with specifications approaching the presently-defined abrupt textural change - would be more appropriately introduced at the great group level.

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APPENDIX I

Analytical methods

Particle-size analysis was done by a pipette method after dispersion with sodium hexametaphosphate and sodium hydroxide; surface horizons were pretreated with 6% hydrogen peroxide until all organic matter was destroyed.

pH was determined using a 1:5 soil:water suspension and in 0.1 M KCl; organic carbon by Walkley-Black wet oxidation and using a factor of X 1.3. Dithionite-extractable iron was determined by the method of Holmgren (1967). Exchangeable basic cations were extracted by 1M ammonium chloride at pH 7.0. Cation exchange capacity (CEC) using ammonium acetate at pH 7.0 was determined by the method of the Soil Conservation Service (1972). It was modified in that soil and washed quartz sand in equal volumes were leached in glass columns. CEC and anion exchange capacity were also determined by the compulsive exchange method of Gillman (in press), and Gillman and Bakker (this workshop). Exchange acidity (H + Al) was determined from a 1M KCl-extractable aluminum expressed as a percentage of the "effective" CEC. Base saturation was recorded with exchangeable basic cations expressed as a percentage of both ammonium acetate CEC and "effective" CEC.

Phosphate sorption properties were measured by shaking 2 g soil with 20 ml 10^{-2}M $CaCl_2$ solutions containing graded amounts of KH_2PO_4 for 24 hours. After centrifuging, phosphate remaining in solution was determined with an autoanalyzer adaptation of the molybdenum blue method and using ascorbic acid as reducing agent.

APPENDIX II

Some comments on LAC soils in New Guinea

New Guinea offers a strong contrast to the greater part of tropical Australia. It is a geologically young country in terms of much of its stratigraphy, and it has had a much more active recent geomor-

phic history. Thus in contrast to Australia, much of New Guinea is characterized by high fold mountains and active or recently active vulcanism. Additionally, much of the country has a very humid climate, with few areas having less than 1500 mm mean annual rainfall. Unfortunately, only broad-scale and rather generalized soil maps are available for most of the region; and there is very little relevant laboratory data for the low activity clay (LAC) Alfisols, Ultisols, or Oxisols.

In spite of its humid tropical climate, it is apparent from available soil maps (Haantjens et al., 1967; Bleeker, 1974; FAO-UNESCO, 1976a, b) that LAC Alfisols, Ultisols, and Oxisols are less extensive than might be expected. Haantjens and Bleeker (1970) have pointed out that in Papua-New Guinea, mature weathering is uncommon despite the favorable climate and lithological conditons. This is mainly because of youthful and unstable land forms, and in the highest areas because of low temperatures. Also, large areas have been blanketed by recent volcanic ash. Ultisols appear to be the most widespread of the LAC soils under consideration, with both LAC Alfisols and Oxisols occupying only relatively small areas.

Although many morphological descriptions are available, particularly from Papua-New Guinea, they have not always been classified into better-known taxonomies. This, together with the general lack of relevant laboratory data, makes it difficult to assess the extent of LAC soils in forms that have been referred to as Alfisols and Ultisols. In particular, there is a lack of adequate particle-size data, mainly because of dispersion difficulties.

Haantjens (1967, 1968) has discussed the problems associated with classification of soils in Papua-New Guinea. He pointed out many of the approximations and probable errors that arise when the soils are classified according to Soil Taxonomy on the basis of field data. Not only does inadequate particle-size data hinder distinction of possible Oxisols, but Haantjens (1967) indicated that a number of soils previously classified as Oxisols largely on

field data, often have more than the allowable amounts of weatherable minerals. Similarly, it is difficult to assess the data available for West Irian (Haantjens et al., 1967), particularly as analytical methods are not given.

Thus, at the present it is not possible to give an adequate assessment of the LAC soils of New Guinea, but it is possible to emphasize some great contrasts with the north Australian tropics. Contents of weatherable minerals are high in many soils; allophane is of common occurrence, and halloysite appears much more common in kaolinitic clays than in tropical Australia.

OXISOLS OF THE SOUTH PACIFIC

M.L. Leamy, L.S. Blakemore & D.M. Leslie

ABSTRACT

The South Pacific Ocean covers a substantial segment of the earth's surface. It has many distinctive features apart from its size. One of these is that the land area is a very small proportion of the total area and occurs almost exclusively as islands. These islands vary widely in age and geological composition, and consequently display a wide spectrum of soils.

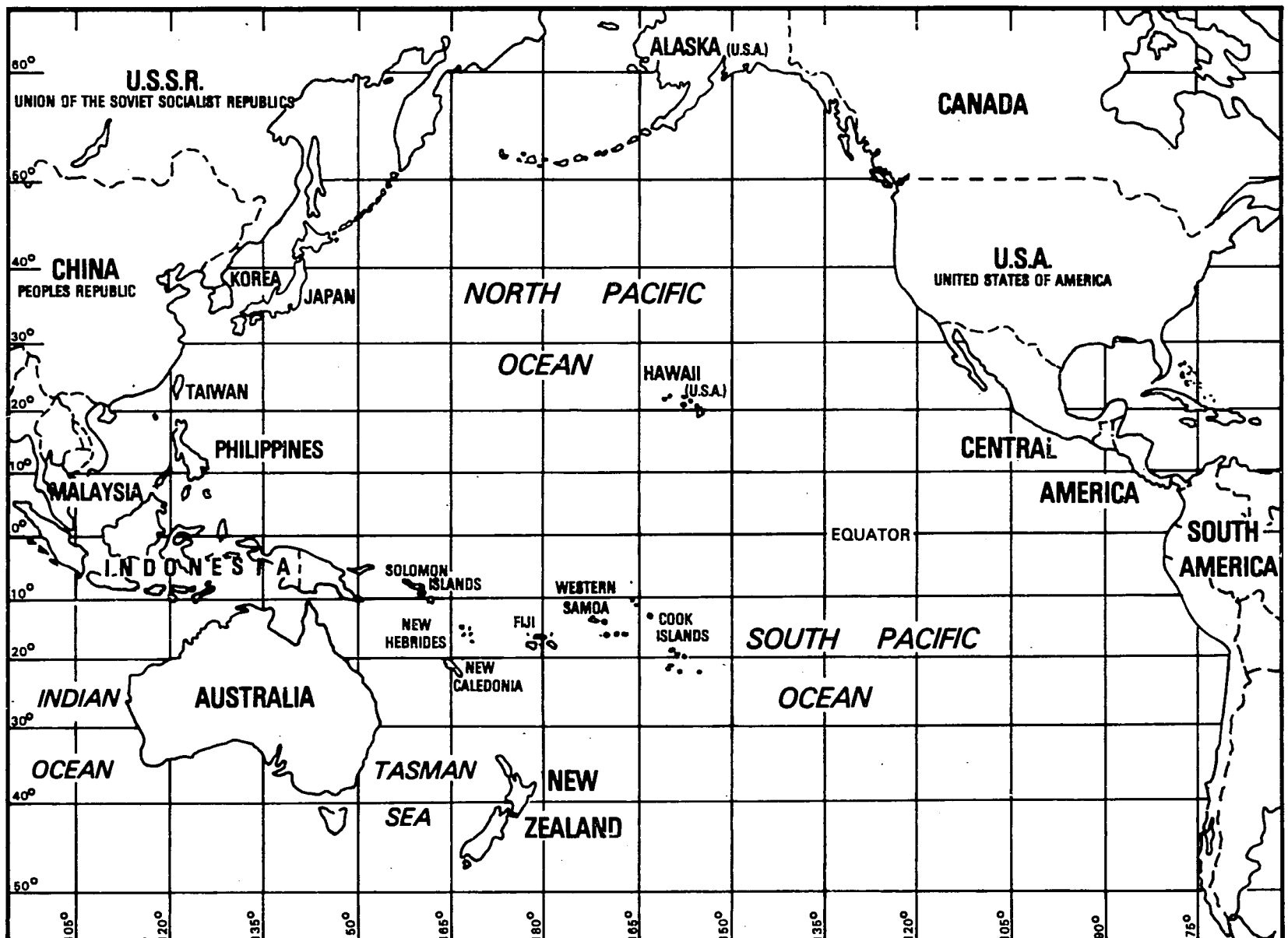
The area considered in this study is confined to that part of the South Pacific where sufficient soil survey work has been carried out, mainly by New Zealand and French pedologists, to provide the data required to assess the soils in terms of Soil Taxonomy. The area is delineated by the Cook Islands in the southeast; Western Samoa in the northeast; the Solomon Islands in the northwest; and the Loyalty Islands in the southwest. The approximate boundaries of this region are 160°E longitude to 160°W longitude and 5°S latitude to 25°S latitude - an area just a little smaller than Australia.

In a number of the island groups old land surfaces on basic volcanic rocks have resulted in the formation of Oxisols published in Soil Taxonomy, and also according to suggested amendments. Modifications which seem to be appropriate for the South Pacific region are proposed.

INTRODUCTION

There are many distinctive features on the earth's surface, and one of the largest is the Pacific Ocean (Fig. 1), which occupies about one-third of the earth's total area. Although dominated by a vast expanse of ocean, the region includes land areas and cultures of a singular character. This study is confined to that part of the Pacific, south of the equator, where sufficient soil data is available to support a generalized taxonomic exercise. The larger land masses such as Papua New Guinea, Australia, and New Zealand are excluded, and attention is directed to an area delineated by the Cook Islands in the southeast; Western Samoa in the northeast; the Solomon Islands in the northwest; and the Loyalty Islands in the southwest. The approximate boundaries of this region are 160°E longitude to 160°W longitude and 5°S latitude to 25°S latitude - an area approximately similar in size to Australia. The territories included are New Hebrides (80 islands comprising 14,763 sq km); Solomon Islands (6 large islands, 3 small islands, and 3 island groups comprising 29,780 sq km); Western Samoa (2 large islands and 7 small islands comprising 2,935 sq km); Fiji (320 islands comprising 18,272 sq km); Loyalty Islands (New Caledonia plus 1 small island and 2 island groups comprising 18,998 sq km); and the Cook Islands (15 islands comprising 240 sq km).

A very distinctive feature of the South Pacific is that the land area is a very small proportion of the total area. For instance, the Cook Islands comprise 240 sq km of land but occupy 2 million sq km of ocean - a little more than 1 sq km of land to 10,000 sq km of sea. The islands are predominantly of basic volcanic composition or coral limestone or both. Towards the west, ultrabasic intrusions are extensive, particularly in the Loyalty group. Andesitic volcanic ash of recent origin is an important soil-forming ingredient in some groups, notably in the New Hebrides. In Tonga the thickness and extent of ash over uplifted coral limestone has precluded the formation of Oxisols. Basalt lava is the predominant rock type in most of the groups discussed here.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90°
75°

The island types can be categorized as "high" islands and "low" islands. The high islands are predominantly volcanic mountains, like Hawaii or Rarotonga, which in some cases are surrounded by coral reefs. The low islands are of coral formation, usually built on top of undersea mountains, or they may be atolls (low, palm-covered islets enclosing a lagoon, e.g. Palmerston atoll in the Cook group), or raised coral platforms sometimes blanketed with volcanic ash, e.g. Vava'u in the Tongan group.

The climate in the tropical South Pacific is reasonably uniform. Except on larger or higher islands, temperatures vary little throughout the year, registering mainly between 21° - 27°C. Here the trade winds dominate. Blowing steadily, they bring more rain to the windward side of high islands. Leeward sides and low islands often have low rainfalls, and droughts are common during the dry season. Temperature regimes are dominantly isohyperthermic, becoming isothermic with altitude on some of the high islands, and moisture regimes are mainly udic and ustic.

THE OCCURRENCE OF OXISOLS BY TERRITORIES

Examples of Oxisols occur in each of the territories under discussion, although in no country are they of very wide extent. They are classified in gibbsic, acric, eutric, and haplic great groups of Humox, Ustox, and Orthox. Despite the fact that they do dominate the soil pattern in any territory, their occurrence in some countries has quite seriously affected those land development projects which have been undertaken without a full understanding of the soil properties. For instance, Acrorthox occurs on the southeastern flank of Upolu in Western Samoa, and has so far defied conventional attempts to develop the land.

Not enough data is available for a comprehensive taxonomic assessment of each territory, but the following is a summary of each with isolated examples of Oxisol occurrence.

New Hebrides

The New Hebrides are a double chain of mountainous volcanic islands lying between 12° and 21°S latitude and 166° and 171°E longitude. Many have raised coral plateaux and cultivatable coastal strips. Five active volcanoes are in the group. Annual rainfall increases from about 2300 mm in the south to 3800 mm in the north. Average monthly temperatures range from 22° - 28°C.

Oxisols have been recorded in two of the southernmost islands, Aneityum and Erromanga. They are all Tropeptic Haplorthox except for one pedon recorded at an elevation of 375 m on Aneityum. There the temperature regime is isothermic and organic carbon contents are high, producing a Typic Haplohumox (Pedons SP1-3).

Solomon Islands

The Solomons are a double chain of six large islands and many smaller ones lying between 5° and 12°S latitude and 155° to 170°E longitude. They are mountainous and volcanic, with some active volcanoes and several small coral islands. Average annual rainfall is high, ranging from 2180 mm to 4060 mm, and average maximum temperatures range from 22° - 31°C. The Solomon Islands are the largest and northernmost territory under discussion and this latter fact is reflected in the pattern of Oxisols recorded there. Six pedons have been recorded from the islands of Santa Isabel, San Christobal, and Kolombangara, and all except one are Acrorthox in the typic, leptic and haplic subgroups. No leptic subgroup has been defined in Soil Taxonomy and it is suggested here to accommodate a pedon with a thin oxic horizon. All the Acrorthox described are in ferritic or gibbsitic families. One pedon on Kolombangara Island is a Tropeptic Haplorthox. In both the New Hebrides and the Solomon Islands, tropeptic subgroups are particularly distinguished by a clearly discernible and well-developed structure in the oxic horizons (Pedons SP4-9).

Western Samoa

Western Samoa is dominated by two large, mountainous volcanic islands. Much of the surface of the islands is covered with lava flows or is littered with black scoria rocks. The group lies between 13° to 15°S latitude and 168° to 173°W longitude. Rainfall increases with altitude (2870 mm at Apia; 6350 mm at 900 m) and is greater on south and east coasts because of the effect of mountain ranges on the southeast trade winds. Temperatures are fairly uniform, averaging 26° - 27°C at sea level but falling to 17° - 18°C at 1200 m. A comprehensive soil map of the country is available (Wright, 1963) and the pattern of Oxisols includes typic subgroups of Gibbsiorthox and Acrorthox with some Tropeptic Haplorthox. All Oxisols belong to oxidic families (Pedons SP10-14).

Fiji

Fiji comprises the largest number of islands of the territories discussed. They are mainly mountainous and were formed from volcanic and sedimentary materials deposited on a submarine platform. Atolls and coral islands occur in the Lau group and coral reefs encircle most of the islands. Average annual rainfall ranges from 1780 mm to 3120 mm and average monthly temperatures from 23° - 27°C.

Fiji lies between 15° and 22°S latitude and 177° and 175°W longitude. A comprehensive soil map of the country is available (Twyford & Wright, 1965).

Oxisols that were identified include tropeptic subgroups of Haplorthox and Eutrustox and typic subgroups of Acrustox. They belong to oxidic and gibbsitic families (Pedons SP15-17).

Cook Islands

This group consists of 15 islands lying between 156° and 167°W longitude and 8° and 23°S latitude. There are two distinct groups of islands: the Northern Cooks, consisting of seven atolls; and the

Southern Cooks, consisting of eight islands, of which six are volcanic and two are atolls. The volcanic islands have a hilly interior and some fertile lowlands. They are surrounded by coral reefs and most have an elevated reef or *makatea* immediately behind the coastline. Average annual rainfall is quite uniform ranging from 2110 mm to 2770 mm and average monthly temperatures range from 22° - 28°C.

A detailed soil survey of the Southern Cooks has recently been completed. Only one Oxisol has been identified and it is a ruptic-lithic subgroup of Eutrorthox, occurring on a raised *makatea* on the oldest island of Mangaia. It belongs to a kaolinitic family (Pedon SP18).

New Caledonia and the Loyalty Islands

The Loyalty Islands occur in the western part of the South Pacific, between 19° and 23°S latitude and 163° and 168°E longitude, and are dominated by the large island of New Caledonia. Average annual rainfall ranges from 1090 mm to 3300 mm and average temperature from 21° - 26°C. Outcrops of ultrabasic rocks are extensive on New Caledonia and profiles of Oxisols have been recorded by Latham (1975). At an elevation of 820 m on Mt. Boulinda, a profile formed on harzburgite under what is probably an isothermic temperature regime has a cation exchange capacity (CEC) in the oxic horizon ranging from 1 to 0.03 per 100 g clay. Percent carbon was not recorded in the oxic horizon, but it is 0.38% in the horizon immediately above it. Although other relevant analyses are not available, it seems probable that this profile is an Acrorthox.

French pedologists affiliated with ORSTROM have worked for many years throughout the South Pacific and have tested the taxonomy of Oxisols in many territories. They have recorded the following main problems (Dr. M. Latham, personal communication):

(1) The 16 me/100 g clay CEC limit is often not very satisfactory for phyllites like metahalloysite, which have a higher CEC than kaolinite.

(2) Some soils in Fiji would fit the Gibbsi- great groups according to their mineralogical composition, but they lack cemented sheets or aggregates.

(3) The Acr- great groups occur on ultrabasics and are mainly correlated with "sols ferrallitiques ferritiques" which are very rich in iron sesquioxides and poor in Al_2O_3, Ca^{++}, etc., and thus very infertile. But Acrorthox or Acrohumox may occur as well on ash over limestone in the uplifted atolls of the Loyalty Islands or of Fiji (Tercinier, 1971; Latham & Denis, 1977) where they do not seem to have the same agronomic limitations.

SOUTH PACIFIC OXISOLS IN DETAIL - THE LAKEBA PATTERN

Because of the meager data available this study of South Pacific Oxisols is by no means comprehensive. However, detailed information is available as the result of D.M. Leslie's work during a Royal Society of New Zealand Scientific Expedition to Fiji and Tonga in 1977. The island of Lakeba in Fiji has been surveyed in detail by Dr. M. Latham of OSTROM and the opportunity was taken during the 1977 expedition to conduct a taxonomic exercise. The pattern of occurrence of Oxisols on Lakeba is in many respects typical of their pattern throughout the South Pacific.

Lakeba is the largest island in the Lau Province of Fiji and lies some 300 km east of Suva at 18°S and 178°E. Nearly circular in shape, the island is 8 km in diameter and approximately 50 km^2 in area. It has a hot, tropical climate with distinct wet and dry seasons. The mean annual rainfall of 2026 mm is unevenly distributed throughout the year. The mean annual air temperature is 25°C with a range of 4.5°C between summer and winter. The temperature regime is thus isohyperthermic. Lakeba is a Miocene volcanic complex of andesitic and dacitic rocks with some basaltic flows. This formation is overlain by Miocene coral limestone on the northwest, west, and southeast parts of the island. The island is essentially a dome-like central massif flanked by dissected hills of diminishing elevation that grade into a fringing, discontinuous

plan at the coast. Plateau remnants occur both inland on andesite, and in coastal locations on coral limestone.

The broad soil pattern comprises Histosols, Entisols, and Inceptisols on the coastal plains; Alfisols and Mollisols in inland valleys; Ultisols on the inland hills and Oxisols on the plateau remnants (Fig. 2).

Oxisols occur on nearly level stable surfaces of the original landscape and contain large quantities of gibbsite and free iron oxides. Those on andesite are a Typic Haplorthox and, on the oldest remnants, a clayey, gibbsitic, isohyperthermic family of Typic Acrustox (Pedon SP16). On old coral limestone remnants, the soil is a clayey, gibbsitic, isohyperthermic Tropeptic Eutrustox (Pedon 17). The distribution of these Oxisols is shown in Fig. 3.

ASSESSMENT OF SOUTH PACIFIC OXISOL TAXONOMY

The exercise conducted in 1977 provided an opportunity to assess the adequacy of current Oxisol definitions and to express the main genetic and practical distinctions between the soils. The following points emerge:

1. Separation of the Humox suborder on the basis of carbon and temperature regime appropriately distinguishes between Oxisols at high and low altitudes on the high islands. With increasing altitude on these islands average annual precipitation increases, mean annual temperature decreases--although retaining its iso- characteristics, and organic carbon contents increase.

2. Tropeptic subgroups allow adequate expression of the good structural properties of Oxisols formed on basic rocks, particularly basalt, although this may be more effective if not linked with the thickness of the oxic horizon.

3. The separation of Acr- great groups from Eutr- great groups is important and directly reflects parent material differences

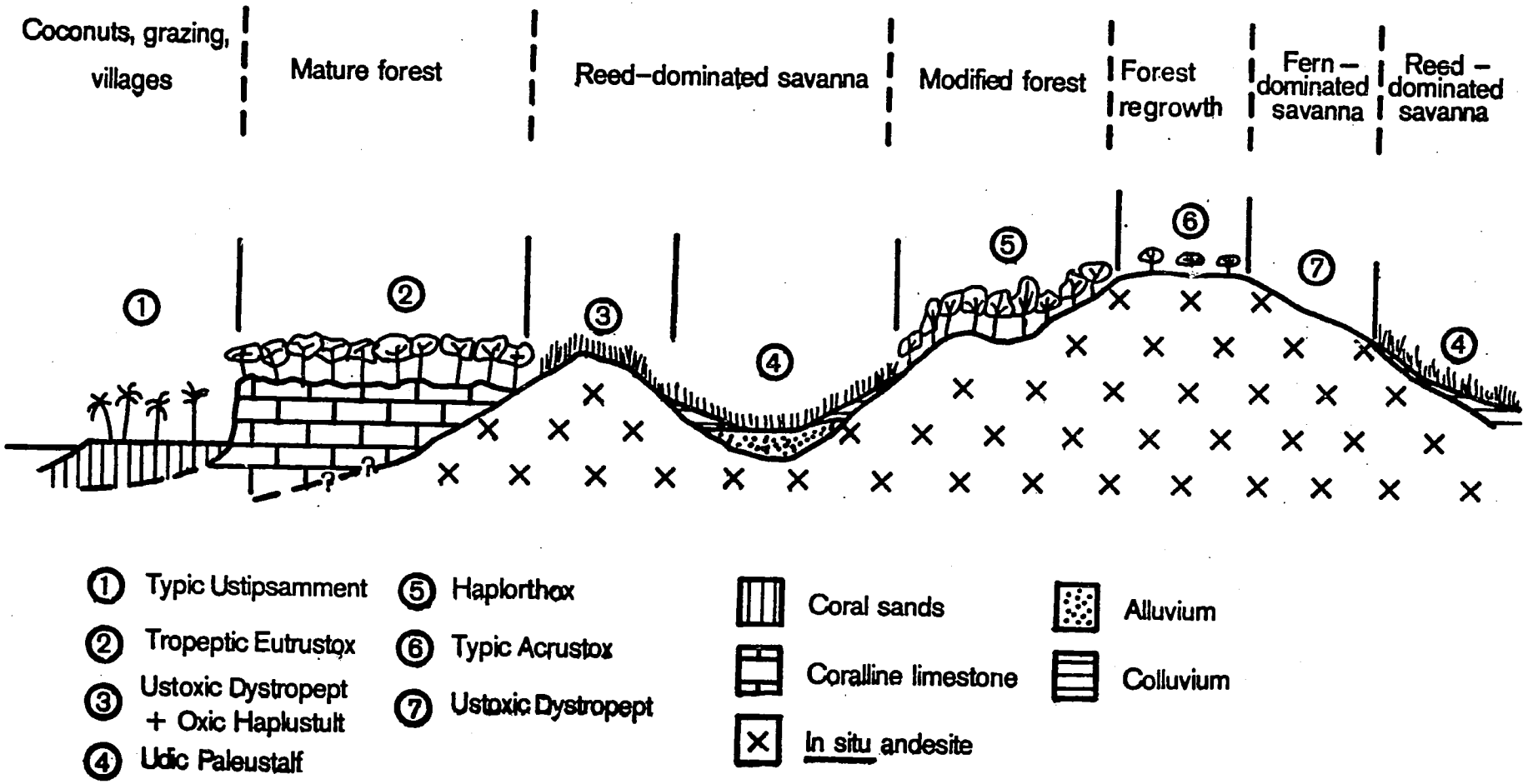
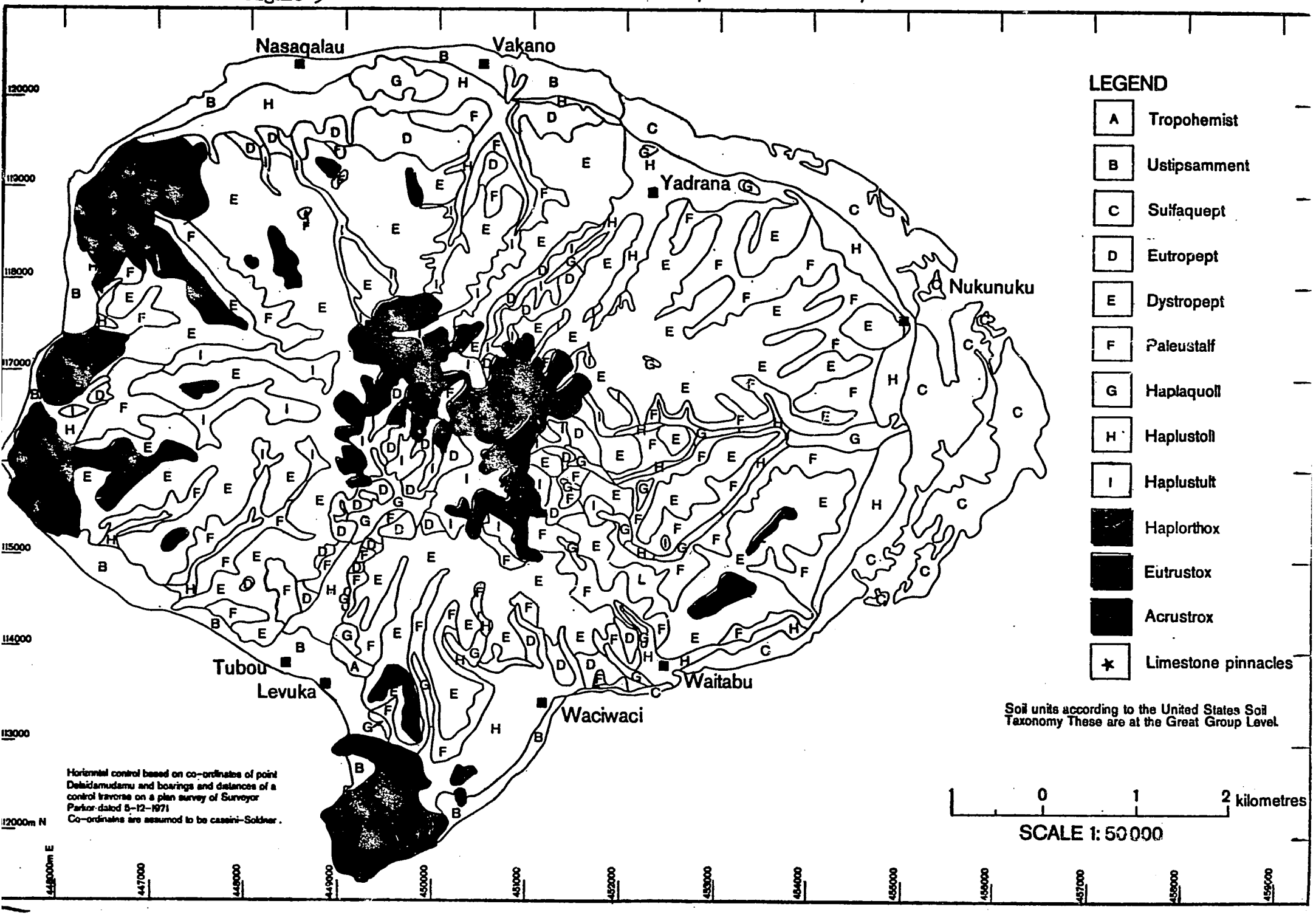


Fig. 2. East-west transect through western Lakeba.

Figure 3

SOIL MAP OF LAKEBA, LAU GROUP, FIJI



(in that Eutr- great groups are formed on coral limestone) and important agronomic differences, according to French pedologists. In order to adequately express this distinction in all cases, the Eutr- great groups should key out before the Acr- great groups.

4. Pedons from Western Samoa and from Fiji (Pedons SP10, 11, 16, and 17) seem to indicate that gibbsitic mineralogy is adequately considered, as it can be used as a parameter at both a great and family level.

5. Evidence is provided for a leptic subgroup of Acrorthox (Pedon SP7). Provision is made for this in item b of the typic definition (p. 327 Soil Taxonomy).

6. In general, Soil Taxonomy expresses well the major genetic and practical differences between these South Pacific Oxisols. For instance Acr- and Gibbsi- great groups occur on the oldest land surfaces at the lowest latitudes; Hapl- great groups occur on old land surfaces at intermediate latitudes, with Humox expressing altitudinal differences; and Eutr- great groups occur on old land surfaces formed on rocks with high base status, such as coral limestone.

THE EFFECT OF PROPOSED OXISOL MODIFICATIONS

The Bennema-Comerma proposal

The inclusion of an argillic horizon with a clay ratio of less than 1.4 and an absence of common clear clayskins would increase the number of Oxisols in the South Pacific - and this may be quite appropriate. For instance Pedon SP19 is presently excluded from Oxisols because the B_2 horizon has 10% more clay than the overlying horizon and also has many thin indistinct coatings. It is, however, associated with Oxisols on the same parent material and under the same environment.

In the Appendix, this pedon is classified following the Bennema-Comerma suggestions. It is also appropriately separated as a leptic subgroup because the present alternative of tropeptic expresses the thin oxic horizon but not the poor structure.

The Eswaran proposals

These proposals, described in Circular No. 1/78 of ICOMOX, are quite radical and clearly were designed to arouse reaction. As far as South Pacific Oxisols are concerned, the provision for a minimum thickness of 50 cm for the oxic horizon would exclude a considerable number (e.g. Pedons SP3, SP15) and would not appear to be particularly appropriate. Clearly, most Oxisols in low latitudes will have thick oxic horizons for obvious genetic reasons, but tropical Oxisols also occur up to 20° from the equator and do not always have thick oxic horizons. The present limit of 30 cm expresses this well.

From South Pacific experience there seems to be no justification for elevating acric properties to suborder level, or for including a parameter apparently designed to exclude amorphous material domination of the exchange complex.

ACKNOWLEDGEMENTS

It would not have been possible to prepare this report without access to data and samples collected by a number of workers throughout the Pacific. Particular akcnowledgement is made to Dr. Marc Latham of ORSTOM, New Caledonia; to Dr. K.E. Lee, Division of Soils, CSIRO, Australia, who provided samples that were collected under quite challenging conditions during the Royal Society Expeditions to the Solomon Islands and the New Hebrides; to Mr. N.M. Kennedy of Soil Bureau, DSIR, New Zealand for data from the New Hebrides; and to the analytical team which processed samples with considerable speed and commendable toxonomic skill, particularly Messrs R.F. Thomas, B.K. Daly, and their assistants at Soil Bureau.

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Appendix 1. Pedon data for selected Oxisols from the South Pacific region.

Pedon	Classification	Territory
SP1	Typic Haplohumox	New Hebrides
SP2	Tropeptic Haplorthox	New Hebrides
SP3	Tropeptic Haplorthox	New Hebrides
SP4	Typic Acrorthox	Solomon Islands
SP5	Typic Acrorthox	Solomon Islands
SP6	Typic Acrorthox	Solomon Islands
SP7	Leptic Acrorthox	Solomon Islands
SP8	Haplic Acrorthox	Solomon Islands
SP9	Tropeptic Haplorthox	Solomon Islands
SP10	Typic Gibbsiorthox	Western Samoa
SP11	Typic Gibbsiorthox	Western Samoa
SP12	Typic Acrorthox	Western Samoa
SP13	Typic Acrorthox	Western Samoa
SP14	Tropeptic Haplorthox	Western Samoa
SP15	Tropeptic Eutrorthox	Fiji
SP16	Typic Acrustox	Fiji
SP17	Tropeptic Eutrustox	Fiji
SP18	Ruptic-lithic Eutrorthox	Fiji
SP19	"Leptic Haplorthox"	New Hebrides

Pedon SP1

Classification:	Typic Haplohumox, clayey, kaolinitić, isothermic.
Location:	Aneityum Island, New Hebrides. 2.5 km inland from Etpoulee on old logging road.
Physiographic position:	Ridge crest, 375 m a.s.l.
Topography:	5° slope.
Drainage:	Well drained.
Vegetation:	Regenerating Kauri trees (*Agathis obtusa*).
Parent material:	Weathered basalt and basaltic ash.
Sampled by:	N.M. Kennedy, 25 June 1977.
Soil No:	SB 9424 A-B.

A_1	0-10 cm	Dark brown (7.5YR 4/2) silty clay loam, 7.5YR 4/4 rubbed, friable, strong fine medium subangular blocky structure, many fine and medium roots, indistinct boundary.
B_2	10-130 cm	Reddish brown (5YR 4/4) silty clay loam, 7.5YR 4/4 rubbed, firm to friable, weak to moderate medium and coarse blocky structure, abundant thin indistinct coatings of matrix color, few moderately weathered stones towards base, few fine roots.

Lab No	Horizon	Depth (cm)	pH (H_2O) dry	pH NaF	C%	CEC	Exch Al	Σ bases
SB9424A	A_1	1-10	4.6	8.4	6.3	19.5	0.89	5.5
SB9424B	B_2	20-120	4.6	9.1	1.2	10.9	2.60	0.9

			%BS	Ca	Mg	K	Na	CRC[a]
SB9424A	A_1	1-10	28	3.1	1.97	0.38	0.09	6.4
SB9424B	B_2	20-120	8	0.2	0.52	0.08	0.12	3.5

			CRC[b]	CEC[b]	15 bar H_2O air dry	2.5 × 15 bar H_2O
SB9424A	A_1	1-10	7.2	22.0	35.4	88.5
SB9424B	B_2	20-120	4.0	12.4	35.1	87.8

[a]Exchangeable Al + Σ bases.

[b]Per 100g clay as determined by 2.5 × 15 bar water.

Mineralogy: kaolinitic (5% gibbsite).

Pedon SP2

Classification:	Tropeptic Haplorthox, clayey, kaolinitic, isohyperthermic.
Location:	Aneityum Island, New Hebrides. 3 km NE of Anelcauhat beside milling road, beside Forestry kauri regeneration plots.
Physiographic position:	Broad rolling ridge crest, 290 m a.s.l.
Topography:	7° slope
Vegetation:	Secondary rainforest with some *Agathis* regeneration.
Parent Material:	Basalt lavas.
Sampled by:	K.E. Lee, J.C. Buckerfield, 24 July 1971.
Soil No:	212/1-4.

A_o	1-2 cm	Very thin layer of dead leaves, twigs etc., overlying thin humus layer with matted fine roots, indistinct boundary.
	2-20 cm	Yellowish red (5YR 4/6) clay, non-plastic, very sticky, medium subangular blocky, breaking to medium crumb structure, many large and small roots, distinct boundary.
	20-90 cm	Weak red (10R 4/4) clay, slightly plastic, very sticky, massive breaking to angular blocky structure, very few fine roots, indistinct boundary.
	90-130 cm	Red (10R 4/4) clay, with patches of dark grey showing morphology of rock, very sticky, fine granular structure, very few fine roots, distinct boundary.
	130-150 cm	Dark red (10R 3/6) clay, with patches of grey weathered rock, non-plastic, very sticky, granular structure, no roots.

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Pedon SP2 (continued)

Lab No.	Depth (cm)	pH (H_2O) dry	pH KCl	C%	CEC	Exch. Al	Σ bases
212/1	0-20	4.6	4.0	3.2	15.2	2.6	4.3
2	20-90	4.6	3.8	0.7	11.1	6.0	0.8
3	90-130	4.7	3.8	0.3	9.4	5.1	0.8
4	130-150	4.6	3.7	0.4	10.8	6.6	0.6

		%BS	Ca	Mg	K	Na	CRC[a]
212/1	0-20	28	1.3	2.57	0.13	0.31	6.9
2	20-90	7	0.2	0.36	0.04	0.22	6.8
3	90-130	9	0.1	0.28	0.05	0.32	5.9
4	130-150	6	0.0	0.34	0.04	0.23	7.2

		CRC[b]	CEC[b]	15 bar H_2O air dry	2.5 × 15 bar H_2O
212/1	0-20	8.9	19.5	31.1	77.8
2	20-90	9.2	14.9	29.7	74.3
3	90-130	8.3	13.2	28.4	71.0
4	130-150	10.0	15.0	28.7	71.8

[a]Exchangeable Al + Σ bases.

[b]per 100g clay as determined by 25 × 15 bar water.

Mineralogy: Kaolinitic (magnetite also present).

Pedon SP3

Classification:	Tropeptic Haplorthox, clayey, kaolinitic, isohyperthermic.
Location:	Erromanga Island, New Hebrides, about 50 m from site 2 km NNE of Nuangkau R. bridge, between two large *Callophyllum neo-ebudicum* trees.
Physiographic Position:	Rolling ridge crest.
Topography:	5° slope.
Vegetation:	Mixed mesophyll evergreen vine forest. *Agathis/Hernandia/Callophyllum.*
Parent Material:	Basalt flows and breccias.
Sampled by:	K.E. Lee, J.C. Buckerfield.
Soil No:	215/1-3.

A_o	< 1 cm	Loose leaf litter, very sharp boundary.
	1-15 cm	Dusky red (5R 3/3) clay, sticky, slightly plastic, closely packed coarse subangular blocky structure, many fine roots, some coarse roots, indistinct boundary.
	15-60 cm	Weak red (5R 4/4) clay, sticky, slightly plastic, very weak blocky structure, compact *in situ*, few fine roots, indistinct boundary.
	60-90 cm	Weak red (5R 4/3) clay, very sticky, non plastic, compact, breaking to fine crumb structure, *in situ* shows structure of strongly weathered rock, no roots.

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Pedon SP3 (continued)

Lab No.	Depth (cm)	pH (H_2O) dry	pH KCl	C%	CEC	Exch. Al	Σ bases
215/1	0-15	4.5	3.8	9.5	22.8	3.0	6.6
2	15-60	4.6	3.7	1.0	12.2	6.2	0.9
3	60-90	4.7	3.6	0.3	11.5	6.8	0.9

		%BS	Ca	Mg	K	Na	CRC[a]
215/1	0-15	29	3.5	2.02	0.46	0.61	9.6
2	15-60	7	0.1	0.37	0.07	0.37	6.1
3	60-90	8	0.1	0.33	0.02	0.41	7.7

		CRC[b]	CEC[b]	15 bar H_2O air dry	2.5 × 15 bar H_2O
215/1	0-15	11.6	27.5	33.1	82.8
2	15-60	8.5	14.6	33.4	83.5
3	60-90	13.7	34.2	33.6	84.0

[a]Exchangeable Al + Σ bases.

[b]Per 100g clay as determined by 2.5 × 15 bar water.

Mineralogy: Kaolinitic (magnetite also present).

Pedon SP4

Classification:	Typic Acrorthox, clayey, ferritic, isohyperthermic.
Location:	Thousand Ships Bay area, Santa Isabel, Solomon Islands about 3 km inland, 244 m above sea level, on ridge top above Tanameko Mining Camp.
Physiographic Position:	Rolling ridge crest.
Topography:	10° slope.
Vegetation:	*Casuarina* forest. Dominant species *C. papuana*, *Dacrydium* sp., bamboo.
Parent Material:	Serpentine.
Sampled by:	K.E. Lee, 1965.
Soil No:	116/1-7.

A_o	8-0 cm	Dusky red (2.5YR 3/2) fibrous litter of *C. papuana* and bamboo, many roots, sharp boundary.
	0-8 cm	Red (10R 4/6) fine sandy clay, medium blocky structure breaking to stable fine granular, many roots up to 2.5-5 cm diameter, indistinct boundary.
	8-15 cm	Red (10R 4/6) fine sandy clay, fine to medium granular structure, many rocks up to 5 cm diameter, indistinct boundary.
	15-84 cm	Red (2.5YR 5/6) clay, sticky, with many small nodular concretions, friable, very few fine roots, distinct boundary.
	84-137 cm	Light reddish-brown (2.5YR 6/4) fine sandy clay, sticky, massive *in situ* breaking to weak fine granular structure, very few fine roots, indistinct boundary.
	137-213 cm	Reddish brown (5YR 5/4) sandy clay with fine mottles, greasy, massive *in situ* breaking to fairly large blocks and further to fine granular structure, very few fine roots, distinct boundary.
	213 cm +	Reddish-brown (5YR 5/4) sandy clay with fine reddish-yellow (5YR 6/8) mottles, greasy, some strongly weathered parent material.

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Pedon SP4 (continued)

Lab No.	Depth (cm)	pH (H_2O) dry	pH KCl	C%	CEC	Exch. Al	Σ bases
116/2	0-8	4.5	3.9	5.2	11.8	0.53	1.00
4	15-84	5.6	6.0	0.7	0.8	0.00	0.08
5	84-137	5.7	6.2	0.3	0.6	0.00	0.03
6	137-213	5.6	6.1	0.2	0.7	0.00	0.06

		%BS	Ca	Mg	K	Na	CRC[a]
116/2	0-8	8	0.2	0.51	0.16	0.10	1.50
4	15-84	10	0.0	0.01	0.03	0.04	0.08
5	84-137	5	0.0	0.00	0.02	0.01	0.03
6	137-213	9	0.0	0.03	0.01	0.02	0.06

		CRC[b]	CEC[b]	15 bar H_2O air dry	2.5 × 15 bar H_2O
116/2	0-8	3.00	23.8	19.8	49.5
4	15-84	0.10	1.0	31.4	78.5
5	84-137	0.04	0.7	32.7	81.8
6	137-213	0.06	0.7	37.6	94.0

[a]Exchangeable Al + Σ bases.

[b]Per 100g clay as determined by 2.5 × 15 bar water.

Mineralogy: Kaolinitic (magnetite also present).

Pedon SP5

Classification:	Typic Acrorthox, clayey, ferritic, isohyperthermic.
Location:	San Christobal, Solomon Islands. Near summit of rounded hilltop about 3 km SE of Wainoni R.C. Mission, about 500 m above sea level.
Physiographic Position:	Rounded hilltop.
Topography:	Flattish, slightly hummocky surface.
Vegetation:	*Casuarina* forest. Dominant species *C. papuana*, *Podocarpus neriifolius*, much moss and fern.
Parent Material:	Serpentine.
Sampled by:	K.E. Lee, 1965.
Soil No:	114/1-5.

13-8 cm	Living moss and decaying fragments.
8-0 cm	Dark brown peat, greasy, many roots, sharp boundary.
0-15 cm	Strong brown (7.5YR 5/6) clay with some gritty inclusions, fairly stable medium crumb structure, very few roots, indistinct boundary.
15-66 cm	Yellowish-red (5YR 5/8) sandy clay, compact, fairly stable medium crumb structure, very few roots, distinct boundary.
66-74 cm	Mottled red (10R 4/6) and reddish-yellow (7.5YR 6/6) coarse sandy clay, many small gritty nodules, very compact, no roots, distinct boundary.
74-99 cm	Strong brown (7.5YR 5/6) sandy clay, prismatic structure (prisms about 2-2.5 cm high, tightly fitting) breaking to fine granular, no roots; water table at about 75 cm at time of sampling, but no obvious gleying.

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Pedon SP5 (continued)

Lab No.	Depth (cm)	pH (H_2O) dry	pH KCl	C%	CEC	Exch. Al	Σ bases
114/2	0-15	5.0	4.6	3.2	6.7	0.00	0.09
3	15-66	5.4	5.6	2.1	2.8	0.00	0.20
4	60-74	5.1	5.6	1.1	2.6	0.00	0.05
5	74-99	5.4	6.0	1.4	1.4	0.00	0.05

		%BS	Ca	Mg	K	Na	CRC[a]
114/2	0-15	1	0.0	0.03	0.02	0.04	0.09
3	15-66	7	0.1	0.04	0.01	0.02	0.20
4	66-74	2	0.0	0.04	0.01	0.00	0.05
5	74-99	4	0.0	0.02	0.01	0.02	0.05

		CRC[b]	CEC[b]	15 bar H_2O air dry	2.5 × 15 bar H_2O
114/2	0-15	0.1	10.2	26.4	66.0
3	15-66	0.3	3.6	31.1	77.8
4	66-74	0.1	4.9	25.4	53.5
5	74-99	0.1	1.5	36.6	91.5

[a]Exchangeable Al + Σ bases.

[b]Per 100g clay as determined by 2.5 × 15 bar water.

Mineralogy: Ferritic (6-10% gibbsite also present).

Pedon SP6

Classification:	Typic Acrorthox, clayey, ferritic, isohyperthermic.
Location:	Thousand Ships Bay area, Santa Isabel, Solomon Islands. About 0.4 km inland, 61 m above sea level, beside ridge-top track leading to Tanemeko Mining Camp.
Physiographic Position:	Rolling ridge crest.
Topography:	10° slope.
Vegetation:	Fern (*Gleichenia* sp.), *Lycapodium* sp., occasional grasses and small shrubs (Myrtaceae).
Parent Material:	Serpentine.
Sampled by:	K.E. Lee, 1965.
Soil No:	115/1-4

0-15 cm	Dusky red (10R 3/3) gritty sandy loam, very stable fine granular structure, very friable, many small dusky red (7.5R 2/2) hard concretions, some large concretions, at and near soil surface composed of cemented masses of small concretions, few fine roots, distinct boundary.
15-23 cm	Weak red (10R 4/4) fine sandy clay, mottled with dusky red (10R 3/4) patches, very stable fine granular structure, no roots, distinct boundary.
23-46 cm	Red (2.5YR 4/8) fine sandy clay, strong fine granular structure, no roots, distinct boundary.
46-91 cm +	Red (2.5YR 4/6) clay, massive, becoming increasingly compact with increasing depth, no roots. This continues to weathered parent material, at depths up to about 3 meters.

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Pedon SP6 (continued)

Lab No.	Depth (cm)	pH (H_2O) dry	pH KCl	C%	CEC	Exch. Al	Σ bases
115/1	0-15	4.7	4.2	5.2	15.1	0.97	0.50
3	23-46	5.8	5.8	1.5	3.2	0.00	0.06
4	46-91	5.7	6.0	1.0	2.0	0.00	0.03

		%BS	Ca	Mg	K	Na	CRC[a]
115/1	0-15	3	0.2	0.17	0.06	0.10	1.50
3	23-46	2	0.0	0.02	0.02	0.02	0.06
4	46-91	2	0.0	0.02	0.01	0.00	0.03

		CRC[b]	CEC[b]	15 bar H_2O air dry	2.5 × 15 bar H_2O
115/1	0-15	2.90	29.6	20.4	51.0
3	23-46	0.10	6.2	20.7	51.8
4	46-91	0.06	3.7	21.6	54.0

[a]Exchangeable Al + Σ bases.

[b]Per 100g clay as determined by 2.5 × 15 bar water.

Mineralogy: Ferritic (6% gibbsite also present).

Pedon SP7

Classification:	Leptic Acrorthox, clayey, gibbsitic, isohyperthermic.
Location:	Kolombangara, Solomon Islands, on 915 m ridge west of Kolombara River.
Physiographic Position:	Steep ridge side.
Topography:	25° slope.
Vegetation:	Mossy montane tropical rain forest. Dominant species *Metrosideros* sp., *Eugenia* spp., *Aporosa papuana*.
Parent Material:	Colluvial debris from olivine pyroxene basalt.
Sampled by:	K.E. Lee, 1965.
Soil No:	85/1-4.

A_o	10-0 cm	Moss peat, wet and greasy, many roots, sharp boundary.
A_1	0-15 cm	Strong brown (7.5YR 5/6) clay with gritty inclusions, some fine roots, indistinct boundary.
A_1G	15-61 cm	Reddish-brown (5YR 4/4) gritty clay, with some gleyed patches, very few roots, indistinct boundary.
AC	61 + cm	Reddish-brown (5YR 4/3) bouldery sand, grading to greyer color at 76 cm +, with increasing proportions of large fragments of strongly weathered rock, no roots. Some stones and boulders were found throughout the profile.

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Pedon SP7 (continued)

Lab No.	Horizon	Depth (cm)	pH (H_2O) dry	pH KCl	C%	CEC	Exch. Al	Σ bases
85/1	A_o	0-15	4.4	4.0	2.1	6.7	0.57	0.05
3	AC	61-76	5.2	5.5	0.5	1.7	0.00	0.05
4	AC	76 +	5.7	6.0	0.2	0.5	0.00	0.03

			%BS	Ca	Mg	K	Na	CRC[a]
85/1	A_o	0-15	1	0.0	0.03	0.02	0.00	0.60
3	AC	61-76	3	0.0	0.00	0.01	0.04	0.05
4	AC	76 +	6	0.0	0.01	0.00	0.02	0.03

			CRC[b]	CEC[b]	15 bar H_2O air dry	2.5 × 15 bar H_2O
85/1	A_o	0-15	1.7	18.7	14.3	35.8
3	AC	61-76	0.1	3.8	18.1	45.3
4	AC	76 +	0.2	3.3	6.0	15.0

[a]Exchangeable Al + Σ bases.

[b]Per 100g clay as determined by 2.5 × 15 bar water.

Mineralogy: Gibbsitic (50-70% gibbsite, geothite and kaolinite also present).

Pedon SP8

Classification:	Haplic Acrorthox, clayey, gibbsitic, isohyperthermic.
Location:	Kolombangara Island, Solomon Islands. 305 m above sea level, ridge west of Kolombara River.
Physiographic Position:	Broad ridge crest.
Topography:	4° slope.
Vegetation:	Lowland tropical rain forest. Grove of *Dillenia salomonensis*.
Parent Material:	Deeply weathered olivine pyroxene basalt.
Sampled by:	K.E. Lee, 1965.
Soil No:	90/1-4.
A_o 2.5-0 cm	Loose leaf litter and granular mull with many fibrous roots, indistinct boundary.
A_{11} 0-10 cm	Weak red (2.5YR 4/2) humus stained clay, sticky, weak medium nut structure breaking to fine crumb, many roots up to 2.5-5 cm diameter, indistinct boundary.
A_{12} 10-28 cm	Reddish-brown (5YR 4/4) sandy clay, non-sticky, fairly stable fine granular structure, few roots up to about 1.5 cm diameter, distinct boundary.
B 28-81 cm	Yellowish-red (5YR 5/6) sandy clay, non-sticky, stable fine granular structure, very few fine roots, diffuse boundary.
81-127 cm	Reddish-brown (2.5YR 4/4) sandy clay with many small iron stained concretions, slightly plastic, fine granular structure, no roots.

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Pedon SP8 (continued)

Lab No.	Horizon	Depth (cm)	pH (H_2O) dry	pH KCl	C%	CEC	Exch. Al	Σ bases
90/1	A_{11}	0-10	4.3	3.7	7.3	23.5	3.9	0.70
3	B	28-81	4.9	4.8	0.9	3.9	0.0	0.03

			%BS	Ca	Mg	K	Na	CRC[a]
90/1	A_{11}	0-10	3	0.1	0.23	0.17	0.15	4.60
3	B	28-81	1	0.0	0.00	0.00	0.03	0.03

			CRC / 100g clay[b]	CEC / 100g clay[b]	15 bar H_2O air dry	2.5 × 15 bar H_2O
90/1	A_{11}	0-10	8.7	44.5	21.1	52.8
3	B	28-81	0.1	7.2	21.8	54.5

[a]Exchangeable Al + Σ bases.

[b]Clay determined by 2.5 × 15 bar water.

Mineralogy: Gibbsitic (gibbsite 40%, kaolinite 35%, geothite also present).

Pedon SP9

Classification:	Tropeptic Haplorthox, clayey, kaolinitic, isohyperthermic.
Location:	Kolombangara Island, Solomon Islands, ridge east of Kolombara River, 68 m above sea level.
Physiographic Position:	Very broad ridge crest.
Topography:	2° slope.
Vegetation:	Lowland tropical rain forest. Dominant species *Calophyllum* sp., *Teysmanniodendron ahernianum*, *Erythroxylum ecarinatum*, *Xanthaphyllum papuanum*, *Amoora* sp., *Neoscortechinia forbesii*, *Celtis latifolia*.
Parent Material:	Deeply weathered olivine pyroxene basalt.
Sampled by:	K.E. Lee, 1965.
Soil No:	91/1-5.
A_o	Very thin layer of leaves, twigs etc.
A 0-25 cm	Reddish-brown (2.5YR 4/4) humus stained clay, slightly sticky, very friable in top 5-8 cm, strong medium-coarse granular structure, earthworms (*Pontoscolex corethrurus*) numerous at 0-5 cm, many roots of forest trees, distinct boundary.
B_1 25-69 cm	Red (10R 5/6) loamy clay, plastic, friable, unstable coarse nut structure breaking to stable fine crumb, very few roots, indistinct boundary.
B_2 69-102 cm	Weak red (10R 4/4) silty clay, compact, massive *in situ*, breaking to stable fine crumb, very few roots, indistinct boundary.
B/C 102-137 cm	Weak red (10R 4/4) silty clay, very compact, massive *in situ*, breaking with difficulty to fine crumb, few roots, some small iron-stained nodules, horizon has consistency of wet concrete. Occasional fragments of strongly weathered parent material.

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Pedon SP9 (continued)

Lab No.	Horizon	Depth (cm)	pH (H_2O) dry	pH KCl	C%	CEC	Exch. Al	Σ bases
91/1	A	0-25	4.4	4.0	3.6	13.3	2.20	0.5
3	B_2	60-102	4.9	4.0	0.5	6.8	1.30	0.2
4	B/C	102-137	4.8	4.0	0.2	6.3	1.70	0.2
5		137+			0.2	1.7	0.11	0.2

			%BS	Ca	Mg	K	Na	CRC[a]
91/1	A	0-25	4	0.1	0.26	0.11	0.05	2.7
3	B_2	69-102	3	0.0	0.09	0.02	0.13	1.5
4	B/C	102-137	3	0.0	0.07	0.02	0.13	1.9
5		137 +	11	0.0	0.02	0.01	0.12	0.3

			CRC[b]	CEC[b]	15 bar H_2O	2.5 15 bar H_2O
91/1	A	0-25	3.4	16.5	32.2	80.5
3	B_2	69-102	1.9	8.4	32.4	81.0
4	B/C	102-137	2.5	8.4	30.1	75.3
5		137 +	0.8	4.8	14.2	35.5

[a]Exchangeable Al + Σ bases.

[b]Per 100 g clay as determined by 2.5 × 15 bar water.

Mineralogy: Kaolinitic (9% gibbsite, maghemite also persent).

Pedon SP10

Classification:	Typic Gibbsiorthox, clayey, oxidic, isohyperthermic.
Location:	Western Samoa, upper foothill regions of northeast Upolu, 150 m above sea level.
Physiographic Position:	Rolling surface.
Topography:	5° slope.
Vegetation:	Second growth forest.
Parent Material:	Strongly weathered basalt.
Sampled by:	A. C. S. Wright, 22 May 1956.
Soil No:	SB6992A-C.

A	0-8 cm	Dark brown (7.5YR 3/2) clay, friable, moderate coarse and medium blocky breaking to moderate fine blocky and coarse granular structure, slightly sticky, slightly to moderately plastic, diffuse boundary.
B	8-31 cm	Dark brown (7.5YR 4/2) clay, friable, weak coarse and medium blocky breaking to coarse granular and crumb structure, slightly sticky and slightly plastic when moist, diffuse boundary.
BC	31-72 cm	Very dark brown (7.5YR 3/2) slightly stony clay, friable, massive breaking to very strong medium granular structure, very slightly sticky, moderately plastic, diffuse boundary.
	on	Dark greyish-brown very stony clay, rock fragments sub-angular and well weathered.

Lab No	Horizon	Depth (cm)	pH	C%	CEC	Exch Al	Σ bases
6992A	A	0-8	4.4	2.9	15.7	0.27	3.5
B	B	8-31	5.3	5.3	4.8	0.00	0.6
C	BC	31-72	5.6	2.2	2.3	0.01	0.3

			%BS	Ca	Mg	K	Na	CRC (Exch.Al +Σ bases)
6992A	A	0-8	13	2.0	1.2	0.20	0.1	3.8
B	B	8-31	0	0.3	0.1	0.05	0.1	0.6
C	BC	31-72	0	0.2	0.0	0.05	0.0	0.3

			CRC 100g clay[a]	CEC 100g clay[a]	15 bar H_2O	25 x 15 bar H_2O
6992A	A	0-8	8.2	33.8	18.6	46.5
B	B	8-31	1.4	11.2	17.2	43.0
C	BC	31-72	0.7	5.4	16.9	42.3

[a]Clay determined by 2.5 x 15 bar water.

Mineralogy: Oxidic (30-36% gibbsite, haematite, goethite, kaolin also present)

Pedon SP11

Classification:	Typic Gibbsiorthox, clayey, oxidic, isohyperthermic.
Location:	Western Samoa, summit of Afiamalu, extinct volcanic cone at 870 m altitude on main watershed of Upolu Island.
Physiographic Position:	Rolling summit of volcanic cone.
Topography:	12° slope.
Vegetation:	Tropical upland forest, Atone, Filimoto, Pipi, Olioli, Manumanu, Toi, etc.
Parent Material:	Basaltic scoria and possibly volcanic ash.
Sampled by:	A.C.S. Wright, 30 May 1956.
Soil No:	SB6866 A-C.
A 0-6 cm	Dark reddish-brown (5YR 3/3) peaty silt loam, friable, weak medium blocky structure breaking to crumb structure, non-sticky, non-plastic, sharp boundary.
B 6-49 cm	Brown (7.5YR 4/4) silt loam, slightly gritty, friable, massive breaking to crumb structure, non-sticky, slightly plastic, merging boundary.
C 49-90 cm	Red (2.5YR 4/6) gritty silty clay loam, friable, massive breaking to crumb structure, non-sticky, moderately to slightly plastic.
on	Red to reddish-yellow gritty silty clay with scoria fragments at 203 cm.

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Pedon SP11 (continued)

Lab No.	Horizon	Depth (cm)	pH	C%	CEC	Exch. Al	Σ bases
SB6866A	A	0-3	4.3	20.6	41.1	3.59	6.7
B	B	3-30	4.7	6.0	11.2	0.00	0.5
C	C	51-66	5.5	1.9	3.1	0.00	0.3

			%BS	Ca	Mg	K	Na	CRC[a]
SB6866A	A	0-3	16	3.3	2.2	0.60	0.6	10.3
B	B	3-30	4	0.3	0.0	0.05	0.1	
C	C	51-66	10	0.2	0.0	0.05	0.0	0.3

			CRC[b]	CEC[b]	15 bar H_2O air dry	2.5 × 15 bar H_2O
SB6866A	A	0-3	15	59.7	27.5	68.8
C	C	57-66	0.7	7.7	16.2	40.5

[a]Exchangeable Al + Σ bases.

[b]Per 100g clay as determined by 2.5 × 15 bar water.

Mineralogy: Oxidic (36% gibbsite, kaolin, goethite, haematite also present.

Pedon SP12

Classification:	Typic Acrorthox, clayey, oxidic, isohyperthermic.
Location:	Western Samoa. Flattish ridge leading to corner of fertilizer trial, T git giga.
Physiographic Position:	Flattish ridge.
Topography:	7° slope.
Vegetation:	Forest.
Parent Material:	Basalt.
Sampled by:	A.C.S. Wright, July 1956.
Soil No:	SB6949 A-C.
0-8 cm	Dark brown (7.5YR 3/2) silty clay, friable, strong fine nutty and blocky structure breaking to very fine granular and crumb structure, non-sticky, very slightly plastic, merging boundary.
8-51 cm	Dark brown to dark yellowish-brown (7.5YR 3/2 - 10YR 4/4) silty clay, friable, massive breaking to strong fine blocky, granular and crumb structure, very slightly sticky, slightly plastic, merging boundary.
on	Dark brown grading to greyish-brown (10YR 3/4 - 5/2) silty clay with a few weathered boulders, boulders becoming very numerous below 120 cm.

Lab No.	Depth (cm)	pH	C%	CEC	Exch. Al	Σ bases
SB6949A	0-15	4.9	8.5	14.8	0.23	2.5
B	15-30	5.5	3.0	5.5	0.00	0.1
C	30-76	5.6	1.2	0.9	0.00	0.0

		%BS	Ca	Mg	K	Na	CRC[a]
SB6949A	0-15	17	0.98	1.1	0.25	0.2	2.7
B	15-30	2	0.00	0.0	0.05	0.0	0.1
C	30-76	0	0.00	0.0	0.00	0.0	0.0

		CRC[b]	CEC[b]	15 bar H_2O air dry	2.5 × 15 bar H_2O
SB6949A	0-15	5.6	30.8	19.2	48.0
B	15-30	0.2	11.5	19.2	48.0
C	30-76	0.0	0.0	19.5	48.8

[a]Exchangeable Al + Σ bases.

[b]Per 100g clay as determined by 2.5 × 15 bar water.

Mineralogy: Oxidic (38% gibbsite).

Pedon SP13

Classification: Typic Acrorthox, clayey, oxidic, isohyperthermic.

Location: Western Samoa, flattish crest of ridge to Mt. Tu.

Physiographic Position: Ridge crest.

Topography: Rolling, 11° slope.

Vegetation: Forest.

Parent Material: Basalt and volcanic ash.

Sampled by: A.C.S. Wright, June 1956.

Soil No: SB6962A-B.

0-20 cm	Dark reddish-brown to very dark brown (5YR 2/2) slightly gritty clay, friable to firm, weak nutty and blocky structure breaking to very fine blocky and coarse granular structure, slightly sticky, very slightly plastic, merging boundary.
20-38 cm	Dark-reddish grey (5YR 4/2) very gritty silty clay, friable to firm, massive breaking to coarse granular structure, moderately sticky, slightly plastic, merging boundary.
38-66 cm	Dark reddish-brown (5YR 3/4) gravelly clay, friable, strong medium blocky structure breaking to fine blocky and coarse granular structure, diffuse boundary.
on	Reddish-grey weathering scoria.

Lab No.	Depth (cm)	pH	C%	CEC	Exch. Al	Σ bases
SB6962A	0-20	5.2	5.4	11.8	0.44	1.1
B	20-38	5.4	2.0	2.7	0.00	0.1

		%BS	Ca	Mg	K	Na	CRC (Exch. Al + Σ bases)
SB6962A	0-20	9	0.60	0.3	0.10	0.1	1.5
B	20-38	4	0.00	0.1	0.00	0.0	0.1

		CRC / 100g clay[a]	CEC / 100g clay[a]	15 bar H_2O air dry	2.5 x 15 bar H_2O
SB6962A	0-20	4.2	33.4	14.1	35.3
B	20-38	0.2	6.6	16.4	41.0

[a]Clay determined by 2.5 x 15 bar water.

Mineralogy: Oxidic (34% gibbsite, goethite and haematite) also present.

Pedon SP14

Classification: Tropeptic Haplorthox, clayey, oxidic, isohyperthermic.

Location: Western Samoa, west side of Tanumalala Development Block.

Topography: 2° slope.

Vegetation: Tall forest - salato etc.

Parent Material: 'aa' type basalt.

Sampled by: A.C.S. Wright, 1956.

Soil No: SB7101 A-B.

0-15 cm Dark greyish-brown to dark brown (10YR 3/2-3/3) stony (silty) clay, friable, weak nutty and blocky structure breaking to strong fine granular and crumb structure, very slightly sticky, very slightly plastic, merging boundary.

15-46 cm Dark brown (10YR 3/3 - 7.5YR 3/2) very stony (silty) clay, very friable, massive breaking to strong crumb structure, slightly sticky, very slightly plastic, diffuse boundary.

on Dark brown to dark yellowish-brown (10YR 3/3 - 4/4) boundary clay, very friable, massive breaking to crumb structure, very slightly sticky and non-plastic, indistinct boundary. Mainly boulders below 97 cm.

Lab No.	Depth (cm)	pH	C%	CEC	Exch. Al	Σ bases
SB7101A	0-5	5.9	7.6	35.6	0.03	15.9
B	15-51	5.7	1.5	8.9	0.00	1.0

		%BS	Ca	Mg	K	Na	CRC[a]
SB7101A	0-5	44	9.6	5.7	0.30	0.3	15.9
B	15-51	11	0.5	0.4	0.10	0.0	1.0

		CRC[b]	CEC[b]	15 bar H_2O air dry	2.5 × 15 bar H_2O
SB7101A	0-5	21.8	49.0	29.2	73.0
B	15-51	1.7	14.9	23.9	59.8

[a]Exchangeable Al + Σ bases.

[b]Per 100g clay as determined by 2.5 × 15 bar water.

Mineralogy: Oxidic (25% gibbsite, kaolin and goethite also present).

Pedon SP15

Classification:	Tropeptic Eutrorthox, clayey, oxidic, isohyperthermic.
Location:	Northwest slopes of Mt. Ulu-i-dali, Bua Province, Vanua Levu, Fiji.
Topography:	10° slope.
Vegetation:	Dakua (*Agathis vitiensis*).
Parent Material:	Basic tuff.
Sampled by:	M.L. Leamy, 22 June 1955.
O 2-0 cm	Dead and decaying leaves of *Agathis vitiensis*.
A 0-8 cm	Dark brown (7.5YR 4/2) friable silt loam, weakly developed medium subangular blocky structure breaking to moderate fine crumb and blocky structure, few fine angular stones, roots common, boundary diffuse.
B 8-23 cm	Dark brown (7.5YR 4/4) friable silty clay loam, moderate medium subangular blocky breaking to strong fine blocky structure, few roots, few stones, boundary district.
C 30-45 cm	Reddish-brown (5YR 4/4) firm clay loam, moderate medium subangular blocky breaking to weak to moderate fine blocky structure, few roots, few large stones.
on	Weathering tuff.

Lab No.	Horizon	Depth (cm)	pH	C%	CEC	%BS	Σ bases
SB6732A	A	0-8	5.5	11	21.8	57	12.5
SB6732B	B	8-23	5.4	3	9.5	39	3.7
SB6732C	C	30-45	5.2	1.3	5.4	39	2.1

			Exch. Al	CRC	15 bar H_2O	2.5 × 15 bar H_2O	CEC[a]	CRC[a]
SB6732A	A	0-8	0.05	12.6	21.3	53.3	40.9	23.6
SB6732B	B	8-23	0.00	3.7	25.5	63.8	14.9	5.8
SB6732C	C	30-45	0.00	2.1	30.0	75.0	7.2	2.8

[a]Per 100g clay as determined by 2.5 × 15 bar water.

Mineralogy: Oxidic (gibbsite 25-40%, kaolinite 15-30%, goethite present).

Pedon SP16

Classification:	Typic Acrustox, clayey, gibbsitic, isohyperthermic.
Location:	Map I 111 (Lakeba) 446200E 115760 N, Fiji.
Physiographic Position:	Slightly convex interfluve, altitude 30 m.
Topography:	West facing, 10 percent slope.
Drainage:	Moderately well drained, moderate permeability, medium runoff.
Vegetation:	Secondary scrub and forest trees.
Parent Material:	Colluvium derived from andesitic rocks.
Sampled by:	D.M. Leslie, July 1977.
Remarks:	Samples as follows: LK20a 5-25 cm; LK20b 32-42 cm; LK20c 48-60 cm; LK20d 90-110 cm; LK20e 120-140 cm.
A_1 0-30	Dark reddish-brown (2.5YR 2/4) (dry), dark reddish-brown (2.5YR 3/4) (rubbed), dark reddish-brown (2.5YR 2/4) (moistened) clay; very friable; non-plastic; non-sticky; strongly developed fine and very fine subangular blocky with crumb structure; profuse coarse medium and fine roots: many casts; indistinct regular boundary.
A_3 30-45 cm	Dusky red (10 R 3/4) (dry), dusky red (10R 3/2) (rubbed), dusky red (10R 3/4) (moistened) clay; friable; sticky; plastic; primary structure weakly developed coarse blocky breaking to secondary structure moderately developed fine and medium subangular blocky plus crumb; few (10R 3/2) mottle coatings; thin discontinuous cutans (10R 3/6); abundant fine medium and coarse roots; many casts; indistinct regular boundary.
B_{21} 45-80 cm	Dusky red (10R 3/4) (dry), dark red (10R 3/6) (moist) clay; firm; sticky; plastic; primary structure developed coarse blocky, secondary structure weak to moderately developed medium subangular blocky; manganese (10R 3/2) coatings; iron coatings along roots and worm channels (10R 3/6); many relict root channels; many fresh fine roots; few casts; porous; indistinct regular boundary.
B_{22} 80-115 cm	Dark red (10R 3/6) and dusky red (10R 3/3 and 3/4) (moist) clay; firm; sticky, plastic; massive breaking to single grain with some very weakly developed medium subangular blocky

structure; few to many manganese coatings (10R 3/2); iron coatings along old root channels (10R 3/6); many old root channels; few medium roots; porous; indistinct regular boundary.

B_3 115-140 cm Dusky red (10R 3/2) and (10R 3/4) (dry) clay; very firm; sticky; plastic; massive and single grain; manganese coatings (10R 3/2); rare medium roots; few very strongly weathered stones (< 2 cm).

Lab No.	Horizon	Depth (cm)	pH H_2O	pH KCl	Total C%	Σ bases	CRC[a]	CEC	2.5 × 15 bar H_2O	%BS
SB9399A	A_1	5-25	6.5	-	2.2	4.9	8.2	7.6	60	65
B	A_3	32-42	6.9	-	0.3	1.7	—	1.2	47	100
C	B_{21}	48-60	6.0	6.2	0.3	0.5	1.12	0.8	45	63
D	B_{22}	90-100	6.5	6.5	0.2	0.4	—	0.5	42	80
E	B_3	120-140	5.7	6.4	0.2	0.3	0.96	0.4	43	75

[a]Per 100g clay as determined by 2.5 × 15 bar water.

Pedon SP17

Classification:	Tropeptic Eutrustox, clayey, gibbsitic, isohyperthermic.
Location:	Map I 111 (Lakeba) 446950 119150.
Physiographic Position:	Linear surface within limestone pinnacles, altitude 55 m.
Topography:	Southeast facing, 4 percent slope.
Drainage:	Well drained, moderately rapid permeability, medium runoff.
Vegetation:	Forest.
Parent Material:	Cemented carolline limestone (with some volcanic derived material?).
Sampled by:	D. M. Leslie, July 1977.
Remarks:	Pit dug adjacent to steep massive coral limestone face. Exposed coral limestone pinnacles at surface. Samples as follows: LK14a 5-20 cm; LK14b 30-45 cm; LK14c 60-80 cm; LK14d coral limestone. 3rd horizon very porous.
A_1 0-22 cm	Dark-reddish brown (2.5YR 2/4) (dry), dusky red (10R 3/4) (rubbed), dark red (2.5YR 2/6) (moistened) clay loam; friable; non-sticky; non-plastic; moderate to strongly developed fine and very fine subangular blocky with granular structure; profuse coarse and medium roots; few casts; many coral stones (5-15 cm); indistinct regular boundary.
B_1 22-50 cm	Dusky red (10R 3/3) (dry), dusky red (10R 3/4) (rubbed), dusky red (10R 3/2) (moistened) clay; non-sticky; weakly developed fine and medium subangular blocky with crumb structure; abundant coarse roots; few casts; few large coral boulders; indistinct regular boundary.
B 50-95 cm	Dusky red (10R 3/3) (dry), dusky red (10R 3/2) (rubbed), dusky red (10R 3/4) (moistened) clay; plastic; slightly sticky; massive, breaking to weakly developed medium subangular blocky structure; few to many fine roots; few to many porous coral stones; distinct irregular boundary.
on	Coral limestone.

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Pedon SP17 (continued)

Lab No.	Horizon	Depth (cm)	pH H_2O	Total C%	Ca	Mg	K	Na	Σ bases	CEC
SB9366A	A_1	5-20	7.4	6.7	28.3	5.90	0.23	0.19	34.6	29.3
B	B_1	30-45	7.5	4.0	15.9	2.62	0.07	0.12	18.7	16.8
C	B	60-80	7.9	1.3	5.6	0.91	0.05	0.08	6.6	5.4

			%BS	CRC / 100g clay[a]	$CaCO_3$ (%)	2.5 × 15 bar water
SB9366A	A_1	5-20	(100)	32	0.3	84
B	B_1	30-45	(100)	20	< 0.1	73
C	B	60-80	(100)	6.8	0.2	59

[a]Clay determined by 2.5 × 15 bar water.

Pedon SP18

Classification:	Ruptic-lithic Eutrorthox, clayey, kaolinitic, isohyperthermic.
Location:	In Temakatea village, 50 m along the road running E-W, about 100 m past the high school, Mangaia, Cook Islands.
Topography:	Flat, raised coral shelf, 40 m a.s.l.
Vegetation:	Banana, pawpaw, tarva.
Parent Material	Basaltic alluvium and weathered coral limestone.
Sampled by:	J. G. Bruce, T. H. Webb, 17 July 1974.
Soil No:	SB9014 A-D.
A_{11} 0-5 cm	Brown to dark brown (7.5YR 4/4) very friable; silty clay; strong medium, fine subangular blocky and granular structure; many fine to large roots; distinct smooth boundary.
A_{12} 5-25 cm	Brown to dark brown (6.5YR 4/4) very friable; silty clay; moderate to strong fine and very fine subangular blocky and granular structure, few roots; distinct smooth boundary.
B_{21} 25-33 cm	Yellowish brown (5YR 4/6) firm; clay; weak medium block breaking to moderate fine subangular blocky; many medium and fine pores, few roots; indistinct smooth boundary,
B_{22} 33-50 cm	Yellowish-red (5YR 3.5/6) friable; clay; moderate coarse subangular blocky breaking to medium, fine and very fine subangular blocky, dull ped faces; few fine pores; few roots; merging boundary.
B_3 50-80 cm	Yellowish-red (6YR 4/8) friable; clay; weak medium fine block, some fine granular; few medium, fine roots, rough ped faces, distinct boundary.
C 80 cm +	Yellowish-red (5YR 4/6) firm; clay; weak medium fine subangular blocky structure.

Lab No.	Depth (cm)	pH H_2O	pH $CaCl_2$	C%	CEC	Σ bases	%BS	% clay
SB9014A	0.25	7.2	6.7	4.8	25.4	30.2	(100)	68
B	25-60	7.3	6.5	1.1	6.1	6.5	(100)	75
C	60-80	7.3	6.7	0.4	5.2	5.3	(100)	77
D	80-95	7.5	6.7	0.7	3.8	4.5	(100)	78

Mineralogy: Kaolinitic.

Pedon SP 19 (Classified according to the Bennema-Comerma proposal - at present this pedon would probably be a Kandiudult.)

Classification:	Leptic Haplorthox, clayey, kaolinitic, iso-hyperthermic.
Location:	Aneityum Island, New Hebrides. 1 km inland from Anelcauhat on old forestry road.
Physiographic position:	Slightly convex slope, 200 m a.s.l.
Topography:	9° slope.
Drainage:	Well drained.
Vegetation:	Bracken fern, *Metrosideros* sp, umbrella fern.
Parent Material:	Highly weathered basalt, possibly some basaltic ash.
Sampled by:	N. M. Kennedy, 26 June 1977.
Soil No:	SB9423 A-D.
A_1 0-10 cm	Reddish-brown (5YR 3/4) silty clay loam, 5YR 3/4 rubbed, friable, peds firm, strong fine and medium nut structure, many fine and medium roots, indistinct wavy boundary.
B_2 10-60 cm	Reddish-brown (5YR 4/4) clay, firm, weak medium and coarse blocky structure, many thin indistinct coatings, no pores or stones, few medium roots, indistinct boundary.
BC 60-120 cm	Dark reddish-brown (2.5YR 3/4) clay loam, 2.5YR 3/4 rubbed, firm to friable, weak medium and fine blocky structure, few coarse broken roots, many moderately to strongly weathered basalt fragments (5-8 mm), indistinct boundary.
C_1 120-170 cm	Red and reddish-brown (2.5YR 4/6 and 5YR 4/4) speckled strongly weathered basalt, many weathered stones and small boulders (to 20 cm).

continued on next page

Pedon SP19 (continued)

Lab No.	Horizon	Depth (cm)	pH (H_2O) dry	pH NaF	C%	CEC	Exch. Al	Σ bases
SB9423A	A_1	0-8	4.9	8.2	4.2	19.0	1.8	6.1
B	B_2	15-45	4.9	9.1	0.7	8.0	1.9	1.5
C	BC	65-100	4.7	9.2	0.2	10.2	6.1	1.6
D	C_1	120-170	4.9	9.1	0.2	11.2	5.4	1.7

			%BS	Ca	Mg	K	Na	CRC[a]
SB9423A	A_1	0-8	32	2.8	2.59	0.55	0.20	7.9
B	B_2	15-45	19	0.4	0.76	0.17	0.16	3.4
C	BC	65-100	16	0.2	1.04	0.15	0.17	7.7
D	C_1	120-170	15	0.4	0.62	0.33	0.37	7.1

			CRC[b]	CEC[b]	15 bar air dry	2.5 × 15 bar H_2O
SB9423A	A_1	0-8	11.1	26.6	28.5	71.3
B	B_2	15-45	4.2	9.8	32.5	81.3
C	BC	65-100	9.8	12.9	31.5	78.8
D	C_1	120-170	11.6	18.3	24.5	61.3

[a]Exchangeable Al + Σ bases.

[b]Per 100g clay as determined by 2.5 × 15 bar water.

Mineralogy: Kaolinitic (4% gibbsite).

THE OXISOLS OF HAWAII

H. Ikawa

The Oxisol soil order represents 5 percent of the land area in Hawaii and is one of the most important agricultural soils of the state. The area represents approximately 80,000 ha or 200,000 acres, and much of the soil is devoted to sugarcane and pineapple production.

Oxisols of Hawaii are generally reddish, well-drained, and featureless soils of the low uplands with nearly level to moderate, and in some cases, steep slopes. They are also generally formed in residual or alluvial and sometimes colluvial material, all derived from basic igneous rocks. Chronologically the surface rocks of the Hawaiian Islands range from approximately 5.5 million years old to recent time. Oxisols are present on the older islands but absent on the youngest one. The degree of weathering is closely related to the amount of mean annual rainfall, which ranges from approximately 380 mm to as much as 5000 mm. Because most of these soils are generally associated with landscapes of nearly level to moderate relief, much of the land is well-suited to agriculture. The present vegetation or land use in many areas is, therefore, either sugarcane or pineapple.

PARENT MATERIAL AND CLIMATE

Hawaiian Oxisols differ from many Oxisols in other parts of the tropics because their parent material is derived from basic igneous rocks. Furthermore, a succession of Oxisols and/or related soils,

such as Ultisols, occur in a climosequence because of the rapid change in the rainfall distribution over a short distance. These two factors, parent material and climate, in particular, therefore, will be discussed in relation to the Oxisols of Hawaii.

The Hawaiian Islands, the main islands of the Hawaiian Archipelago, are located in the Pacific Basin between 19° and 22° N latitude and between 155° and 160° W longitude. They are made up of oceanic basic igneous rocks, primarily basalts, formed through volcanism. Thus the parent rock, and the soils derived from the parent material, are free of primary quartz. Soils that are formed have a high clay content because of the absence of quartz, and they have appreciable amounts of secondary minerals such as kaolinite and the sesquioxides. The latter contribute to the reddish color of the soils.

There are lesser amounts of andesite parent rock (hawaiite and mugearite), but soils such as Oxisols derived from the andesites are not easily distinguished from those derived from the basalts because of pedogenic convergence. Differentiation is possible only by means of a discriminant function using zirconium and nickel (Kimura and Swindale, 1966). Although a detailed analysis of the microelements can differentiate these soils, the important feature of Hawaiian Oxisols derived from basic igneous rocks is the absence of primary quartz when compared with other Oxisols that are derived from acid igneous rocks, such as granite (such as occur in Brazil, Malaysia, and Thailand).

The Hawaiian Islands have a subtropical climate because the currents from the Bering Sea cool the region. Although the air temperature can be below freezing at times on the high peaks (3000-4000 m), it is between 22° and 36° C at sea level (Stearns, 1966).

The northeasterly trade winds, and occasional winter southerly winds, bring rain to the islands. Although the southerly winds may cause rain of high intensity over a short period, the northeasterly trade winds are responsible for most of the rainfall. The northeastern sides of the mountains, therefore, are subject to most of these rains, with the maximum occurring between the altitudes of 600 and 1800 m.

The leeward sides of the islands are in general dry with arid or semi-arid climates (Stearns, 1966). The rainy months are generally between November and April.

Because of the diversity in the temperature and rainfall over a short distance in the landscape, the dominant soil-forming factor in Hawaii is climate. Oxisols of the low rainfall area (380-650 mm) have weak structure, moderate to high base saturation with corresponding near-neutral pH, and dominantly kaolinite as soil minerals. On the other hand, Oxisols of the higher rainfall areas (1000-1500 mm) contain more clay, have at least a moderate structure, low base saturation with pH 5.0-5.5. The mineral composition is still mainly kaolinite but there are increasing amounts of the oxides of Fe, Mn, and Al. Organic matter also shows an increase with increase in rainfall. Oxisols of the still higher rainfall areas (1500-5000 mm) show more stable soil aggregates and a stronger soil structure. The bases are nearly depleted and the soil pH is very strongly acid (4.5-5.0). Kaolinite is still present in lesser amounts but the sesquioxides are present in appreciable amounts and gibbsite and the oxides of Fe are present as nodules, concretions, or sheets.

According to Soil Taxonomy (Soil Survey Staff, 1975), moisture regimes of the very dry, dry, and moist areas are torric, ustic, and udic, respectively. Temperature regimes of the lower (less than 300 m) and higher (300-1200 m) elevations are isohyperthermic and isothermic, respectively.

THE FOUR SUBORDERS

Based on soil moisture regimes, the four suborders of Hawaiian soils are Torrox, Ustox, Orthox, and Humox. The Torrox, Ustox, and Orthox have an isohyperthermic temperature regime, while the Humox has an isothermic temperature regime. Classification of these four suborders at the lower categories is shown in Table 1.

Table 1. Classification of the Oxisols of Hawaii.

Suborder	Great Group	Subgroup	Family	Series
Torrox	Torrox	Typic Torrox	clayey, kaolinitic, isohyperthermic	Molokai
Ustox	Eutrustox	Tropeptic Eutrustox	clayey, kaolinitic, isohyperthermic	Lihue Wahiawa
			clayey, kaolinitic, isohyperthermic, shallow	Koloa
	Haplustox	Tropeptic Haplustox	clayey, kaolinitic, isohyperthermic	Helemano Kahana Lahaina Niu Wailuku
Orthox	Eutrorthox	Tropeptic Eutrorthox	clayey, oxidic, isohyperthermic	Puhi
	Umbriorthox	Tropeptic Umbriorthox	clayey, oxidic, isohyperthermic	Hanamaulu Lawai Makapili
	Gibbsiorthox	Typic Gibbsiorthox	clayey, oxidic, isohyperthermic	Kapaa Pooku
	Acrorthox	Plinthic Acrorthox	clayey, ferritic, isothermic	Kunuweia
Humox	Gibbsihumox	Typic Gibbsihumox	clayey, ferritic, isothermic	Halii
	Acrohumox	Typic Acrohumox	clayey, oxidic, isothermic	Mahana
		Petroferric Acrohumox	clayey, ferritic, isothermic	Kahanui

CHARACTERISTICS OF SELECTED SOILS

Morphological characteristics of four soils representing the four suborders are presented in the following paragraphs. The genetic factors of these soils are listed in Table 2, while selected laboratory data are presented in Tables 3 through 6. These soils represent the following suborders and families:

Typic Torrox, clayey, kaolinitic, isohyperthermic

Tropeptic Eutrustox, clayey, kaolinitic, isohyperthermic

Typic Gibbsiorthox, clayey, oxidic, isohyperthermic

Typic Gibbsihumox, clayey, ferritic, isothermic

Morphological Characteristics

The Molokai series is a member of the clayey, kaolinitic, isohyperthermic family of Typic Torrox. A description of a representative profile is as follows:

Ap1 — 0 to 30 cm, dark reddish-brown (2.5YR 3/4) silty clay loam; very weak coarse granular structure; slightly hard, friable, sticky and plastic; many roots; many interstitial pores; many fine black (Fe-Mn) concretions; strong effervescence with hydrogen peroxide; slightly acid; clear wavy boundary.

Ap2 — 30 to 82 cm, dark red (10R 3/6) silty clay; weak coarse prismatic structure; hard friable to firm, sticky and plastic; fine common roots; many fine and very fine tubular pores; common black (Fe-Mn) concretions; strong effervescence with hydrogen peroxide; clear smooth boundary.

B21 — 82 to 110 cm, dark red (10R 3/6) silty clay loam; weak to moderate blocky structure; hard friable to firm, sticky and plastic; few fine roots; few very fine black (Fe-Mn) concretions; moderate effervescence with hydrogen peroxide; gradual wavy boundary.

B22 — 110 to 130 cm, dark red (10R 3/6) silty clay; strong medium angular and subangular blocky structure; soft, friable compaction in place, sticky and plastic; very few fine roots; very fine pores; prominent thin patchy clay films on peds.

The Wahiawa series is a member of the clayey, kaolinitic, isohyperthermic family of Tropeptic Eustrustox. A description of a representative profile is as follows:

Table 2. Some genetic factors of four Oxisols of Hawaii (Foote et al., 1972).

Series	Mean Annual Rainfall (mm)	Mean Annual Temp. (°C)	Vegetation	Parent Rock Material	Elevation (m)
Molokai	500-635	23	sugarcane, pineapple, pasture, wildlife habitat, homesites	Basic igneous	0-460
Wahiawa	1000-1500	22	sugarcane, pineapple, pasture, homesites	Basic igneous	150-365
Kapaa	2000-3000	23	sugarcane, pineapple, pasture, orchard & truck crops woodland, wildlife habitat, water supply	Basic igneous	60-245
Halii	2500-5000	21	water supply wildlife habitat, sugarcane, pasture	Basic igneous	90-300

Table 3. Laboratory data of Molokai silty clay loam[a].

Soil Name: Molokai Classification: Typic Torrox, clayey, kaolinitic, isohyperthermic
Location: Kunia, Oahu, Hawaii

Depth	Horizon	Particle Size Analysis Sand	Silt	Clay	Water Content 15-bar	Org C	Extr Iron Fe	Fe_2O_3
(cm)		(%)			(%)	(%)	(%)	
0-30	Ap1	38.4	22.4	36.4	20.8	1.91	12.8	18.2
30-82	Ap2	23.0	15.8	52.2	19.9	0.85	13.8	19.8
82-110	B21	16.7	43.3	40.0	20.4	0.40	15.2	21.7
110-130	B22	38.0	17.8	44.3	21.7	0.52	15.6	22.3

Depth	Extr bases Ca	Mg	Na	K	Sum	CEC NH_4OAc	Extr Al	Base Satura NH_4OAc	pH H_2O	KCl	Diff
	(me/100 g)					(me/100 g)		(%)			
0-30	4.05	1.92	0.53	0.37	6.87	14.38	0.12	48	6.11	5.47	-0.64
30-82	1.80	1.04	0.38	tr	3.22	9.51	0.03	34	5.95	5.60	-0.35
82-110	1.55	1.04	0.34	0.04	2.97	7.75	0.11	38	6.15	6.00	-0.15
110-130	1.35	0.97	0.64	0.38	3.34	7.32	0.09	46	6.72	6.32	-0.40

[a]Analysis by N. Yaibuathes, 1969.

Table 4. Laboratory data of Wahiawa silty clay.

Soil Name: Wahiawa

Classification: Tropeptic Eutrustox, clayey, kaolinitic, isohyperthermic
Location: Waipio, Oahu, Hawaii Source: Hawai Benchmark Soils Project

Depth	Horizon	Particle Size Analysis Sand	Silt	Clay	Org C	Tot N	C/N	Extr Iron Fe	Fe_2O_3
(cm)		(% LT 2mm)			(%)	(%)		(%)	
0-10	Ap1	9.9	30.3	59.8	2.27	0.32	7	8.51	12.16
10-27	Ap2	8.5	28.6	62.9	1.72	0.26	7	7.52	10.75
27-40	AB	8.5	35.7	55.8	1.41	0.24	6	7.72	11.03
40-65	B21	8.2	39.4	52.4	0.59	0.14	4	8.10	11.58
65-90	B22	1.6	24.8	73.6	0.36	0.11	3	9.75	13.93
90-120	B23	4.2	20.9	74.9	0.27	0.08	3	7.30	10.43
120-150	B24	6.4	23.7	69.9	0.24	0.08	3	9.56	13.66

Depth	Extr bases Ca	Mg	Na	K	Sum	Extr acid	Cat Exch Cap NH_4OAc	Sum	Extr Al	Base Satura NH_4OAc	Sum	pH H_2O	KCl	Diff
(cm)	(me/100 g)					(me/100 g)	(me/100 g)		(me/100 g)	(%)				
0-10	6.52	4.35	0.17	2.69	13.73	9.16	20.81	22.89	0.03	66	60	5.41	4.80	-0.61
10-27	4.93	2.36	0.10	0.85	8.24	11.48	18.43	19.72	0.03	45	42	4.95	4.18	-0.77
27-40	6.07	3.05	0.12	0.11	9.35	9.93	17.58	19.28	0.05	53	48	5.31	4.48	-0.83
40-65	5.28	3.13	0.12	0.20	8.73	6.26	13.74	14.99	0.03	64	58	5.78	5.13	-0.65
65-90	4.78	3.64	0.13	0.23	8.78	5.15	13.01	13.93	--	67	63	6.12	5.61	-0.51
90-120	4.77	3.68	0.16	0.21	8.82	4.79	14.11	13.61	--	62	65	6.27	5.77	-0.50
120-150	5.19	3.46	0.36	0.38	9.39	4.71	14.42	14.13	--	65	66	6.37	5.85	-0.52

Chemical analysis by A. E. Chu, 1977; physical analysis by D. T. Tanoue, 1977.

Table 5. Laboratory data of Kapaa silty clay.

Soil Name: Kapaa

Classification: Typic Gibbsiorthox, clayey, oxidic, isohyperthermic
Location: Kapaa, Kanai, Hawaii
Source: SSIR 29, SCS, USDA

Depth	Horizon	Bulk Density	Water Content .3-bar	Water Content 15-bar	Org C	Tot N	C/N	Extr Iron Fe	Extr Iron Fe_2O_3
(cm)		(g/cc)	(%)		(%)	(%)		(%)	
0-30	Ap	1.14	36.3	30.0	3.92	0.22	18	24.1	34.5
30-40	B21	1.09	40.1	35.6	1.46	0.07	21	23.3	33.3
40-63	B22	1.04	37.3	30.5	1.09	0.04	27	21.3	30.5
63-90	B23	1.13	38.4	32.1	0.64	0.02	32	18.5	26.5
90-123	B24	1.16	38.9	31.7	0.46	0.02	23	17.1	24.4
123-150	B25	1.18	40.5	34.8	0.48	0.02	24	17.2	24.6

Depth	Extr bases Ca	Extr bases Mg	Extr bases Na	Extr bases K	Extr bases Sum	Cat Exch Cap NH_4OAc	Cat Exch Cap Sum	Extr Al	Base Satura NH_4OAc	pH H_2O	pH KCl	pH Diff
(cm)	(me/100 g)					(me/100 g)		(me/100 g)	(%)			
0-30	0.7	0.4	0.20	0.40	1.7	15.9		0.6	11	5.0	4.5	-0.5
30-40	0.2	0.0	0.10	0.20	0.5	3.7		-	14	5.5	5.7	0.2
40-63	0.4	0.1	0.20	0.10	0.8	2.6		-	31	5.5	5.7	0.2
63-90	0.1	0.1	0.20	0.10	0.5	1.9		-	26	5.8	5.7	-0.1
90-123	0.8	0.1	0.20	0.10	1.2	3.7		0.1	32	5.3	5.4	0.1
123-150	1.0	0.1	0.30	0.10	1.5	6.1		-	24	5.5	4.9	-0.6

Table 6. Laboratory data of Halii Gravelly Silty Clay.

Soil Name: Halii

Classification: Typic Gibbsihumox, clayey, ferritic, isothermic
Location: Wailua, Kauai, Hawaii

Depth	Horizon	Bulk Density	Water Content 15-bar	Org C	Extr Iron Fe	Extr Iron Fe_2O_3
(cm)		(g/cc)	(%)	(%)	(%)	
0-33	Ap	1.40	17.7	2.87	25.8	36.9
33-58	B21	1.22	21.3	1.91	27.5	39.3
58-76	B22	1.15	22.3	1.31	26.5	37.9
76-112	C1	1.15	20.6	0.99	24.7	35.3

Depth	Extr bases Ca	Mg	Na	K	Sum	Cat Exch Cap NH_4OAc	Extr Al	Base Satura NH_4OAc	pH H_2O	KCl	Diff
(cm)	(me/100 g)					(me/100 g)	(me/100 g)	(%)			
0-33	3.04	0.45	0.15	0.15	3.79	16.01	0.1	24	4.98	4.59	-0.39
33-58	1.16	0.18	0.12	0.07	1.53	12.97	0.1	12	5.27	5.07	-0.20
58-76	0.37	0.04	0.06	0.05	0.52	8.12	<0.1	6	5.23	5.28	0.05
76-112	0.28	0.03	0.07	0.06	0.44	6.97	<0.1	6	5.00	5.22	0.22

Ap1 0 to 10 cm, dark reddish-brown (2.5YR 2.5/4) silty clay; strong very fine, fine, and medium subangular structure; strong very fine and fine granular structure on surface; extremely hard, firm, sticky and plastic; many very fine and fine roots, few medium roots; many very fine and fine pores; many black concretions, less than 1 to 1 mm in diameter, slightly larger (approx. 2mm) concretions are on surface; gradual smooth boundary.

Ap2 10 to 27 cm, dark reddish-brown (2.5YR 2.5/4) silty clay; moderate very fine, fine, and medium subangular blocky structure; friable, sticky and plastic; many very fine and fine roots, few medium roots; many very fine and fine pores; many black concretions, less than 1 mm in diameter; clear smooth boundary.

AB 27 to 40 cm, dark reddish-brown (2.5YR 2.5/4) silty clay; moderate fine and medium subangular blocky structure; firm, sticky and plastic; many very fine and fine roots; many very fine and fine pores; many black concretions, less than 1 mm in diameter; abrupt smooth boundary.

B21 40 to 65 cm, dusky red (10R 3/3) and dark reddish-brown (2.5YR 2.5/4) silty clay; moderate fine and medium subangular blocky structure; hard, friable, slightly sticky and plastic; common very fine roots; many very fine and fine pores; many black concretions, less than 1 mm in diameter; few thin clay film-like material on peds and in pores; clear smooth boundary.

B22 65 to 90 cm, dusky red (10R 3/3) and dark reddish-brown (2.5YR 2.5/4) silty clay; strong very fine, fine, and medium subangular blocky structure; extremely hard, friable, sticky and plastic; few very fine roots, many very fine and fine pores; common black concretions, less than 1 mm in diameter; common thin clay film-like material on peds and in pores; gradual smooth boundary.

B23 90 to 120 cm, dusky red (10R 3/3) and dark reddish-brown (2.5YR 2.5/4) silty clay; strong very fine, fine, and medium subangular structure; extremely hard, friable, sticky and plastic; many fine pores; some root pores coated with black material; many thin and moderately thick clay film-like material on peds and in pores; diffuse boundary.

B24 120 to 150 cm, dusky red (10R 3/3) and dark reddish-brown (2.5YR 2.5/4) silty clay; strong very fine and fine subangular blocky structure; extremely hard, friable, sticky and plastic; many fine pores; some root pores coated with black material; many thin and moderately thick clay filmlike material on peds and in pores.

The Kapaa series is a member of the clayey, oxidic, isohyperthermic family of Typic Gibbsiorthox. A description of a representative profile is as follows:

Ap 0 to 30 cm, brown (10YR 4/3) silty clay; weak fine granular structure; friable, sticky and plastic; abundant roots; many pores; about 20% made up of yellowish red (5YR 4/6) material turned up by plowing; slight reaction to hydrogen peroxide; definite matting of roots between Ap and B21; abrupt smooth boundary.

B21 30 to 40 cm, yellowish-red (5YR 4/6) silty clay; weak coarse prismatic, breaking to weak medium subangular blocky structure; friable, sticky and plastic; few roots; many medium and fine pores; dark lining in pores; about 5 percent strongly weathered gravel impregnated with gibbsite; no reaction to hydrogen peroxide; clear smooth boundary.

B22 40 to 63 cm, yellowish-red (5YR 4/8) silty clay; weak medium and fine subangular blocky structure; friable sticky, plastic and weakly smeary; very few roots; many medium fine and very fine pores, thin patchy gelatinous coatings on ped faces; 20% strongly weathered gravel (with rock structure) impregnated with white material, probably gibbsite; no reaction to hydrogen peroxide; clear smooth boundary.

B23 63 to 90 cm, yellowish-red (5YR 4/6) silty clay with pockets of loam; massive in places, weak coarse prismatic breaking to weak medium subangular blocky structure; friable, sticky, plastic and smeary; loam material is slightly sticky, slightly plastic and smeary; very few roots; thin patchy coatings of strong brown (7.5YR 5/8) on ped faces and in pores; about 40% of material is strongly weathered (loam texture) with a sandy appearance; vertical streaks 5 mm wide of black and white; no reaction to hydrogen peroxide; clear smooth boundary

B24 90 to 123 cm, yellowish-red (5YR 4/8) silty clay and dark reddish-brown (5YR 3/4) loam; weak coarse prismatic breaking to weak medium subangular blocky structure; firm, sticky and plastic (loam material is friable, slightly sticky, slightly plastic) and smeary; very few roots; patchy coatings of strong brown (7.5YR 4/6) on ped faces and in pores; up to 60% of material is strongly weathered (loam texture) with a sandy appearance; vertical and angled streaks 5 to 25 mm wide of black and white; no reaction to hydrogen peroxide except black material has a slight, delayed reaction; gradual smooth boundary.

B25 123 to 150 cm, reddish-brown (5YR 4/4) silty clay and loam; weak coarse prismatic breaking to weak medium subangular blocky structure; firm, sticky and plastic (loam material is friable, slightly sticky and slightly plastic); no roots; patchy coatings of strong brown (7.5YR 5/6) on ped faces and in pores; no reaction to hydrogen peroxide.

The Halii series is a member of the clayey, ferritic, isothermic family of Typic Gibbsihumox. A description of a representative profile is as follows:

Ap 0 to 33 cm, dark brown (10R 3/3) gravelly silty clay loam; strong, medium, fine and very fine granular structure; friable, slightly sticky and slightly plastic; no roots; many fine pores; many fine and medium iron concretions; few saprolite fragments from lower horizons; abrupt wavy boundary.

B21 33 to 58 cm, dark yellowish-brown (10YR 3/4) silty clay loam; moderate, medium and coarse subangular blocky structure; friable sticky, plastic and weakly smeary; no roots; many fine and very fine pores; about 10 to 20% saprolite about 2.5 to 7.5 cm in diameter; common fine and medium iron concretions; common fine gibbsite concretions; clear wavy boundary.

B22 58 to 76 cm, dark brown (7.5YR 4/4) and reddish-brown (5YR 4/4) silty clay loam; moderate, medium subangular blocky structure; friable, sticky, plastic and moderately smeary; no roots; many very fine pores; about 50 percent soft saprolites; common fine gibbsite concretions; gradual wavy boundary.

C1 76 to 112 cm, variegated colors of reddish-brown (5YR 4/4) and dark reddish-brown (5YR 3/4) silty clay loam; moderate, medium and fine subangular blocky structure; friable, sticky, plastic and strongly smeary; no roots; many medium and fine pores; about 80 to 90% soft to hard saprolites.

THE TAXONOMIC CLASSIFICATION

Typic Torrox

The Torrox are Oxisols having a torric moisture regime; that is, they are soils of arid climates with isohyperthermic temperature regime and are apparently relict soils once formed under a wetter climate. They are nearly featureless soils without clearly marked horizons. The base saturation is relatively high throughout the profile and the soil pH is only slightly acid. At present, the soils of the suborder are so similar that no differentiation is made at the categories of the great group and subgroup. Furthermore, all are considered to be typic soils of the suborder (Soil Survey Staff, 1975). In Table 3, the Molokai series has more than 35 percent clay in the fine earth fraction (less than 2 mm) which is composed of more than half kaolinite. This series, therefore, is a member of the clayey, kaolinitic, isohyperthermic family of Typic Torrox.

Because of the arid climate, irrigation is necessary for crop production, and when irrigated, these soils are very productive. In Hawaii they are used for sugarcane, pineapple, pasture, wildlife habitat, and homesites.

The clay content as determined by the pipette method (Table 3), and as observed for most oxide soils of the tropics, is lower than the actual amount of clay. When the 15-bar water is used to estimate clay content (2.5 × 15-bar water), its amount in the subhorizon increases from 40 and 44 percent to 51 and 54 percent, respectively. The latter, however, is still lower than the actual clay content of about 70 percent when obtained with a stronger concentration of dispersing agent and mechanical sonication (G.Y. Tsuji, personal communication, 1978). X-ray diffraction analysis shows the mineralogy of the sand and silt fractions to be similar to that of the clay fraction, giving support to the idea that the coarser fractions are primarily aggregates of clay.

The surface horizon is high in exchangeable Ca and Mg, most likely due to cultivation and liming. Phosphorus fixation is one of the problems associated with this soil, although not as serious as in other Oxisols.

Tropeptic Eutrustox

The Ustox are soils having an ustic moisture regime and an isothermic, thermic, or warmer temperature regime. They also have less than 16 kg organic C per m^2 to a depth of 1 m. The Eutrustox, furthermore, have a base saturation of 50 percent or more (by neutral ammonium acetate method) in the major part of the oxic horizon if the soil is clayey, or a base saturation of 35 percent or more if the soil is loamy. The soils are classified as Tropeptic Eutrustox instead of Typic Eutrustox if the oxic horizon is not deep enough to extend to a depth of 1.25 m or more below the soil surface and/or the soils have at least a moderate structure.

The Wahiawa series has more than 35 percent clay (Table 4) in the fine earth fraction which is composed of more than half kaolinite.

With a mean annual soil temperature of 22° C, this series, therefore, is a member of the clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox. In Hawaii, these soils are extensively utilized for irrigated sugarcane or non-irrigated pineapple. These soils are also well-suited for vegetables and field crops such as maize. Moderate to large amounts of phosphorus fixation occur in these soils and the various crops respond favorably to phosphorus fertilization (Fox et al., 1974).

As in the case of the Molokai series (Typic Torrox), the actual clay content of the Wahiawa series is much higher (approximately 70 to 80 percent) than values obtained by either the pipette method or use of the 15-bar water content (G.Y. Tsuji, personal communication, 1978). The cation exchange capacity requirement of less than 16 me/100 g of clay in the oxic horizon is, therefore, fulfilled.

Typic Gibbsiorthox

The Orthox are Oxisols having a short or no dry season. They have less than 16 kg organic C per m^2 in the soil to the depth of 1 m and have a udic moisture regime and/or an isothermic, mesic, or a cooler temperature regime. They may also have 16 kg or more organic C, and have either an isohyperthermic or hyperthermic temperature regime or an average base saturation (by ammonium acetate) of 35 percent or more in the oxic horizon. They are not saturated with water or, if there are no mottles, have a chroma of 3 or more immediately below any epipedon that has a color value, moist, of 3.5 or less. If there are mottles, the chroma is more than 3. If saturated with water at some time of the year, they have no plinthite of continuous phase within 30 cm of the soil surface.

The Gibbsiorthox are characterized by having within 1.25 m of a soil surface, sheets containing 30 percent or more gibbsite or a subhorizon with 20 percent or more gravel-size aggregates (volume basis) containing 30 percent or more gibbsite. The Typic Gibbsiorthox, furthermore, have gravel-size aggregates cemented by gibbsite within the upper 50 cm and do not have mottles having a chroma or 2 or less within the upper 1 m of the soil or above the uppermost gibbsite sheet, whichever is shallower.

In the Kapaa series, the apparent soil texture of the control section is mainly silty clay. An estimate of the clay content based on the product of 2.5 times the 15-bar water content ranges from 76 to 89 percent. In the control section, the content of the extractable Fe_2O_3 ranges from 24 to 33 percent while that of gibbsite ranges from 30 to 35 percent, with kaolinite being less than 10 percent. The mean annual temperature is 23° C according to Table 2. Thus, the particular Kapaa series is a member of a clayey, oxidic, isohyperthermic family of Typic Gibbsiorthox.

The Kapaa series is located on the older islands of Hawaii in areas of appreciable amounts of rainfall. As indicated in Table 5, the soil has low activity and low base saturation. Furthermore, the delta-pH --the difference of soil pH as measured in 1 N KCl solution and distilled water--is zero or positive rather than negative in the subsurface horizons. The inability of a soil to hold onto nutrient cations is drastically reduced under such conditions. These soils also have a high capacity to sorb phosphorus (Keng and Uehara, 1973).

The Kapaa series, therefore, is one of the highly weathered Oxisols of Hawaii that is infertile and requires liming and appreciable amounts of fertilization, especially phosphorus, for crop production. In addition to sugarcane and pasture, it is also used for pineapple, orchard and truck crops, woodland, wildlife habitat, and water supply.

Typic Gibbsihumox

The Humox are Oxisols that have 16 kg or more organic C per square meter to a depth of 1 m, have a weighted average base saturation in the oxic horizon (by ammonium acetate) of less than 35 percent, and have an isothermic, thermic, or cooler temperature regime with generally a udic or perudic moisture regime. The requirements of the chroma and occurrence of plinthite are the same as for the Orthox. As in the case of Gibbsiorthox, the Gibbsihumox are Humox that have within 1 m of the soil surface either cemented sheets with 30 percent or more gibbsite, or a subhorizon that has 20 percent or more by volume gravel-size

aggregates containing 30 percent or more gibbsite. The Typic Gibbsihumox, like the Typic Gibbsiorthox, have gravel-size aggregates cemented by gibbsite within the upper 50 cm and do not have mottles with chroma of 2 or less within the upper 1 m of the soil or above the upper-most gibbsite sheet, whichever is shallower. In addition, the Typic Gibbsihumox have less than 5 percent by volume plinthite in all horizons to a depth of 1.25 m.

Clay content of the control section of the particular Halii series is 53 to 56 percent when estimated from the 15-bar water content. The high percentage of extractable Fe_2O_3 of the fine earth fraction is close to 40 percent. The temperature regime is isothermic. Therefore, the Halii series is a member of a clayey, ferritic, isothermic family of Typic Gibbsihumox.

The cation exchange capacity and the base saturation are low and the delta-pH is positive in the subsurface horizons. As explained earlier, these properties indicate low nutrient retention and high P fixation. Much of the cation exchange capacity can be attributed to the organic matter. The high phosphorus-fixing capacity of this soil is associated with the abundance of sesquioxides, and there is favorable crop response to phosphorus fertilizer and liming material, especially slag (material containing soluble silicate). Phosphate sorption by this soil and other soils is covered in a comprehensive review by Fox and Searle (1978).

Although the base saturation of this particular pedon (Table 6) ranges from 12 to 24 percent in the upper portion of the solum and 6 percent in the lower solum, the base saturation of another pedon is less than 1 percent (Sherman et al., 1967). The data in Table 6 represent a pedon that was previously limed and taken from the grounds of the Kauai Experiment Station of the Hawaii Agricultural Experiment Station. The pedon described by Sherman et al. (1967), however, is from an uncultivated area which was once under forest cover and today is primarily under Melastoma.

Like the Kapaa series (Typic Gibbsiorthox), the Halii series is a highly weathered Oxisol with a gravelly surface. The pH is acid and

the exchangeable bases are low, being correlated with the high rainfall. This soil requires much input of lime and fertilizers, especially phosphorus, for crop production. Although sometimes used for sugarcane, it is used primarily for water supply, wildlife habitat, and pasture.

RELATIONSHIP OF THE OXISOLS

As shown in Table 1, the suborders of the Oxisols of Hawaii are distinguished one from the other by differences in the soil moisture regime. The Humox differs from the others by having an isothermic temperature regime.

The Torrox form a unique group by having a torric moisture regime.

The Haplustox are differentiated from the Eutrustox by having a base saturation (by ammonium acetate) of less than 50 percent or 35 percent in the major part of the oxic horizon that has a clayey or loamy particle size class, respectively.

When the Eutrorthox, Umbriorthox, and Acrorthox are compared with the Gibbsiorthox, the former do not have the gibbsite content of the Gibbsiorthox. In addition, the Acrorthox have in some subhorizon of the oxic horizon a cation retention capacity of 1.5 me or less (from ammonium chloride) per 100 g clay (or 1.5 me of less extractable Al per 100 g clay) and do not have discernible structure in the oxic horizon or have only weak blocky or prismatic peds. The Eutrorthox, on the other hand, have base saturation of 35 percent or more (by ammonium acetate) in the epipedon and in all subhorizons of the oxic horizon to a depth of at least 1.25 m, while the Umbriorthox have either an umbric epipedon or an ochric epipedon that has more than 1 percent C in the subhorizons to a depth of 75 cm or more below the mineral soil surface.

The Acrohumox do not have the gibbsite content of the Gibbsihumox and have a cation-retention capacity (from ammonium chloride) of 1.5 me or less per 100 g clay in some subhorizon of the oxic horizon (or have 1.5 me or less extractable bases plus extractable Al per 100 g clay).

SUMMARY

The Oxisols of Hawaii, being derived from parent material of basic igneous rocks, are free of primary quartz. Consequently, the soils are high in clay content and have secondary minerals such as kaolinite and especially sesquioxides. The dominant soil-forming factor influencing the formation of Oxisols in Hawaii is climate, more specifically, rainfall. The moisture regime is either torric, ustic, or udic, and the temperature regime is either isohyperthermic or isothermic. The four suborders are, therefore, the Torrox, Ustox, Orthox, and Humox. Under irrigation, the Torrox and the Ustox are productive soils for crops such as sugarcane. They are also well-suited for pineapples. The Orthox and Humox, being more leached of bases, are infertile and require adequate liming and fertilization for crop production. All of these soils, expecially the Orthox and the Humox, fix large amounts of phosphorus. Phosphorus must, therefore, be applied in large amounts in crop management. The oxisols of Hawaii include the clayey, kaolinitic, isohyperthermic families of Typic Torrox, Tropeptic Eutrustox, and Tropeptic Haplustox; the clayey, oxidic, isohyperthermic families of Tropeptic Eutrorthox, Tropeptic Umbriorthox, and Typic Gibbsiorthox; and the clayey, ferritic, isothermic families of Plinthic Acrorthox, Typic Gibbsihumox, and Petroferric Acrohumox.

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AFRICAN OXISOLS

C. Sys and R. Tavernier

Tropical Africa is part of an old continent that has emerged for the greater part since the Secondary Period. Old erosion surfaces cover important areas, particularly in Central and East Africa.

Soil materials often originate from old, deep weathering zones. After having been reworked by geological erosion, they were further subjected to aggressive soil-forming processes.

Since the most extensive erosion surface represents the group of "End Tertiary Peneplains," Oxisols are the most common soils. However, the presence of important Pleistocene rejuvenations--particularly in West Africa, but also in other coastal regions, some large Pleistocene basins and uplifted mountains--permit the study of the complete ferrallitic chronosequence from Entisols over Tropepts and Ultisols to Oxisols.

Before starting a discussion on classification it may be useful to draw attention to what one wishes to classify. The identification and description of natural soil individuals is the first necessity. Next these soil individuals can be commented upon with regard to their logical place in a classification system.

We thus will start with the identification of the natural soil individuals; next we will try to situate the African Oxisols within these natural soil bodies and classify them according to Soil Taxonomy (Soil Survey Staff, 1975).

Finally some problems are formulated and suggestions made in order to complete the classification of African soils with low activity clays.

THE NATURAL SOIL INDIVIDUALS

Looking at African soils with regard to their distribution in the landscape, it is clear for everyone, even the untrained observer, that three main kinds of soil occur:

1. red and yellow upland soils on undulating plateaus and hilly lands;
2. rock outcrops;
3. more or less hydromorphic valley soils.

The last two soil groups cover the former azonal and intrazonal soil concept; the red and yellow upland soils are zonal soils called Latosols. These soils have one main common characteristic: the general dominance of low acitivity clays. They represent the most extensive natural soil unit in the humid and semi-humid tropics. Consequently some investigators suggested to regroup them in one order of Kaolisols (Sys et al., 1961; Tavernier and Sys, 1965).

Taking into account variations in climate and vegetation, the African upland soils, characterized by the dominance of low activity clays, can be subdivided in several important eco-climatological zones: the tropical rainforest; the humid Guinean savanna; the semi-humid Soudano-Zambesian savanna and Miobo woodlands; and the tropical mountain forest and savanna.

The general relation between rainfall and base saturation has been mentioned by different investigators.

The red and yellow upland soils under rain forest having an udic moisture regime, have B horizons with low base status (50% by NH_4OAc). Variations within this zone were suggested by Charter (Brammer, 1956). Under Guinean savanna with ustic moisture regime, base saturation varies according to the nature of the substratum. On highly weathered soils it is low while on richer parent material it can be medium to high. Under the dryer Soudano-Zambesian savanna types, base saturation is medium to high. All these soils normally have a low organic matter content.

Soils of the tropical mountain forest and savanna situated above 1500 m elevation have lower soil temperatures; humification is slower and the soils are rich in organic matter. An organic carbon content of 160 tons/ha in the upper 1 m can reasonably be used to separate the soils of the tropical highlands from those of the warmer tropical lowlands. Within each of these eco-climatological soil zones, natural soil individuals are identified with regard to age and the weathering stage of the parent material, the horizon differentiation, and the presence or absence of some specific horizons.

The recent stage of tropical weathering has a dominance of 2:1 clays or presence of rock fragments within 50 cm depth. It characterizes most alluvial valley soils, lithosols and soils of lower slopes on a rich substratum.

Upland soils on dissected lands have reached the intermediary stage of tropical weathering characterized by one or more of the following:

1. A 2-20μ fraction/0-2μ fraction ratio higher than 0.2 on sedimentary rocks; higher than 0.15 on eruptive and metamorphic rocks.
2. More than 5% weatherable minerals in the fine sand fraction.
3. A well-developed structure with clay cutans on the ped surfaces.

Upland soils on old peneplains and pediments originating from these dissected old surfaces, have reached the ultimate stage of tropical weathering; in this case each of the following three characteristics are observed:

1. Less than 5% weatherable minerals in the fine sand fraction.
2. A 2-20μ fraction/0-2μ fraction ratio less than 0.2 on sedimentary rocks, less than 0.15 on eruptive and metamorphic rocks.

3. Absence of well-developed macro structure in B2 and no or only patchy clayskins on some ped surfaces.

Fig. 1 shows these weathering stages with the possible evolution of the profile horizon sequence.

In addition to the cambic, argillic, and oxic horizons, other specific horizons may appear and characterize natural soil individuals. These horizons are mainly related to different evolutionary stages of the plinthite.

Plinthite is a soft material *in situ*, and few African soils have plinthite as defined in Soil Taxonomy within the depth of 1 m. However, many profiles have horizons enriched in hardened, reworked iron concretions, iron crust, or mixtures of iron concretions and quartz gravel.

Under African conditions it is typical that one group of soil materials is directly weathered from rock while another group is formed on reworked materials representing erosion products of formerly highly weathered alteration zones. This last group has mainly a stone-line, sometimes a hard crust, both representing an evolutionary stage of the plinthite. These stages can be recognized by the following:

1. Petro-plinthite - irreversibly hardened plinthite *in situ* in a saprolite (Sys, 1968);
2. Litho-Plinthite - irreversibly hardened dense plinthite horizon, forming a tubular iron oxide crust with some permeability for roots and water (Smith et al, 1977);
3. Petroferrite - hard, compact ferruginous crust, impermeable for roots and water (see petroferric in Soil Taxonomy, 1975);
4. Gravel layer - reworked material with concentration of coarse fragments, mainly petro-plinthitic material or quartz or a mixture of both, but sometimes including weathered rock fragments. For this layer Haantjens (1965) suggested the term "petric horizon."

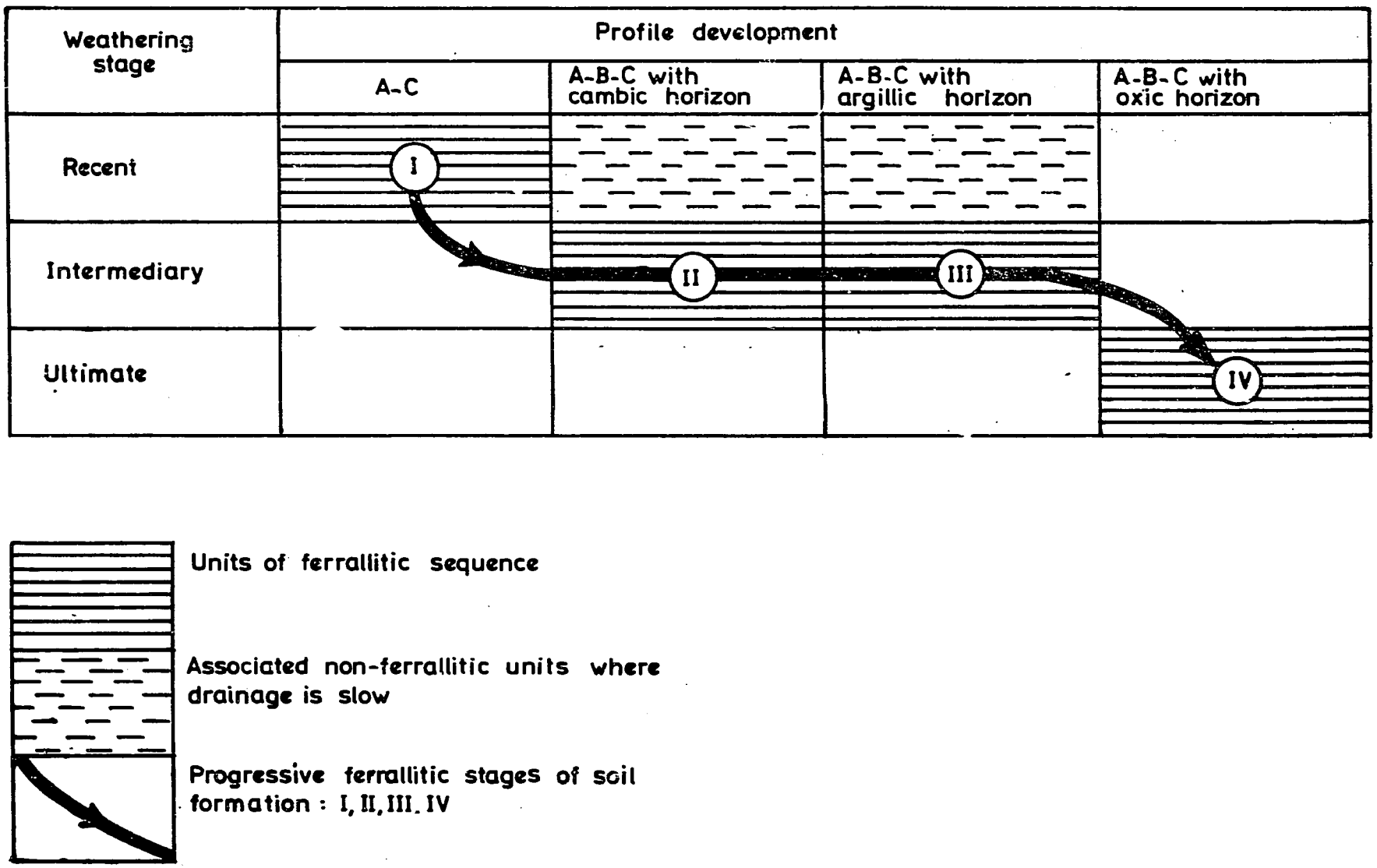

Fig. 1. Ferrallitic evolution sequence of central African soils with regard to weathering stage and horizon differentiation.

PLACE OF THE NATURAL SOIL INDIVIDUALS IN SOIL TAXONOMY

Table 1 gives a general picture of the place of the natural soil individuals according to Soil Taxonomy. Only the low activity clay materials are considered (which includes the evolution stages II, III and IV of Fig. 1).

COMMENTS AND SUGGESTIONS

The B2 horizon in tropical soils

Table 2 illustrates the possible B2 horizons in tropical soils.

Table 2. Characteristic low activity clay B2 horizons.

Clay increase	Illuviation cutans	
	Present	Absent
satisfies criteria of argillic horizon	I argillic horizon	II oxic (or argillic ?) horizon
does not satisfy criteria of argillic horizon	III cambic, oxic or argillic horizon	IV oxic horizon

Situations I and IV need not be subjected to discussion as they satisfy the respective criteria of the argillic and oxic horizons. Situation II may be subject to confusion. Such soils in African conditions were classified as Latosols, leached Ferralsols (Sys et al., 1961), "Sols Ferrallitiques appauvris" (CPSC, 1967). Later most of them were correlated with the Oxisols (Smith et al., 1975). In Southeast Asia similar profiles were mainly assimilated with Red and Yellow Podzolic Soils and later correlated with Ultisols (Paledudults, Paleustults).

Table 1. Place of the red and yellow tropical upland soils, with low activity clays, in Soil Taxonomy.

Evolution stage (Fig. 1)	Red and yellow upland soils with low activity clays: oxic subgroups of Tropepts, Alfisols, Altisols and Oxisols			
	rain forest udic (suborder) normally ochric epipedon sometimes umbric	moist Guinean savanna suborder: ustic sometimes intergr. udic normally ochric epipedon sometimes umbric	Dry Sudano-Zambesian savanna and Miobo woodland suborder: ustic normally ochric epipedon sometimes mollic	Mountain forest and savanna udic or ustic umbric or mollic epipedon
II	Orthic Dystropept (Orthoxic Humitropept)	Ustoxic Dystropept (Ustoxic Humitropept)	Oxic Ustropept (Oxic Haplustoll)[a]	Humoxic Humitropept Humoxic Haplustoll
III	Oxic Plinthudult Oxic Paleudult Oxic Rhodudult Oxic Tropudult --- Orthoxic Palehumult Orthoxic Tropohumult	Oxic Plinthustult Oxic Paleustult Oxic Rhodustult Oxic Haplustult --- Ustoxic Palehumult Ustoxic Tropohumult	Oxic Plinthustalf Oxic Paleustalf Oxic Rhodustalf Oxic Haplustalf --- Oxic Paleustoll Oxic Argiustoll	Humoxic Sombrihumult Humoxic Palehumult Humoxic Plinthohumult Humoxic Tropohumult --- Humoxic Paleustoll Humoxic Argiustoll
IV	Sombriorthox Gibbsiorthox Acrorthox Eutrorthox Umbriorthox Haplustox	Sombriustox Acrustox Eutrustox Haplustox		Sombrihumox Gibbsihumox Haplohumox Acrohumox

[a] Exceptional.

According to the present horizon definitions situation III represents either a cambic horizon or an oxic horizon. If the clay content of the overlaying horizon is less than 40% it is a cambic horizon; it is argillic if the clay content is more than 40%. However, in practice it is mostly argillic because the profiles without textural differentiation have generally more than 40% clay.

Many very deep and highly weathered soils on the End Tertiary African peneplains have some thin patchy cutans in the upper B2. Examination of thin sections reveals few but often more than 1% illuviation cutans. In many cases these can not even be detected in the field, particularly when the soil is dry, so that the field description always refers to Oxisols. This is particularly the case under semi-deciduous forests, where base saturation and organic matter content of the top soil are somewhat higher. According to Soil Taxonomy, the upper part of these B2 horizons (mostly 30-50 cm) represents an argillic horizon in profiles with or without textural differentiation; therefore the classification should be a Paleudult. In this case micromorphology leads to undesirable changes in classification. As we are classifying soils and not horizons, one should give priority to the Oxisol field morphology. Therefore, we suggest to maintain soils with such argillic horizons--not recognizable or difficult to recognize in the field, and overlying an oxic horizon that dominates the profile morphology--in the Oxisols as ultic subgroups.

In addition, definition of Oxisol to Ultisols (Alfisols) intergrades should be based on characteristics of the B2 horizon, rather than on the currently suggested criterion of clay increase. As such the use of tropeptic subgroups is undesirable.

Another feature in highly weathered tropical soils is the appearance of an agric horizon (Coelus, 1973). When such a horizon is developed in the upper part of the B2 horizon of an Oxisol, we should maintain the soil in that order. This indicates the need for man-made groups, such as Agriorthox, etc.

Pedological features for classification purposes

The pedological features described above for petroplinthite, lithoplinthite, petroferrite, and petric horizons are common characteristics in African soils. It can be useful to comment on their use in soil classification at group, subgroup, or family levels.

The INEAC classification developed in Zaire (Sys et al, 1961) suggests distinguishing the geological from the pedological profile. The gravel layer (petric horizon) and the iron crusts (petroplinthite, petroferrite, lithoplinthite) were considered as a layer in the geological profile, and rejected as a soil horizon. Therefore they were considered at family level in the classification.

The French classification (CPSC, 1967) defines a group of "reworked soils" in each of their ferrallitic sub-classes mainly based on the presence of a gravel layer. The presence of a hard iron crust in the other groups is considered at subgroup level ("sols groupes indures").

Sys (1968) formulated suggestions to assimilate the French concept in the 7th Approximation, and proposed Palegroups for soils having reworked lateritic materials concentrated in a gravel layer at a depth of less than 2 m. The nature of the gravel layer is indicated at subgroup level.

At present we suggest that the appearance of the hard evolution stages of plinthite, not be used at group level. We support the Soil Taxonomy concept to use the presence of a petroferric contact at subgroup level, and suggest using the lithoplinthic contact at the same level. The loose gravel layer (petric horizon) can best be considered as part of the parent material and used as family criteria.

Acroxic subgroups in Ultisols

Acric characteristics may be present throughout the whole ferrallitic weathering sequence. In Zaire they have been found in the argillic horizon of a Paleudult. We propose to maintain the

Acro-group in Oxisols and to introduce an Acroxic subgroup in the Ultisols.

Classification based on color

It looks like Rhodo-groups, as defined on the basis of color value, have no meaning for the classification of soils with an argillic horizon in the African soil pattern. The study of a great many weathering are more related to chroma than to value. Generally, chroma increases with increasing weathering. The INEAC classification defines subgroups of Ultisols intergrading to Tropepts, based on color and having a chroma of 4 or less in the argillic horizon.

For classification of Oxisols, we do not favor color as a criterion at group level. Its use at the family level could be justified, but in the INEAC classification color was considered at series level.

GENERAL CONCLUSIONS

In African conditons Oxisols cover the old Tertiary Peneplains and some low Pleistocene stable surfaces. They may also occur on reworked materials from old weathering zones that have spread over more recent surfaces.

We highly recommend orienting classification of the Oxisols based on field morphology, and assimilating with the Oxisols profiles having some thin, very patchy cutans in the upper B2. We propose this even if micromorphological examination suggests an argillic horizon for that upper part of the B2.

This remark being taken into consideration, the classification of African Oxisols according to criteria of Soil Taxonomy is satisfactory, and no other major changes are needed at group level. For some exceptional profiles with an agric horizon we may foresee the definition of Agri-groups as man-made soils. We are not in favor of recent suggestions for using soil color to define groups of Oxisols.

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SOME REMARKS ON BRAZILIAN LATOSOLS IN RELATION TO THE OXISOLS OF SOIL TAXONOMY

Jakob Bennema and Marcelo Camargo

GENERAL

The Latosols recognized in Brazil are defined as having a latosolic B horizon, which is, however, not quite equal to the oxic horizon. A major difference is that the latosolic B horizon should have a cation exchange capacity (CEC) of less than 13 me/100 g clay after correction for organic matter (Bennema, 1966). The CEC is determined at pH 7 by a method which is not the same as the one specified in Soil Taxonomy (Soil Survey Staff, 1975) and results in somewhat lower values, as demonstrated by Ikawa (1978).

The correction for organic matter in a profile is made graphically (for method see remark 1 in Appendix), but it can also be calculated. This correction is necessary; otherwise the organic matter to clay ratio influences the results too much. In the field it often looks as if organic matter (expressed as C) is virtually absent below a shallow A horizon. However, this is not true. Organic matter decreases strongly with depth at first, and then more gradually. The C percentages in deeper layers, e.g. at 100 cm depth, are small, yet they can still have a sizable influence on CEC per 100 g clay. As a consequence, without correction for C, some Latosols are excluded from Oxisols, e.g. soils that are rather shallow or of coarser texture (see remark 2 in Appendix).

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There is another relevant reason to use CEC data corrected for organic matter. The latosolic B horizon can be defined to start directly under the A horizon. The layer below the A horizon may have a CEC/100 g clay, not corrected for C, greater than 16 me due to a higher C/clay ratio. In this case, there is no possibility in the field to trace the upper boundary of the oxic horizon. It can only be determined by taking enough samples from the presumable transition zone to the oxic horizon, and determining CEC and clay content in these samples, which is an undesirable procedure.

DIFFERENT "GROUPS" OF LATOSOLS DISCUSSED

First, the three main physio-geographical groups are discussed. Then, some remarks are made about the Humic Latosols and related soils in Brazil. The four groups of soils considered

a. The "kaolinitic yellow Latosols" with low sesquioxide contents occur most often on marine or fluviatile sediments (sometimes very old sediments). These soils are very extensive in the lower Amazon region, and occur further on coastal terraces, on some old planation surfaces ("chapadas"), and locally along some rivers.

b. The "umbreptic" subgroups of Humox and Haplorthox are found outside the tropics in the highlands of southern Brazil. They are mostly formed from basalts.

c. A third group, mainly occurring within the tropics (some also occur at higher latitudes outside the tropics), includes soils formed in materials derived from consolidated rocks. The material has practically always undergone some colluvial action.

d. The Humic Latosols and related soils.

The kaolinitic yellow Latosols

These are soils with little or no gibbsite content and a relatively low iron content. The soil material does not contain traces of halloysites or allophanes. Total phosphorus is relatively low for a Latosol.

The colors of the B horizon are mostly 10 YR, 7.5 YR (sometimes 2.5 Y, 5 YR) with values of 5-6 and chromas of 6-8. The yellow color is not related to impaired drainage conditions; these soils are often well or even excessively drained. Clay content in the B2 horizon varies between 15% and 90%. Quite often clay content increases from the top downwards, increments being far more pronounced in the coarser-textured, and almost negligible in the very fine-textured varieties of this kind of Latosol. Concurrently, there is a tendency to major increases in moister regions, as discussed by Volkoff (1976). Silt/clay ratios are low. The silt and sand fraction is mainly (95 to 100%) quartz. Macrostructure is absent in the coarser-textured soils; finer textures favor a weak, sometimes weak to moderate blocky structure, which easily breaks down when moist into a very fine granular structure. Peculiar to this kind of Latosol is the distinctive great cohesion - hard to very hard consistence - especially in the upper B and A3 horizons when dry, rather coarse textured soils excepted. The CEC (pH 7)/100 g clay after correction for C is most often less than 6.5 me. The effective CEC/100 g clay --[(Al^{+++} x Bases)/%clay]100-- is sometimes less than 1.5 me.

This kind of Latosol has long been discerned in Brazil by the Commissao de Solos (1960, 1962) and was also reported by Bennema (1963) and Sombroek (1966). Comparable soils occur in other areas of the world, e.g. in Yangambi (Zaire): Yangambi series (de Leenheer et al., 1952). These soils are recognized by most soil surveyors as being closely related. This is not expressed in Soil Taxonomy (Soil Survey Staff, 1975). These soils are members of different classes, e.g.: Haplorthox (Typic, Ultic, Tropeptic, Quartzipsammentic); Umbriorthox; Haplustox (Typic, Ultic, Tropeptic); Acrustox (Haplic, never Typic). Pedon 103 in Soil Taxonomy is an

example of a Haplic Acrorthox belonging to this "group" of kaolinitic yellow Latosols. This list is not complete: Aquic or Plinthic subgroups also occur. Thus, the soils are widely scattered in Soil Taxonomy. They are grouped together with soils of a quite different nature.

Some limited areas of these soils were occupied by ancient populations and constitute the so-called "Black Soils of the Indians." They are partly soils with an anthropic epipedon; but, towards the periphery of the sites, A horizons may not have enough available P_2O_5 to be included in the anthropic epipedon whereupon they fit umbric epipedons. These "Black Soils of the Indians" have been erroneously described by some as plaggen epipedon soils. The A horizon pertains to the original soil and it is not a man-made layer on top, as in plaggen epipedon soils.

The kaolinitic yellow Latosols as a "group" have some properties in common which are important for their management. These properties are mainly due to the low content of sesquioxides, which makes their structure (used in a general sense of macro and microfabric) less stable. They easily form dense layers in the upper B horizon at about 20-80 cm depth as discussed by Oliveira et al (1968) and Janssen and van der Wert (1976). Density is also increased through the use of heavy agricultural machinery or by clearing forests. Furthermore, these Latosols are more liable to surfacial sealing than others.

The topsoil can, particularly in the more sandy members, easily lose clay and organic matter by agricultural use due to different processes:

1. Differential erosion - clay together with organic matter is lost;

2. Infiltration of clay into the layers below the A_p, or by infiltration of a mass of fine soil material (clay, organic matter + silt and fine sand), forming a thin argillic horizon (Boer, 1972) or perhaps an "agric" horizon.

Another kind of significant "degradation" of the topsoil is the breakdown of clay particles by chelating or solution processes. For example, the alternation of dry and wet conditions, either under natural vegetation or under agricultural use is conducive to the destruction of kaolinite. Above and in the top of the denser layer, temporary reduction might occur, particularly in flat or very slightly depressed areas.

A sandy epipedon, eventually comprising a bleached horizon, might exist, with a marked change to the underlying yellower layer with a higher clay content. (The horizon transition is most often not "abrupt" as defined in Soil Taxonomy, because the absolute clay increase seldom reaches 20%). In the underlying layer some mottling can normally be observed. Ferrolysis, as described by Brinkman (1970), might be the prominent process. In the layers below, a fragipan is formed in extreme cases. Spodosols may develop in the bleached layer (Jacomine, 1974).

Oxisols are often regarded as the ultimate soils, which might in many cases be true (at least using a time scale of millions of years). With the coarse- and medium-textured "kaolinite yellow Latosols" the situation seems to be different, at least under some physiographic conditions. As can be concluded from the foregoing, the chronosequence (or weathering sequence) Ultisol-Oxisol-degraded Oxisol (again, often classified as Ultisol)-Spodosol is not uncommon. In Brazil these "degraded Oxisols" have in recent years been mostly classified as "Red-Yellow Podzolic soils with low base saturation and low clay activity", in other words, as Ultisols, or in the terms of ICOMLAC, as Kandi great group of Ultisols, notwithstanding that the presence of clay illuviation cutans is often doubtful.

Some of the considerations mentioned above bear on questions discussed in the proceedings of the First International Soil Classification Workshop (Camargo and Beinroth, 1978), as referred to in profiles 21, 24, 13, 4, 23, 20, 30 and 31. As a whole, the preceding indications suggest that some departures should be made according to poligenesis concepts, as a multi-soil variant approach might prove worthwhile in

pursuing an array of such intervening soils. Much of the matters concerned constitute the intricate and uncertain grounds implicit in the areas entrusted to ICOMLAC and ICOMOX. Depending on the conceptual standpoint favored, the topics in question might or might not pertain when discussing Latosols or Oxisols.

If for medium-textured soils a relative clay content increase of 40% within 30 cm depth is used as a limit for Ultisols and Oxisols, some soils with a gradual but strong increase in clay content--presently classed as Latosols--will have to be included in the Ultisols. Anyway, the contention that soils of the "group" under discussion (which remain members of the Oxisols) should be set apart at the great group level is based on their mineral constituents, i.e. dominance of well-crystallized kaolinite, absence or only small amounts of gibbsite (SiO_2/Al_2O_3 molecular ratio 1.7 to 2.1) and low iron content (provisional total iron/clay ratio less than 0.11 and $SiO_2/Al_2O_3 + Fe_2O_3$ molecular ratio greater than 1.5).

It should be stressed that the separation cannot be made on the basis of color alone. Other yellow (or strong brown) Oxisols occur which have quite different characteristics, e.g. a high gibbsite content (see profile in Appendix) or a high iron content, particularly in areas with a perudic climate. In Brazil the proposed great groups will mainly include soils on sediments (fluviatile or marine), but some soils formed in material mostly derived from consolidated rock may be included. It should further be stressed that not all Oxisols on sediments will be members of the proposed great groups. Provisionally, the name "Olix" is suggested from "oligo" for poor and "x" for sesquioxides. Groups are proposed for Orthox (Olixorthox) and Ustox (Olixustox).

The Umbreptic subgroups

These subgroups include the subtropical Latosols, which are found under a thermic, udic climatic regime. In contrast to the former "group" they cover a small area, but they are worthy of

discussion for their special characteristics. They were first studied in the highlands of northern Rio Grande do Sul (approx. 30° south latitude), where they occur over basaltic rocks, at between 900 m and 500 m altitude on the undissected parts of an old erosion surface (DPP, 1973). There is a distinct temperature decrease and humidity increase with increasing altitude. Above 900 m under a thermic, perudic climate (tending to mesic), Umbrepts of brown to strong brown colors in the B horizon border on Oxisols. These are not Oxisols because their CEC at pH 7 exceeds the limit. This is due to a considerable content of interstratified clay minerals, as well as amorphous constituents - quite probably allophanes - complementary to poorly crystallized kaolinite (Goedert, 1967). Below about 500 m, a meridional variety of Dusky Red Latosols (Terra Roxa Legitima, Typic Haplorthox) is found on the basalts. In the subtropical Latosols the color of the B horizon is chiefly strong brown (7.5 YR 4/6,4/7), varying through yellowish red to dark red (2.5 YR 3/6,3/7). The difference of color (chroma of about 6 above 500 m and less than 6 in lower parts) is at least partly related to the distribution of the MnO in the soil mass. At the higher altitudes it occurs as concretions where it has not been leached; below 500 m it seems present in a diffuse state throughout the soil mass.

In the high part of the zone (about 900 m) yellow Haplohumox are found (unit Vacaria). Their strong brown to yellowish color (color of goethite) is due to wetness of the climate and is not related to low iron content (Fe_2O_3 is ± 20%). Many of the soils are epiaquic in the manner of the Epiaquic subgroup of Haplorthox.

At somewhat lower altitudes redder Humox (unit Durox) are found-- 5 YR to 2.5 YR, values 4 to 3 chromas 6 to 7. Still lower, the soils are mostly dark red Haplorthox (unit Erexim)[1/] -- 2.5 YR 3/6 or 3/7. The Humox and Haplorthox in this region have some character-

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1/ 10-14 kg organic carbon per square meter to 1 m depth.

istics in common that show they are to be regarded as Oxisols intergrading to Inceptisols, if not as a distinct "group" of Oxisols. They are clayey soils with weakly or weakly to moderately developed peds (subangular blocks, eventually composite prisms) in which clayskins do not seem to be present. They have a kind of "glaze" or "coating," sometimes shiny in the red soils and sometimes duller in the yellow soils. The SiO_2/Al_2O_3 ratio is somewhat below 2.0. Poorly crystallized kaolinite is the major component of the clay fraction, and interstratified clay minerals are always present in small proportions. Gibbsite is absent or scanty. In the yellow members of the Humox, if not in all these soils, halloysite and traces of allophanes are present (Kämpf, 1971; Pötter, 1977). Iron content is relatively high and increases as altitude decreases. The CEC (pH 7, Brazilian method for 100 g clay corrected for organic matter) is more than 6.5 me. Ordinarily in Brazilian Oxisols, at least in the dystrophic members, the CEC is less than 6.5 me. The base saturation is low, while the Al^{+++} saturation is always high. The absolute content of exchangeable Al^{+++} is also high due to the relatively high effective CEC of these soils. The total exchangeable Al^{+++} in the Humox is greater than 4 me/100 g clay. For the soils fitting Orthox, this is not always the case.

Typic Haplohumox should have an absolute content of exchangeable Al^{+++} of less than 4 me/100 g clay. A name has not been coined for the subgroup with exchangeable Al^{+++} of more than 4 me. They could in this case (outside the isoclimates) possibly be called Umbreptic. Within the Haplorthox, absolute contents of exchangeable Al^{+++} of more than 4 me also occur; but most probably have less than 4 me/100 g Al^{+++} clay. It would therefore be better to use the occurrence of "glazes" and the composition of the clay fraction (dominance of poorly crystallized kaolinite, presence of interstratified clay minerals, halloysite, amorphous constituents--some allophanes included--and molecular SiO_2/Al_2O_3 ratio around 2) together with the relatively high CEC/100 g clay as differentiating characteristics. This could then be used in the Humox as well as in the Haplorthox. Al^{+++} saturation could further be used at a phase level.

Alternatively, this "subgroup assemblage" can be seen as a distinctive kind of Oxisol, forming a "group" that might deserve recognition by itself. Lately, this has been the option most favored concerning Latosols in Brazil. This seems conceivable in view of the previous considerations. Additionally, such soils--in terms of Latosols or of Oxisols, owing to their special characteristics and the phytoclimatic environment--are part of an individualized physiographic section of the subtropical domain, and its altitudinal zonation equivalent occurs northward as far as 20° latitude.

Of more importance still is the interpretation of transformations that affect the mineral constituents of the soils. From a pedogeochemical standpoint, this entails evolution of surface formations, as discussed by Melfi and Pedro (1977). The present case is concerned with geochemical evolution of soil material characterized by a heterogeneous clay mineralogy constitution, shown by the dominance of kaolinite and incomplete degree of alteration, as revealed by the coexistence of silicate clay minerals less resistant to weathering.

If instead of a distinction of "Umbreptic" subgroups, the option is for setting those soils apart at the great group level, the following suggestions for naming may be presented: juv from juvenilis; int from inter - (connotative either of occurring between or of interstratified); emb from embryon - (connotative of rudimentary); rud from rudis (connotative of a rudimentary, crude or unfinished state); ad from adolescent; im from immaturus (connotative of unripe); sub (connotative of less than perfect, also nmenomic of subtropical).

The mentioned soils are very difficult to manage for agricultural use, due to their high Al^{+++} saturation, the related low pH and, presumably, the occurrence of toxicites (in particular Mn) and deficiencies of minor nutrients. The greater part of these soils will be classified as Humic and Dystric Nitosols in the FAO/UNESCO legend of the Soil Map of the World.

It should be noticed that apparently different intergrades be-

tween Oxisols and Inceptisols are involved based on structure, depth, and clay mineralogy. This last kind refers to a lesser degree of transformation plus decomposition of mineral constituents, which is reflected in the SiO_2/Al_2O_3 ratio and CEC. Further, intergrades are important owing to the presence of minerals that are in the sand or coarser fractions less resistant to weathering. In this respect, recognition of intergradation between Oxisols and Cambisols, Ferralsols, Nitosols, Acrisols, Luvisols, Latosols, Terra Roxa Estruturada, and Red-Yellow Podzolics. For instance, profiles No. 8 and 13 pertain to this assemblage, and were discussed in the proceedings of the First International Soil Classification Workshop (op. cit.).

The intertropical Latosols or Oxisols on erosional and/or depositional land surfaces derived from consolidated rocks

Within this section are included Latosols pertaining to two physiographic domains: 1) landscapes of southeastern and eastern Brazil under udic, perudic and sometimes ustic moisture regimes; thermic, hyperthermic and occasionally isohyperthermic temperature regimes; hilly to mountainous topography with accentuated relief reflecting complex geomorphic processes which have been operative on crystalline rocks of the exposed Brazilian shield; and constituting an outstanding habitat of tropical moist forest; and 2) the Central Brazilian landscapes typified by ustic or udic moisture regimes; isohyperthermic and seldom hyperthermic or isothermic temperature regimes; vast extension of cerrado (S. American form of savanna) and lesser amounts mesophytic forest; gentle or somewhat rougher landforms with widespread erosion surfaces resulting from polycyclic geomorphic evolution, originally older planation surfaces and later erosional-depositional lower surfaces whose evolution has progressed at the expense of Precambrian crystalline rocks or the overlying Paleozoic to Mesozoic sediments, involving in most instances, a variably thick detrital mantle, conformably underlying country rock and commonly capped by a "drift" cover of pseudo-autochthonous or allochthonous nature. In spite of the relevant environmental differences prevailing which would suggest otherwise,

the Latosols related to either physiographic domain will be dealt with jointly in this section, mainly for ease.

This gathering comprises Latosols consisting of relatively more weathered soil material as expressed by lower SiO_2/Al_2O_3 molecular ratio (likely below 1.8-1.7), dominance of kaolinite and gibbsite or vice versa in the clay fraction followed by iron oxides besides amorphous constituents, and CEC less than 6.5 me (pH 7, Brazilian method for 100 g clay corrected for organic matter); further, the iron content is normally higher than for related soils dealt with in section A (provisional total iron clay ratio above 0.11 and SiO_2/Al_2O_3 molecular ratio below 1.5). Most of the materials from which these soils were formed, consisting of rather weathered mineral residues, have undergone some transfer or relocation of variable importance. Transfers are partly of biogenetic character. The structure of the soils and the presence of stone lines are more likely related to biogenic influence and sorting through movement of soil material. The distribution of the Oxisols in these areas is related to the landscape history. The best Oxisols are found on gently undulating older planation surfaces. A relation with the actual climatic conditions in this circumstance is uncertain. The most extreme Oxisols are found in smooth ancient geomorphic sections with an ustic moisture regime (Typic Acrustox). In the southeastern coastal range with its rejuvenated landscape the relationship with climate is noticeable. Here, under high rainfall conditions, and in a perudic climate with an isohyperthermic temperature regime, Oxisols may form on hilly or even mountainous relief. Also evident is the tendency of colors with 5 YR hue or yellower.

The relationship with the kind of country rock is recognizable, as expressed by the constituents of the non-clay fraction. In well-drained areas outside the perudic climate zones, color and texture change with the kind of rock of the parent soil material. Color has in these areas been used as an outstanding field criterion for mapping. The following kinds of Latosols were classified by color:

1. Dusky-Red Latosols on basic rocks and metabasites. Within this "group" are the ones richer in iron, manganese, and titanium oxides. In well-drained soils, the color of the B horizon is dusky red or dark reddish brown within hues of 10 R to 2.5 YR, value 3, chromas 3 to 6. It is not always easy for a soil surveyor to determine the limit of dusky red soils and dark red soils on the basis of color alone. Sometimes H_2O_2 is used to detect MnO presence and a magnet is used for the estimation of magnetic minerals (dry, crushed sample)--which are quite evident in these soils unless drainage is restricted.

2. Dark-Red Latosols often derived from shales, intermediate to acidic igneous or metamorphic rocks, limestone, and sandstones high in iron content. The color in the B horizon is mostly within the 2.5 YR hue, values 4 to 3, chromas 4 to 7.

3. Red-Yellow Latosols e.g. from acidic crystalline rocks, sandstones poorer in iron or other sediments. Within this "assemblage" are soils low in iron oxides. The color may vary widely but values are 4 or higher, chromas are high, and hues commonly 5 YR but may reach 2.5 YR and 10 YR.

The color of Dusky-Red Latosols in the mentioned areas is an important diagnostic value. The mineral assemblage of clay and sand fractions is different from other Oxisols; iron, titanium, and manganese contents are relatively high. They are among the more stable soils. Clay content does not decrease markedly with depth, which is in contrast to soils lower in sesquioxides. The chemical composition is also different in many aspects. Total P content for example is high. The majority of it is present as fixed iron phosphate; but, some plant species with mycorrhizae can still use a part of it. On the other hand, it is to be expected that long-term phosphorus fixation of added fertilizers is high.

The high MnO content, which influences the low chroma, is of importance because if the pH is low, manganese toxicity can result.

However, this is not always the case, as is obvious in some "eutrophic Dusky-Red Latosols" (Eutrothox and Eutrustox) which are, from a chemical fertility viewpoint, among the good agricultural soils of the tropics. The manganese toxicity is possibly greater in the dark red "Umbreptic" Haplorthox of subtropical southern Brazil, than in many tropical Dusky-Red Latosols.

If a separation would be adopted for the soils derived from basic parent materials, then this separation would best be based on the constituents of the soil mass. Dusky-Red Latosols, the Dark-Red Latosols of Rio Grande do Sul, and some yellow soils with high iron content (e.g. Kuantan series in Malaysia) could be brought together, possibly at the great group level. However, a restriction should be considered. As will be discussed later, it is felt that soils with extremely high amounts of sesquioxides should be set apart from the "normal Oxisols" as derived from basic rocks (like basalts and metabasites) at a higher level of classification. The mineral composition is at present expressed at the family level in Soil Taxonomy (Soil Survey Staff, 1975). If the gibbsite content in the fine earth is higher than 40%, the family is gibbsitic; if the Fe_2O_3 content is higher than 40%, it is ferritic. If Fe_2O_3 and gibbsite are taken together, and if the sum is equal to or more than 0.20 × the clay percentage, the family is oxidic. Hereafter it will be suggested a) to make a similar separation already at higher levels, and b) to set apart soils with a high gibbsite/kaolinite ratio.

The differentiation based on texture and Al^{+++} saturation will not be discussed at length here. The possible pertinence of distinction based on texture should be appraised, taking into account evidence from the investigations of Weaver (1974). Verifications of Goedert et al. (1976) might improve the analysis of the matters involved. A more elaborate appraisal of the relevance of differentiation based on Al^{+++} saturation will necessarily have to encompass the Umpreptic "subgroups" of Oxisols previously discussed. In this context, consideration of the insights presented by Pedro (1970) and more recently by Melfi and Pedro (1977) are of value.

Soils with humic A horizons will be discussed in the following part. Regarding soils related to (c) above, some attention will be given to criteria relating to natural fertility (presence of available nutrients) and management aspects.

Oxisols are mostly soils with low contents of available plant nutrients, but when taking all the Oxisols together, important differences can be noticed. It was already mentioned that the Eutrorthox and Eutrustox (e.g. eutrophic Dusky-Red Latosols), which have relatively high base saturation, are fertile soils. The differentiation of the other Oxisols in relation to fertility and response to fertilizers is presently difficult based on profile characteristics or laboratory data. The combination of total bases, Al^{+++} saturation, pH, phosphorus availability, and deficiencies of minor elements play a role. A feasible division, at least for Central Brazil, is one based on the nature of the primary vegetation that was or is present (forest vs cerrado). In fact, it should be stressed that the fertility of the whole ecosystem is regarded and not that of the soil alone (a great part of the existing nutrients may be present in the organic cycle). Cerrado grows on quite poor soils while forests grow on relatively better, as well as rich, soils.

A positive delta pH (pH KCl - pH H_2O) at a certain depth, which is often mentioned as an indication of low fertility, has drawn the attention of soil scientists in Brazil for about the last 20 years; but it has never been implemented as a differentiating characteristic in Oxisols because of uncertainties of operationality. The hypothesis that a positive delta pH is an important differentiating characteristic related to soil fertility is not substantiated by the facts. Most soils with a positive delta pH are indeed found under cerrado vegetation, but many cerrado soils which are as poor have no positive delta pH. On the other hand, Oxisols considered to be fertile, such as Eutrorthox and Eutrustox, e.g. Sao Paulo 37 (Comissao de Solos, 1960) and a few soils belonging to the Pale groups of Alfisols (Eutric Nitosols in the FAO/UNESCO legend) may have a positive delta pH, e.g. Minas Gerais 4

(Comissao de Solos, 1962). The above-mentioned data show that a positive delta pH *per se* cannot be used as a relevant differentiating characteristic at a high level of classification.

Fertile soils with a positive delta pH are all derived from basic rocks or metabasites and have a high iron content. The pH at which pH KCl and pH H_2O are equal is most often between 5.0 and 5.5. This probably means that in the more fertile soils with a positive delta pH, higher negative charges occur together with higher positive charges at the zero point of charge. The higher negative charges are saturated with bases and appear to be an important aspect of the fertility of these soils. It seems better to delete the use of a positive delta pH at higher levels of classification, and to study if and how this characteristic could be used at lower levels of classification. It could perhaps be used in Eutrorthox and Eutrustox at the subgroup level if the soils with a positive delta pH would appear to have other management characteristics (e.g. in relation to anion adsorption) than Eutrorthox or Eutrustox without a positive delta pH.

This leaves us with the question of how to separate Oxisols with very low fertility from other Oxisols, if not done on the basis of vegetation and land use. It has already been expressed that many soil characteristics play a role, but it is without doubt that the exchange complex (low effective CEC, small amount of bases, relatively high Al^{+++} saturation) is important here. The values which are critical, however, are so low that with the present laboratory methods no worldwide correlation can be made. The laboratory of SNLCS of EMBRAPA, for example, finds somewhat lower values for Al^{+++} and extractable bases, and hence lower values for effective CEC, than the laboratories of the USDA Soil Conservation Service (Ikawa, 1978). Thus the most important criteria to be used still cannot be applied. The relevant laboratory methods have to be properly established in greater detail before this can be done.

At the present state-of-the-art, particularly as concerns the more weathered Oxisols or Latosols, there persists the need for re-

appraisal envisaging possible pathways to the improvement of their classification basis, criteria, and scheme. Some suggestions are given hereafter, but it should be emphasized that they are suggestions made from "behind the desk," and that the mappability, which is a very important aspect, has still to be tested:

1) To place Eutrorthox and Eutrustox high in the key.

2) To distinguish other Oxisols with an iron content above 19% in the fine earth fraction, perhaps together with TiO_2 content above 1.5. These percentages have to be seen as tentative. Mn content as an accessory mineral is often high. In this group, soils of different color will be included: dusky red, dark reddish brown, and dark red soils (the Umbreptic Haplorthox of Rio Grande do Sul) and even some strong brown soils (Una series in Brazil). The group could be called Ferriorthox or Kandiferriorthox.

3) To revise and rename the Gibbsiorthox. The new name could be Sesquiorthox (and Sesquiustox). Apart from soils with gibbsite sheets and gravel placement, a taxon should be provided for other Oxisols very high in sesquioxides, viz. those derived from ultrabasic rocks (serpentinized periodotites)--among which the Nipe clay of Puerto Rico is included--from itabirites (quartz-hematite schists), and modified derivatives consisting of iron ores. To the definition should then be added: "or soils with a gibbsite ($Al_2O_3 3H_2O$)/kaolinite ($SiO_2Al_2O_3$ $1H_2O$) ratio greater than 1, which would mean in Brazilian terms a Ki molecular SiO_2/Al_2O_3 ratio less than 0.75 or soils with a gibbsite/kaolinite ratio smaller than 1, but a molecular SiO_2/Fe_2O_3+MnO ratio lower than 0.55." (value tentative.)

It is advocated to use for the molecular ratios the Brazilian method of "total analysis" of the SNLCS. The different soils of this great group can then further be divided on subgroup level (mostly as extragrades). It is expected that the soils with a positive delta pH and low fertility will be placed in a subgroup with a gibbsite/kaolinite

ratio greater than 1, i.e. more sesquioxidic soils.

The more recent views on Brazilian Latosols favor the distinction of the "ultra weathered" Latosols, bearing on 3) above, as they constitute the utmost in the Latosol progression (known extremes reaching SiO_2/Al_2O_3 ratio around 0.20 and silica sesquioxides ratio of 0.15). Relevant influences on soil behavior of these properties are explained by Uehara & Keng (1975). In this context inferences can also be drawn from "differentiation trials" concerning the main Central Brazil Latosols as developed by Cavalcanti (1977). This study shows that a strong relationship exists between the charge characteristics and the dominant mineralogy.

If we regard these suggestions and the proposal of the Olix great group (section a) with alternatives indicated in section b, then it becomes obvious that much emphasis is placed on the mineral composition of soil constituents. This is conceivable because the different properties of Oxisols and their reflections in soil behavior are strongly related to differences in composition, more so than for soils of other orders.

At the end of this section a remark has to be made about soils on erosional landscapes which intergrade to Inceptisols. Some of the soils classified in Brazil as being similar to Acid Brown Forest Soils show most of the characteristics of Oxisols, only the amount of minerals less resistant to weathering and the silt/clay ratio are somewhat on the high side. They will partly be included in the Oxisols if higher contents of easily weatherable minerals are allowed. A provision should then be made to separate these soils as intergrades at the subgroup level, i.e. "Dystropeptic" as well as "Dystrochreptic" Oxisols. It could be noted that these intergrades refer to soils which are intermediate, mainly because of the greater content of minerals less resistant to weathering in the sand or coarser fractions, clay mineralogy not always being indicative.

Humic Latosols

Soils mapped in Brazil as Humic Latosols include those with high

organic matter. Some of these soils are difficult to classify by using Soil Taxonomy. Some in the cooler climate will belong to the Humox. The high organic matter soils depend on the kind of vegetation; Humox are often associated with grassland and show the expected decrease in carbon content with depth. Other Humic Latosols outside regions with a mean year temperature less than 22° C may also have a normal decrease in carbon content with depth (related to the kind of vegetation and land use). The reason for recognition of Humox being restricted to the cooler climate is not very clear, more so because the soil temperature regime will be expressed at the family level. It would perhaps be better to include in the Humox all pertinent soils with a regular decrease in carbon content.

There are other Humic Latosols which do not have the necessary amount of carbon, or which show abnormal organic matter distribution. Worthy of mention is the uncertainty of field identification of Humox, for color and thickness of actual epipedons may not indicate if the organic matter content is above or below the required limit. In addition to the aforementioned, there are soils with a second darker layer, which may be an infiltration layer, a burried A horizon, or a layer formed by termites.

For classification in Soil Taxonomy it is necessary to know if the second horizon is a sombric horizon or not; but, actually no means are provided in Soil Taxonomy to make a conclusion in this respect. It is said "The sombric horizon can be distinguished from burried epipedons by lateral tracing." This is obviously not in agreement with the philosophy of Soil Taxonomy. It is said elsewhere in Soil Taxonomy "We should be able to classify a polypedon by its own properties if the Taxonomy is to serve the purpose of the soil survey." Moreover, it is not always easy to make a conclusion on the basis of lateral tracing, even more so outside Brazil. In Africa, around the Rift Valley, old ash profiles are sometimes covered by younger but already strongly weathered ash layers.

We have the impression that infiltration of organic matter, as presumed for the formation of the sombric horizon, plays a role in some

Oxisols and probably some Ultisols also. This is not restricted to soils with so-called sombric horizons. Some soils with deep organic matter profiles, in which the decrease of organic matter with depth to 1 m or more is absent or very weak, may belong to the same group. What the mechanism is behind their formation, and how the pertinent soils could be recognized, is still not clear. There seems to be consensus about one point. They are soils that look, at first sight, to be excellent soils, e.g. for horticulture; particularly when used, they appear to have low fertility, with deficiencies of minor elements, e.g. boron. A working hypothesis could be that microbiological destruction is hampered due to deficiencies of some minor elements. Anyhow, the conclusion has to be again that the present state-of-the-art in this respect is such that the concept of the sombric horizon cannot be properly used in Soil Taxonomy. Descriptions and laboratory data of profiles which might belong to soils with humus infiltration should be collected, distributed, studied and discussed before ICOMOX can make any decision on this point.

Apart from the preceding "groups" or "subgroups" reported, it should be mentioned that semi-arid Latosols are also present in Brazil. These are referred to as the Torrox suborder in Soil Taxonomy. Their distribution is not of great extent and knowledge about them is insufficient, there being a need for more research relative to concepts and eventual differentiation from other Latosols. Semi-arid Latosols which conform to the quite distinct fifth physiographic domain--the dry northeastern region of Brazil--are not considered in this paper, other than to mention their existence.

SUMMARY AND CONCLUSIONS

Taking into account the Brazilian Latosols in relation to the placement of Oxisols in Soil Taxonomy, and considering subgroup to suborder levels, the main characteristics and some of their relations and implications are discussed. Various suggestions were considered for making appropriate classification schemes:

1) To use a correction for organic carbon for CEC/100 g clay in the definition of the oxic horizon.

2) At the great group level, to give more emphasis to the composition of the soil material. Three great groups have been suggested in this respect:

   a) Olix great group with low iron and gibbsite contents.

   b) Sesqui great groups in Orthox and Ustox, replacing the Gibbsi great group in Orthox. The Sesqui great groups should, next to the present Gibbsi great group, include:

      i) Soils with a gibbsite/kaolinite ratio greater than 1.0 (Brazilian molecular SiO_2/Al_2O_3 ratio smaller than 0.75).

      ii) Soils in which the sum of gibbsite and iron oxides in the fine earth is very high, e.g. molecular SiO_2/Fe_2O_3 ratio smaller than 0.55 (tentative).

   c) Great groups of other soils with high iron content in the fine earth fraction (more than 19%) mostly related to basic rocks, like basalts.

It was further stressed that knowledge for classification of soils with high amounts of organic matter (with a sombric horizon or an umbric horizon) is still too insufficient to serve as the basis for a classification system. These soils have to be collected, analyzed and discussed.

At the subgroup level, "Umbreptic" subgroups were submitted for consideration. This was done to encompass particular kinds of Oxisols under thermic, udic regimes and with incomplete alteration and transformation of mineral constituents of the clay fraction. As an alternative suggestion stands the eventual recognition of distinct great groups for logical placement of these soils.

It was stressed that different kinds of Oxisol subgroups should be envisaged. In the overall assemblage of subgroups, "Dystropeptic" and "Dystrochreptic" are proposed besides the aforementioned "Umbreptic"

subgroups. The final conclusion is that the different possibilities for classification of Oxisols have still to be discussed before firm proposals can be made.

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APPENDIX

Remark 1: Correction of CEC for Organic Carbon

The CEC in the definition of the Oxic horizon is expressed as me/100 g clay. To the 100 g clay belongs a certain amount of carbon (C) namely (100 : % clay) x % C present. If for the samples of the solum of one profile the me/100 g clay and the corresponding amount of C in grams (g) are calculated, the result is a variable CEC and a variable amount of C in presence of 100 g clay (A1 and lower part of B3 may be omitted if necessary). The CEC as a function of C can be shown graphically (Figs. 1-3). In the figures, g C is put on the vertical axis, which is against the rules because CEC is dependent on g C and not the reverse. This was done (the authors being pedologists, not mathematicians) to show the relationship in conformity with a sequence of "depth" as in a soil profile.

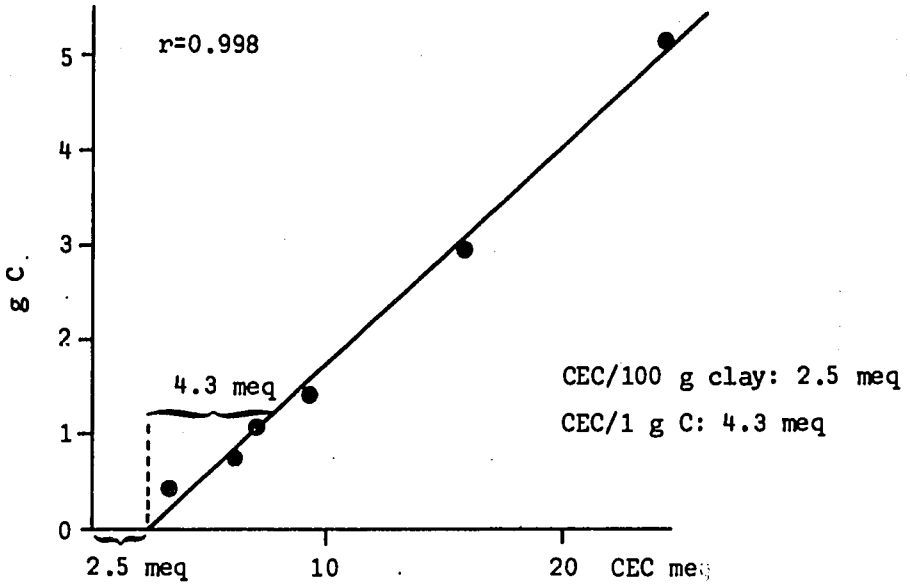
Remark 2: Concerning the need to Correct for Organic Carbon in Coarser-textured Oxisols

The carbon content at a certain depth in soils of the same kind, with the same kind of land use history or vegetation and under the same climatic conditons, is related to the clay content. Organic carbon as a function of clay content can be expressed as follows:

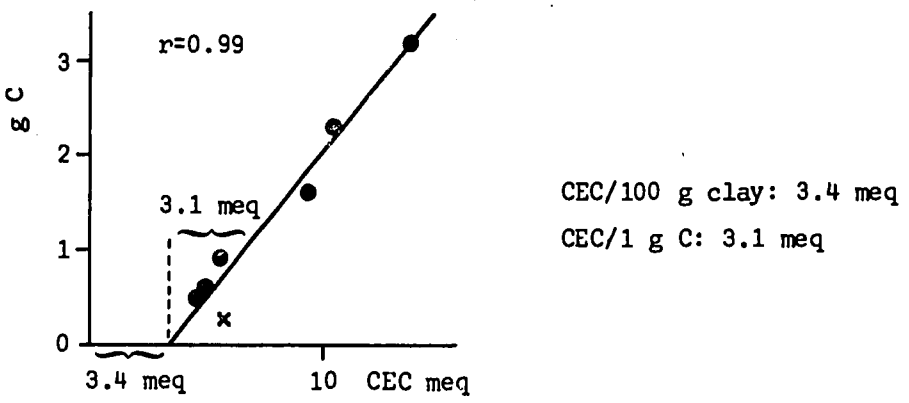
$$\% \text{ C} = a_0 + a_1 \text{ \% clay.}$$

The constant a_1 indicates the increase in organic carbon content with 1% increase in clay content; the constant a_o indicates the theoretical value for C if no clay were present. The C/clay ratio is a_1 + (A_0 : % clay). The (a_0 : % clay) decreases with clay content. Thus the C/clay ratio also decreases with clay content. The consequence is that per 100 g clay in sandy soils, more C is present than in finer-textured soils, and that with the same kind of clay minerals a higher CEC/100 g clay will be found. This may result in an undesirable exclusion of some sandy Latosols

Graph 1: Ortho Red Yellow Latosol.Sp 47, Atibaia.

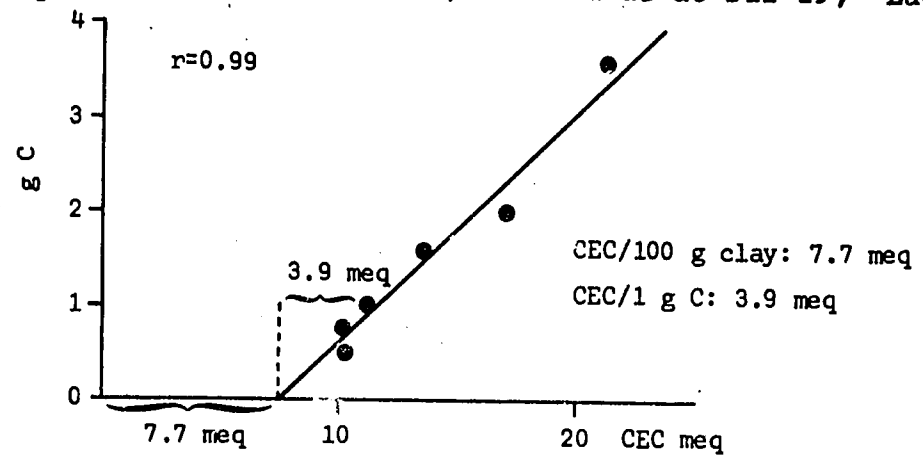


Graph 2: Dark Red Latosol, Savannah phase. Furnas 9, Boa Esperanca.



from Oxisols. The C/clay ratio is furthermore dependent on climate. In colder climates, i.e. higher altitudes or higher latitudes, soils with the mineral assemblage suited to Oxisols may be excluded from this order.

Graph 3: Latosol "Erechim", Rio Grande do Sul 29, "Lagoa Vermelha".



Relation cation exchange capacity and g carbon with presence of 100 g clay (CEC NH_4OAc, pH 7)

Remark 3. Profile of a Typic Acrustox, from NE Sao Paulo (cerrado region)

The profile of an extreme Oxisol is added for different reasons. It is often believed that:

1. extreme Oxisols are red-colored--yet this one has yellow (strong brown) colors;
2. extreme Oxisols are derived from basic rocks--yet iron, titanium and siliceous nature of the sand fraction show that the soil material in this case has not been derived from basic rocks;
3. extreme Oxisols (typic Acrorthox or Acrustox) have high amounts

CLASSIFICATION: Red-Yellow Latosol Typic Acrustox, clayey, oxidic isohyperthermic

PROFILE Nº Sao Paulo 57
SAMPLE Nº 30703/706

SNLCS

HORIZON	DEPTH cm	GRAVEL >20 mm %	GRAVEL 20-2mm %	FINE EARTH < 2 mm %	PARTICLE SIZE ANALYSIS NaOH % CORS 2-.20 mm	FNES .20-.05 mm	SILT .05-.002 mm	CLAY <.002 mm	WATER DISP CLAY %	FLOC DEGREE %	SILT / CLAY
A1	0- 25	0	0	100	41	22	5	32	9	72	0.12
A3	- 60	0	0	100	42	18	5	35	8	77	0.14
B1	-110	0	0	100	40	17	4	39	2	95	0.10
B2	-250+	0	0	100	34	21	5	40	10	75	0.13

pH (1:2.5) H2O	pH (1:2.5) KCL N	EXTRACTABLE BASES mE/100g Ca++	Mg++	K+	Na+	SUM EXTR	EXTB ACTY mE/100g Al+++	H+	CAT EXCH mE/100g	BASE SAT %	100.Al+++ / Al+++ +S
4.5	4.5	0.3	0.1	0.04	0.02	0.5	3.5		4.0	13	
4.4	4.7	0.3	0.1	0.03	0.03	0.5	3.2		3.7	14	
4.7	5.1	0.3	0.1	0.03	0.03	0.5	2.2		2.7	19	
5.3	6.2	0.3	0.1	0.03	0.04	0.5	0.6		1.1	45	

ORG C %	N %	C/N	ATTACK BY H2SO4 (d=1.47) % SiO2	Al2O3	Fe2O3	TiO2	ATTACK BY Na2CO3 (5%) % SiO2/Al2O3	SiO2/R2O3	Al2O3/Fe2O3	AVLB PHOS ppm
							MOLECULAR RATIO			
0.97	0.08	12	5.3	15.6	6.7	0.82	0.58	0.45	3.60	1
0.90	0.08	13	5.7	17.8	7.2	0.79	0.55	0.43	3.67	1
0.66	0.05	13	6.2	19.6	7.8	0.87	0.54	0.43	4.00	1
0.36	0.04	9	6.2	19.3	7.9	0.89	0.55	0.44	4.31	1

The mineral constituents of the coarse fraction are for 99%-100% quartz. A simplified "normanalyses" suggests the following percentage of kaolinite, gibbsite and goethite.

Kaolinite	gibbsite	goethite	gibbs./kaol. ratio
11.3	17.0	7.5	1.50
12.3	19.3	8.0	1.57
13.4	21.9	8.7	1.63
13.4	21.5	8.7	1.60

of iron oxides--yet this soil has a relatively low amount of iron oxides;

4. yellow colors in Oxisols are related to present drainage conditions--yet that is not the case with yellow, well-drained cerrado soil.

Further, the soil is a good example of one with positive delta pH (pH KCl greater than pH H_2O). In the topsoil, water-dispersible clay is present (negative clay) as well as in the subsoil (positive clay). Note that the pH H_2O at which pH KCl becomes greater than pH H_2O, is lower than the pH H_2O at which positive water dispersible clay occurs. This is normally the case. The soil is also a good example of the proposed "sesqui" great groups.

Profile:	Sao Paulo 57. Described and sampled 1959.
Classification:	Red-Yellow Latosol; Typic Acrustox, clayey, oxidic, isohyperthermic.
Location:	County Franca - 20°30' S, 47°25' W
Situation:	Roadcut. On top of an elevation with 5% slope. Old planation surface.
Altitude:	960 m.
Topography:	Gently rolling.
Parent rock:	Botucatu sandstone.
Present and primary vegetation:	Cerrado (S. American form of savanna).
Drainage:	Well-drained.
Climate:	Cwb Köppen; mean yearly rainfall 1550 mm; sum of three dryest months 63 mm; mean yearly temperature 20.0°C; mean three coldest months 17.7°C; three warmest months 21.3°C.

Field description:

A_1 0 - 25 cm brown to dark brown (10 YR 4/3); sandy clay loam, weak medium granular; soft, friable, slightly plastic and nonsticky; transition diffuse and smooth; abundant roots.

B_1	25 - 60 cm	dark yellowish-brown (10 YR 4/4); clay loam; weak fine granular; soft, friable, slightly plastic and nonsticky; transition gradual and smooth; roots abundant.
B_{21}	60 - 110 cm	strong brown (7.5 YR 5/8); sandy clay; massive porous[1/] breaking down into fine granular; soft, very friable, slightly plastic and nonsticky; transition gradual and smooth; roots rare.
B_{22}	110 - 250 cm	strong brown (7.5 YR 5/8); sandy clay; massive porous[1/] breaking down into fine granular; soft; very friable, slightly plastic and nonsticky; roots rare.

Below the B_{22} horizon a gravel layer is found with ironstone and quartz cobbles (stone line).

[1]weakly coherent soil mass whose structure could be better described as strong fine and ultrafine granular.

THE OXISOLS OF PUERTO RICO

F.H. Beinroth

The purpose of this paper is to discuss the taxonomy of the Oxisols of Puerto Rico and to examine the validity of current Oxisol taxa in light of local conditions. Some environmental background information related to soil formation is given, but no effort is made to dwell upon the properties and land use characteristics of these soils.

PHYSIOGRAPHY OF PUERTO RICO

General

Puerto Rico is the smallest and easternmost island of the Greater Antilles and is located at 18°15' N latitude and 66°30' W longitude. It is roughly rectangular, about 175 km long from east to west and about 60 km wide from north to south, with a total land area of approximately 8860 km^2 or 886,000 ha.

Geology

During Lower and early Upper Cretaceous times a geosyncline elongated through the Antillean Region. In this trough active volcanism occurred until the end of Middle Eocene and gave rise to a predominantly submarine accumulation of andesitic volcaniclastics (tuffs, lavas, tuffaceous breccias and shales) and other volcanic rocks.

At the very end of the Cretaceous period and extending through Middle Eocene, mountain-forming processes caused by compressive forces

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resulted in folding of these rocks into an anticlinorium and intensive faulting, which produced hundreds of fault blocks. This orogeny was accompanied by the emplacement of plutonic rocks (largely composed of granodiorite, quartzdiorite, and some diorite) which are now exposed in two plutons. The serpentinized peridotite of southwest Puerto Rico intruded earlier, probably in the Lower Cretaceous.

The diastrophism entailed the appearance of an island which, during mid-Tertiary, was bordered by marine basins to the north and south. There the Younger Tertiary limestones were formed from Middle Oligocene to Middle Miocene. This interim of quiescence was succeeded by a revival of tectonic movements which caused further uplifting and slight tilting, thus shaping the island's present form. The periodic movements also controlled cycles of erosion in the interior: at least two peneplains were denuded and, as a result of subsequent uplift, were dissected by rejuvenated rivers. In the Quaternary, a variety of sedimentary rocks accumulated ranging from indurated dunes to unconsolidated alluvial and organic deposits.

For simplicity, Puerto Rico can be divided into three geologic provinces:

1. An axial volcanic-plutonic province that traverses the island from the east to west coasts and makes up most of the mountainous interior;
2. A northern limestone province extending from west of Loiza Aldea to Aguada along the north and northwest coasts. Included in this unit are the alluvial, blanket, swamp, and beach deposits that overlay the calcarenitic and chalky limestones; and
3. A southern limestone province along the southwestern coast, similar to the one in the north but dipping southward off the central highland.

In terms of area, volcanic rocks crop out over 4500 km^2 or 51% of the total area of Puerto Rico. Intrusive igneous rocks are exposed over about 1400 km^2 (16%); serpentinite underlies roughly 100 km^2 (1%);

limestone forms the surface of about 1500 km^2 (17%); and surficial deposits cover some 1300 km^2 (15%).

Structurally, Puerto Rico consists of a central core of strongly faulted and folded Cretaceous and Lower Tertiary rocks unconformably overlain by Younger Tertiaries on its northern and southern flanks. The general strike is NW-SE or WNW-ESE. Besides folds, transcurrent faults are the dominant structural feature. The hiatus between Eocene and Middle Oligocene marks the most profound lithological and structural break in Puerto Rico's geology.

For a more complete account of the geology of Puerto Rico, reference is made to Beinroth's (1969) outline of this subject, which contains an exhaustive bibliography.

Geomorphology

Christopher Colombus, who discovered the island in 1493, is said to have described Puerto Rico to Queen Isabel of Spain by crumbling a piece of parchment. The analogy seems appropriate as mountainous terrain covers more than 80% of the island. Altitudes range from sea level to a maximum of 1338 m at Cerro La Punta in the Cordillera Central.

A large variety of landforms make the island an especially interesting place for the study of geomorphology. The landforms are characteristic of those tropical areas in the trade wind belts which have high mountains and extremely varied rainfall.

According to Monroe (1966), the island can be divided into three principal physiographic areas of greatly contrasting topography:

1. Coastal lowlands with many types of beaches, tombolos, ancient deltas, lagoons, sand dunes, and mangrove swamps;
2. A belt of karst in northern Puerto Rico, with a variety of solution features including deep, precipitous dolines or sinkholes, river and ring ramparts, cockpit karst, mogote karst, and natural tunnels; and
3. A central upland, which is exceedingly varied in physiographic features because of complex geologic structure,

variation in lithology, and a long and complicated history of erosion.

Climate

The climate of Puerto Rico is controlled by the island's relief and its location north of the intratropical convergence zone which is in the path of the trade winds. Thus, Puerto Rico is exposed to a considerable air flow of surface winds which originate in the semipermanent Bermuda-Azores high-pressure cell. The trades reach Puerto Rico relatively persistently from the east-northeast after having attained a high degree of water vapor saturation over warm ocean currents in subtropical latitudes. As a result of the orographic effect, much of this moisture precipitates on northern windward slopes and the highest peaks of the central mountains of Puerto Rico. Therefore, a large quantity of rainfall occurs in such areas, whereas it diminishes considerably in the rainshadows on leeward mountainsides.

By the Thornthwaite system of classification, the climate of the northern, eastern, and western coasts and the northern foothills is humid tropical; the central mountain ranges have a humid mesothermal or, in the highest areas, a wet mesothermal climate; the southern foothill zone and the south coast are subhumid tropical or semiarid tropical.

Annual rainfall ranges from about 600 cm in the Luquillo Mountains to less than 75 cm on the south coast. The yearly distribution is uneven: the dry winter period is followed by moderate spring rains; a lull in rainfall occurs in the first part of summer; and late summer and fall typically are the wettest periods, with precipitation reaching a maximum in September and October.

Mean annual air temperatures are subject to less local variation than rainfall, but characteristically temperature decreases with increasing altitude. At the lower elevations (up to 200 m above sea level) mean annual temperatures are about 25° C; intermediate altitudes have temperatures between 23 and 24.5°C; the highest locations are also the coolest places with mean values between 21 and 20° C.

Puerto Rico also experiences hurricanes whose centers touch the island every 25 to 30 years on the average. The massive circulation of moist air impinging on the island during these storms causes intense rainfall which results in disastrous floods. In addition, severe flooding is caused by hurricanes passing nearby and by tropical disturbances which occur about every 5 to 6 years. These events are accompanied by massive landslides, soil creep, uprooting of trees and accelerated erosion which are not without impacts on soil formation.

Pedologically, the udic soil moisture regime is dominant in Puerto Rico, but ustic conditions prevail along the south coast in the rainshadow of the Cordillera Central. Most of the island has an isohyperthermic soil temperature regime and the only isothermic areas are above approximately 700 m.

Vegetation

By virtue of its climate and location Puerto Rico belongs to the Caribbean province of the paleotropical plant kingdom. This province, set up according to floristic coincidence, comprises essentially all of Central America. There is every reason to believe that at the time of Columbus' arrival the island of Puerto Rico was covered by extensive and luxuriant forests. Because today the plant cover is almost entirely controlled by man, the delineation of ecologic zones can only be made by extrapolation from the few remaining relics and by inference from physiographic and climate conditions. Little and Wadsworth (1964) have distinguished seven types of climax forest in Puerto Rico: tropical dry forest south of the Cordillera Central, tropical moist forest on the northern coastal plain, tropical and subtropical moist forest in the lower mountains up to 750 m, and subtropical rain forest in the wettest and highest parts of the central mountains.

OCCURRENCE OF OXISOLS

As may be inferred from the preceding statements, Oxisols are not

extensive in Puerto Rico. They amount to only about 5% of the total land area. The youthful geomorphology that characterizes most of the island's landscapes precludes the large-scale attainment of advanced stages of weathering and pedogenetic development. Consequently, various kinds of Inceptisols are the most common soils of Puerto Rico (43%). Ultisols are the second most extensive soils (25%). The remaining third part of the island is, in order of decreasing extent, occupied by Mollisols, Oxisols, Vertisols, Alfisols, Histosols, Entisols, and rockland (Beinroth, 1971; Buol, 1973).

Oxisols of Puerto Rico occur in three distinct geomorphic and lithologic settings on Miocene, Pliocene, and Pleistocene surfaces. Their occurrence there can be attributed to particular geomorphic conditions, ultrabasic rocks, and pre-weathered sediments, respectively.

First, there is a discontinuous band of varying width extending from the northwest corner of the island to the periphery of the metropolitan area of San Juan. This area comprises some 31,000 ha. Here the Oxisols are developed in clayey to sandy sediments of largely Quaternary age known as "blanket deposits" (Briggs, 1966). These deposits originated as the result of a concurrent process of uplift, erosion of laterized landscapes in the interior, and littoral sedimentation and redistribution along the north coast.

The eastern part of this zone of Oxisols lies between a belt of Tertiary limestones to the south and the recent floodplains, marshes, and lagoons to the north. The topography is subdued, hummocky and characteristically contains karst features in the form of cone-shaped limestone hills and some sinkholes. These almost level areas lie at altitudes between 10 and 50 m and are probably Pleistocene marine terraces. In the western part, the plains assume a plateau-like aspect and the littoral alluvials diminish to a narrow band. There the broad undulating plains range in elevation from 50 to 100 m and are bordered to the south by limestone hills and to the north by a cliff-like escarpment to the Atlantic Ocean.

Second, Oxisols are found in southwestern Puerto Rico in the outcrop area of Early Cretaceous serpentinite. For the most part this area is strongly dissected and only in a few places have Pliocene erosion and deposition surfaces been preserved. The Oxisols occur mainly on these rare remnants and are, therefore, of minor extent (about 1,000 ha).

Third, Oxisols are found in the central uplands of the island. There they are developed in andesitic-basaltic volcanic rocks of Cretaceous age and occupy moderately sloping, bench-like positions that are strikingly contrasted to the very dissected adjacent mountains. These isolated areas are mainly found at altitudes between 600 and 750 m in the headwaters of streams north of the main water divide of the island and are considered part of a Miocene peneplain that is now greatly dissected (Daniels et al, 1979). Consequently, preservation of ancient surfaces is the exception rather than the rule. Since Oxisols are found only on these remnants, they are not the predominant soil type of the uplands, but are estimated to comprise approximately 17,000 ha.

For a more complete discussion of the geology, geomorphology, climate, and vegetation of the Oxisols areas, reference is made to a comprehensive study by Beinroth (1979).

CLASSIFICATION

The soils of Puerto Rico were first mapped, named, and classified by Roberts et al (1942). Recently a contemporary soil survey of the whole island was completed by the Soil Conservation Service of the U. S. Department of Agriculture, but only two soil survey reports have been published to date.

For the roughly 46,000 ha of Oxisols in Puerto Rico, eight soil series have been officially established and correlated by the Soil Conservation Service. The classification of these series according to Soil Taxonomy (Soil Survey Staff, 1975) is presented in Table 1. The Oxisols represent a rather narrow taxonomic range because they are all Orthox. However, they comprise Typic or Tropeptic subgroups of Acrorthox,

Eutrorthox, and Haplorthox. At the family level, all eight series are clayey, isohyperthermic, and either oxidic or kaolinitic. In addition to the soils listed in Table 1, two other kinds of Oxisols, an Ultic Haplorthox and an Eqiaquic Haplorthox, have been identified, but their extent is too small to warrant the establishment of two new series.

Table 1. Classification of the Oxisols of Puerto Rico according to Soil Taxonomy.

Subgroup	Family	Series
Typic Acrorthox	clayey, oxidic, isohyperthermic	Nipe
Tropeptic Eutrorthox	clayey, kaolinitic, isohyperthermic, shallow	Cotito
	clayey, oxidic, isohyperthermic	Matanzas
Typic Haplorthox	clayey, kaolinitic, isohyperthermic	Bayamon
	clayey, oxidic, isohyperthermic	Delicias
Tropeptic Haplorthox	clayey, kaolinitic, isohyperthermic	Coto
	clayey, oxidic, isohyperthermic	Catalina
	clayey, oxidic, isohyperthermic, shallow	Rosario

Three of these series--Nipe, Delicias and Rosario--are developed in serpentine or in colluvium derived from it. The Bayamon, Coto, Cotito and Matanzas series are formed in blanket deposits along the north coast. The Cataline series typifies the upland Oxisols.

The Oxisols of Puerto Rico have been studied in considerable detail. Complete characterization data and profile description of 19 representative pedons are contained in SSIR No. 12 (Soil Conservation Service, 1967). Detailed mineralogic data on five Oxisols are provided by Jones et al (1979). Eswaran et al (1979) investigated the micromorphology of the same soils. Daniels et al (1979) conducted a study on the landscape relationships of upland Oxisols, and Beinroth (1979) discussed the genesis, morphology, and geomorphology of the Puerto Rican Oxisols. The taxonomic placements presented in Table 1 are thus supported by substantial field observations and laboratory data.

ANALYSIS OF CURRENT PLACEMENTS AND TAXA

The classes presently established in Soil Taxonomy allow unequivocal placements of Oxisols of Puerto Rico. This reflects, at least in part, the fact that definitions of differentiae and taxa of Oxisols were largely conceived on the basis of experience in Hawaii and Puerto Rico. However, the placements are not necessarily satisfactory in all instances.

The oxic horizon, as described and defined in Soil Taxonomy (Soil Survey Staff, 1975, p. 38), may contain clay films, but the relative increase in clay content within a vertical distance of 30 cm should be less than that required for the argillic horizon. It is further stated that "...clayskins may be present only at a depth greater than 1 m if roots are scarce, but if they occupy more than 1 percent of the volume of any subhorizon, they indicate the presence of an argillic horizon."

Table 2 shows the clay distribution in select Oxisol pedons of Puerto Rico. These data from SSIR No. 12 (Soil Conservation Service, 1967) indicate that no argillic horizons are present because the clay increase with depth is minimal or gradual. However, in the Coto soil, 12% argillans were identified in the B23 horizon (65-90 cm), and the B23 horizon of the Bayamon soil has 23% cutans (Eswaran et al, 1979). But there is no corresponding increase in clay content which precludes the recognition of argillic horizons. Although there exists an ambiguity in the definitions of the argillic and oxic horizons, it seems obvious that the B23 horizon of the Bayamon soil is neither one. Therefore, the classification of the Bayamon series should be changed to Tropeptic Haplorthox as the oxic horizon does not extend to 125 cm. Assuming a udic soil moisture regime, classification of the Coto series as Tropeptic Haplorthox is correct since it has an essentially cutan-free oxic horizon of more than 30 cm thickness.

Table 2. Clay distribution in four Oxisols of Puerto Rico.

Series	Depth (cm)	Clay (%)
Bayamon	69	7
	69	21
	70	38
	66	66
	64	100
	67	135
	72	150
Catalina	8	76
	25	82
	45	82
	68	75
	95	66
	127	60
	150	57
Coto	11	61
	29	66
	42	70
	57	72
	80	74
	150	57
Nipe	14	55
	37	58
	58	60
	84	56
	109	60
	140	53
	150	38

In further reference to the Coto series, a computer analysis (kindly provided by Dr. A. Van Wambeke of Cornell University, Ithaca, N.Y.), indicates that the moisture regime of this soil is marginally ustic rather than udic, at least at the series' type location. It should be pointed out in this context that a ustic moisture regime in an essentially maritime climate as found in Puerto Rico, is vastly different from a ustic regime in a continental environment, e.g. in central Brazil. Therefore, a redefinition and a refinement of the ustic soil moisture regime seems strongly indicated. Anyhow, acceptance of a ustic regime for the Coto series would change the classification of this series from a Tropeptic Haplorthox to a Tropeptic Eutrustox since the major part of the oxic horizon of this soil has a base saturation of more than 50%. Similarly,

the Cotito series, which occurs in association with the Coto series, would also become a Tropeptic Eutrustox.

In Soil Taxonomy, the adjective "tropeptic" is used to differentiate great groups of Oxisols for soils that have either an oxic horizon extending to less than 125 cm depth, or a stronger than weak blocky or prismatic structure, or both. Two distinct properties are thus used for one subgroup, which results in a rather heterogeneous class of deep and shallow soils. Two separate subgroups should, therefore, be provided. It is realized that this will entail two adjectives in the subgroup name for soils that have both a shallow oxic horizon and moderate structure.

In the Acrorthox, no subgroups are recognized for soils having discernible structure. The Nipe soil, however, has weak to moderate structure in the major part of the oxic horizon. It is therefore proposed to either change the definition of the typic subgroup or establish a subgroup for Acrorthox with discernible structure in analogy with tropeptic subgroups of other Oxisol great groups.

The other Oxisol series of Puerto Rico--Catalina, Delicias, Matanzas, and Rosario--conform well to the concepts of the taxa in which they have been placed (Table 1). The Catalina series in particular is a fine example of a deep Tropeptic Haplorthox. It must be noted, however, that the positive identification and delineation of Oxisols in the field is often difficult, especially where they border on Orthoxic Tropohumults. The difficulty relates to the apparently universal problem of identifying argillans and assessing soil structure objectively. For example, thin section studies of an oxic horizon with no field evidence of clayskins revealed 4% argillans. Conversely, only 2% argillans could be determined in the argillic horizon of an Orthoxic Tropohumult where field examination suggested an abundance of clayskins (Eswaran et al, 1979).

Finally, it has been proposed recently to increase the thickness requirement of the oxic horizon from 30 to 50 cm, and to exclude from the Oxisol order such soils in which an oxic horizon is underlain by an argillic or natric horizon at less than 1 m depth from the soil surface, or

75 cm in the case of a lithic or paralithic contact (ICOMOX Circular No. 1/78). This proposition, if accepted, would affect the classification at the order level of at least 3 and more likely 4 series in Puerto Rico and reduce Oxisols to about half their present area. The rationale of the proposal is not entirely clear. From a soil management point of view it would certainly seem desirable to retain the current definitions. Moreover, additional restrictions in the taxonomy of Oxisols would further diminish the extent of what already appears to become an "endangered species."

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I. PHYSICAL ENVIRONMENT

1.1 LOCATION

Peninsular Malaysia is situated near the Equator between latitudes 1° 15'N and 6.45'N and longitudes 99°E and 104° 20'E (Fig. 1). To the east of the Peninsular lies the South China Sea while to the west is the Straits of Malacca. The country has an area of 13.2 million hectares. Its greatest length is about 736 kilometres and the maximum width is about 320 kilometres.

Peninsular Malaysia consists of 11 states: Perlis, Kedah, Penang, Perak, Selangor, Negeri Sembilan, Malacca, Johore, Kelantan, Trengganu and Pahang. It has a population of 10.3 million (1976 estimate) which is made up of 5.5 million Malays, 3.6 million Chinese and about 1 million Indians.

1.2 PHYSIOGRAPHY

The physical relief is dominated by the central mountain range which runs through the middle of the Peninsular and which reaches a height of about 2,200 metres. Secondary ranges fan out from this, mainly in the northern half of the country. These ranges consist of steepland with slopes exceeding 25° and constitute some 40% of the total land surface. From these mountain systems, many rivers flow through hilly, rolling and undulating lowlands towards the floodplains, coastal flats and beach ridges. The intermediate lowlands lie mainly between 20-160 metres above see level. The west coast is dominated by clayey deposits of marine and riverine origin while the east coast is dominated by sandy beach ridges (Fig. 2).

About 9 percent of the land area is swampland, mainly in the coastal depressions. Peninsular Malaysia has about 1200 miles of coastline.

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FIG I LOCATION OF SOIL PITS

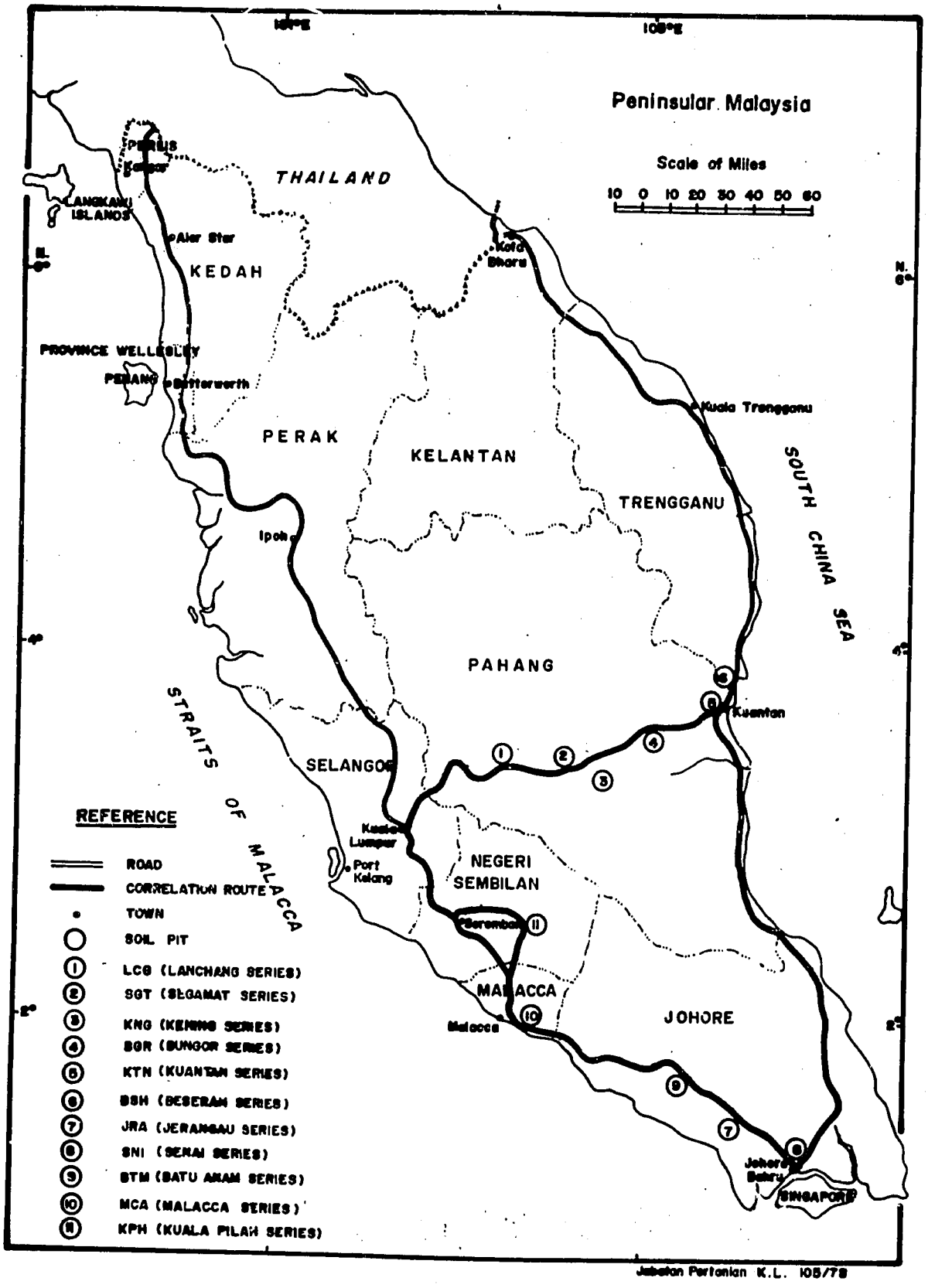

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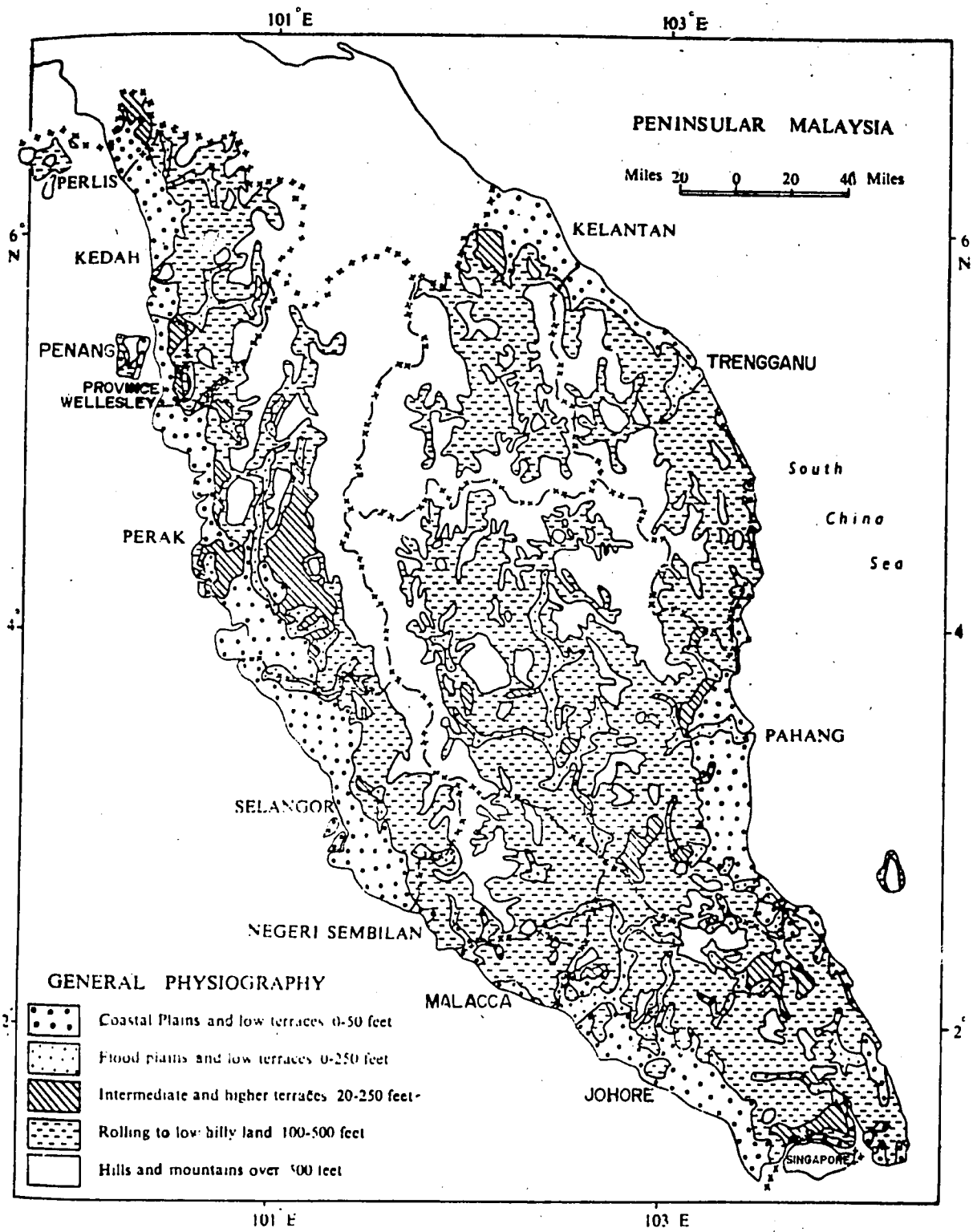
FIG. 2 GENERAL PHYSIOGRAPHY



1.3 CLIMATE

The climate of Peninsular Malaysia is characterized by high humidity, abundant rainfall and little variation of temperature throughout the year (see Table 1). The diurnal variations of weather is the predominant feature, producing strong contrasts of rain and cloud between day and night.

TABLE 1. CLIMATE DATA FOR KUALA LUMPUR INTERNATIONAL AIRPORT (SUBANG)
1969-1973. 03° 07'N, 101° 33'E, 16 m above m.s.l.

		J	F	M	A	M	J	J	A	S	O	N	D	Year
Temp.	°C	25.9	26.5	26.7	26.8	27.0	26.8	26.4	26.3	26.2	26.1	25.9	25.6	26.4
	°F	(78.7)	(79.7)	(80.1)	(80.2)	(80.7)	(80.2)	(79.5)	(79.3)	(79.2)	(79.0)	(78.6)	(78.1)	(79.5)
Precip.	cm	22.78	14.61	16.31	31.45	25.10	15.16	11.51	16.51	14.78	27.15	21.08	29.21	245.6
	inch	(8.97)	(5.75)	(6.42)	(12.38)	(9.88)	(5.97)	(4.53)	(6.50)	(5.82)	(10.69)	(8.30)	(11.50)	(96.71)
R.H.	%	82.6	81.0	82.3	84.9	84.9	84.3	82.9	83.6	84.8	85.6	86.9	86.9	84.2

The average daily temperature throughout Peninsular Malaysia varies from 21°C (70°F) to 32°C (90°F) though at greater elevations temperatures are lower. For example, at Cameron Highlands, elevation 1,700 m (5600 ft) the mean annual temperature is 17.6° (63.8°F), and the extreme temperatures recorded are 26°C (79°F) and 2°C (36°F). Relative humidity is everywhere generally high (mean value 85%) though night temperatures in most places are comparatively cool.

There are two main seasons in the year, namely, the southwest monsoon season and the northeast monsoon associated with the periodic changes in the prevailing winds. There are two transitional periods separating the two monsoons. The southwest monsoon is usually established in the latter half of May or early June and ends in September. The winds are light southwesterly. The northeast monsoon usually commences in late October or November and ends in March. During this season northeasterly winds blow strongly over the South China Sea and the east caost but lightly elsewhere. In the two transitional seasons, April to May and October, winds are generally light and variable.

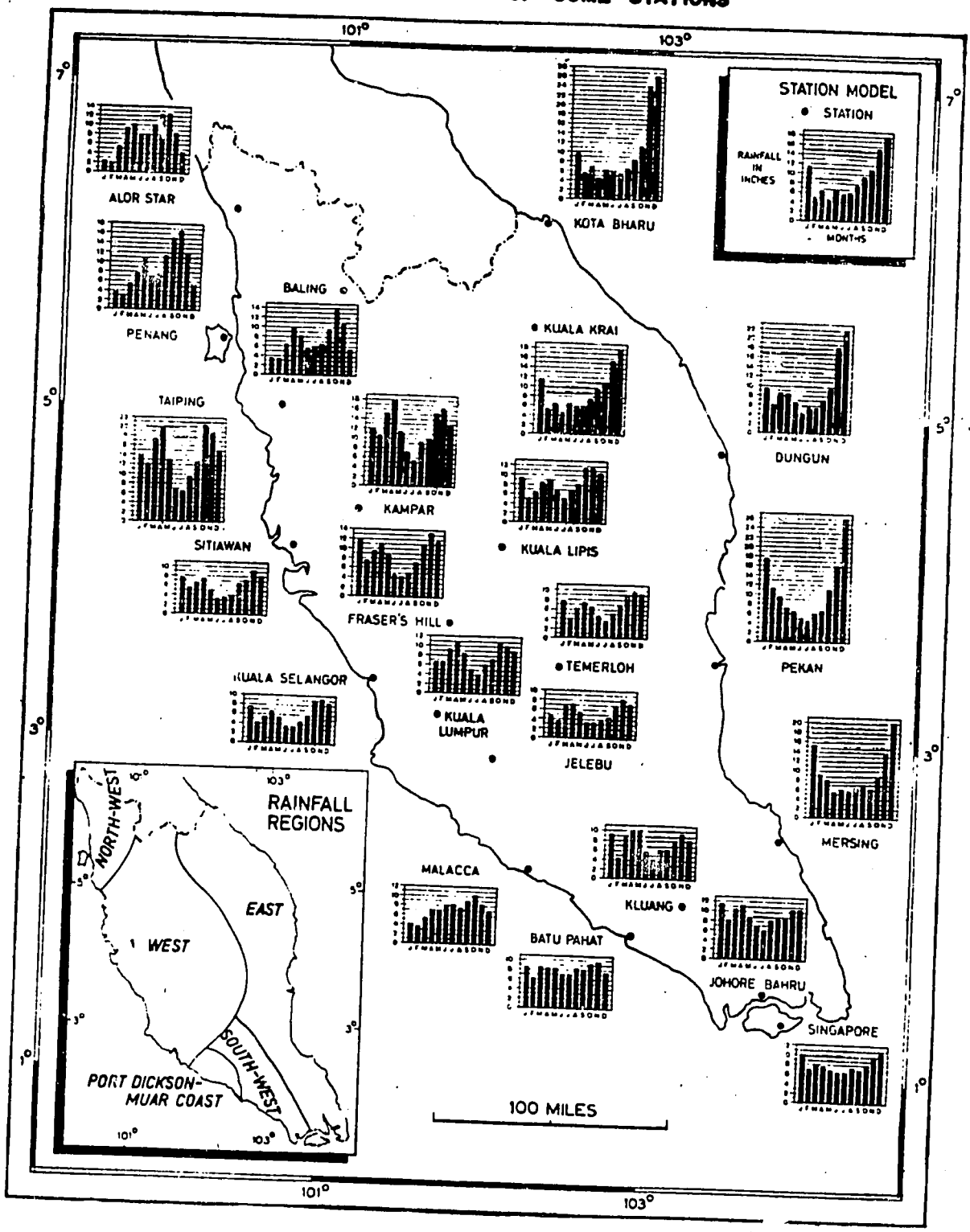
From April to November, line squalls, known locally as 'Sumatras', accompanied by heavy thunderstorms and rain, develop in the Malacca Straits in the night and move with the prevailing south-westerly winds onto the west coast between Port Klang and Singapore bringing early morning rain. Throughout this period the region is overlain by a warm, moist, conditionally unstable, equatorial maritime air mass.

The seasonal variations of rainfall are of three main types. During the northeast monsoon (November -January) the east coast districts get the maximum rainfall, while June - July (during the south-west monsoon) are the driest months in most districts. Over the central and north-eastern parts of the Peninsular, which are sheltered from the northeast monsoon by the eastern ranges and from the southwest monsoon by those of Sumatra, highest rainfall occur between the seasons, due to convective activity. The southwest coastal area, which is sheltered from the southwest monsoon by the highlands of Sumatra, is, however, very much affected by 'Sumatras' during the period May to August.

The annual rainfall is high over the whole of the Peninsular and varies from place to place, generally ranging between 2,000 mm (78 in.) and 3,000 mm (120 in.) with no one place being extremely dry or wet. The driest town is Jelebu with 1,670 mm (65 in.) and the wettest is near Taiping town with 5,900 mm (232 in.) (see Fig. 3). Heavy falls are common but they are of short duration, except on the east coast during the north-east monsoon, particularly in November and December. Very heavy rain storms often causing severe flooding are not infrequent and more than 380 mm (15 in.) in 24 hr. have been recorded on occasions on the east coast. Dry spells, sometimes lasting for three or four weeks, may occur at times.

According to Köppen's classification, Peninsular Malaysia has Afi climate (tropical Rainforest), with temperature and precipitation both remaining high throughout the year and the range of temperature between warmest and coldest months less than 5° (9°F). In the extreme northwest of the Peninsular, the climate tends to be Am (Tropical Monsoon) with a distinct dry season dry season in January and February. In the 1948 Thornthwaite classification, Peninsular Malaysia has Humid Tropical Rain-forest climate, ArA'a', which is per humid, megathermal with no season of

FIG.3 RAINFALL PATTERN OF SOME STATIONS



water deficiency, and a temperature-efficiency regime normal to a mega-thermal climate.

As distinct from the atmospheric climate, the soil climate, or pedoclimate, is characterized by the soil temperature and soil moisture regimes.

Mean daily soil temperatures of 3 soils under mature rubber (measured at 50 cm depth in 1970)

Soil Series	Taxonomy	Mean daily soil temperature (°C)		
		Feb 18th – Mar 31st	June 1st – July 17th	Difference of means
Malacca	Oxisol	30.2	27.2	2.9
Munchong	Oxisol	26.4	26.1	0.3
Rengam	Ultisol	25.9	25.8	0.1

(After Chan, 1975)

The mean daily soil temperatures at 50 cm depth are around 26° (80°F). These values are about 2-3°C higher than the mean annual air temperatures (24°C). The difference of the mean daily soil temperatures for the periods compared does not exceed 5°C, and therefore the soil temperature regime for the lowlands is deemed to be isohyperthermic.

Generally, the *udic* soil moisture regime is found in the lowlands of Peninsular Malaysia (less than 300 m or 1000 ft elevation) while the perudic moisture regime is confined mainly to the areas above 300 metres, where the increase in elevation lowers the rate of evapotranspiration. In the northwest (Kedah-Perlis), which has a distinct dry season; the moisture regime tends to be *ustic*.

The udic moisture regime is common to the soils of humid climates that have well-distributed rainfall. Water moves down through the soil at some time in most years.

1.4 VEGETATION

1.4.1 General

Over 60% of the total land area of Peninsular Malaysia is under forest (Wong, 1971). The dryland vegetation of Peninsular Malaysia can be classified into three main formation types, namely lowland rain forests, lower montane rain forests and the upper montane rain forests.

1.4.2 Lowland Rain Forests

The lowland rain forest formation type occuring at elevations below 800 metres (± 2,500 ft), can be divided into Lowland Dipterocarp Forest, and Hill Dipterocarp Forest. (Symington, 1943).

The Lowland Dipterocarp Forests which occur below 300 metres (± 1,000 ft) are dominated by the family *Dipterocarpaceae* with species of the Red Meranti Group of *Shorea* forming a high percentage of the upper storey. Variations in the dominant species with the different parts of the country is quite evident.

The Hill Dipterocarp Forests occur between altitudes of 300 to 800 metres (± 1,000 to 2,500 ft). Many of the lowland species become scarce and are replaced by species such as *Shorea curtisii* particularly on ridge tops. At elevations above 300 metres (± 1,000 ft), the tree fern *Thelypteris chlamydophora* is found and its population increases with elevation.

1.4.3 Lower Montane Rain Forests

Lower Montane rain forests occur between altitudes of 800 to 1,600 metres (± 2,500 to 5,000 ft). This formation type is subdivided into the Upper Dipterocarp Forests between 800 to 1,200 metres (± 2,500 to 4,000 ft) and the Oak-Laurel Forests.

The Upper Dipterocarp Forest is characterized by the species *Shorea platyclados*. Though peat formation is not characteristic of this forest, litter starts to accumulate on the forest floor due to the slowing down of the processes of decomposition with reduced temperature.

With increasing altitude there are more oaks and laurels and at about 1,200 metres (± 4,000 ft) the Oak-Laurel Forests dominate. These forests are dominated by *Lauraceae* and oaks (*Lithocarpus* and *Quercus* spp.). Humus accumulation increases and ephytes become more common with increasing altitude.

1.4.4 Upper Montane Rain Forests

In Peninsular Malaysia this formation type occurs in the cloud zone and consists entirely of the Montane Ericaceous Forests. The lower limit of this formation is quite variable. On the Main Range the transition between the Oak-Laurel Forests and the Montane Ericaceous Forest is often very sharp and takes place at about 1,600 metres (± 5,000 ft.).

The Montane Ericaceous Forest is typically stunted, rarely reaching more than 16 metres (± 50 ft) in height and often less than 3 metres (± 10 ft). The trees are crooked and sometimes prostrate, and a thick covering of moss and other epiphytes on the stems and branches is characteristic. Peat is common.

1.5 GEOLOGY

Peninsular Malaysia has a complete geological history without any major breaks from the late Cambrian to the late Triassic. The succeeding Jurassic and Cretaceous is less complete while the Tertiary has a very limited distribution. Quaternary deposits are extensive and have economic importance. The Peninsular is composed of a great variety of a great rock types reflecting a spectrum of environments in space and time.

The geology of Peninsular Malaysia is predominated by granite and allied acid igneous intrusive rocks. This group of rocks forms the bulk of the mountain ranges of the Peninsular. Occasionally sedimentary formations occur at high altitudes.

At lower elevations, sedimentary formations are more predominant. The main sedimentary formations date from Upper Cambrian to Cretaceous; four of these formations contain calcareous rocks, of which two (Ordovician-Silurian and Permian) are mainly calcareous, and two (Lower Carboniferous and Triassic) are mainly argillaceous; the other groups contain arenaceous rocks.

Tertiary sediments consisting mainly of lacustrine deposits – sandstones and shales, probably Miocene in age, occur in five small areas. They are similar and thought to be basin deposits.

The extrusive igneous rocks are of varying age from Permian to Quaternary. They include tuffs and lavas and range in composition from rhyolites through andesites to basalts. The only extensive body of schists occurs in north Kelantan. They are believed to be of Permian age. Most of the sedimentary formations have often undergone low grade metamorphism during the Jurassic.

Recent riverine and marine alluvium occur on the coastal plains and low hills inland particularly in Johore. Their thickness is variable but can attain depths reaching 160 metres (± 500 ft). On the west coast they are predominantly clayey while on the east coast they are distinctly sandy. As a result of Quaternary eustatic changes in sea level, riverine sediments have been deposited further inland than the present day coastal plain. This is particularly true for the southern part of Johore where unconsolidated sediments, known as the "Older Alluvium" form low hills (Burton, 1964).

1.6 Present Land Use

The existing land use in Peninsular Malaysia has been estimated for the year 1966 by the use of aerial photographs taken throughout the country in 1966. Based on this study Wong (1971), reported that 63.9% of Peninsular Malaysia under forest, 20.7% under agricultural use and the remaining 15.4% consisted of swampland, scrub grassland and urban and other assosiated areas.

The general pattern of development, is one of extensive cultivation on the plains of the west coast and the low hills adjoining the plains. The availability of extensive flat and undulating land with agriculturally suitable soils together with uniformly calm climatic conditions throughout the year have been significant contributing factors to the development of this region.

The east coast, by contrast, is less well developed; except for padi in the Kelantan coastal plain, large contiguous blocks of single crops are few and far between so that in comparison the pattern of development in the east coast is one of conglomeration of multiple variable small units.

Recent intensive development of these potential areas on the east coast by the Government has however changed the land use situation drastically. Large scale land development schemes such as the Jangka Triangle, Pahang Tenggara and Johor Tenggara have changed drastically the land use patterns in the east coast over the recent years.

The major land use categories in Peninsular Malaysia identified in the 1974 survey are given in Table 2.

TABLE 2. DISTRIBUTION OF AREA UNDER AGRICULTURE (Based on 1974 statistics)

Crops	(Hectares)
Rubber	1,693,052
Oil Palm	550,958
Rice	380,530
Coconuts	217,956
Cocoa	18,698
Coffee	7,530
Tapioca	11,562
Pineapple	21,842
Tea	3,354
Fruit trees	76,420
Other annual crops	173,371
Land area sq. km.	127,560.2
Total potential agricultural Land (ha.)	8,100,000

Source: Land Use Section Department of Agriculture, Ministry of Agriculture, Malaysia.

2. PROFILE DESCRIPTIONS AND ANALYTICAL DATA

PEDON M1 : LANCHANG SERIES

Classification: (a) Soil Taxonomy: Very fine clayey, kaolinitic, isohyperthermic Typic Paleudult.

(b) FAO/UNESCO: Dystric Nitosol.

Location:	Lanchang – Kg. Balok Road, Temerloh District; 88/092242
Parent Material:	Granodiorite
Topography:	Undulating
Elevation:	50 m
Slope:	6°
Vegetation/Land Use:	Secondary jungle
Drainage:	Well drained

Horizon	Depth	
Ap	0 - 15 cm:	Dark yellowish brown (10YR 4/4) clay loam; strong crumb and some fine medium subangular blocky; very friable; many fine and medium roots; many pores, many charcoal fragments; gradual wavy boundary.
B_1	15 - 33 cm:	Yellowish brown (10YR 5/6) clay; weak to moderate, medium and coarse subangular blocky breaking to medium and fine granules; friable; patchy discontinuous clayskins on ped faces and continuous along root channels; many fine and medium roots; many pores; few termite nests; diffuse boundary.
$B_{21}t$	33 - 58 cm:	Yellowish brown (10YR 5/8) clay; coarse and medium subangular blocky; friable; discontinuous to continuous clayskins on large ped faces and along root channels; many fine roots few channels; many pores, diffuse boundary.
$B_{22}t$	58 - 89 cm:	Yellowish brown (10YR 5/8) clay; moderate to strong, medium and fine subangular blocky breaking to fine subangular blocky; friable; patchy to discontinuous clayskins on larger ped faces; few fine and medium roots; many pores; few channels; diffuse boundary.
$B_{23}t$	89 - 120 cm:	Yellowish brown (10YR 5/8) clay; moderate coarse and medium subangular blocky; friable; discontinuous to continuous clayskins on large ped faces; few coarse and medium roots; few pores; no channels; diffuse boundary

PEDON M1 : *-(cont'd)*

$B_{24}t$	120 - 167 cm:	Yellowish brown (10YR 5/8) clay; moderate coarse and medium subangular blocky; friable to slightly firm; discontinuous to continuous clayskins on large ped faces; few fine roots; no channels; few pores; diffuse boundary.
$B_{25}t$	167 - 210 cm:	Reddish yellow (7.5YR 6/8) clay with few indistinct fine yellowish red (5YR 5/8) mottles; moderate coarse and medium subangular blocky; friable to slightly firm; discontinuous to continuous clayskins on large ped faces; few fine roots; no channels; few pores; diffuse boundary.
B_3t	210 - 237 cm:	Reddish yellow (7.5YR 6/8) clay with few fine and medium distinct yellowish red (5YR 5/8) and brownish yellow (10YR 6/8) mottles; moderate and coarse medium and fine subangular blocky; friable to slightly firm; discontinuous to continuous clayskins on larger ped faces; very few fine roots; no channels; few pores; sharp boundary.
C(R)	237 - 250 cm:	Weathering parent material with some weathered feldspars and few iron coated quartz gravel. Matrix colour strong brown (7.5YR 5/8); massive structure.

PEDON M1 : LANCHANG SERIES

Depth (cm)	Horizon	Granulometry				Percentage		C/N	% Free Iron
		Clay	Silt	Fine Sand	Coarse Sand	O.C	N		
0- 15	Ap	35.2	21.9	20.8	22.2	2.33	0.20	12	6.80
15- 33	B_1t	50.9	19.0	13.5	16.6	0.93	0.14	7	7.41
33- 58	$B_{21}t$	58.2	15.5	10.9	15.4	0.77	0.11	7	7.96
58- 89	$B_{22}t$	61.3	14.3	10.4	14.0	0.54	0.10	5	8.22
89-120	$B_{23}t$	63.9	11.8	10.0	14.2	0.25	0.07	4	7.93
120-167	$B_{24}t$	63.6	13.4	11.1	11.9	0.22	0.06	4	8.23
167-210	$B_{25}t$	66.7	11.5	10.1	11.8	0.15	0.05	3	8.52
210-237	B_3t	65.3	14.7	9.7	10.3	0.21	0.04	5	8.91
237-250	C(R)	47.1	19.0	13.4	20.5	0.14	0.03	5	9.97

Horizon	Bulk Density gms/cc	Moisture (Volume %) at pF					Av. Moist (mm/m)		Porosity %
		0	1	2	2.54	4.19	1/3-15	1/10-15	
$B_{21}t$	1.17	66.9	53.8	46.7	43.0	38.6	44.0	81.0	66
$B_{23}t$	1.20	68.9	54.0	50.6	45.2	41.4	38.0	92.0	68
$B_{24}t$	1.21	73.6	58.1	51.4	47.8	44.8	30.0	66.0	73
$B_{25}t$	1.20	67.7	59.3	52.4	49.9	45.7	42.0	67.0	67
C(R)	1.17	70.9	62.0	55.8	49.0	45.2	38.0	106.0	70

Horizon	pH		Δ pH	1N – KCl		Exch. Cat.meq/100 gms Soil				Extr. Acidity
	H_2O	KCl		Al	H+	Ca	Mg	Na	K	
Ap	3.5	3.4	– 0.1.	2.91	0.6	0.25	0.27	0.08	0.18	15.28
B_1t	3.8	3.7	– 0.1	2.3	0.4	0.04	0.06	0.03	0.16	8.88
$B_{21}t$	4.0	3.6	– 0.4	2.1	0.3	0.04	0.06	0.03	0.06	8.08
$B_{22}t$	4.5	3.8	– 0.7	1.7	0.2	0.07	0.06	0.05	0.03	6.88
$B_{23}t$	4.6	4.0	– 0.6	1.4	0.3	0.08	0.10	0.05	0.05	6.08
$B_{24}t$	4.9	4.4	– 0.5	0.6	0.1	0.07	0.03	0.03	0.03	5.10
$B_{25}t$	5.2	4.4	– 0.8	0.6	0.1	0.10	0.04	0.03	0.03	4.60
B_3t	5.3	4.8	– 0.5	0.6	0.1	0.07	0.03	0.03	0.04	4.88
C(R)	5.3	4.5	– 0.8	0.4	0.1	0.05	0.02	0.03	0.05	4.10

PEDON M1 : -*(cont'd)*

Horizon	CEC meq/100 gms soil			CHARGE meq/100 gms clay					Base Sat. %		Al Sat. % on PC
	ECEC	NH_4OAc	Sum	PC	ECEC	NH_4OAc	Sum	POC	NH_4OAc	Sum	
Ap	4.28	8.64	16.06	10.4	12.1	24.5	45.6	35.2	9.0	4.8	78.8
B_1t	2.99	5.68	9.17	5.1	5.9	11.2	18.0	12.9	5.1	3.2	68.8
$B_{21}t$	2.59	5.53	8.27	3.9	4.4	9.5	14.2	10.3	3.4	2.3	91.7
$B_{22}t$	2.11	4.72	7.09	3.1	3.4	7.7	11.6	8.5	4.4	3.0	89.0
$B_{23}t$	1.98	4.36	6.36	2.6	3.1	6.8	9.9	7.3	6.4	4.4	83.3
$B_{24}t$	0.86	4.12	5.26	1.2	1.3	6.5	8.3	7.1	3.9	3.0	76.9
$B_{25}t$	0.90	4.40	4.80	1.2	1.3	6.6	7.2	6.0	4.5	4.2	75.0
B_3t	0.87	4.20	5.05	1.2	1.3	6.4	7.7	6.5	4.0	3.4	77.9
C(R)	0.65	3.40	4.25	1.2	1.4	7.2	9.0	7.8	4.4	3.5	72.7

Horizon	TOTAL ANALYSIS % (CLAY)									Molar Ratio
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	H_2O	H_2O+	SiO2 / A1203
$B_{21}t$	46.5	32.4	11.1	0.1	0.1	0.2	0.1	ND	ND	2.4
$B_{23}t$	42.5	31.2	10.3	0.1	0.1	0.2	0.3	ND	ND	2.3
$B_{25}t$	42.5	32.2	11.1	0.2	0.1	0.3	0.2	ND	ND	2.2
C	41.6	31.6	12.5	0.1	0.1	0.3	0 2	ND	ND	2.2

Pedon M1 – Mineralogy

Clay	
Kaolinite	XXX
Mica	X
Quartz	X
Gibbsite	XX
Silt	
Kaolinite	XX
Mica	X
Quartz	XX
Gibbsite	XX

PEDON M2 : SEGAMAT SERIES

Classification:	(a) Soil Taxonomy:	clayey, oxidic, isohyperthermic Tropeptic Haplorthox
	(b) FAO/UNESCO:	Acric Ferralsol

Location:	11th Milestone Temerloh – Kuantan Road
Parent Material:	Andesite
Topography:	Gently undulating
Elevation:	55 m
Slope:	6°
Vegetation/Land Use:	Secondary jungle
Drainage:	Somewhat excessive

Horizon

A_{1-3}	0 - 4 cm:	Dark reddish brown (2.5YR 3/4) clay; strong crumb; very friable; many fine roots gradual boundary.
B_1 ox	4 - 33 cm:	Dark red (2.5YR 3/6) clay; moderate medium subangular blocky; very friable; thin coatings on ped faces; many medium and few fine roots; diffuse boundary.
B_{21} ox	33 - 66 cm:	Dark red (2.5YR) clay; weak fine subangular blocky; friable; thin patchy coatings on ped faces; few medium roots; diffuse boundary.
B_{22} ox	66 - 115 cm:	Dark red (2.5YR 3/6) clay; weak to moderate; medium and fine subangular blocky; friable; thin coatings on ped face; few fine roots; diffuse boundary.
B_{23} ox	115 - 147 cm:	Dark red (2.5YR 3/6) clay; moderate medium and fine subangular blocky; friable to firm; thin coating on ped faces; few fine roots.

PEDON M2 : SEGAMAT SERIES

Depth (cm)	Horizon	GRANULOMETRY				Percentage		C/N	% Free Iron
		Clay	Silt	Fine Sand	Coarse Sand	O.C.	N		
0- 4	A_{1-3}	51.2	33.9	12.5	2.4	2.99	0.37	8	18.04
4- 33	B_{1ox}	65.8	28.1	3.7	2.4	1.45	0.09	17	17.50
33- 66	B_{21ox}	70.2	24.0	3.8	2.0	0.66	0.20	3	18.57
66-115	B_{22ox}	73.7	22.4	2.3	1.6	0.41	0.06	7	16.79
115-147	B_{23ox}	66.4	26.1	5.4	2.2	0.38	0.05	8	16.43
147-200	B_{24ox}	75.1	21.5	2.3	1.1	0.05	0.05	6	16.79

Horizon	Bulk Density gms/cc	Moisture (Volume %) at pF					A. Moist. mm/m		Porosity %
		0	1	2	2.54	4.19	1/3-15	1/10-15	
B_{21ox}	0.94	65.15	54.15	47.69	46.39	39.06	73.3	86.3	65
B_{22ox}	1.01	74.52	61.64	55.20	52.23	43.00	92.3	122.0	74
B_{23ox}	1.10	66.11	62.29	59.48	56.55	47.50	90.5	119.8	66
B_{24ox}	1.10	75.67	63.50	56.07	53.61	45.92	76.9	101.5	75

Horizon	pH		Δ pH	IN-KCL Al	Exch. Cat. meq/100 gms SOIL				Extr. Acidity
	H_2O	KCl			Ca	Mg	Na	K	
A_1	5.2	4.9	– 0.3	2.54	6.97	2.39	0.09	0.42	13.56
B_{1ox}	4.6	4.3	– 0.3	1.72	1.16	0.69	0.07	0.19	12.12
B_{21ox}	4.8	4.3	– 0.5	0.71	0.30	0.48	0.07	0.14	9.12
B_{22ox}	4.7	4.4	– 0.3	0.39	0.10	0.37	0.03	0.07	8.31
B_{23ox}	5.2	4.7	– 0.5	0.53	0.24	0.62	0.03	0.02	9.31
B_{24ox}	5.4	4.8	– 0.6	0.58	0.25	0.36	0.03	0.02	9.45

PEDON M2 *(cont'd)*

Horizon	CEC meq/100 gms SOIL			CHARGE meq/100 gms CLAY					Base Sat. %		Al Sat. %
	NH_4Cl	NH_4OAc	Sum	PC	NH_4Cl	NH_4OAc	Sum	PDC	NH_4OAc	Sum	
A_{1-3}	8.24	10.88	23.43	24.2	16.1	21.3	45.8	21.5	90.7	42.1	20.5
B_1ox	3.18	5.68	14.23	5.8	4.8	8.6	21.6	15.8	37.1	14.8	44.9
$B_{21}ox$	3.12	4.68	10.11	2.4	4.4	6.7	14.4	12.0	21.1	9.8	41.8
$B_{22}ox$	1.22	4.12	8.88	1.3	1.7	5.6	12.0	10.7	13.8	6.4	40.6
$B_{23}ox$	2.16	4.00	10.22	2.2	3.3	6.0	15.4	13.2	22.7	8.9	36.8
$B_{24}ox$	2.12	4.04	10.11	1.7	2.8	5.4	13.5	11.8	16.3	6.5	46.8

TOTAL ANALYSIS (SOIL)

Horizon	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	H_2O-	H_2O+	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
A_{1-3}	34.0	35.2	17.7	0.3	0.1	0.1	0.1	2.4	10.3	1.6	1.2
B_1ox	34.1	35.0	18.0	0.2	Tr	0.1	Tr	2.2	10.4	1.6	1.2
$B_{21}ox$	33.3	36.0	18.0	0.2	Tr	0.1	Tr	2.2	10.0	1.6	1.2
$B_{22}ox$	31.9	36.2	18.4	0.1	Tr	0.1	Tr	2.4	10.3	1.5	1.1
$B_{23}ox$	33.3	35.7	18.6	0.1	Tr	0.1	Tr	2.3	10.6	1.6	1.2
$B_{24}ox$	32.8	35.7	18.3	0.2	Tr	0.1	Tr	2.2	10.5	1.5	1.2

TOTAL MICRONUTRIENTS (ppm)

Horizon	Mn	Cu	Zn	Co	Ni
A_{1-3}	935	138	168	125	3.8
B_1ox	550	102	175	125	3.8
$B_{21}ox$	435	108	243	100	10.8
$B_{22}ox$	650	120	211	75	2.0
$B_{23}ox$	585	126	183	65	2.0
$B_{24}ox$	420	146	175	90	7.2

Pedon M2 – Mineralogy

Clay	
Kaolinite	65%
Gibbsite	9%
Goethite	20%

Silt	
Kaolinite	XX
Gibbsite	XX
Quartz	XX
Goethite	XXX
Ilmenite	X

PEDON M3 : KENING SERIES

Classification:	(a)	Soil Taxonomy:	fine clayey, kaolinitic isohyperthermic Typic Paleudult.
	(b)	FAO/UNESCO:	Dystric Nitosol.

Location:	Chenor, Pahang
Parent Material:	Andesitic Alluvium
Topography:	Undulating
Elevation:	34 m.
Slope:	8°
Vegetation/Land Use:	Old rubber
Drainage:	Somewhat excessive

Horizon	Depth	
A_1	0 - 8cm:	Clay loam to clay; 2.5YR 3/6 (dark red); very friable to friable, strong crumb structures; many fine and medium roots, abundant pores and some coarse roots; no clayskins; no channels; diffuse boundary.
$B_{21}t$	8 - 27 cm:	Clay with few distinct quartz (1-2 mm); 2.5YR 3/6 (dark red); weak to moderate, medium subangular blocky structures breaking down to strong crumb structures and weak, fine subangular blocky structures; many pores; patchy clayskins; many fine and medium roots; no channels; diffuse boundary.
$B_{22}t$	27 - 57 cm:	Clay with few quartz grits; 2.5YR 3/6 (dark red); very friable to friable; weak medium subangular blocky structures breaking down to strong crumb structures; patchy clayskins on large ped faces and root channels; few fine and medium roots; no channels; many pores; diffuse boundary.
$B_{23}t$	57 - 91 cm:	Clay with few to many quartz grits; 2.5YR 3/6 (dark red); weak medium subangular blocky structures breaking down to strong crumb structures; no clayskins; few fine roots; few channels; wavy sharp boundary.

PEDON M3 *(cont'd)*

II B+C 91 - 125 cm

Gravelly to stony clay, gravels generally 5-10 mm size; friable; 2.5YR 3/6 (dark red); weak, medium and fine and some coarse subangular blocky structures; patchy to discontinuous clayskins on large ped faces and coatings on gravel. Gravels predominantly quartz; few fine roots; sharp wavy boundary.

III B+C 125 - 170 cm

Stony clay; 2.5YR 3/6 (dark red); stones predominantly rounded quartz pebbles 10 - 15 mm size; friable; weak, coarse and medium and some fine subangular blocky structures breaking down to granules; patchy and discontinuous clayskins on large ped faces and coatings on gravel surfaces; few fine roots; no channels; sharp boundary.

IV B+C 170 - 209 cm

Gravelly to stony clay, gravels and stones ranging 10-14 mm size and rounded; 2.5YR 3/6 (dark red); weak, coarse and medium subangular blocky structures breaking down to fine subangular and granules; friable; patchy and discontinuous clayskins on gravel surfaces only; very few fine roots; no channels; diffuse boundary.

V B+C 209 - 250 cm

Gravelly to stony clay, many large pebbles as large as 60 mm and rounded; friable; weak, coarse and medium subangular blocky structures breaking down to granules and weak, fine subangular blocky structures; patchy to discontinuous clayskins on large ped faces and on gravel as coating; very few medium roots; few pores; few channels.

PEDON M3 : KENING SERIES

Depth (cm)	Horizon	Granulometric Composition (%)						Percentage		H_2O Disp. Clay	% Free Iron
		Clay	Silt	Fine Sand	Coarse Sand	Gravel	Stone	O.C.	N		
0- 8	A_{1-3}	18.0	23.2	19.9	38.9	-	-	1.79	0.20	18.3	8.52
8- 27	B_{21t}	36.9	17.3	17.2	28.5	-	-	0.70	0.10	26.05	10.01
27- 57	B_{22t}	44.8	11.3	14.8	29.1	-	-	0.54	0.08	0.26	10.58
57- 91	B_{23t}	50.3	8.7	13.9	27.1	-	-	0.23	0.06	Tr.	10.72
91-125	IIB+C	47.3	7.1	12.1	33.5	38.4	7.20	0.28	0.05	Tr.	11.01
125-170	IIIB+C	43.1	8.4	12.2	36.2	35.2	5.30	0.22	0.03	Tr.	10.02
170-209	IVB+C	39.3	7.7	11.5	41.0	31.0	4.20	0.19	0.03	Tr.	9.62
209-250	VB+C	39.2	8.7	11.6	40.5	37.9	2.20	0.16	0.02	Tr.	9.13

Depth (cm)	B.D. gm/cc	Moist. (Vol. %) at pF					Moist. between diff. pF			
		0	1	2	2.54	4.19	0-1	1-2	2-2.54	2.54-4.19
50	1.28	64.3	55.5	35.5	31.90	30.1	8.78	20.0	3.50	1.82
100	1.47	65.0	54.1	36.9	30.60	30.1	10.90	17.2	4.90	0.50
150	1.50	50.3	45.5	26.6	25.05	19.8	4.8	18.6	1.55	5.25
200	1.61	53.3	50.9	30.7	21.30	17.4	2.4	20.2	9.44	3.85

Horizon	pH		Δ pH	ZPC	1NKCl		Ex. Cat. meq/100gm Soil				Extr. Acidity
	H_2O	KCl			Al	H	Ca	Mg	Na	K	
A_{1-3}	4.6	4.4	– 0.2	4.1	0.30	0.20	0.48	0.74	0.07	0.25	7.10
B_{21ox}	4.3	3.8	– 0.5	3.8	1.33	0.27	0.12	0.21	0.05	0.04	5.10
B_{22ox}	4.4	3.9	– 0.5	3.8	1.32	0.24	0.08	0.07	0.05	0.02	5.60
B_{23ox}	4.2	3.9	– 0.3	3.9	1.29	0.19	0.09	0.06	0.05	0.02	6.10
IIB+C	4.5	4.0	– 0.5	3.9	1.30	0.80	0.07	0.06	0.03	0.03	5.68
IIIB+C	4.5	4.0	– 0.5	3.9	1.28	0.18	0.09	0.08	0.03	0.02	3.28
IVB+C	4.4	3.9	– 0.5	3.9	1.12	0.16	0.10	0.07	0.05	0.02	4.88
VB+C	4.3	3.9	– 0.4	3.9	1.03	0.17	0.11	0.10	0.03	0.03	5.28

Horizon	CEC meq/100 gm Soil			Charge meq/100gm Clay		PDC		Base Sat. %		Al Sat. %
	NH_4OAc	ECEC	Sum	PC	Sum	PDC	PC	NH_4OAc	Sum	
A_{1-3}	4.24	2.04	8.64	10.2	48.0	37.8	3.7	36	17.8	16.2
B_{21ox}	3.84	2.02	5.52	4.7	14.9	10.2	2.2	11	7.6	75.8
B_{22ox}	3.48	1.78	5.82	3.4	12.9	9.5	2.8	6	3.8	85.6
B_{23ox}	3.18	1.70	6.32	3.0	12.6	9.6	3.2	7	3.5	85.4
IIB+C	3.28	2.29	5.87	3.2	12.4	9.2	3.9	6	3.2	87.4
IIIB+C	2.88	1.68	3.50	3.5	8.1	4.6	1.3	8	6.3	85.4
IVB+C	2.92	1.52	5.12	3.5	13.0	9.5	2.7	8	4.7	82.5
VB+C	2.60	1.47	5.50	3.3	14.2	10.9	3.3	10	4.9	79.2

PEDON M3 *(cont'd.)*

Total Analysis of Clay

Horizon	SiO2	A1203	Fe203	CaO	MgO	K2O	Na2O	Total H2O	Total	SiO2 / A1203	SiO2 / R203
B_{22ox}	44.72	31.29	13.12	0.10	0.09	0.24	0.17	10.26	99.9	2.42	1.9
IIB+C	45.16	32.88	12.60	0.16	0.11	0.29	0.29	8.50	99.9	2.32	1.9
IVB+C	45.16	32.59	15.58	0.05	0.09	0.25	0.17	6.10	99.9	2.34	1.8

Pedon M3 – Mineralogy

Clay

Kaolinite	XXX
Goethite	XX

Silt

Kaolinite	XXX
Mica	XX
Quartz	XX
Haematite	XX

PEDON M4 : BUNGOR SERIES

Classification:	(a) Soil Taxonomy:	fine clayey, kaolinitic isohyperthermic Typic Paleudult
	(b) FAO/UNESCO:	Dystric Nitosol.

Location:	37 milestone Kuantan – Temerloh Road
Parent Material:	Shale interbedded with sandstone
Topography:	Undulating
Elevation:	50 m
Slope:	12°
Vegetation/Land Use	Poorly regenerating secondary forest
Drainage	Well drained

Horizon	Depth	
Ap	0 - 20 cm:	Dark greyish brown (10YR 4/2) fine sandy loam; very weak fine subangular blocky and coarse crumbs; friable; high biological activity; common worm casts; common fine roots, few coarse roots; rather sharp boundary.
B_1	20 - 35 cm:	Brownish yellow (10YR 6/6) fine sandy clay loam; weak medium and fine subangular blocky; friable; moderate biological activity few termite nests and many biopores; few fine roots, diffuse boundary.
B_{21t}	35 - 52 cm:	Brownish yellow (10YR 6/6) fine sandy clay; weak medium and fine subangular blocky; very thin continuous clayskins on ped faces, friable; common biopores and few termite nests; few fine roots; diffuse boundary.
B_{22t}	52 - 70 cm:	Brownish yellow (10YR 6/6) fine sandy clay; weak, medium and fine subangular blocky; continuous clay coatings on ped faces and in pores; friable; very few fine roots; diffuse boundary.
B_{23t}	70 - 90 cm:	Brownish yellow (10YR 6/6) fine sandy clay; very weak subangular blocky; patchy coatings on ped faces; slightly firm; very few biopores and an occasional termite nest; very few roots; diffuse boundary.

PEDON M4 *(cont'd)*

B_{31}	90 - 135 cm:	Brownish yellow (10YR 6/6) very few fine reddish mottles; weak medium and fine subangular blocky; very few patchy coatings on ped faces; slightly firm; very little biological activity; very few roots; diffuse boundary.
B_{32}	135 - 190 cm:	Brownish yellow (10YR 6/6) fine sandy clay with coarse distinct red (2.5YR 4/8) mottles; slightly massive; no clayskins; firm; no biological activity; no roots; diffuse irregular boundary.
C_1	190 - 226 cm:	Yellow (10YR 7/6) fine sandy clay with few coarse distinct red (2.5YR 4/6) mottles (mottled areas have slightly sandier texture); massive; no clayskins; firm; no biological activity; no roots; diffuse boundary.
C_2	226 - 266 cm:	Yellow (10YR 7/6) fine sandy clay loam with common to abundant coarse red (2.5YR 4/6) mottles (mottled areas have slightly sandier texture); massive; firm; no roots; diffuse boundary.
C_3	266 - 300 cm:	Very pale brown (10YR 7/4) fine sandy clay loam with common distinct (2.5YR 4/6) mottles; massive; firm; no roots.

PEDON M4 : BUNGOR SERIES

Depth (cm)	Horizon	GRANULOMETRY				Percentage		% Free Iron
		Clay	Silt	Fine Sand	Coarse Sand	O.C	N	
0- 20	Ap	18.1	10.3	52.5	19.1	0.94	N.D.	0.84
20- 35	B_1	30.7	9.7	44.2	15.4	0.42	N.D.	1.40
35- 52	B_{21t}	35.3	9.0	41.2	14.4	0.32	N.D.	1.58
52- 70	B_{22t}	36.1	9.1	41.1	13.7	0.26		1.58
70- 90	B_{23t}	41.2	8.4	38.5	11.9	0.20		1.60
90-135	B_{31}	44.3	8.1	36.4	10.2	0.20		1.87
135-190	B_{32}	47.1	7.7	35.2	10.0	0.19		2.06
190-226	C_1	39.0	8.8	40.8	11.4	0.11		1.88
226-266	C_2	32.9	9.6	44.4	13.1	0.09		1.77
266-300	C_3	31.0	10.5	33.1	15.4	0.06		1.12

Horizon	pH		ΔpH	—IN— KCl Al	Exch. Cat. meq/100 gms SOIL				Extr. Acidity
	H_2O	KCl			Ca	Mg	Na	K	
Ap	4.8	4.2	– 0.6	1.89	0.22	0.15	0.04	0.12	5.50
B_1	4.6	4.0	– 0.6	2.28	0.10	0.06	0.04	0.06	4.90
B_{21t}	4.9	4.1	– 0.8	2.28	0.14	0.07	0.07	0.07	4.80
B_{22t}	5.0	4.2	– 0.8	2.22	0.08	0.05	0.04	0.02	4.40
B_{23t}	5.0	4.1	– 0.9	2.22	0.10	0.04	0.04	0.02	4.28
B_{31}	5.1	4.1	– 1.0	2.24	0.08	0.04	0.03	0.02	4.23
B_{32}	5.1	4.0	– 1.1	2.28	0.04	0.03	0.04	0.07	4.18
C_1	5.6	4.4	– 1.2	2.28	0.07	0.02	0.04	0.02	3.82
C_2	5.3	4.3	– 1.0	2.13	0.03	0.02	0.02	0.03	3.42
C_3	5.2	4.3	– 0.9	1.83	0.03	0.02	0.04	0.02	3.02

Horizon	CEC meq/100 gms SOIL		CHARGE meq/100 gms CLAY				Base Sat. %		Al Sat. % on PC
	NH_4OAc	Sum	PC	NH_4OAc	Sum	POC	NH_4OAc	Sum	
Ap	3.06	6.03	13.4	16.9	33.3	19.9	17	9	78
B_1	3.12	5.16	8.2	10.2	16.8	8.6	8	5	90
B_{21t}	3.53	5.15	7.4	10.0	14.6	7.2	10	7	87
B_{22t}	3.05	4.59	6.6	8.4	12.7	6.1	6	4	92
B_{23t}	3.39	4.48	5.8	8.2	10.9	5.1	6	4	92
B_{31t}	3.39	4.40	5.4	7.6	9.9	4.5	5	4	93
B_{32t}	3.37	4.36	5.2	7.1	9.3	4.1	5	4	93
C_1	2.82	3.97	6.2	7.2	10.2	4.0	5	4	93
C_2	2.52	3.52	6.8	7.7	10.7	3.9	4	3	95
C_3	2.39	3.13	6.9	7.7	10.1	3.2	5	3	94

Pedon M4 – Mineralogy

Clay	
Kaolinite	XXX
Mica	XX
Quartz	X

Silt	
Kaolinite	XXX
Mica	XX
Quartz	XXX

PEDON M5 : KUANTAN SERIES

Classification:	(a) Soil Taxonomy:	clayey, kaolinitic, isonyperthermic Haplic Acrorthox
	(b) FAO/UNESCO:	Acric Ferralsol.

Location:	Bukit Goh Oil Palm Scheme, Kuantan district, Pahang.
Parent Material:	Basalt
Topography:	Gently undulating
Elevation:	30 m
Slope:	10 midslope
Vegetation/Land Use:	Oil Palm
Drainage:	Somewhat excessive

Horizon	Depth	
A_{1-3}	0 - 18 cm:	Brown to dark brown (10YR 4/3); weak fine subangular blocky and strong crumb; friable to firm; few medium roots; few channels; diffuse boundary.;
B_{21ox}	18 - 46 cm:	Dark yellowish brown (10YR 4/4) clay; weak, medium subangular blocky; very friable; few fine roots; few channels; thin coatings on ped faces; diffuse boundary.
B_{22ox}	46 - 121 cm:	Dark yellowish brown (10YR 4/4) clay; weak, medium and coarse subangular blocky; very friable; few fine roots; thin coatings on ped faces; diffuse boundary.
B_{23ox}	121 - 200 cm:	Dark yellowish brown (10YR 4/4) clay; weak, medium and fine subangular blocky; friable; few fine roots; thin coatings on ped faces.

PEDON M5 : KUANTAN SERIES

Depth (cm)	Horizon	GRANULOMETRY				Percentage		C/N	% Free Iron
		Clay	Silt	Fine Sand	Coarse Sand	O.C.	N		
0-18	A_{1-3}	59.8	24.7	8.3	7.3	1.93	0.29	7	12.42
18- 16	B_{21ox}	65.2	24.1	6.7	4.0	0.40	0.12	3	12.51
46-121	B_{22ox}	65.3	20.3	10.8	3.6	0.30	0.06	5	13.04
121-200	B_{23ox}	69.1	21.0	6.9	2.9	0.18	0.06	3	14.92

Horizon	Bulk Density	Moisture (Volume %) at pF					A. Moist mm/m		Porosity %
		0	1	2	2.54	4.19	1/3-15	1/10-15	
B_{21ox}	0.86	68.4	55.4	38.0	31.9	23.7	82	143	68
B_{22ox}	0.89	72.6	59.6	43.0	35.5	29.0	65	140	72
B_{23ox}	0.88	74.1	61.3	44.3	38.9	31.1	78	132	74
B	0.93	66.6	62.4	48.9	46.6	37.9	87	110	66

Horizon	pH		ΔpH	IN–KCL Al	Exch. Cat. meq/100 gms SOIL				Extr. Acidity
	H_2O	KCl			Ca	Mg	Na	K	
A_{1-3}	4.3	3.9	– 0.4	1.66	0.70	0.32	0.03	0.12	11.7
B_{21ox}	4.6	4.1	– 0.5	0.82	0.15	0.07	0.02	0.04	9.8
B_{22ox}	4.8	4.8	– 0.6	0.80	0.12	0.05	0.02	0.02	8.5
B_{13ox}	4.8	4.3	– 0.5	0.55	0.17	0.04	0.02	0.02	7.5

Horizon	CEC meq/100 gms SOIL			CHARGE meq/100 gms CLAY					Base Sat. %		Al Sat. %
	NH_4Cl	NH_4OAc	Sum	PC	NH_4Cl	NH_4OAc	Sum	PDC	NH_4OAc	Sum	
A_{1-3}	2.32	9.24	12.87	4.7	3.9	15.4	21.5	16.8	12.7	9.1	58.7
B_{21ox}	0.90	5.20	10.08	1.7	1.4	8.0	15.5	13.7	5.4	2.8	74.6
B_{22ox}	0.82	4.08	8.71	1.5	1.2	6.2	13.3	11.8	5.1	2.4	79.2
B_{23ox}	0.72	3.16	7.75	1.1	1.0	4.6	11.2	10.0	7.9	3.2	68.8

PEDON M5 *(cont'd)*

TOTAL ANALYSIS (SOIL)											
Horizon	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	H_2O-	H_2O+	SiO_2 / Al_2O_3	SiO_2 / R_2O_3
A_{1-3}	26.0	36.5	19.0	0.1	0.1	0.1	Tr	3.2	14.3	1.2	0.9
B_{21ox}	26.1	36.7	20.4	Tr	0.1	Tr	Tr	2.8	14.1	1.2	0.9
B_{22ox}	23.6	39.8	20.2	Tr	0.1	Tr	Tr	2.5	14.1	1.2	0.8
B_{23ox}	25.4	36.2	20.6	0.1	0.1	Tr	Tr	2.7	14.2	1.2	0.8

TOTAL MICRONUTRIENTS (ppm)					
Horizon	Mn	Cu	Zn	Co	Ni
A_{1-3}	297	172	157	60	64.2
B_{21ox}	290	190	168	50	39.5
B_{22ox}	314	204	168	100	46.5
B_{23ox}	430	208	168	110	41.2

PARTIAL ANALYSIS (CLAY)					
Horizon	SiO_2	Al_2O_3	Fe_2O_3	SiO_2 / Al_2O_3	SiO_2 / R_2O_3
A_{1-3}	31.7	31.0	19.3	1.8	1.3
B_{21ox}	33.7	31.0	20.6	1.9	1.3
B_{22ox}	35.0	34.6	18.6	1.7	1.3
B_{23ox}	33.0	37.8	19.3	1.5	1.1

Pedon M5 – Mineralogy

Clay

Kaolinite	65%
Gibbsite	14%
Goethite	20%
(and others)	

Silt

Ilmenite
Magnetite
Kaolinite
Quartz
Gibbsite

PEDON M6 : BESERAH

Classification:	(a) Soil Taxonomy:	fine clayey, kaolinitic, isohyperthermic Typic Paleudult.
	(b) FAO/UNESCO:	Dystric Nitosol.

Location:	12th milestone Kuantan – Kuala Trengganu Road
Parent Material:	Granite
Topography:	Hilly
Elevation:	50 m
Slope:	15°
Vegetation/Land Use:	Secondary jungle
Drainage:	Well drained

Horizon	Depth	
A_{1-3}	0 - 9 cm:	Coarse sandy loam; dark yellowish brown (10YR 4/4); weak medium and fine subangular blocky, and weak, fine crumb; few roots; few pores; very few worm casts; diffuse boundary.
B_{21ox}	9 - 38 cm:	Coarse sandy clay loam; strong brown (7.5YR 5/8); weak, medium and fine, subangular blocky; very few roots, few, small termite nests; diffuse boundary.
B_{22ox}	38 - 63 cm:	Coarse sandy clay loam; strong brown (7.5YR 5/8); weak, coarse to medium, subangular blocky; thin patchy clay skins; no roots; rather diffuse boundary.
B_{23t}	63 - 100 cm:	Coarse sandy loam; strong brown (5YR 5/8); weak, medium to fine subangular blocky; thin patchy clay skins; no roots; rather diffuse boundary.
B_3	100 - 150 cm:	Coarse sandy loam; red (2.5YR 5/8) weak fine subangular blocky; few, thin, clay skins in pores; no roots; diffuse boundary.
C_1	150 - 275 cm:	Coarse sandy loam; red (2.5YR 4/8); massive; pores lined with cutans; diffuse boundary.

PEDON M6 *(cont'd)*

C_2	275 - 500 cm:	Coarse sandy loam; red (2.5YR 4/8); slightly variegated; few white (10YR 7/2) mottles, elongated vertical streaks; cutan like material present in some voids; diffuse boundary.
C_3	500 - 800 cm:	Coarse sandy loam; yellowish red (5YR 5/8); massive; bleached spots increasing; rather diffuse boundary.
C_4	800 - 950 cm:	Sandy loam; strong brown (7.5YR 5/6) with common light grey (10YR 7/6) with common light grey (10YR 7/2) streaks; few kaolinised feldspares, white; rather diffuse boundary.
C_5	950 - 1250 cm:	Gravelly clay loam; dark yellowish brown (7.5YR 5/8) with many red (10YR 4/6) and white (10YR 8/2) coarse mottles; many kaolinised feldspares; diffuse boundary.
C_6	1250 -1360 cm:	Gravelly clay loam; as previous horizon but with increasing white (10YR 8/2) patches; kaolinised feldspars increasing; rather abrupt boundary.
C_7	1360 - 1500 cm:	As above but more compact, rock structure evident; diffuse boundary.
C_8	1500 - 1600 cm:	Gravelly clay; white (10YR 8/2); many kaolinised feldspars; few red (10YR 6/8) mottles rather abrupt boundary.
$(R)_1$	1600 - 1660 cm:	Weathering rock; white (10YR 8/1); with reddish spots (10YR 5/9); rock structure intact.
$(R)_2$	1660 - 1850 cm:	Weathering rock, matrix colour white (10YR 8/1); many slightly weathered feldspares; few reddish yellow (7.5YR 5/8) mottles; wet; abrupt contact with rock.
R_3	1850 - 1900 cm:	Weathering crust of relatively fresh granite.

PEDON M6 : BESERAH SERIES

Horizon	Depth (cm)	GRANULOMETRY					% Silt	pH (1:1)	
		Clay	Silt	Fine Sand	Coarse Sand	Gravel	% Clay	H_2O	KCl
A_{1-3}	0- 9	36.7	7.9	39.2	16.2	5.0	0.22	4.36	3.90
B_{21ox}	9- 38	37.5	10.8	46.2	5.5	7.[illegible]	0.29	4.40	3.90
B_{22t}	38- 63	36.7	12.2	46.2	4.9	31.3	0.33	4.20	4.00
B_{23t}	63- 100	32.5	5.7	57.8	4.0	33.3	0.18	4.20	4.00
B_3	100- 150	37.6	7.9	49.7	4.8	37.4	0.21	-	-
C_2	275- 500	18.1	13.8	62.5	5.6	31.8	0.76	4.40	4.10
C_3	500- 800	20.1	27.9	44.4	7.6	27.4	1.39	4.60	3.75
C_4	800- 950	10.2	35.5	46.6	7.9	37.5	1.77	4.70	4.00
C_5	950-1250	18.4	32.5	33.1	16.0	37.5	1.77	4.70	4.00
C_6	1250-1360	15.5	25.9	44.6	14.0	32.7	1.67	4.84	3.85
C_7	1360-1500	11.7	22.5	45.0	20.8	40.0	1.92	4.80	3.85
C_8	1500-1600	8.5	21.7	51.0	18.8	47.0	2.55	4.85	3.85
$(R)_1$	1600-1660	10.5	29.7	41.4	18.4	38.2	2.82	-	-
$(R)_2$	1660-1850	-	-	-	-	53.4	-	-	3.90
$(R)_3$	1850-1900	-	-	-	-	-	-	-	-

– not determined

Horizon	Depth (cm)	(meq/100g Soil)					
		Exchangeable (IN KCl)			Extractable Acidity	ECEC	CEC Sum
		Acidity	A_1	H			
B_{21ox}	9- 38	0.98	0.62	0.36	9.44	1.48	9.94
B_{23t}	63- 100	0.73	0.48	0.25	5.12	0.94	5.33
B_3	100- 150	0.48	0.25	0.23	3.52	0.82	3.86
C_2	275- 500	0.79	0.52	0.27	2.56	0.83	2.60
C_4	800- 950	1.72	1.33	0.39	6.08	1.82	6.18
C_5	950-1250	2.77	2.26	0.56	8.80	2.88	8.91
C_7	1350-1500	2.59	2.05	0.54	8.96	2.73	9.10
$(R)_1$	1600-1660	2.84	2.22	0.62	8.16	2.97	9.29
$(R)_2$	1660-1850	2.61	2.00	0.61	7.52	2.75	7.66

PEDON M6 *(cont'd)*

Horizon	(meq/100 g Clay)		P.C./ P.D.C.	Base Saturation %			Al Saturation %	
	Permanent Charge (P.C.)	pH Dependent Charge (P.D.C.)		P.C.	CEC NH_4OAc	CEC Sum	P.C.	ECE
B_{21ox}	2.99	23.52	0.13	44.6	13.02	5.03	55.35	41.81
B_{23t}	2.12	14.28	0.15	30.6	6.93	3.93	69.57	51.06
B_3	1.57	8.70	0.18	57.6	16.90	8.80	42.37	30.49
C_2	3.09	11.27	0.27	7.1	2.12	1.53	92.86	62.65
C_4	14.02	46.57	0.30	7.0	2.48	1.61	93.00	73.08
C_5	12.88	35.54	0.36	4.6	1.78	1.23	95.38	78.47
C_7	18.72	59.06	0.32	6.4	2.10	1.53	93.60	75.09
$(R)_1$	22.38	56.57	0.40	5.5	1.83	1.56	94.47	74.75
$(R)_2$	-	-	-	6.5	2.11	1.82	93.46	72.73

Horizon	O.C. %	N %	C/N	(meq/100 g Soil)					
				Exchangeable			Sum of Bases	CEC NH_4OAc	% Free Fe_2O_3
				Ca	Mg	K			
A_{1-3}	1.34	0.146	9.79	0.38	0.26	0.15	0.79	5.91	3.16
B_{21ox}	0.76	0.087	8.74	0.08	0.25	0.17	0.50	3.84	3.90
B_{22t}	0.59	0.078	7.56	0.06	0.21	0.14	0.14	3.02	4.20
B_{22t}	0.35	0.046	7.61	0.06	0.08	0.07	0.21	3.03	4.18
B_3	0.30	0.041	7.32	0.13	0.12	0.09	0.34	2.01	3.92
C_2	0.12	0.080	1.50	0.01	0.02	0.01	0.04	1.88	3.04
C_3	0.08	-	-	0.02	0.05	0.01	0.08	3.09	3.13
C_4	0.05	-	-	0.02	0.07	0.01	0.10	4.03	1.92
C_5	-	-	-	0.02	0.08	0.01	0.11	6.16	2.78
C_6	-	-	-	0.02	0.09	0.02	0.13	6.39	2.93
C_7	0.03	-	-	0.03	0.07	0.04	0.14	6.66	2.39
C_8	0.01	-	-	0.02	0.07	0.05	0.14	7.70	1.81
$(R)_1$	-	-	-	0.03	0.07	0.03	0.13	7.09	2.44
$(R)_2$	-	-	-	0.02	0.08	0.09	0.19	6.61	2.25

PEDON M6 : Semi-quantitative estimate of minerals in clay and soil samples of the deep weathering profile

I. CLAY	Percentage Minerals			
Horizon	Kaolinite and Halloysite	Gibbsite	Goethite Amorphous Iron Oxyhydrates	Others e.g. quartz
B_{21ox}	64.0*	18.4	7.7	9.9
B_{23t}	63.3*	21.9	8.0	6.8
B_3	58.6*	23.4	8.2	9.8
C_2	69.4**	11.2	10.2	9.2
C_4	69.0**	12.6	7.7	10.7
C_5	84.6***	4.2	3.0	8.2
C_7	80.8***	5.2	3.8	10.2
$(R)_1$	82.6***	6.7	4.3	6.4
$(R)_2$	80.5***	6.6	4.4	8.5
II. SOIL (Fine earth)				
A_{1-3}	27.0*	20.3	3.5	49.2
B_{21ox}	33.4*	18.5	4.3	43.8
B_{22t}	32.8*	16.5	4.7	46.0
B_{23t}	27.6*	11.5	4.6	56.3
B_3	27.2*	11.2	4.3	57.3
C_2	30.4**	8.7	3.4	57.5
C_3	38.6**	12.7	3.5	45.2
C_4	39.3**	13.1	2.1	45.5
C_5	50.5***	1.7	3.1	44.7
C_6	43.2***	0.7	3.3	52.8
C_7	62.0***	1.0	2.7	34.3
C_8	58.5***	1.6	2.0	37.9
$(R)_1$	64.5***	1.4	2.7	31.4
$(R)_2$	40.7***	1.7	0.9	56.7

Content of halloysite

* Traces ** Significant *** Predominant

PEDON M6 : Distribution of light and heavy minerals in the sand fraction (50 - 500 u) of the weathering profile.

Horizon	Light Minerals %*	Heavy Minerals %				
	% of Total	% of Total	Opaque	Zircon	Tourmaline	Alterite
B_{21ox}	98.24	1.76	50	78	-	22
B_{23ox}	98.24	1.76	74	88	-	12
B_3	97.21	2.79	74	88	2	10
C_2	98.90	1.10	68	95	2	3
C_4	98.63	1.37	60	88	4	8
C_5	98.44	1.56	43	62	1	37
C_7	98.76	1.24	28	66	-	34
$(R)_1$	98.88	1.12	14	51	-	49
$(R)_2$	99.27	0.73	30	67	1	32
R_3	99.51	0.49	50	88	-	12

* Predominantly of quartz with some gibbsitic and kaolinitic nodules.

PEDON M7 : JERANGAU SERIES

Classification:	(a) Soil Taxonomy:	clayey, oxidic, isohyperthermic Haplic Acrorthox.
	(b) FAO/UNESCO:	Acric Ferralsol.

Location:	20½ mile Air Hitam – Johor Baru Road
Parent:	Granodiorite
Topography:	Undulating to rolling
Elevation:	35 m
Slope:	10°
Vegetation/Land Use:	Shrub and other secondary vegetation
Drainage:	Well drained

Horizon	Depth	
Ap	0 - 25 cm:	Clay loam; dark brown (7.5YR 4/4) moderate, fine, subangular blocky and coarse crumbs; many fine roots; many biopores; rather sharp boundary.
B_1	25 - 57 cm:	Clay yellowish red (5YR 5/8); weak, medium subangular blocky; no clayskins; very friable; many fine roots; few biopores; diffuse boundary.
B_{21ox}	89 - 130 cm:	Clay; yellowish red (5YR 5/8); weak, medium to fine subangular blocky; no clayskins; few roots; diffuse boundary.
B_{22ox}	89 - 130 cm:	Clay; yellowish red (5YR 5/8); weak, fine subangular blocky; very friable few, patchy clayskins in pores; no roots; diffuse boundary.

PEDON M7 : JERANGAU SERIES

Depth (cm)	Horizon	GRANULOMETRY				Percentage		C/N	% Free Iron
		Clay	Silt	Fine Sand	Coarse Sand	O.C.	N		
0-25	Ap	51	2	20	27	1.80	0.17	10	11.4
25-57	B_1	51	1	18	30	0.90	0.15	6	12.1
57-89	$B_{21}ox$	51	3	16	30	0.48	0.09	5	12.2
89-130	$B_{22}ox$	50	2	14	34	0.24	0.07	3	11.8
130+	$B_{22}ox$	50	2	16	32	0.12	0.07	2	12.4

Horizon	pH		ΔpH	IN–KCl Al	Exch. Cat. meq/100 gms SOIL				Extr. Acidity
	H_2O	KCl			Ca	Mg	Na	K	
Ap	4.5	3.9	– 0.6	1.10	1.32	0.91	0.08	0.15	12.2
B_1	4.5	4.1	– 0.4	0.74	0.10	0.11	0.14	0.14	9.8
$B_{21}ox$	4.7	4.3	– 0.4	0.32	0.06	0.05	0.01	0.06	8.6
$B_{22}ox$	4.5	4.3	– 0.2	0.30	0.04	0.04	0.01	0.07	7.6
$B_{23}ox$	4.6	4.6	0	0.14	0.05	0.03	0.01	0.08	8.0

Horizon	CEC meq/100 gms SOIL			CHARGE meq/100 gms CLAY					Base Sat. %		Al Sat. %
	NH_4Cl	NH_4OAc	Sum	PC	NH_4Cl	NH_4OAc	Sum	PDC	NH_4OAc	Sum	
Ap	1.89	13.8	14.66	7.0	3.7	27.1	28.7	21.8	17.8	16.8	30.9
B_1	1.51	8.5	10.16	2.2	3.0	16.7	19.9	17.8	4.2	3.5	67.3
$B_{21}ox$	1.21	8.5	8.78	1.0	2.4	16.7	17.2	16.2	2.1	2.0	64.0
$B_{22}ox$	1.32	7.2	7.76	0.9	2.6	14.4	15.5	14.6	2.2	2.1	45.2
$B_{23}ox$	1.32	7.6	8.17	0.6	2.6	15.2	16.3	15.7	2.2	2.1	45.2

Pedon M7 – Analysis and Mineralogy of the Clay Fraction

Horizon	Free Iron %	Total SiO_2	Al_2O_3	SiO_2 / Al_2O_3	Kaolinite %	Gibbsite %	Goethite %
Ap	16.7	17.67	39.67	0.77	43	33	19
B_1	18.1	19.64	38.98	0.85	48	32	20
B_{21ox}	17.3	17.04	36.67	0.73	-	-	-
B_{22ox}	16.5	19.64	38.56	0.86	46	33	20
B_{23ox}	17.4	18.91	40.01	0.80	44	32	20

PEDON M8 : SENAI SERIES

Classification:	(a) Soil Taxonomy:	clayey, oxidic, isohyperthermic Haplic Acrorthox
	(b) FAO/UNESCO:	Acric Ferralsol.

Location:	Senai Rubber Estate, Senai, Johore
Parent Material:	Gabbro
Topography:	Hilly
Elevation:	45 m
Slope:	12°
Vegetation/Land Use:	Mature Rubber (Hevea)
Drainage:	Well drained

Horizon	Depth	
Ap1	0 - 10 cm:	Clay; dark brown (7.5YR 4/4); moderate medium subangular blocky; firm; few roots; many biopores; clear boundary.
Ap2	10 - 25 cm:	Clay; dark brown (7.5YR 4/4); moderate, medium to fine subangular blocky; firm; many biopores; rather sharp boundary.
B1ox	25 - 52 cm:	Clay; strong brown (7.5YR 5/6); moderate, coarse prismatic, breaking into moderate, medium subangular blocky; friable; few roots; few biopores; diffuse boundary.
B21ox	52 - 110 cm:	Clay; yellowish red (5YR 5/6); moderate, coarse prismatic breaking easily into moderate, medium subangular blocky; friable; few roots; few biopores; diffuse boundary.
B22ox	110 - 140 cm:	Clay; yellowish red (5YR 5/6); moderate, coarse to fine subangular blocky; very friable; very few roots; diffuse boundary.
B3	140 cm+	Clay; strong brown (7.5YR 5/6); weak, fine subangular blocky.

PEDON M8 : SENAI SERIES

Depth (cm)	Horizon	GRANULOMETRY				Percentage		C/N	% Free Iron
		Clay	Silt	Fine Sand	Coarse Sand	O.C.	N		
0- 10	Ap_1	25.9	20.0	30.0	24.0	1.59	0.16	10	13.40
10- 25	Ap_2	40.2	25.2	19.4	15.2	1.28	0.12	11	12.66
25- 52	B_{1ox}	56.4	18.9	14.7	10.0	0.94	0.09	10	11.97
52-110	B_{21ox}	64.2	18.4	9.7	7.7	0.55	0.06	9	12.59
110-140	B_{22ox}	66.6	18.1	8.2	7.0	0.45	0.05	9	11.88
140+	B_3	51.9	17.2	18.5	12.4	0.44	0.05	9	14.47

Horizon	Bulk Density	Moisture (Volume %) at pF					A. Moist. mm/m		Porosity %
		0	1	2	2.54	4.19	1/3-15	1/10-15	
Ap_2	1.17	53.7	49.3	39.0	37.6	32.1	55	69	54
B_{1ox}	1.17	59.3	47.1	41.2	38.5	34.3	42	69	59
B_{21ox}	1.12	60.2	46.3	37.9	37.9	31.7	62	62	60
B_{22ox}	1.12	51.7	45.6	38.0	36.2	30.7	55	73	52

Horizon	pH		ΔpH	IN–KCl Al	Exch. Cat. meq/100 gms SOIL				Extr. Acidity
	H_2O	KCl			Ca	Mg	Na	K	
Ap_1	4.1	3.9	– 0.2	2.20	0.06	0.07	0.05	0.06	10.3
Ap_2	4.4	4.0	– 0.4	0.62	0.02	0.04	0.05	0.04	8.2
B_{1ox}	4.6	4.1	– 0.5	0.41	0.02	0.03	0.03	0.07	7.5
B_{21ox}	4.6	4.3	– 0.3	0.32	0.02	0.03	0.05	0.03	8.4
B_{22ox}	4.7	4.4	– 0.3	0.33	0.01	0.02	0.03	0.01	8.7
B_3	4.9	4.7	– 0.2	0.27	0.01	0.02	0.03	0.03	8.1

Horizon	CEC meq/100 gms SOIL			CHARGE meq/100 gms CLAY					Base Sat. %		Al_1 Sat. %
	NH_4Cl	NH_4OAc	Sum	PC	NH_4Cl	NH_4OAc	Sum	PDC	NH_4OAc	Sum	
Ap_1	1.24	5.78	10.54	9.4	4.8	22.3	40.7	31.3	4.1	2.3	90.2
Ap_2	1.06	5.02	8.35	1.9	2.6	12.5	20.8	18.8	3.0	1.8	80.5
B_{1ox}	1.44	3.38	7.65	1.0	2.5	6.0	13.6	12.6	4.4	2.0	73.2
B_{21ox}	0.60	3.31	8.53	0.7	0.9	5.1	13.3	12.6	3.9	1.5	71.1
B_{22ox}	0.70	2.17	8.77	0.6	1.0	3.2	13.2	12.6	3.2	0.8	82.5
B_3	0.60	2.01	8.19	0.7	1.1	3.9	15.8	15.1	4.5	1.1	75.0

Pedon M8 – Mineralogy

Clay	
Kaolinite	54%
Gibbsite	16%
Goethite	20%
(and others)	

Silt

Gibbsite

Goethtie

Kaolinite

Quartz

PEDON M9 : BATU ANAM SERIES

Classification: (a) Taxonomy: clayey, mixed, isohyperthermic Aquoxic Dystropept.

(b) FAO/UNESCO: Ferralic Cambisol.

Location:	Department of Agriculture Station, Ayer Hitam, Johore
Parent Materials:	Argillaceous shale
Topography:	Undulating
Elevation:	30 - 45 m
Slope:	6°
Vegetation/Land Use:	Secondary jungle
Drainage:	Moderately well drained to imperfectly well drained.

Horizon

Ap	0 - 15 cm:	Light grey to grey (10YR 6/1); clay, moderately strong medium and few coarse subangular and angular blocky and few medium crumbs; moist friable; many pores; many roots; clear boundary.
$(B)_1$	15 - 45 cm:	Pale yellow (2.5Y 7/4); clay; strong coarse prismatic and few subangular and angular blocky; moist very firm; common pores; few roots; common; fine, distinct, Brownish Yellow (10YR 6/8) blotches of mottlings; few termite channels; diffuse boundary.
$(B)_2$	45 - 63 cm:	Pale yellow (2.5Y 8/4); clay; moderate strong coarse and very coarse prismatic; moist very fine; few pores; roots nil; many fine, medium, prominent dark yellowish brown (10YR 4/4) and brownish yellow (10YR 6/8) blotches of mottlings; clear boundary.
B_{2cn}	63 - 75 cm:	Light grey (10YR 8/2); clay; a band of somewhat compact gravelly laterite (60-70%) and gravelly quartzite (5-10%); many fine and medium prominent, brownish yellow (10YR 6/3) blotches of mottlings clear boundary.
C	75 - 138 cm:	Light grey (10YR 8/1); clay weak; coarse and very coarse subangular and angular blocky and few coarse prismatic; moist very firm; few pores; roots nil; with abundant, medium and coarse prominent brownish yellow (10YR 6/8) blotches and streaks of mottlings.

PEDON M9 : BATU ANAM SERIES

Horizon	Depth (cm)	GRANULOMETRY				pH		O.C. %	N %
		Clay	Silt	Fine Sand	Coarse Sand	H_2O	KCl		
Ap	0- 15	50.6	38.8	4.9	1.1	4.70	3.86	1.38	.167
$(B)_1$	15- 45	58.7	35.9	5.8	0.9	4.70	3.68	0.46	.111
$(B)_2$	45- 63	62.5	32.0	6.3	1.5	4.92	3.80	0.38	.098
$+B_{2cn}$	63- 75	64.0	26.9	5.2	4.6	4.95	3.92	0.38	.114
C	75-138	68.4	31.0	4.2	0.3	4.90	3.92	0.25	.097
		+ contains 8.4% gravels, 7.4% stones							

Horizon	C.E.C. NH_4OAc me/100 g Soil	Exch. Cations (me/100 g Soil)					Base Saturation %	
		Ca	Mg	Na	K	Al	NH_4OAc	Perm. Charge
Ap	6.70	0.42	0.46	0.05	0.19	2.69	16.0	28.5
$(B)_1$	6.50	0.21	0.31	0.04	0.11	5.38	9.7	10.5
$(B)_2$	5.92	0.14	0.26	0.05	0.09	4.79	8.3	9.3
B_{2cn}	5.95	0.10	0.14	0.05	0.06	2.75	5.0	9.8
C	3.88	0.10	0.28	0.05	0.05	2.51	11.1	14.6

Horizon	Total Cations (me/100 g Soil)			p.p.m.		% Al_2O_3
	K	Ca	Mg	P	Mn	
Ap	3.52	0.78	1.70	100	41	15.31
$(B)_1$	4.00	0.60	1.74	64	31	15.31
$(B)_{2cn}$	3.77	1.39	1.87	72	99	22.51
C	3.58	1.03	1.60	61	40	24.59

Horizon	Exch./Total Cations			Charge Characteristics (me/100 g Clay)	
	K	Ca	Mg	NH_4OAc	Perm. Charge
Ap	0.054	0.54	0.27	7.4	13.2
$(B)_1$	0.028	0.35	0.18	10.2	11.7
$(B)_2$	0.024	0.25	0.16	8.4	9.5
B_{2cn}	0.016	0.07	0.07	4.8	9.3
C	0.014	0.10	0.18	4.3	5.7

Pedon M9 – Mineralogy

Clay	
Kaolinite	XX (halloysite also detected)
Illite	X
Mica	X
Lepidochrosite	X
Quartz	X
Goethite	trace
Mont.	trace

PEDON M10 : MALACCA SERIES

Classification:	(a) Soil Taxonomy:	Clayey-skeletal, oxidic, isohyperthermic Tropeptic Haplorthox.
	(b) FAO/UNESCO:	Acric Ferralsol.

Location:	7½ milestone Malacca – Muar Road
Parent Material:	Schist
Topography:	Level
Elevation:	12 m
Vegetation/Land Use:	Old rubber
Drainage:	Excessive

Horizon	Depth	
A_{1-3}	0 - 10 cm:	Gravelly clay; strong brown (7.5YR 5/6); few roots; no biological activity; sharp boundary.
B_{21ox}	10 - 110 cm:	Gravelly clay; strong brown (7.5YR 5/6); few roots; structure not discernable; diffuse boundary.
B_{22ox}	110 - 200 cm:	Gravelly clay; composed almost completely of loose pisolitic laterite gravels; no roots; diffuse boundary.
B_{23ox}	200 - 310 cm:	Gravelly clay; strong brown (7.5YR 5/6); no roots; compact gravel; abrupt boundary.
B_3	310 - 400 cm:	Gravelly clay; red (2.5YR 4/6); weak, structures, patchy clay skins on ped faces and pores; abrupt boundary.
C_1	400 - 550 cm:	Clay, red (2.5YR 4/6); massive; few weathering rock fragments; sharp boundary.
C_2	550 - 750 cm:	Clay loam; dark red (2.25YR 3/6); bands of weathered schist; massive; breaking according to cleavage planes.
C_3	750 - 850 cm:	Weathering rock. Pallid zone.
C_4	850 - 950 cm:	Weathering rock. Pallid zone.
C_5	950 - 1150 cm:	Weathering rock. Pallid zone.

PEDON M10 : MALACCA SERIES

Depth (cm)	Horizon	GRANULOMETRY				ORIGINAL		O.C. %	% Free Iron
		Clay	Silt	Fine Sand	Coarse Sand	Gravels	Stones		
0- 10	A_{1-3}	45.4	18.1	21.0	15.5	30.0	28.0	1.01	13.7
10- 110	B_{21ox}	49.8	25.6	9.8	14.8	12.6	74.8	0.53	18.4
110- 200	B_{22ox}	43.5	27.9	11.7	16.9	16.3	64.3	0.29	20.4
200- 310	B_{23ox}	30.9	29.8	12.9	39.3	39.3	9.5	0.13	12.3
310- 400	B_3	34.8	38.8	16.8	9.6	NIL	NIL	0.10	10.2
400- 500	C_1	26.7	39.7	24.8	8.8	NIL	NIL	0.07	45.7
550- 750	C_2	22.1	32.8	35.5	9.6	NIL	NIL	0.06	39.2
750- 850	C_3	13.3	57.0	27.6	2.1	NIL	NIL	0.05	12.7
850- 950	C_4	19.8	64.0	12.6	3.6	NIL	NIL	0.05	11.3
950-1150	C_5	12.3	60.2	18.0	9.5	NIL	NIL	0.05	1.6

Horizon	pH		pH	IN–KCl Al	Exch. Cat. meq/100 g Soil			
	H_2O	KCl			Ca	Mg	Na	K
A_{1-3}	4.6	4.1	– 0.5	1.71	0.04	0.08	0.08	0.06
B_{21ox}	4.6	4.5	– 0.1	1.82	0.09	0.12	0.05	0.04
B_{22ox}	4.8	4.6	– 0.2	1.51	0.07	0.09	0.04	0.03
B_{23ox}	5.1	5.0	– 0.1	0.21	0.08	0.04	0.05	0.08
B_3	5.1	4.5	– 0.6	0.25	0.08	0.02	0.03	0.02
C_1	5.7	4.9	– 0.8	0.01	0.04	0.01	0.03	0.03
C_2	5.0	4.4	– 0.6	0.31	0.06	0.03	0.06	0.04
C_3	4.3	4.0	– 0.3	1.51	0.08	0.06	0.09	0.03
C_4	4.7	4.2	– 0.5	1.57	0.13	0.06	0.09	0.03
C_5	4.6	4.0	– 0.6	1.82	0.02	0.04	0.02	0.80

Horizon	CEC meq/100gm SOIL	CHARGE meq/100g CLAY		Base Sat. %	Al^{3+} Sat. % on PC
	NH_4OAc	P.C.	NH_4OAc	NH_4OAc	
A_{1-3}	3.78	4.25	8.32	6	87
B_{21ox}	2.98	4.25	5.98	10	86
B_{22ox}	3.79	4.00	8.55	6	87
B_{23ox}	2.14	1.49	6.92	12	46
B_3	2.96	0.86	8.50	5	83
C_1	2.64	0.44	9.88	4	8
C_2	2.31	2.26	10.45	8	62
C_3	4.56	13.3	34.28	6	85
C_4	4.98	9.49	25.15	6	83
C_5	4.78	21.95	38.86	18	67

PEDON M11 : KUALA PILAH SERIES

Classification: (a) Taxonomy: clayey, oxidic, isohyperthermic Haplic Acrorthox.

(b) FAO/UNESCO: Acric Ferralsol.

Location:	5th milestone, Kuala Pilah – Tampin Road
Parent Material:	Serpentinite
Topography:	Gently undulating
Elevation:	80 m
Slope:	8°
Vegetation/Land Use:	Primary jungle
Drainage:	Excessively drained

Horizon	Depth	
A_{1-3}	0 - 10 cm:	Clay loam; brown (10YR 4/3); moderate medium subangular blocky and coarse granular; very friable; many fine roots, rather sharp boundary.
B_{21ox}	10 - 57 cm:	Clay; dark yellowish brown (10YR 4/4); very weak coarse prisms breaking down to fine granules; friable; many fine roots; very few pores; diffuse boundary.
B_{22ox}	57 - 171 cm:	Clay; dark yellowish brown (10YR 4/4); very weak, coarse prisms breaking down to fine subangular blocky with granules; coarse prisms appear to have coatings on ped faces; very friable; few termite activity; many fine and medium roots; boundary diffuse.
B_{23ox}	171 - 213 cm:	Clay; dark yellowish brown (10YR 4/4); weak prisms breaking down to weak, medium and fine subangular blocky; very friable; many patchy coatings on ped faces; boundary abrupt.
B_{24}	213 - 283 cm:	Clay; reddish brown (5YR 4/3); coarse prismatic compact – present as a distinct horizon; few roots plenty of continuous clayskins on ped faces; boundary very abrupt.
B_{25}	283 - 333 cm:	Clay; reddish brown (5YR 4/4); weak coarse prismatic breaking down to fine subangular blocky; continuous clayskins on ped faces; few roots; boundary diffuse.
B_{26}	333 – 483 cm:	Clay; brown (7.5YR 4/4). Other features same previous horizon.

Note: The compact pan at 213 cm to 283 cm is probably due to bulldozers going over the soil to make terraces at the roadcutting.

PEDON M11 : KUALA PILAH SERIES

Depth (cm)	Horizon	GRANULOMETRY				Percentage		C/N	% Free Iron
		Clay	Silt	Fine Sand	Coarse Sand	O.C.	N		
0- 10	A_{1-3}	26.8	29.9	34.7	8.6	0.05	0.18	11	25.19
10- 57	B_{21ox}	28.2	19.4	44.7	7.7	0.79	0.09	9	27.33
57-171	B_{22ox}	41.5	21.8	31.2	5.5	0.41	0.05	8	27.87
171-213	B_{23ox}	43.1	22.1	29.1	5.4	0.38	0.05	8	28.58
213-283	B_{24}	34.4	23.8	35.0	6.9	0.67	0.11	10	27.33
283-333	B_{25}	43.1	23.6	28.5	4.8	0.50	0.03	17	27.87
333-483	B_{26}	38.2	21.0	35.2	5.6	0.22	0.03	7	29.29

Horizon	Bulk Density	Moisture (Volume %) at pF					A. Moist. mm/m		Porosity %
		0	1	2	2.54	4.19	1/3-15	1/10-15	
B_{21ox}	1.18	55.6	52.8	40.7	36.4	28.0	84	127	56
B_{22ox}	1.27	59.1	48.8	40.0	39.3	30.3	90	97	59
B_{23ox}	1.31	65.0	54.2	45.8	39.1	30.1	90	157	65
B_{24}	1.47	56.9	48.3	44.6	41.5	35.8	57	88	57
B_{26}	1.31	48.4	44.1	44.0	39.7	32.5	72	115	48

Horizon	pH		Δ pH	iN–KCl Al	Exch. Cat. meq/100 gms SOIL				Extr. Acidity
	H_2O	KCl			Ca	Mg	Na	K	
A_{1-3}	4.4	4.0	– 0.4	0.98	0.08	0.56	0.05	0.19	11.2
B_{21ox}	4.8	4.7	– 0.1	0.82	0.14	0.17	0.05	0.05	10.7
B_{22ox}	5.4	5.0	– 0.4	0.71	0.05	0.27	0.03	0.03	8.1
B_{23ox}	5.5	5.0	– 0.5	0.55	0.03	0.13	0.03	0.03	8.3
B_{24}	4.7	4.5	– 0.2	0.41	0.07	0.28	0.03	0.08	8.6
B_{25}	5.6	4.9	– 0.7	0.32	0.02	0.06	0.03	0.02	7.5
B_{26}	5.6	5.1	– 0.5	0.31	0.02	0.18	0.03	0.02	7.7

PEDON M11 : *(cont'd)*

Horizon	CEC meq/100 gms SOIL			CHARGE meq/100 gms CLAY					Base Sat. %		Al_1 Sat. %
	NH_4Cl	NH_4OAc	Sum	PC	NH_4Cl	NH_4OAc	Sum	PDC	NH_4OAc	Sum	
A_{1-3}	2.34	6.00	12.08	5.8	8.7	22.4	25.1	38.1	14.7	7.3	52.7
B_{21ox}	0.92	1.88	11.11	4.4	3.3	6.7	39.4	35.0	21.8	3.7	66.7
B_{22ox}	0.78	1.52	8.48	2.6	1.9	3.7	20.4	17.8	25.0	4.5	65.1
B_{23ox}	1.16	1.48	8.52	1.8	2.7	3.4	19.8	18.0	14.9	2.6	71.4
B_{24}	1.68	2.64	9.06	2.5	4.9	7.7	26.3	23.8	17.4	5.1	47.1
B_{25}	1.38	1.48	7.63	1.0	3.2	3.4	17.7	16.6	8.8	1.7	71.1
B_{26}	1.02	1.20	7.95	1.5	2.7	3.1	20.8	19.3	20.8	3.1	55.4

TOTAL ANALYSIS (SOIL)

Horizon	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	H_2O-	H_2O+	SiO_2 / Al_2O_3	SiO_2 / R_2O_3
A_{1-3}	33.6	20.9	26.6	0.1	0.1	0.1	Tr	2.2	16.4	2.8	1.5
B_{21ox}	32.7	21.7	28.9	0.1	0.1	0.1	0.1	2.1	14.2	2.6	1.4
B_{22ox}	33.7	21.1	29.1	Tr	0.1	Tr	Tr	2.1	14.3	2.7	1.4
B_{23ox}	32.7	20.5	29.6	Tr	0.1	Tr	Tr	2.1	15.1	2.7	1.4
B_{24}	31.6	20.5	30.0	0.1	0.1	0.1	0.1	2.2	15.4	2.6	1.3
B_{25}	31.4	22.0	28.9	0.1	0.1	0.1	0.1	2.3	15.2	2.5	1.3
B_{26}	29.0	22.0	31.0	0.1	0.1	0.1	Tr	2.2	15.3	2.3	1.2

TOTAL MICRONUTRIENTS (PPM)

Horizon	Mn	Cu	Zn	Co	Ni
A_{1-3}	1,000	196	175	160	128
B_{21ox}	970	214	160	175	142
B_{22ox}	1,070	218	175	150	98
B_{23ox}	970	236	183	180	123
B_{24}	900	225	290	130	128
B_{25}	885	214	175	175	124
B_{26}	1,270	254	175	250	137

PEDON M11 : *(cont'd)*

TOTAL ANALYSIS (CLAY)											
Horizon	SiO_2	Al_2O_3	Fe_2O_3	Cao	MgO	K_2O	Na_2O	H_2O-	H_2O+	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
$B_{21}ox$	15.1	29.7	33.3	0.1	Tr.	0.1	0.1	2.3	17.5	0.9	0.5
$B_{22}ox$	16.2	31.2	34.7	0.1	Tr.	Tr.	0.1	1.7	16.9	0.9	0.5

Pedon M11 – Mineralogy

Clay

Kaolinite	35-40%
Gibbsite	22-27%
Goethite	33-35%

3. SOURCES OF INFORMATION

All the information on the soil profiles presented in this Tour Guide has been obtained from unpublished data. In the table below each pedon is listed giving the source of the information.

1	Lanchang	"A study of some highly weathered soils of Pahang State", LIM Jit Sai, 1977, M.Sc. Thesis, Univ. of Gent.
2	Segamat	"Soil Genesis on Igneous and Metamorphic Rocks in Malaysia", S. Paramananthan, 1977, D.Sc. Thesis, Univ. of Gent.
3	Kening	"A study of some highly weathered soils of Pahang State", LIM Jit Sai, 1977, M.Sc. Thesis, Univ. of Gent.
4	Bungor	Unpublished data – Department of Agriculture.
5	Kuantan	"Soil Genesis on Igneous and Metamorphic Rocks in Malaysia", S. Paramananthan, 1977, D.Sc. Thesis Univ. of Gent.
6	Beserah	"A study of a deep weathering profile and toposequence on granite in Peninsular Malaysia", WONG Chaw Bin, 1976, M.Sc. Thesis Univ. of Gent.
7	Jerangau	"Soil Genesis on Igneous and Metamorphic Rocks in Malaysia", S. Paramananthan, 1977, D.Sc. Thesis Univ. of Gent.
8	Senai	"Soil Genesis on Igneous and Metamorphic Rocks in Malaysia", S. Paramananthan, 1977, D.Sc. Thesis Univ. of Gent.
9	Batu Anam	"Genesis of some shale derived soils of Peninsular Malaysia", Noordin Daud, 1974, M.Sc. Thesis Univ. of Gent.
10	Malacca	Unpublished data – V. Sooryanarayana, Department of Geography, University of Malaya.
11	Kuala Pilah	"Soil Genesis on Igneous and Metamorphic Rocks in Malaysia", S. Paramananthan, 1977, D.Sc. Thesis Univ. of Gent.

4. METHODS OF ANALYSES

1.	Mechanical Analysis	–	Pipette Method.
2.	Organic Carbon	–	Wakley and Black.
3.	Nitrogen	–	Micro-Kjeldahl Method.
4.	Free Iron	–	Citrate-Dithionite.
5.	pH(H_2O and 0-IN KC1)	–	Glass electrode (1:1).
6.	Aluminium	–	IN-KC1 Extraction.
7.	Cation Exchange Capacity	–	Ammonium Acetate at pH7 and Unbuffered. Ammonium chloride.
8.	Extractable Acidity	–	Barium Chloride at pH 8.2.
9.	Trace Elements	–	Teflon Bomb Fusion (Bernas 1968).
10.	Total Analysis	–	After Teflon Bomb Fusion (Bernas 1968).

5. ACKNOWLEDGEMENT

The organising committee wishes to extend its sincere gratitutde to a number of persons who have in one way or another given their collaboration to the preparation of the Workshop and this Tour Guide.

Special thanks go the Director-General of Agriculture, Peninsular Malaysia, for granting permission to the National Soil Survey Section to organise and host the Workshop in Kuala Lumpur. The Director of the Soil and Analytical Services is also gratefully acknowledged for his support for the Workshop.

Appreciation is also extended to soil survey officers in Pahang and Johore for the preparation of the soil profiles in their respective states.

Due acknowledgement and thanks are extended to the various agencies and persons for allowing the use of their soil information.

Last but not least, we wish to thank the University of Puerto Rico (UPR) and the U.S. Agency for International Development (AID) for granting Malaysia the opportunity to host the Workshop.

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APPENDIX A

WORKSHOP PROGRAM IN MALAYSIA

MONDAY, 28 AUGUST 1978 - MERLIN HOTEL, KUALA LUMPUR

OPENING CEREMONY
Chairman: S. Paramananthan

0900 Inaugural Address - Director-General of Agriculture
Keynote Address - F. H. Beinroth

1000 Coffee recess

WORK SESSION I:
Soil Taxonomy and Soils of the Tropics
Chairman: R. W. Arnold

1030 Paper 1. Adequacy of soil surveys and soil classification for practical applications in developing countries
R. Dudal

1100 Paper 2. Proposal for modifications of the definitions of soil climatic regimes.
R. Tavernier and A. Van Wambeke

1200 Lunch

WORK SESSION II:
Concepts of Oxisols
Chairman: R. Tavernier

1400 Paper 3. Changing concepts of Oxisols.
A. Van Wambeke

1430 Paper 4. Geomorphology of some Oxisols.
W. W. Buol

1500 Paper 5. Mineralo-chemical properties of Oxisols.
G. Uehara

1530 Paper 6. Micromorphology of Oxisols.
H. Eswaran

1600 Tea recess

WORK SESSION III:
Classification of Oxisols
Chairman: J. Comerma

1615 Paper 7. The classification of highly weathered soils in the French classification.
P. Segalen

1645 Paper 8. Report on ICOMOX
H. Eswaran

1715 Briefing on field trips in Malaysia
S. Paramananthan

1730 Adjourn

TUESDAY, 29 AUGUST 1978

FIELD TRIP, Kuala Lumpur to Kuantan
Pedon M1: Lanchang series, Typic Paleudult
Lunch at Temmerloh
Pedon M2: Segamat series, Tropeptic Haplorthox
Pedon M3: Kening series, Typic Paleudult
Pedon M4: Bungor series, Typic Paleudult
Overnight in Kuantan, Hotel Merlin Kuantan

WEDNESDAY, 30 AUGUST 1978

FIELD TRIP, Kuantan to Johore Bahru
Pedon M5: Kuantan series, Haplic Acrorthox
Pedon M6: Beserah series, Typic Paleudult
Lunch at Kuantan
Travel to Johore Bahru
Overnight in Johore Bahru, Orchid Hotel

THURSDAY, 31 AUGUST 1978

FIELD TRIP, Johore Bahru to Kuala Lumpur
Pedon M7: Jerangau series, Haplic Acrorthox
Pedon M8: Senai series, Haplic Acrorthox
Pedon M9: Batu Anam series, Aquoxic Dystropept
Lunch at Kluang
Pedon M10: Malacca series, Tropeptic Haplorthox
Pedon M11: Kuala Pillah series, Haplic Acrorthox
Overnight in Kuala Lumpur, Merlin Hotel

FRIDAY, 1 SEPTEMBER 1978 - MERLIN HOTEL, KUALA LUMPUR

WORK SESSION IV:
Oxisols in Asia and Oceania
Chairman: J. Bennema

0830 Paper 9. Oxisols of Malaysia.
S. Paramananthan and C. P. Lim

0855 Paper 10. Oxisols of Thailand.
S. Rojanasoonthon and S. Panichapong

0920 Paper 11. LAC Alfisols, Ultisols and Oxisols in tropical Australia and New Guinea.
R. F. Isbell

0945 Paper 12. Oxisols of the South Pacific.
M. L. Leamy, L. S. Blakemore and D. M. Leslie

1010 Paper 13. The Oxisols of Hawaii
H. Ikawa

1035 Coffee recess

WORK SESSION V:
Oxisols in Africa and the Americas
Chairman: S. W. Buol

1100 Paper 14. African Oxisols
C. Sys and R. Tavernier

1130 Paper 15. Some remarks on Brazilian Latosols in relation to the Oxisols of Soil Taxonomy.
J. Bennema and M. Camargo

1200 Paper 16. The Oxisols of Puerto Rico.
F. H. Beinroth

1220 Lunch

WORK SESSION VI:
ICOMOX
Chairman: H. Eswaran

1430 General discussion

1600 Tea recess

CLOSING SESSION
Chairman: R. Dudal

1630 Review of the week's field trips and discussion - H. Eswaran
Vote of thanks - R. Dudal
Closing remarks - S. Paramananthan

1730 Adjourn

SATURDAY, 2 SEPTEMBER 1978

Kuala Lumpur to Bangkok
A.M.: Depart for Bangkok
P.M.: Check-in, Asia Hotel, Bangkok
Free afternoon

APPENDIX B

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APPENDIX C

TAXONOMIC EQUIVALENT OF THE PEDONS IN DIFFERENT SYSTEMS

PEDON	SOIL SERIES	SOIL TAXONOMY	FAO/UNESCO LEGEND	FRENCH SOIL CLASSIFICATION
M 1	LANCHANG	Typic Paleudult; clayey, kaolinitic, isohyperthermic	Dystric Nitosol	Sols ferralitiques fortement desaturesen (B) typiques jaune (X/312)
M 2	SEGAMAT	Tropeptic Haplorthox; clayey, oxidic, isohyperthermic	Rhodic Ferralsol	Sols ferralitiques moyennement desaturesen (B) typiques modal (X/211)
M 3	KENING	Typic Paleudult; clayey, kaolinitic, isohyperthermic	Dystric Nitosol	Sols ferralitiques fortement desaturesen (B) lessives, modal (X/361)
M 4	BUNGOR	Typic Paleudult; clayey, kaolinitic, isohyperthermic	Dystric Nitosol	Sols ferralitiques fortement desaturesen (B) typiques jaune (X/312)
M 5	KUANTAN	Haplic Acrorthox; clayey, kaolinitic, isohyperthermic	Acric Ferralsol	Sols ferralitiques fortement desaturesen (B) typiques, modal (X/311)
M 6	BESERAH	Typic Paleudult; clayey, kaolinitic, isohyperthermic	Dystric Nitosol	Sols ferralitiques fortement desaturesen (B) typiques, jaune (X/311)
M 7	JERANGAU	Haplic Acrorthox; clayey, oxidic isohyperthermic	Orthic Ferralsol	Sols ferralitiques fortement desaturesen (B) typiques, jaune (X/312)
M 8	SENAI	Haplic Acrorthox; clayey, oxidic isohyperthermic	Acric Ferralsol	Sols ferralitiques fortement desaturesen (B) typiques, faiblement appauvri (X/316)
M 9	BATU ANAM	Aquoxic Dystropept; fine, mixed, isohyperthermic	Gleyic Cambisol	Sols hydromorphes peu humiferes a gley, profond (XI/312)
M 10	MALACCA	Typic Haplorthox; clayey-skeletal, oxidic, isohyperthermic	Orthic Ferralsol	Sols ferralitiques fortement desaturesen (B) remanies, modal (X/341)
M 11	KUALA PILAH	Typic Haplorthox; clayey, oxidic, isohyperthermic	Rhodic Ferralsol	Sols ferralitiques moyennement desaturesen (B) typiques, faiblement appauvri (X/316)

c.3

PROCEEDINGS OF

SECOND INTERNATIONAL SOIL CLASSIFICATION WORKSHOP

PART II : THAILAND
3 to 9 September 1978

SOIL SURVEY DIVISION
LAND DEVELOPMENT DEPARTMENT
BANGKOK, THAILAND

1979

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SECOND INTERNATIONAL SOIL CLASSIFICATION WORKSHOP

PART II: THAILAND

Proceedings of a Workshop held in Thailand
from 3 to 9 September 1978

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Study and Research in Agriculture
University of Ghent

Editors: F. H. Beinroth and S. Panichapong

Managing Editors: Sheila and Tom Ferrari

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FOREWORD

Since 1976 the University of Puerto Rico has been concerned with the improvement of the taxa established in the U.S. system of soil classification, Soil Taxonomy, for soils of the lower latitudes. The strategy in these activities, which were supported through grants from the Agency for International Development, has been to collaborate with international committees created to re-examine relevant aspects of Soil Taxonomy and to hold workshops with field tours in countries where the soils under scrutiny can be studied in situ. National institutions have been centrally involved in these endeavors. The first such workshop was held in Brazil in 1977 in cooperation with the Servico de Levantamento e Conservacao de Solos and future workshops are contemplated for the Near East and Africa.

The Second International Soil Classification Workshop held in Malaysia and Thailand in 1978 thus formed part of a comprehensive international effort to adapt Soil Taxonomy to the edaphic conditions of the tropics and subtropics. It addressed mainly the respective mandates of the International Committee on the Classification of Alfisols and Ultisols with Low Activity Clays (ICOMLAC) and the International Committee on the Classification of Oxisols (ICOMOX).

The workshop was initiated by the University of Puerto Rico, and organized and conducted by the National Soil Survey of the Department of Agriculture in Malaysia and by the Land Development Department in Thailand. Financial support of the workshop by the U.S. Agency for International Development under grant AID/DSAN-G-0003 to the University of Puerto Rico and by the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA) is gratefully acknowledged.

The duties of host in Thailand were assumed by the Land Development Department which, in cooperation with the University of Puerto Rico and the University of Ghent, developed the program, organized the workshop,

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prepared a tour guide and conducted the field trips. The University of Puerto Rico arranged the travel for invited participants. The preparation of Part II of the Proceedings was the joint responsibility of the University of Puerto Rico and the Land Development Department which also printed and published both volumes of the Proceedings.

In addition to the authors of papers and reports many persons have contributed to the workshop and to the contents of the Proceedings. Staff of the Soil Survey Division of the Land Development Department of Thailand provided site and profile descriptions and analytical data for all pedons studied in the field. The National Soil Survey Laboratory of the USDA Soil Conservation Service supplied companion data for most pedons. The University of Hawaii furnished mineralogical data, and Dr. H. Eswaran of the University of Ghent contributed the micromorphological information. The Organizing Committee flawlessly arranged the logistics of the conference session and field trips and provided a multitude of helpful services and courtesies. Sincere appreciation is expressed for all of these individual and institutional efforts.

The Editors further wish to thank the Managing Editors, Sheila and Tom Ferrari of Editorial Services, who performed the complex task of editing the technical papers with diligence and competance.

Part II of the Proceedings contains the papers presented at the conference sessions in Bangkok and Chantaburi, and descriptive and analytical data for the soils studied during the field trips in Thailand. Part I contains similar materials for the Malaysia portion of the workshop. The Proceedings constitute a reference publication on the taxonomy of tropical Alfisols, Ultisols and Oxisols in general, and key soils of Southeast Asia in particular. It is hoped that the Proceedings will also be of value to international soil correlation work.

S. PANICHAPONG

F. H. BEINROTH

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OPENING REMARKS

F. H. Beinroth

Colonel Surin Chonprasert, Dr. Bancherd Balankun, Mr. Anunt Komes, distinguished guests, ladies and gentlemen:

We are honored and privileged indeed that the Deputy Under-Secretary of the Ministry of Agriculture and Cooperatives, the Director-General of the Land Development Department and the Deputy Director-General of the Land Development Department have found it possible and pertinent to be present at the Opening Ceremony of the international soil classification workshop in Thailand. I trust that I may interpret the presence of these dignitaries here today, and on a Sunday at that, as an expression of the importance of our meeting and of our work as soil scientists. Needless to say that this is a source of real satisfaction for all of us.

I wish to take this opportunity to sincerely thank the Government of Thailand and the respective authorities for hosting and co-sponsoring this workshop. We are particularly grateful to Mr. Panichapong and his staff of the Land Development Department for organizing the event in Thailand. There is no way we can adequately express our gratitude and appreciation for the tremendous amount of time and effort they have put in the planning and conducting of this workshop. I am sure that we have caused Mr. Panichapong and his colleagues not only much hard work but probably also some nights of troubled sleep. In exchange, we have brought some of the great leaders in soil classification to your country and I am confident that, as the rest of us, our Thai colleagues will greatly benefit from the personal dialogue and interaction with these distinguished scientists.

The workshop here in Thailand is really the continuation of an event that began in Malaysia last week. So I will refrain from delivering the keynote address I presented in Malaysia once again. Let it suffice to say that we are looking forward to fruitful discussions during the conference sessions and to exciting days in the field.

While in Malaysia our discussions and field studies focused mainly on Oxisols, we will be primarily concerned with low activity clay Alfisols and Ultisols in Thailand. This is the central mandate of ICOMLAC. It is a fortunate coincidence that the chairman of this International committee, Professor Frank Moormann, has spent the earlier days of his career in Thailand.

In addition to the charges of ICOMLAC and ICOMOX, we may want to give some thought to other related subject matter areas. Several topics for future activities transpired in informal discussions during the past week. For example, there appears to be a need for the international correlation and standardization of soil analytical procedures. These and other topics will be taken up during the Summary Session of the workshop. It would, therefore, appear propitious if you can think about such matters during the days ahead so that our discussions on Saturday will be expedient.

To those of you who are joining us here, a most cordial welcome. Allow me to particularly welcome Dr. Guy Smith and his wife. As you all know, Dr. Smith is the spiritual father and principal author of Soil Taxonomy. Unfortunately he is also retired. Even more are we pleased that Dr. Smith "retired from retirement" to be here with us today and through the remainder of the workshop.

For the field tour, Mr. Panichapong guarantees us some heavy rains. I trust this will not dampen your spirits. Ironically, we will be traveling mainly in areas with an ustic moisture regime. So, if nothing else, the excessive precipitation will lend substance to Professor Tavernier's contention that the ustic regime is not always as dry as one might think.

Our travels through Thailand may also reveal that the soils as they occur in nature do not always perfectly fit our systems of classification.

In this context, let me quote Bertrand Russell who said that "nature herself cannot err because she makes no statements. It is men who may fall into error when they formulate propositions". Happily, the expertise and wisdom represented at this workshop will assure that these errors are kept to a minimum.

Again, our thanks to the Government of Thailand and to our Thai colleagues for making this part of the workshop possible.

PROBLEMS OF APPLICATION OF SOIL TAXONOMY WITH SPECIAL REFERENCE TO TROPICAL SOILS WITH LOW ACTIVITY CLAYS

G.D. Smith

I am extremely gratified that a meeting such as this can take place. I tried to avoid attending because some day a new generation of pedologists must take the responsibility for keeping the taxonomy current, and I believed they might as well start here. It is hardly unreasonable for me to have some curiosity about what you do here, so I was finally persuaded to attend the second week of the meetings.

There are individuals here who work with many facets of soil science. This is good. Some of you work primarily in the laboratory and see problems in a different light than those who work in the field. We must remember that the taxonomy we are talking about must be useful for the soil survey. In the laboratories, you develop new parameters, such as the surface area of the free oxides, and these may be extremely important to the use and management of the soils. But, unless the pedologist who is making a soil survey can recognize them in the field, perhaps by their color, texture or consistency, he cannot use them. Those who work in the laboratories must help those who work in the field to find ways to identify limits between kinds of soil that will behave differently.

In Soil Taxonomy, dark and dusky red colors were used to define rhodic great groups of Alfisols and Ultisols, but not of Oxisols. In the abstracts I have read for this meeting, some objected to this use of color for intertropical soils. Others have suggested that the distinction is important, but perhaps needs another definition. The ab-

stracts do not suggest what this definition should be, but those who classify soils in the field need all the help they can get from those who work in the laboratories. And, those who work in the laboratories need to be aware of problems that field workers have in applying the significant limits that would show up if every field sample could be examined in the laboratory the same day.

Soil biologists, chemists, physicists, and mineralogists must work with pedologists to define soil classes that are important and that can be recognized in the field by one means or another. The problem that should concern this group is not only what the classification parameters should be, but how they can be recognized in the field.

So, these joint meetings of field and laboratory workers are particularly important. We must help each other.

Soil Taxonomy makes an imperfect attempt to define its taxa in unambiguous terms by specifying methods and limits between taxa. There were three principal reasons why the attempt was imperfect. One was the limited number of soils with low activity clays that were available for study in the United States. A second was the limited knowledge about methods for their study, and the general lack of knowledge about their chemistry and reasons for their peculiar behavior. The third was the pressing need to develop a system for classifying soils in the United States, which left little time and few funds for the study of intertropical soils. The universities and international research stations were better situated for such studies than the U.S. Department of Agriculture, which is not authorized to make such studies outside the United States. But the work has been highly productive over the past 20 years, and we now have new knowledge that is crying to be incorporated into the taxonomy.

There is much more to soil taxonomy than determining properties of a soil and finding its classification by applying definitions. Soils that were not foreseen by those who developed a particular classification are sometimes classified by the definitions in absurd ways. Manifestly,

a great many soils could be misclassified, and many definitions need modification to classify the soils where they belong.

How does one decide where a soil belongs? We pointed out in the text of Soil Taxonomy that "The definitions must be continually tested by the nature and functioning of the soils grouped in a taxon...The grouping that helps us make the most precise and most important interpretations is the best. A taxonomy for the use of the soil survey must be tested by the nature of the interpretations that can be made" (p. 10, Soil Taxonomy). There were too few of the soils that concern us in this meeting to permit such testing.

Let me give an example or two. Udic and Ultic subgroups of Ustalfs were defined in part on the depth to secondary lime. Aridic subgroups were defined on the length of the period when the moisture control section was moist in temperate regions, but no comparable provision was made for intertropical soils. When the definitions were applied to Venezuelan soils, virtually no distinctions could be made between the Ustalfs that are marginal and the Aridisols on the one hand, and those that are marginal to the Udalfs on the other. Consequently, few interpretations were possible at the family level without using climatic phases, which have not yet been defined, are difficult to define, and cause unnecessarily complicated legends. Similar differences between the intertropical Ustults can appear only at the series level, a level far too low for soil maps at scales of 1:50,000 or 1:100,000, common reconnaissance scales. The inclusion in a single family of soils that are rarely or never dry in the entire moisture control section, with soils that are moist for barely 90 consecutive days, does not facilitate the purposes of the soil surveys.

The lack of soil series, time, and funds for studies of soils that concern this meeting required that Soil Taxonomy be published without providing subgroups for several great groups.

THE ARGILLIC HORIZON

One of the troublesome features of Soil Taxonomy's definition has been the argillic horizon, and I want to go into its background a bit. Many presently used taxonomies introduce its presence or absence in various places. The categoric level at which it is used, high or low, has no effect on the problems of its definition.

The concept of Ultisols started with the Ruston and Norfolk series, the type Red-Yellow Podzolic soils. There were many intergrades between the Red-Yellow Podzolic soils and the Gray-Brown Podzolic soils. The type series of the latter was the Miami series which later gave rise to the concept of Alfisols. In the first few approximations, these were all grouped in a single order, together with some of the present Inceptisols which had previously been considered Azonal soils. The latter, because they had no horizon of accumulation of sesquioxides, had been considered by some to have AC or A (B) C profiles rather than ABC profiles. Most classifications in use at that time separated such soils at a rather high categoric level, and their grouping in the early approximations displeased many pedologists. Likewise, an approximation that grouped all soils with ABC profiles in a single order displeased many. This cut directly across the present Mollisols. There seemed to be no general agreement on the concept of a B horizon. The present oxic horizon, for example, was variously considered a B horizon, a (B), and a C. The difficulty of getting agreement on a definition of a B horizon led to the concept of named diagnostic subsurface horizons. The distinction between the B horizons of Miami, a Hapludalf, and Nipe, an Acrorthox, was not difficult. Most Red-Yellow Podzolic soils of the United States had a B horizon that resembled that of the Miami, but the type Red-Yellow Podzolic soils, the present Paleudults, did not. The C horizon of these soils, which was then considered to be the horizon with reticulate mottles, had as much or more clay than the B. To find a decrease in the clay percentage of these soils, one had to look at depths of two or more meters. Then the drawn bow shape of the clay per-

centage became evident, but the bow was much longer, and the clayskins were less obvious and much deeper.

None of the diagnostic horizon definitions were easy to prepare, and none are entirely satisfactory. An effort was made to prepare definitions such that soils of the United States would be grouped in a manner to facilitate interpretations for phases of families in large-scale soil maps and phases of taxa in higher categories for small-scale soil maps. Among the Red-Yellow and Gray-Brown Podzolic soils later included with Ultisols and Alfisols, the use of the argillic horizon retained much of the previous concept of Zonal soils. There were difficulties in applying the definition for the argillic horizon in the United States, but they were not considered more serious than difficulties with other horizons.

When the definitions were applied to the soils of Puerto Rico and Hawaii, the pale- great groups were so poorly represented that it was virtually impossible to test the definitions. There were only seven series of Paleudults, three of Palehumults, and no Paleustults or Paleaquults. This contrasts with the 60 series of Tropepts, 31 series of Tropohumults, and 16 series of Tropudults. The soils of the islands are generally too steep, the surfaces too young, and the rocks too basic to be representative of the vast gently sloping ancient surfaces of Australia, South America, and Africa. It is not surprising, therefore, that troubles of application arose on those continents when definitions written for the United States were applied.

The presence of clayskins, emphasized in the argillic horizon definition, was first intended primarily as a diagnostic tool for translocated clay; but, the significance was reinforced by a number of studies on their composition relative to the ped matrices in several orders. Dr. Leamy has recently called the attention of the International Committee on the Classification of Alfisols and Ultisols with Low Activity Clays (ICOMLAC) to this point.

Some 45 years ago, as a very young man, I used concentric rings to study soil permeability (saturated hydraulic conductivity as it is

called now) and soil water movement. I measured infiltration into argillic horizons of Albaqualfs, Natraqualfs, Argiudolls, and Albolls, using a 15 cm head of water. After I had measured the rate of water intake, I added a negatively charged dye and allowed some 15 cm of the dyed water to enter the argillic horizons. Then I dissected the soil to see where the water moved. Without exception, the dye was evident only on the ped faces and in root and animal channels, even in the natric horizon which would accept only a few cm per week. The important thing was that the water moved between the peds of the argillic horizon or in channels formed by roots or animals. Consequently, in later years, I could understand why clayskins were plastered on ped faces, and why the nutrients that are cycled by plants would be most abundant in those clayskins.

The composition of clayskins relative to ped interiors should be most significant to root development in Ultisols. These are soils in which the principal mechanism by which bases are retained against leaching from the soil, is cycling by plants. In many Ultisols, the plant roots do not enter the peds of the argillic horizon. Some of the Haplustults, Tropohumults, Hapludults, and Tropudults have an argillic horizon in which there are nearly continuous clayskins. The importance of these clayskins should be considered carefully relative to the importance of low activity clays. We need to be sure that we are not "throwing the baby out with the bath water."

The studies of Khalifa and Buol (1968, Soil Sci. Soc. Amer. Proc., v. 32) of a Typic Hapludult that has kaolinitic clay, showed that the clayskins were significantly higher in N, P, and K, than the total B horizon and the clay had a higher activity. Calcium, which can also be inadequate for root growth in Ultisols, unfortunately was not studied. Nor did the description mention whether the roots entered the peds.

In the pale- great groups of Ultisols, peds are generally weakly developed in the argillic horizon, and clayskins are scarce. Their importance to the plant roots should be less but I know of no studies on their ped surfaces. At the Brazil meeting of ICOMLAC, there were

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many arguments in the field about the presence or absence of clayskins, and I rashly expressed some opinions about the more doubtful horizons, based on microscopic examination of the dry or driest peds. In the United States, the binocular examination of dry peds has been long used by the Lincoln laboratory of the Soil Conservation Service, and perhaps Dr. Holzey can comment on their experience later.

The definition of the argillic horizon was complicated by the innumerable examples of eroded soils in the United States in which part of the former argillic horizon is now incorporated in the plow layer. Because the plow layer may have as much or more clay than the remaining argillic horizon, we were forced to place emphasis on the clayskins in order to keep eroded and uneroded soils in the same series.

In conclusion, I want to repeat that it is time for a new generation to take over the responsibility for Soil Taxonomy. It will be necessary for the pedologists, chemists, biologists, and physicists to work together with horticulturists, agronomists, range conservationists, foresters, agricultural engineers, highway planners, city planners, and others to decide how different soils are best classified, and to find definitions that can be applied in the field to classify them in the best way. This was how we arrived where we are, and many points of view will have to be compromised if Soil Taxonomy is to attain its potential value.

TAXONOMIC PROBLEMS OF LOW ACTIVITY CLAY ALFISOLS AND ULTISOLS

F.R. Moormann

Soils dominated by low activity clays (LACs), i.e. clays of the kandite (kaolinite) group with or without an admixture of considerable proportions of ferric oxides, have received relatively scant attention in the present Soil Taxonomy (Soil Survey Staff, 1975). This is acceptable in the context of the mandate of Soil Taxonomy (preface) as a classification system for soils in the U.S., Puerto Rico, and the Windward Islands. However, when applying the classification system to other regions of the world, specific limitations become apparent. In particular in tropical and some subtropical regions, soils dominated by low activity clays abound. In the present Soil Taxonomy system, this soil property is catered for at three levels:

- At the order level where a diagnostic characteristic of Oxisols is the dominance of low activity clays in the oxic horizon (see summary of properties of the oxic horizon, page 39 of Soil Taxonomy);

  At the subgroup level where the oxic subgroups of Inceptisols (but not Andepts), Mollisols, Alfisols and Ultisols have--in horizons specified according to the order--a cation exchange capacity (CEC) per 100 g clay (by NH_4OAc) of less than 24 me and a cation retention capacity from NH_4Cl of less than 12 me per 100 g clay; and

  At the family level where the dominance of low activity clays can be indicated by the mineralogy class, but not if it concerns soils with coarse particle size classes.

The level at which taxa dominated by low activity clays, other than Oxisols, can be distinguished appears too low for a meaningful taxonomic classification for most tropical and some subtropical soils. Geographically, certain subgroups may have a very wide distribution, e.g. Oxic Paleustalfs. Taxonomically, such oxic subgroups often combine widely divergent (poly)pedons which merit distinction at a level higher than that of the family or series. The management properties of soils are often more closely linked with the specific mineralogical composition of the clay fraction than with almost any other diagnostic property.

The International Committee on the Classification of Alfisols and Ultisols dominated by low activity clays (ICOMLAC) was charged to work out recommendations for the upgrading in Soil Taxonomy of the present and possible oxic subgroups belonging to the two orders mentioned. Oxic subgroups of Inceptisols and Mollisols will be dealt with at a later stage, but their classification can be expected to follow rules recommended by ICOMLAC. Implied in the ICOMLAC mandate is the requirement that the present structure of Soil Taxonomy should be changed as little as possible and only when a more meaningful grouping of LAC soils is required.

PROBLEMS OF CLASSIFICATION

In its endeavour to upgrade the categorical level of LAC Alfisols and Ultisols, the following main taxonomic problems were topics for international discussions.

The argillic horizon

The presence of an argillic horizon, as described in Soil Taxonomy, is a main diagnostic property of Alfisols and Ultisols. Discussions covering a wide range of topics included:

A. The pedogenetic significance of the argillic horizon, whereby the basis for classification of LAC-dominated soils according to Soil Taxonomy was challenged;

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B. The properties (clay increase from the epipedon downward, and the presence of clayskins) used to diagnose an argillic horizon by field observation and by supporting laboratory and micromorphological data, notably:

   i. The absence or near absence of clayskins in many LAC Alfisols and Ultisols, most often in Udults of perudic tropical areas with a kaolinitic-ferri(hydr)oxidic clay mineralogy, but also in other taxa. The boundary between many LAC Ultisols and Oxisols is very vague;

   ii. The interpretation of a clay increase from the epipedon downward which, apart from eluviation-illuviation as in a "true" argillic horizon, may be caused by lateral removal of the clay fraction (as in slowly eroding soils), by clay breakdown in the epipedon (as in soils subject to ferrolysis) or by depositional layering;

   iii. The presence and the maximum admissable thickness in Alfisols and Ultisols of a horizon with properties of an oxic horizon, overlying a "distinct" argillic horizon;

   iv. The magnitude of a clay increase from A to B and the maximum vertical distance within which this clay increase should take place for the finer textured subsurface horizon to be considered as an argillic horizon.

C. The wide variation in nature and field appearance of argillic horizons, and the desirability and feasibility of subdividing such a horizon or "endopedon" according to characteristics (structure, bulk density, etc.) other than just clay increase ratios and the presence of clayskins.

Classification level for LAC soils

The present level of distinction of LAC Alfisols and Ultisols in Soil Taxonomy is the subgroup ("oxic" subgroups) and in a number of cases, the family. In several cases, the dominance of LAC soils is

implied in the taxa definitions, but no specific LAC taxa are distinguished. This is the case in the great groups of Udults where at present no oxic subgroups are foreseen (except in Tropudults). On the contrary, in the suborder of Humults most great groups have oxic subgroups.

The trend of the discussions has been to upgrade distinction of all LAC Alfisols and Ultisols to the great group level by introduction of, where appropriate, kandi great groups under the existing suborders. No kandi great groups were proposed for the suborders of Boralfs, Xeralfs, and Xerults; but the possibility for kandi taxa in the latter two suborders must remain open if such pedons were found, mapped, described, and analyzed.

The possibility of distinguishing the kandi properties of all LAC soils (except Oxisols) at higher categorical levels was discussed and studied. Such high level upgrading, though having attractive aspects (e.g. closer relations with existing national and international classification systems), would mean a considerable change in the present structure of Soil Taxonomy. Assuming the classification of kandi properties of Alfisols and Ultisols at the great group level, a point of discussion was the ranking to be given to the kandi taxi in the great group keys. Especially as regards the existing plinth great groups (often dominated by LAC pedons), the ranking of the kandi great groups poses problems. Though not strictly included in the mandate of ICOMLAC, a point of discussions was (is) the relevancy of trop taxa in the higher categories of Soil Taxonomy.

Diagnostic properties of kandi taxa

Central in the discussions of diagnostic properties to distinguish kandi taxa from the others in Alfisols and Ultisols is the question of CEC and cation retention properties. In the first instance, it was thought to adopt the present boundary of the oxic subgroup as the boundary of the kandi great groups. For oxic subgroups, the requirement is that they should have a CEC of less than 24 me per 100 g clay by NH_4OAc at pH 7 and a cation retention by NH_4Cl of less than 12 me per 100 g clay.

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Points of contention and discussion on this requirement were:

A. Should the 24 me boundary be maintained or should it be lowered to 16 (as in Oxisols) for all or part of the kandi taxa belonging to Ultisols. If the limit is lowered to 16 me, should kandic subgroups be introduced to cover those pedons now belonging to oxic subgroups and having a CEC of less than 24 me but more than 16 me.

B. Is the cation retention by NH_4Cl a relevant measure or should it be replaced by ECEC (sum of cations + exchangeable Al and H, by 1N KCl extraction at the pH of the soil). If so, what is the relevant diagnostic level of ECEC. Also, should ECEC be an alternate criterion to the CEC by NH_4OAc or an additional one.

C. Which is the diagnostic depth of the CEC and/or the ECEC, e.g. the upper 50 cm of an argillic horizon.

D. Should CEC and ECEC be determined on the whole soil or, as in Brazil on the soil with exclusion of organic matter.

E. In view of the difficulties in obtaining reproducible data with the present methods of CEC/ECEC determination, can other methods to determine charge properties be found, tested, and recommended for taxonomic purposes? Also, can relevant accessory field and laboratory measures be identified which can help to better characterize LAC taxa.

F. How can we accommodate in a revision of Soil Taxonomy those pedons in which the surface charge of the clay fraction is mainly of the constant surface potential (or pH dependant) type. Collateral to this question: should the presence of considerable contents of "active" Fe(hydr)oxides (with an important specific surface and a dominance of constant surface potential) be recognized at the great group level, parallel with but separate from the kandi taxa. The pedons involved are mainly those developed on basic and ultrabasic materials.

G. In general, we are only in the early stages of study and recognition of properties of "low activity clays," and further efforts

are required to "translate" the research data of soil chemists and mineralogists into usable taxonomic criteria.

Discussions pertained also to the significance and role of weatherable minerals, defined according to Soil Taxonomy, in the distinction of kandi taxa of Ultisols. Data available indicate that the dominance of kaolinite-sesquioxide clay systems does not necessarily go together with a low level of weatherable minerals, as has been generally assumed in the literature on soils of the tropics. Hence, the relevance of a low content of weatherable minerals to distinguish kandi taxa from other Alfisols and Ultisols was seriously queried. Especially, the presence of muscovite in considerable quantities (more than 10%) seems irrelevant in regard to the (presumed) degree of weathering of soils. Muscovite is, in many cases, less weatherable and can occur in measurable quantities even in pedons which for all practical purposes should be classified as Oxisols. A review of the diagnostic characteristic "weatherable minerals" is deemed necessary.

SUBGROUPS IN KANDI TAXA

Typic versus leptic subgroups

An original premise of ICOMLAC was that by upgrading present and possible oxic subgroups to the kandi great group level, more room would be created for introducing relevant subgroups without the necessity for double or even triple subgroup names. In this concept, the typic subgroups of kandi taxa would have a clay distribution of the argillic horizon such that the clay content does not decrease more than 20%. from its maximum at 150 cm, or clayskins are present at that depth. Kandi pedons with a thinner argillic horizon, or with a lithic, paralithic, or petroferric contact at less than 150 cm depth, would belong to leptic subgoups.

The disadvantage of "lumping" all LAC pedons into a single kandi taxa, irrespective of the depth of the argillic horizon, became clear

for countries such as Malaysia where virtually all Ultisols (Udults) are dominated by low activity clays. Here, the present distinction between Paleudults and Tropudults would disappear at the great group level. Similarly, for other Udult areas, as in the southeastern United States, no distinction at the great group level would be possible between LAC Paleudults and Hapludults. "Lumping" then would also occur in other taxa: Oxic Paleustalfs and Oxic Haplustalfs, for instance, would become respectively, Typic Kandiustalfs and Leptic Haplustalfs. Apparently, the simple "lumping" of all oxic subgroups into one kandi great group will diminish the taxonomic usefulness of the kandi distinction, and it appears necessary to introduce two parallel kandi great groups per suborder, i.e. a deep one with characteristics parallel to the present pale great groups, and a "shallow" one, which would accommodate the present oxic subgroups of mainly the trop, rhod, and hapl great groups.

Subgroup with very low activity clay

In certain kandi pedons, especially of Udults, a very low CEC or ECEC of the clay fraction occurs. The introduction in Oxisols of a relevant subgroup, parallel to the present acr great groups, was discussed. If so, the diagnostic ECEC value for 100 g clay should be chosen and tested. A proposal was made for the acric subgroup to have an ECEC of less than 5 me per 100 g clay in the major part of the argillic horizon, but this value may be too high.

Subgroup with very low base saturation

The necessity was discussed for the introduction of a subgroup with very low base saturation or, alternately, with high Al^{3+} saturation. The difficulty is to agree on the diagnostic depth of such a very low base saturation or high Al^{3+} saturation. Because it is a characteristic of the upper part of the profile subject to change, e.g. by liming, a greater diagnostic depth would be required. In such cases, however, this subgroup would become taxonomically less meaningful.

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Other subgroups

Other possible subgroups not specific for kandi taxa, but possibly more frequent in such taxa than in other Alfisols and Ultisols, were tentatively discussed. These included soils with characteristics similar to the present epiaquic subgroups, and also soils with strong reticulate mottling ("mottled clay") that do not harden upon drying (like plinthite) and are therefore not indicative of an aquic moisture regime.

Not enough firm data are at hand to make a complete list of subgroups for the kandi taxa, though generally the existing lists of subgroups from related taxa in Soil Taxonomy can be used. Subgroups that will occur in various kandi great groups include: aquic, arenic, grossarenic, rhodic, plinthic, psammentic, spodic, lithic, petroferric, or combinations of those "basic" subgroups.

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CONCEPT OF THE ARGILLIC HORIZON AND PROBLEMS OF ITS IDENTIFICATION

Richard W. Arnold

THE SEARCH

In the book, movie and TV spectacular entitled ROOTS, Alex Haley, an American Negro, searched for his heritage--back through generation after generation of slavery, domination and mistreatment until he found the initial freedom of his African forefathers that provided the link to his freedom in the modern world. I would like to call this presentation, "In Search of the Argillic Horizon," but the trip into antiquity will not be so long, nor will it have all the thrilling episodes that were provided in ROOTS.

Unbeknownst to me, I grew up on clayey Argiudolls, got tractors stuck in Argialbolls, and witnessed fantastic crops of corn and soybeans. The local people I heard expressed the day-to-day experiences of several generations of sod farmers, including their fears and frustrations, their joys, and even their dreams for the future well-being of their families.

Many years later, after training in classical theories of soil genesis, I observed for the first time soils in the tropics. Wide-eyed and naive, I saw, touched, dug and tasted soils that turned out to be clayey Ultisols and Oxisols on the island of Fiji. From that moment until now the struggle with mental bondage has been unsure, confusing, and to say the least, a bit embarrassing. Why didn't my early experiences in a microcosm help me comprehend the complexities of this larger world? What was making this journey a fragmented torture of uncertainty? From the known to the unknown my working concept of an argillic horizon was falling apart, but now I realize there are many of us on this same journey in search of the argillic.

Let us examine first several points in Taxonomy, then some principles of studying soil genesis, and then decide if there are any road signs to guide us in this journey together.

Logic of a multi-categoric system

The order category is the highest and most abstract level in Soil Taxonomy; therefore, it must bring together and distill the essence of what we conceive to be a logical organization of our knowledge. Being more abstract it must also be defined in abstract terms or concepts; however, to be consistently useful it must rely on measurable features and facts of soils that are closely related to these abstractions.

The order category is defined as "soils whose features are the result of soil-forming processes," That is, they reflect both their past and their present. We all know it is impossible to measure directly any of these processes in a satisfactory way other than the present condition of aridity. Consequently, the understanding of relationships between our models of genesis and observable and measurable features, provide the evidence to divide the order category into classes that will satisfy the abstract definition of the category.

In a similar manner we note that the suborder category is also abstract and may be defined as soils whose features reflect the dominant control on current processes. Again, soil properties are selected to provide information on what is believed to be controlling the processes affecting the soil in its present environmental condition.

This same philosophy carries throughout Soil Taxonomy and is the strength of the system. Its logic, if understood, is straightforward, clever, and comprehensible even to laymen.

The argillic horizon as a diagnostic criterion

The concept of an argillic horizon is recorded in ancient history--only the words are different. In modern day parlance, we read that the

argillic horizon is an illuvial accumulation of clay-sized silicate minerals and thus is surely one indication of a process. Yet the significance of the argillic is attributed not to the process itself, but to the consequences of soil behavior and the notion of at least a modest degree of stability of the soil landscape, and of bioclimatic forces that might otherwise destroy the evidence.

Accessory properties considered to be important are those of increased cation exchange capacity (CEC) of soil associated with the accumulated clay, structure formation and stability, and a change of the internal air-water relationships of which some are favorable, some not.

Implications of the pedogenic process include:

a) a dominance of translocation of clay-sized particles over processes of destruction, of removal or of mixing;
b) evidence that climate and biota, mainly vegetation, have had at some time an opportunity to affect profile differentiation;
c) a relative stability of ped surfaces, seasonal moisture deficit, and dynamic equilibrium of organic matter; and
d) as a corollary of "a" it is suggested that weatherable minerals, or a lack of extreme mineral alteration, will be observed in argillic horizons.

The concept of the argillic horizon also suggests criteria that may be used to judge its presence. Is there evidence of clay translocation? Does CEC reflect clay accumulation? Do water relationships relate to illuvial clay in such soils? Is there evidence of structure formation influenced by the translocated clay? And is there material present to produce clays that can be translocated? We need only satisfy ourselves that observable and/or measurable features of a horizon capture the essence of this concept and its implications. Defining the limits for each of these conditions has consumed us far more than assuring ourselves that what we have placed on either side of those limits truly reflect the working concept of an argillic horizon as stated. When the evidence does not hold up to closer scrutiny, should

we tinker and patch, or do we reexamine the concept we wish to use? Is the concept wrong, or have we been bending our rules of scientific integrity?

SOME WORKING CONCEPTS IN GENESIS STUDIES

Fundamental considerations

The first consideration is a need to establish the unity of the soil system. All too often assumptions are made without obtaining the necessary field observations. The unity of a soil system may be indicated by depth functions of appropriate parameters (the more the better) and confirmed by field stratigraphic methods. A lack of unity indicates that two or more materials belonging to separate soil systems form part of the present landscape.

A second consideration is the need to estimate the uniformity of parent materials that have been altered to form soil horizons and related features. The test of unity indicates whether one or several parent materials were precursors of the observed soil profile. Uniformity within a soil material is based on trends of indicator components, such as resistant minerals. Several lines of evidence are preferable to a depth function of a single parameter.

A third consideration is a need to estimate the initial state of the system and of materials that have been modified by pedogenic processes. We measure what is present now; however, we need to compare that against a set of properties which approximate the material when it was exposed to soil-forming processes. Such assumptions are based on trends within the materials identified while testing the profile unity and uniformity.

Some brief highlights of these working concepts which underlie soil genesis studies are provided below.

System unity

Figure 1 illustrates classical sedimentary layering. The Law of

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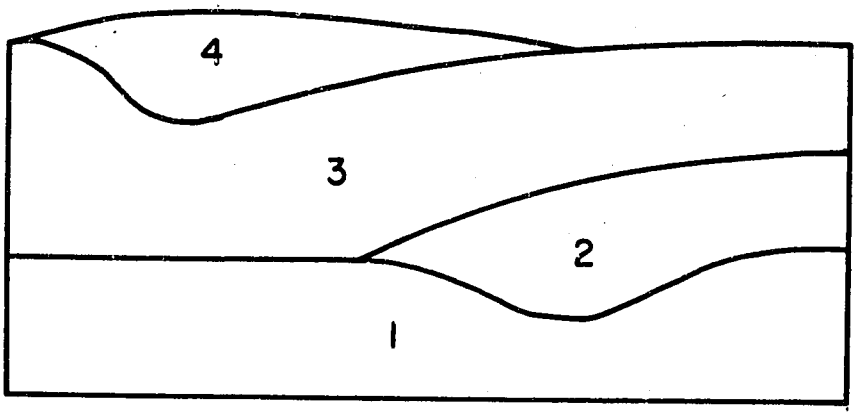

Figure 1. Schematic diagram representing a sequence of depositional layers. Each layer is a separate unit.

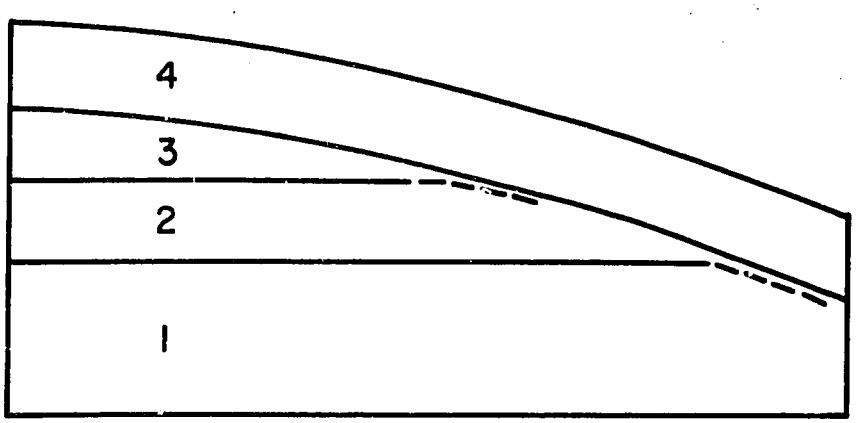

Figure 2. Schematic diagram representing a buried erosional surface. Layers 1, 2, and 3 are part of the same assemblage.

Superposition allows us to give relative ages to the layers. That is, the bottom layer is the oldest, and the top one is the youngest. Without stratigraphically examining soil horizons and materials in the field, we may misinterpret the age relationships of layering that exist in many pedons. For example, layer 3 overlies both layer 2 and 1 at different places; consequently, it is a separate unit from these two substrates, differing in time and probably other properties.

The unity of a system is established if all layers are present in all parts of the system. In this example, only the individual layers have unity and the system itself lacks unity.

Figure 2 is a schematic diagram representing a mantled erosion surface. The surficial layer may consist of soil creep. Layer 4 is a separate assemblage because it covers all others; however, evidence of erosion and truncation permits us to conclude that 3, 2, and 1 belong to the same assemblage even though layers 3 and 1 are separated.

Figure 3 illustrates how depth functions assist in locating and/or confirming changes in a profile. Figure 3A is the commonly expected exponential function of organic matter, whereas in Figure 3B there are segments of two curves suggesting that two materials may be present if supported by other evidence. Thus, it can be seen that even mobile constituents assist in testing the unity of a soil system.

Figure 3C is a familiar clay distribution for translocated clay in a uniform material, and Figure 3D schematically shows an example of a truncated profile as might be observed on the shoulder or upper backslope of an eroding hillslope. This latter condition could be related to adjacent portions of the landscape by field stratigraphy which would confirm the unity of the system and also provide evidence of its partial assemblage.

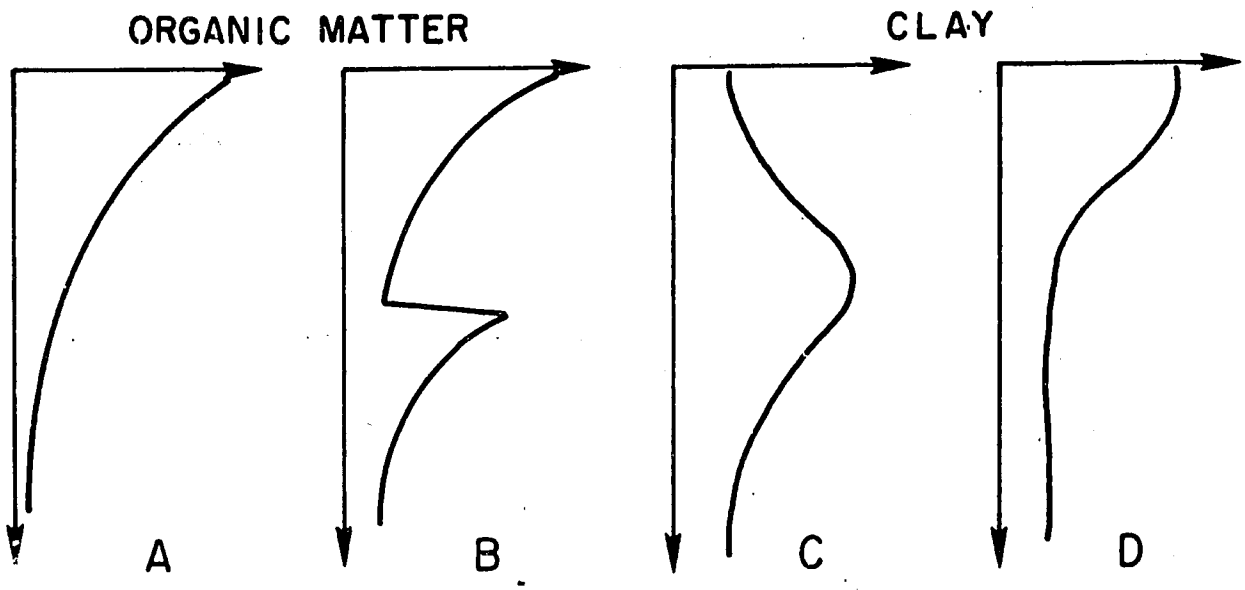

Figure 3. Schematic depth functions of organic matter and clay. A is a usual trend; B is from a depositional sequence; C is a usual trend; and D is from a truncated soil.

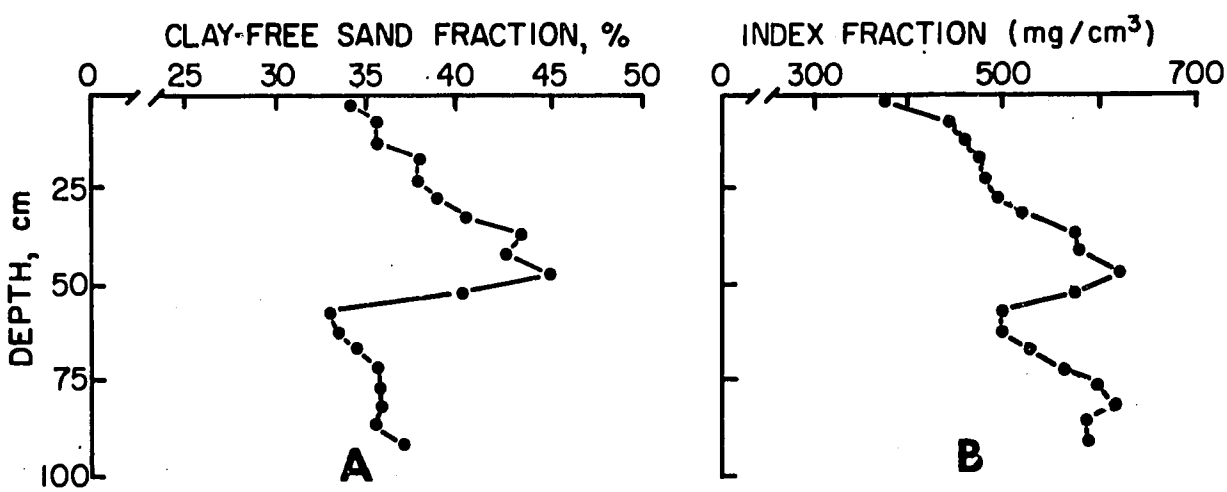

Figure 4. Depth function of weight percent of sand fraction calculated on a clay-free basis (A), and the same clay-free sand fraction multiplied by bulk density to express the index as weight per unit volume.

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Material uniformity

Continuity of simple trends of some depth functions does not necessarily establish the uniformity of a material already demonstrated to be a separate assemblage. It is more common to examine trends of the more resistant or stable components as indicators of the degree of uniformity within a material or deposit. Although ratios of resistant minerals are sometimes used to estimate uniformity, such ratios might not detect a truncated profile or a time difference between two layers if their sediment source was similar.

In many soil materials lacking readily soluble compounds, there appears to have been minimal changes of volume during soil development. Consequently, bulk density values can be used to calculate the weight per unit volume of the indicator minerals or fractions.

In Figure 4A, the sand fraction of a slightly weathered soil has been expressed as clay-free sand in order to remove the influence of any clay translocation. This same curve might also be observed for the sand fraction of highly weathered soils containing appreciable quartz. The rather abrupt change in the depth function suggests that two materials may be present, and the minor fluctuations would be thought of as variations within each material.

In Figure 4B, the clay-free sand has been multiplied by the bulk density of each sample to provide an index fraction which is expressed as weight per unit volume. The inflection in the upper material suggests that a third layer of material may also be present and leads one to carefully examine additional data to confirm or deny its presence.

If three layers are confirmed, the obvious conclusion is that each layer has its own internal trend. Internal uniformity can often be represented by simple linear trends; however, the degree of refinement depends on the interpreter.

Initial state of a soil

Judgments about conditions near pedogenic time zero are complex and difficult, but without them how do we obtain independent estimates of clay illuviation or of weathering?

In Figure 4B, the trends of clay-free sand suggest that original contents of clay may also have had simple linear trends within a given material. The bulk density depth function in Figure 5A reflects the presence of two or three layers suspected from inflections of the index fraction curves.

Estimating mobile constituents, including clay, at the system's initial state is not easy. However, if a zone of minimal disturbance can be selected, such as a B3 or C horizon in a single material, or where similar materials occur together (Figure 5B), it is possible to estimate the percent of clay and then express it as weight per unit volume.

The estimate of clay percent (Figure 5B) was taken low in the profile where values become asymptotic and the zone is thought to have undergone minimal gain, loss, or transformation. The clay content and bulk density in this zone (indicated by the stars in Figure 5) are used to calculate a uniformity value for clay.

Assume that clay was initially distributed uniformly thoughout a material. But uniformity is expressed by weight per unit volume; thus the measured clay content will vary according to the estimated trend of original bulk density, and seldom will be a constant weight percent throughout a soil material.

Figure 6A estimates the initial trend of bulk density in the several materials indicated in the previous figures. It does not differ greatly from the existing bulk density curve because of the assumption that volume changes for most sediments have been minimal. The original clay distribution shown in Figure 6B results from multiplying the estimated bulk density of the initial state by the uniformity value for clay. Where materials differ markedly in degree of weathering or composition, it is necessary to provide a uniformity value for each material.

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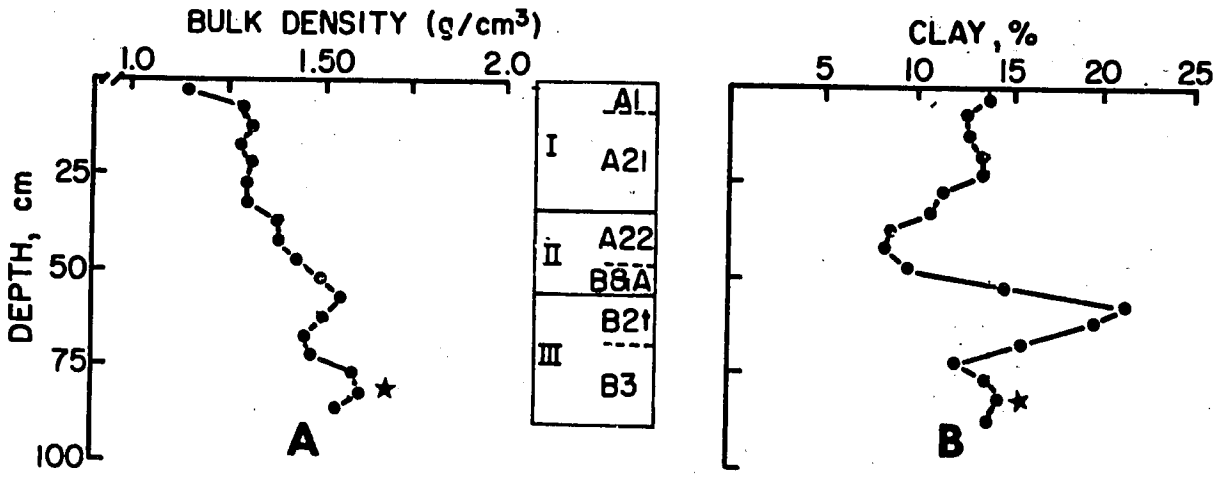

Figure 5. Depth functions of bulk density and percent clay for the profile illustrated in Figure 4. Values from the zone indicated by a star were used to estimate a uniformity value for clay.

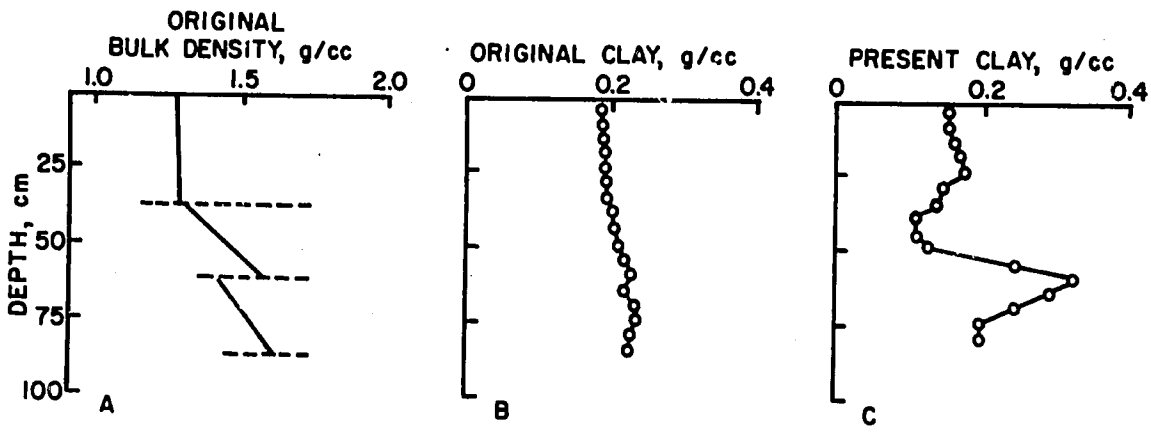

Figure 6. Estimated trend of original bulk density for a three-layered profile (A); calculated depth function of original clay content as weight per unit volume (B); and depth function of actual clay expressed as weight per unit volume (C).

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Once data have been reworked to give estimates of the initial state of the soil system, results can easily be compared with the existing values in the soil (compare Figures 6C and 6B). Calculated changes of the mobile constituents can then be compared with micromorphological evidence of translocation and transformation.

Although the values and interpretations of soil genesis studies are approximations of what may have happened, they lend support and quantification to observable field evidence. They alert us to the complexities of landscape evolution that are recorded in soil profiles, and help us retain the philosophy and conceptual basis of diagnostic horizons.

SOME ROAD SIGNS

Now that we have reviewed the stated intent of the argillic horizon, and some of the methods used in soil genesis, are there any road signs to assist us on this journey in search of the argillic horizon? Yes, I think some post holes have been dug, the posts set, and we are ready to add some road signs.

Sign No. 1. STOP. INFORMATION AVAILABLE. USE IT.

In most of the data presented for the two correlation workshops--in fact, for most pedons of the world--we have the basic ingredients for examining both the unity of soil systems and estimating the uniformity of materials in which horizons have been differentiated. Additional stratigraphic information for the associated landscapes would be welcome, but are not necessary for our first approximations. So far we have made little use of the existing information. What a shame.

Sign No. 2 WINDING ROAD. STAY ALERT.

Goro Uehara and others have repeatedly tried to tell us that highly weathered materials--that is, those we are now considering as low activity clays and soil materials--have logical explanations for their behavior, such as minimal changes in exchange capacity,

plasticity, impoverished water relationships, and in many cases, a reasonable relation to stability. Furthermore, these materials are either low in weatherable minerals, or they are in such a condition that they cannot readily provide clays for translocation. Thus a reasonable limit occurs at or near 16 me by NH_4OAc, or 12 me ECEC.

Sign No. 3. DO NOT DETOUR.

The conclusion is that such materials and/or horizons do not at all correspond to the concept of an argillic horizon as previously explained. The Oxisol concept could readily be expanded and yet embrace the important accessory properties and qualities associated with textural differentiation in such soils. The consequences of their properties on soil behavior and the implications of pedogenic processes are not those attributed to argillic horizons.

Sign No. 4. KEEP RIGHT.

The argillic horizon should be restricted to those materials having more than 16 me, and it should also confirm to the other necessary prerequisites for proper evaluation. Accessory features are important. Micromorphology is a tremendous addition to other techniques, but it will primarily confirm lines of evidence available to pedologists.

Sign No. 5. CAUTION. DANGEROUS CURVE.

Of course, many soils will be affected by renaming or recataloging, but of more importance is the fact that our scientific integrity will be improved and reestablished if we agree to retain the initial concept and implications of an argillic horizon. The argillic horizon serves us well in grouping together a large number of soils that have been well studied.

Sign No. 6. DO NOT PASS ON HILLS.

We should not violate the philosophy and logic of the system, such as we are in danger of doing now. Both the genetic basis and the interpretive implications of soils deserve to be preserved as we continue along our journey, and by so doing, it will once again make us free.

CAPTIONS FOR FIGURES

Fig. 1. Schematic diagram representing a sequence of depositional layers. Each layer is a separate unit.

Fig. 2. Schematic diagram representing a buried erosional surface. Layers 1, 2, and 3 are part of the same assemblage.

Fig. 3. Schematic depth functions of organic matter and clay. A is a usual trend; B is from a depositional sequence; C is a usual trend; and D is from a truncated soil.

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CONCERNING THE MINERALOGY CLASSES IN THE CLASSIFICATION OF LOW ACTIVITY CLAY SOILS

A.J. Herbillon and L. Rodrique

ABSTRACT

This paper questions the adequacy and usefulness of mineralogy classes, as they now stand in Soil Taxonomy, for supplying predictive values. The broad variability of structure, texture and properties existing in the mineralogical constituents most common in low activity clay soils clearly demonstrates the limitations of classification criteria based on a static inventory approach. A more systematic appraisal of the surface and charge properties of soils is presented as a possible substitute to the approach presently used in Soil Taxonomy.

INTRODUCTION

Soil Taxonomy is organized in such a way that the clay mineralogical composition of soils is explicitly taken into consideration at the family level, where the mineralogy classes occur. Simultaneously, however, Soil Taxonomy makes use of other mineralogical criteria and/or properties of clay minerals at higher classification levels. So, an Oxisol, a Paleudult, an Oxic Paleustalf, and an Oxic Ustropept, for instance, all have to meet, but at different levels, charge requirements that obviously provide a rough but nevertheless interesting indication of their mineral-

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ogical composition. Later on, at the level where it is intended to provide information useful for "management and manipulations for use," a semi-quantitative (or when possible a quantitative) analysis of the clay fraction will be needed to define the mineralogy class.

Seen from the point of view of clay mineralogists, the Soil Taxonomy system should implicitly assume that a description of the properties of the soil system can be reached by the comprehensive inventory of its various components. For example, it is taken for granted that a soil belonging to the kaolinite family class shall exhibit, by definition, behavioral properties different from soils belonging to the "oxidic" or "mixed" mineralogy classes, even when all these soils have in common low activity clays (LAC).

At the present state of our knowledge, especially considering that a general agreement seems to have been reached to upgrade the LAC criterion in the taxonomy, we are of the opinion that it is time to also raise questions concerning the meaning and usefulness of mineralogy classes. More precisely, one should give some consideration to whether a description of the contents of the clay fraction is the best possible way to complement, at the appropriate classification levels, information already provided by the definition of low activity clays.

To comment on this topic, this report will be divided into two parts. First, examples taken from the literature will attempt to recall that even for pure clays very common in soil, the same mineralogical name may cover materials exhibiting a definitively broad range of chemical composition, particle size, morphology, and thus of properties. Hopefully, this part of the report should demonstrate almost "ad absurdum" the need for improving criteria presently taken into consideration at a level where the taxonomy intends to provide predictive characteristics. The second part is intended to open a discussion concerning possible alternatives.

VARIABILITY AMONG KAOLINITES

The kaolinite class is probably the most widely represented mineralogy class among the LAC soils. This first example will show the possible range of variations covered by the name "kaolinite," even when applied to a pure or almost pure clay fraction (less than 2 μm). Kaolinite is generally presented as a very simple and perhaps the simplest, clay mineral found in soil. Its regular superposition of octahedral and tetrahedral sheets, its chemical composition very close to the theoretical one, and its typical pseudohexagonal facies are characteristics well known to any soil scientist. As a matter of fact, this apparent simplicity hides a rather broad diversity.

Whatever the approach, it rapidly became evident that a certain classification of kaolinite was needed. In geology, some kaolinites have been defined as soft and some as hard. From the crystallographic point of view, some are defined as ordered: others are qualified as disordered. For chemists, some kaolinites develop relatively high total, and even permanent, negative charges; a few others exhibit positive and negative charges more closely corresponding to ones expected from their theoretical crystallochemical formula. Actually, kaolinite is a family name which groups many individuals.

From works dealing with sorption properties of pure kaolinites (Schofield and Samson, 1953; Follet, 1965; Sumner and Reeve, 1966; Mashali and Greenland, 1976), it clearly appears that several parameters should be known before attempting to make any predictive use of the word "kaolinite" when this mineral is a component of a colloidal system. Unfortunately, these parameters are not easily measured during routine mineralogical soil analyses, especially when kaolinite is, as is generally the rule, in a mixture with other minerals. At this time, we can ascertain that there are different types of kaolinite in soils, and that tools and techniques are available to appreciate, and possibly to understand, their variability.

In this context, the direct observation by electron microscopy of the shape, size, and more recently (Jepson and Rowse, 1975) chemical composition of individual kaolinite particles is noteworthy. Fig. 1 illustrates facies common for LAC soil kaolinites (micrographs b, c, d, e, f) as compared to a reference geological kaolinite (micrograph a). The decreasing particle size and the less typical pseudohexagonal facies--evident when going through this collection of selected kaolinites--appear to be correlated with the evolution of their BET N_2 specific surface area. The surface area ranges here from 15 m^2/g (sample a) to 60 m^2/g (sample f). Studies such as these by Gastuche et al (1960), Sumner and Reeve (1966), and Lietard (1977) suggest that when kaolinite particle size decreases, the ratio of edge surface area with respect to both total area and basal surface area increases. It is a commonly reported opinion that the edge surface of kaolinite behaves in sorption process much more similarly to an aluminum oxide surface (Schofield and Samson, 1953; Rand and Melton, 1975) than its basal surface. Thus, this would suggest that kaolinites exhibiting a small particle size would generally be qualified as more "oxidic" than larger kaolinites, such as the one exemplified by Fig. 1a. Examination of particles in micrograph f, which are characterized by small, very thin, almost transparent, and irregularly shaped kaolinite platelets, suggests however, that the above-mentioned positive relation between the magnitude of the total specific surface and the surface due to edges is likely to suffer exceptions.

Fig. 2 illustrates how the mean size of kaolinite platelets, as measured by BET N_2 surface area, is correlated with the index of crystallinity (I_c). It is an empirical parameter designed by Hinckley (1963) to measure on the x-ray spectra layer stacking disorders in kaolinite crystals. In the same way, the high surface kaolinite appears to be richer in structural iron than the low surface ones (Fig. 3), a fact suggesting that iron introduced into the kaolinite structure may impede its growth (Mestdagh et al, in preparation). Results by Fripiat (1958) as well as more recent studies (Hugues, 1978; Herbillon et al,

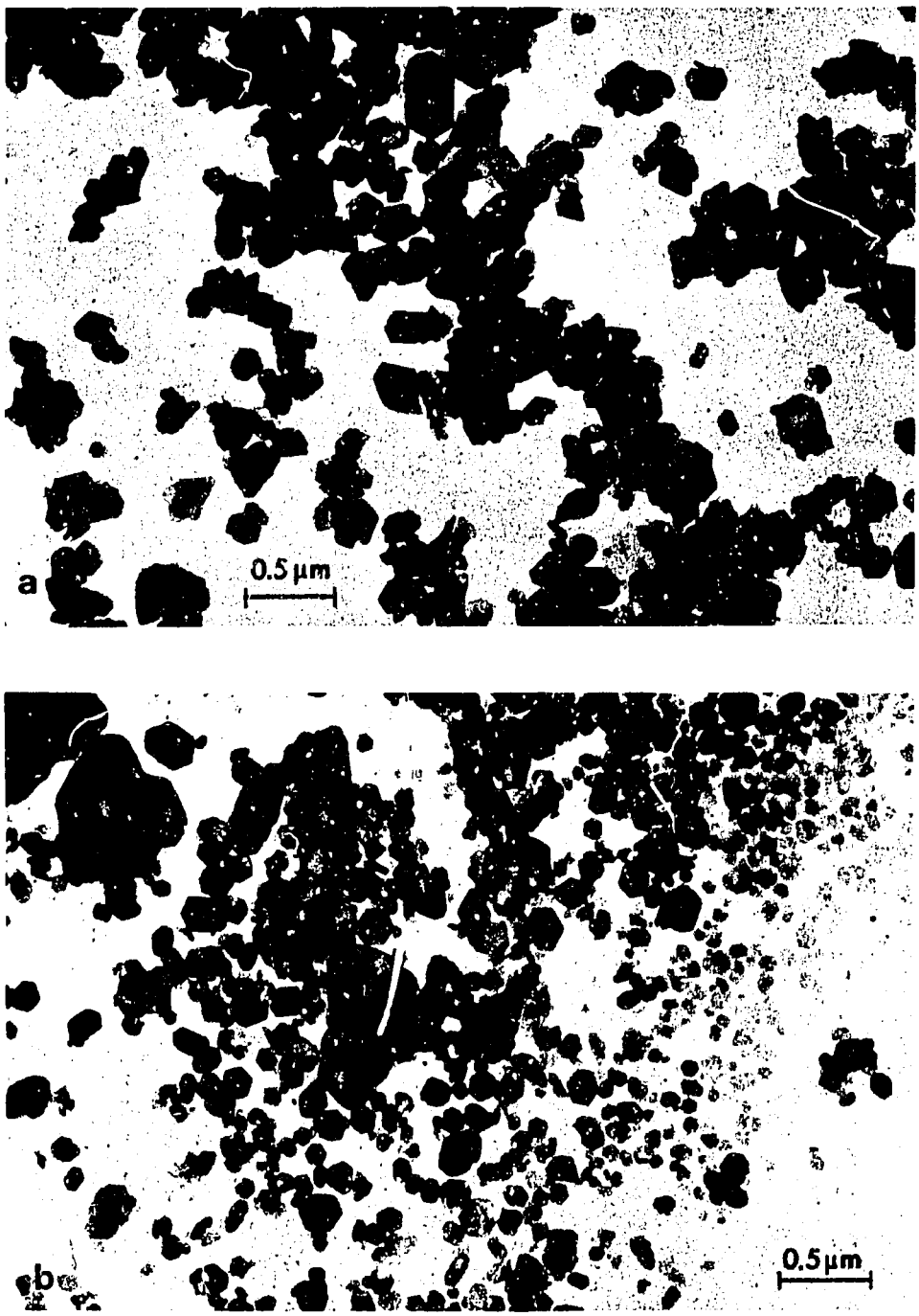

FIG. 1. Electron micrographs of a geological clay kaolinite [(a) quarry of Font-Bouillant, France (14.9 m^2/g)] as compared to soil clay kaolinites : (b) Sefa, Sénégal (43.6 m^2/g); (c) Yangambi, Zaïre (45.0 m^2/g); (d) Ibadan, Nigéria (49.5 m^2/g); (e) Camaguay, Cuba (57.4 m^2/g); (f) Onne, Nigéria (60.2 m^2/g).

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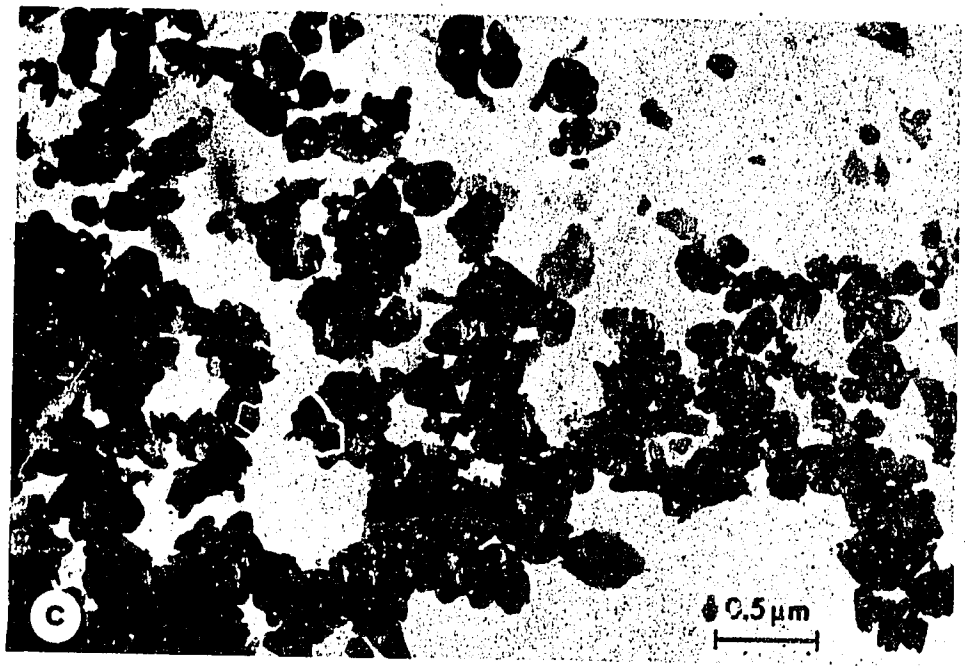

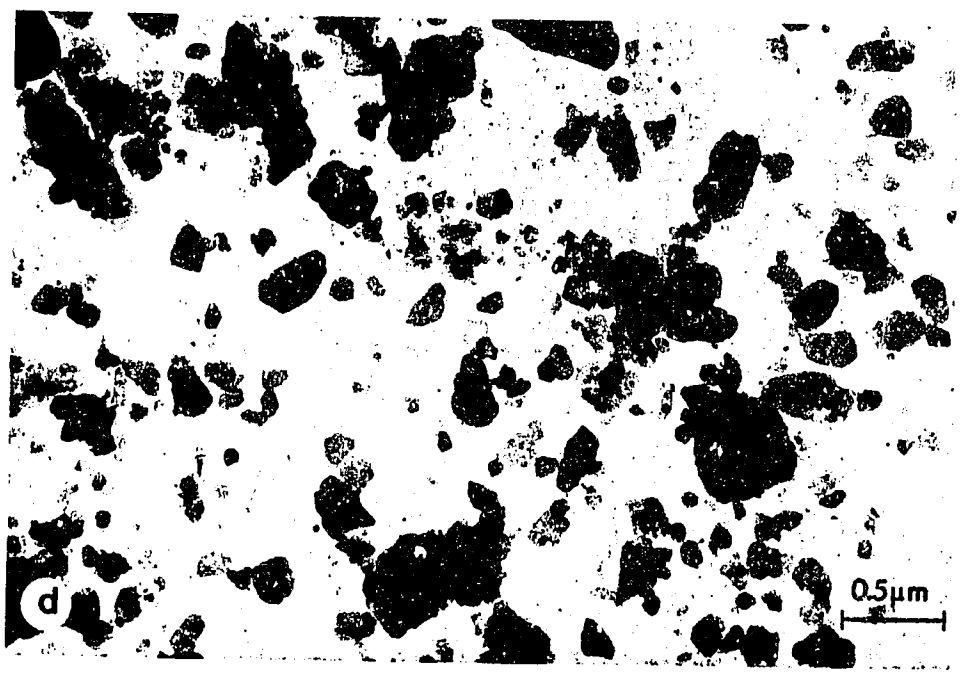

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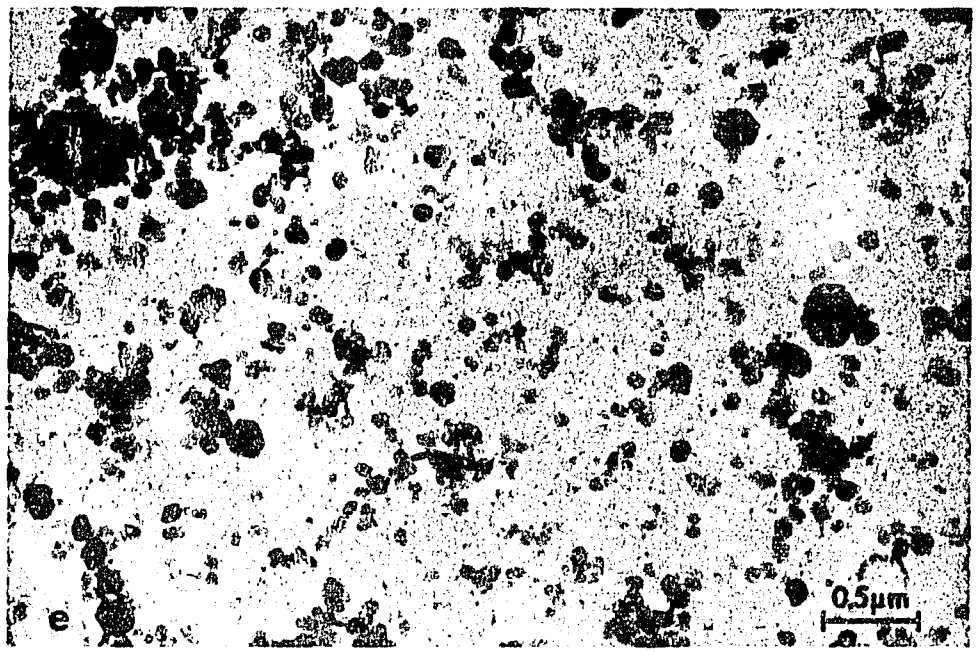

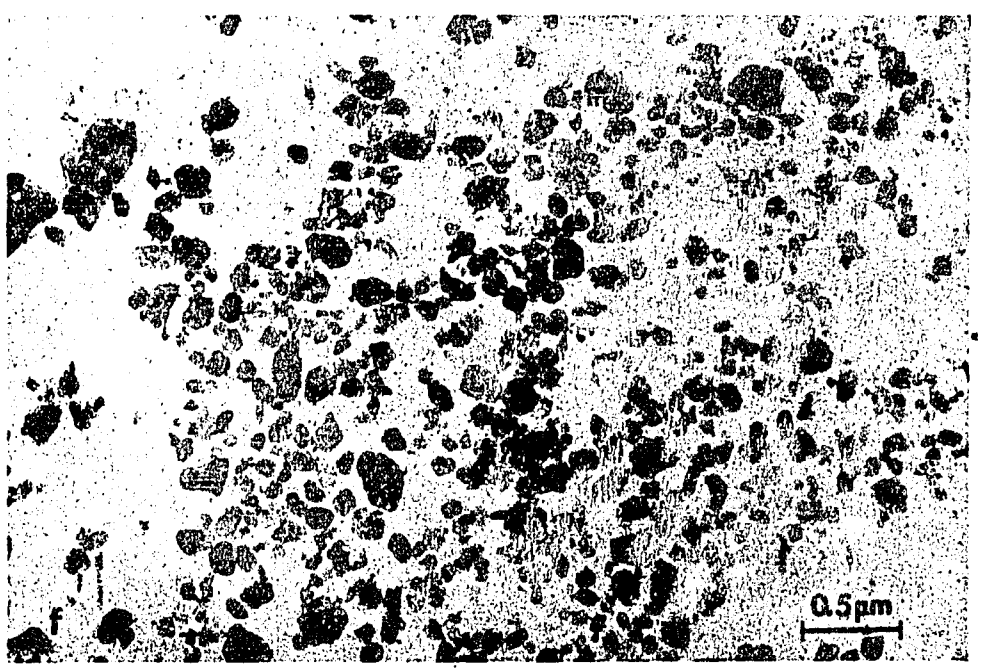

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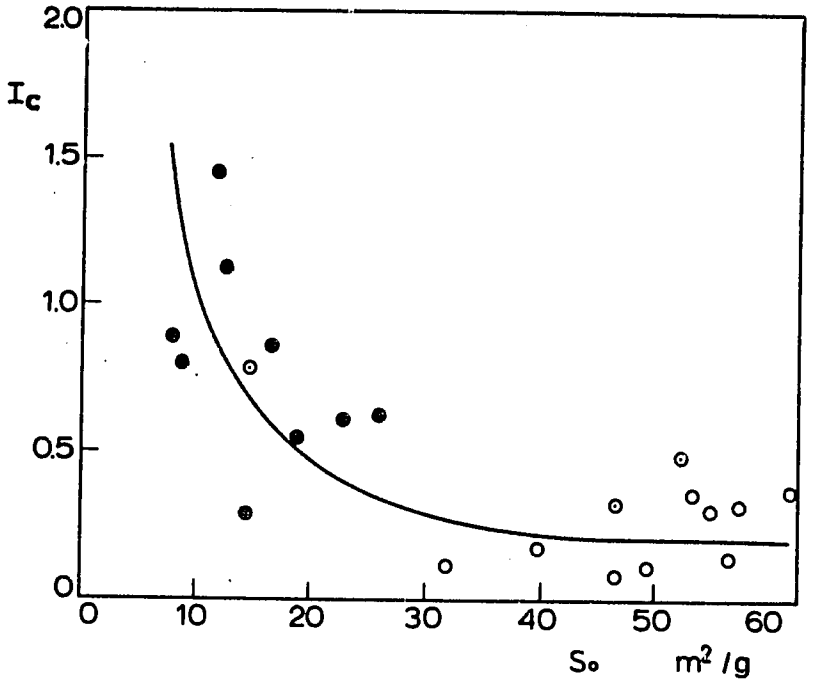

FIG. 2. Hinckley's index of crystallinity of kaolinite samples plotted against the BET N_2 surface area.

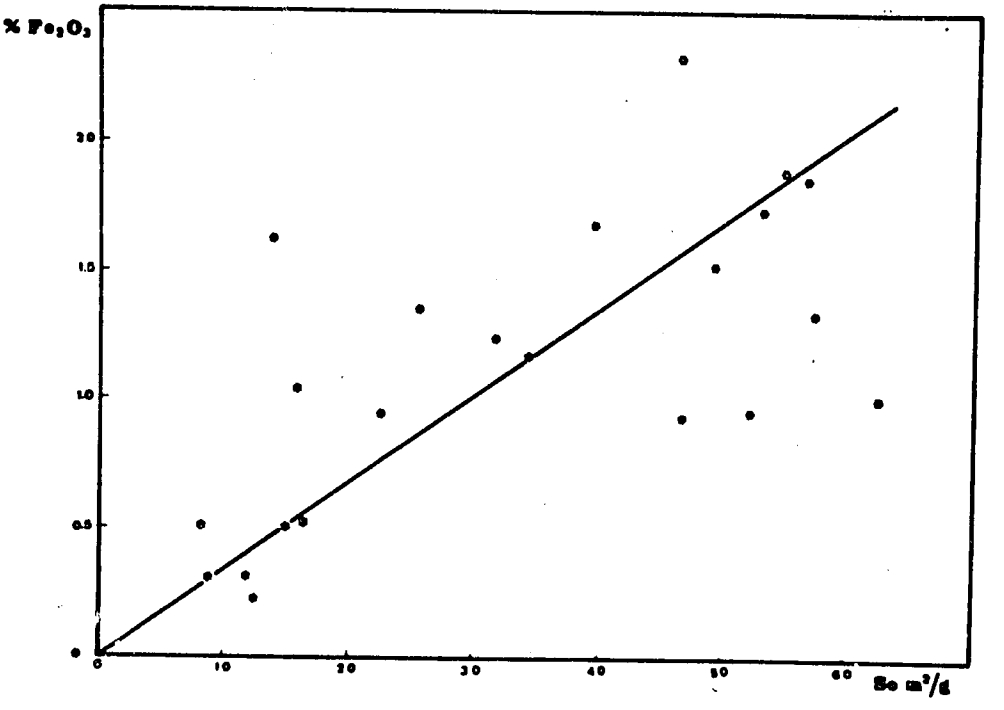

FIG. 3. Kaolinite "structural iron" content (% Fe_2O_3) with respect to the BET N_2 surface area.

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1976), tend to support the hypothesis that kaolinites with low Hinckley's crystallinity index that are rich in structural iron are the most common kaolinites in LAC soils. Therefore, if model studies relevant to these soils have to be undertaken, it would be wise to select as starting materials the poorly crystallized and rather chemically impure kaolinites, rather than the "good" kaolinites generally available as reference minerals. As we will see later on, the same conclusion will apply to iron oxides.

Charge properties are also a cause of variability within the kaolinite family. The origin of the low but nevertheless significant permanent negative charge exhibited by most kaolinite samples is, however, still a matter of debate (Marshall and Greenland, 1976). It is difficult indeed to assess whether the origin of this permanent charge is due to substitutions present within the structure of the kaolinite itself (Schofield and Samson, 1953), or in mineralogical impurities generally accompanying the kaolinite. There is now an alternative way to consider this problem. According to Thiry and Weber (1977), and in agreement with observations reported by Altschuller et al (1963), Lee et al (1975), Lucas et al (1975), and Plancon and Tchoubar (1977), the poorly crystallized kaolinites (sometimes called the "fire-clay type kaolinites") would be end-members of irregular interstratification sequences involving 2:1 and 1:1 clay minerals. In such a case, permanent negatively charged 2:1 layers could be occluded within the kaolinite platelets themselves. The nature as well as the amount of these occluded lamellae could account for the broad variation in charge magnitude. The relevance of these findings to soil mineralogy comes from a recent report by Ormerod and Brown (1976) who point out that 2:1/1:1 interstratified minerals occur rather frequently in the LAC savanna soils derived from basement complex rocks of Central Nigeria.

Let us also note that the kaolinite-rich members of such 2:1/1:1 interstratification series are easily confused with poorly ordered kaolinites on X-ray diffraction diagrams (Lucas et al., 1975). This by no means simplifies the task of clay mineralogists who face the problem of determining whether a sample contains more or less than 10 percent montmorillonite.

Another possible type of difficulty is encountered when facing the problem of properly naming a mineralogy class. Micrograph a (Fig. 4) represents the clay fraction of an Oxic Haplustalf common on the IITA site in Ibadan. In spite of the fact that it was impossible to observe the characteristic swelling of the clay in water and in glycol, this soil was reported to contain rather large amounts of halloysite by Gallez et al (1975). These authors believed, as it was generally admitted, that the fibrous morphology exhibited by some particles in this and other electron micrographs could be attributed to halloysite. More recently, Hugues and Brown (1977) reported that the long, apparently tubular material originating from the same site was not halloysite, but fibrous kaolinite similar to the mineral in a granitic saprolithe from Brazil (Fig. 4b) described by de Souza Santos et al (1965). Such fibrous clay particles are not uncommon in soils. For instance, they have been reported to exist (generally in association with trioctahedral mica and vermiculite) in some Tropudults of Southern Nigeria (Hugues, 1978) and in some Malaysian LAC soils (Paramananthan, 1977; Eswaran and Wong Chaw Bin, 1978). The question is still open, however, as to whether these kandites should be considered as fibrous kaolinites rather than as halloysites. To the best of our knowledge, no data is presently available concerning the specific properties of such fibrous 1:1 minerals. Obviously, the general distinction between the behavior of basal and edge surfaces will no longer apply to this type of kaolinite.

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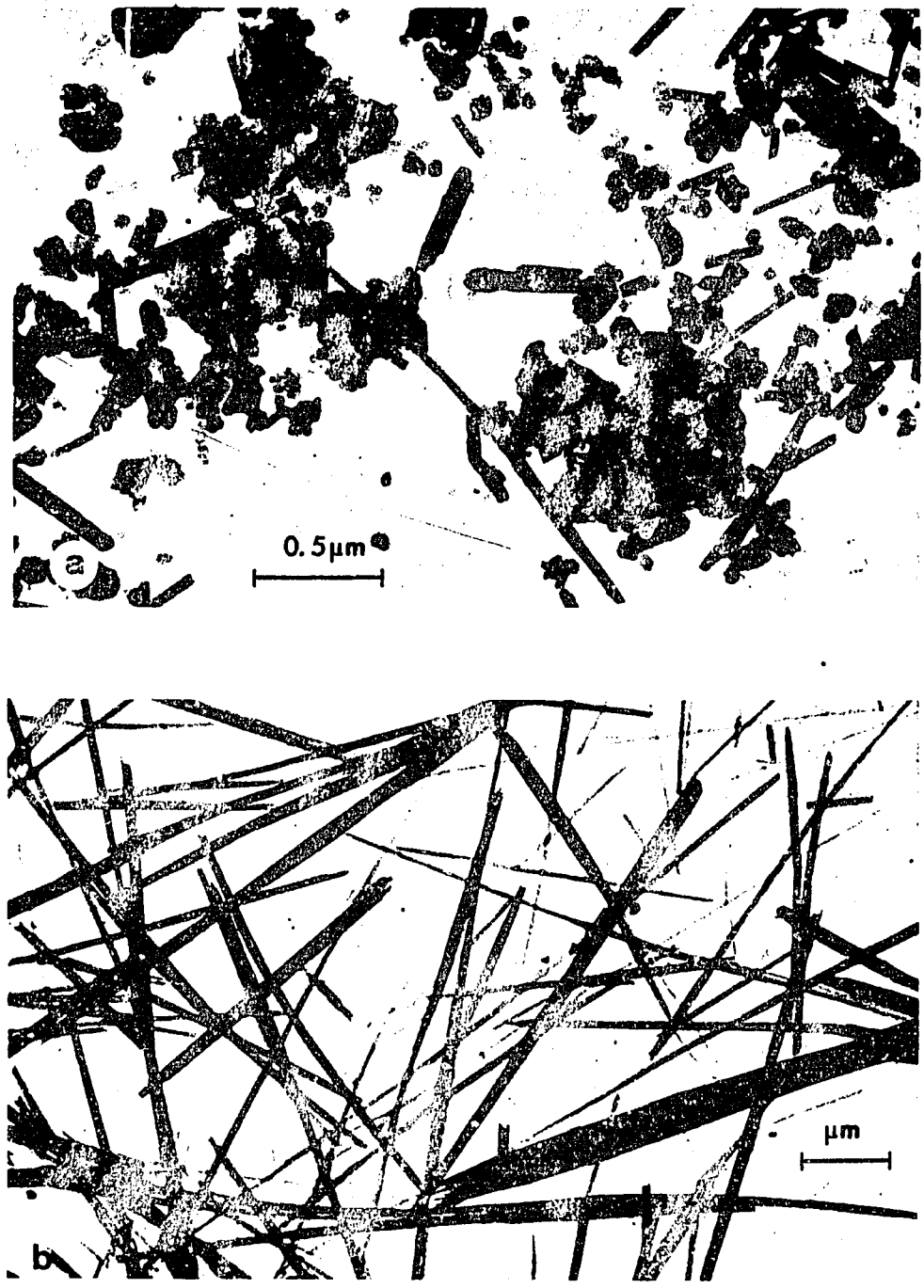

FIG. 4. Electron micrographs of: (a) a soil clay from an Ekiti pedon (Ibadan, Nigéria); (b) a fibrous kaolin mineral from Piedade, São Paulo, Brazil.

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VARIABILITY AMONG IRON OXIDES

The variability in properties of colloidol minerals due to the effect of heterogeneity in chemical composition and its consequences on crystal growth, are also topics of importance for iron oxide minerals frequently found in LAC soils. The iron oxides present in such soils are generally formed of poorly crystallized and ill-defined particles difficult to identify by x-ray diffraction and electron microscopy. Very few goethites, for instance, exhibit the typical acicular morphology reported in textbooks as being characteristic for this mineral (Fig. 5). During the sodium dithionite-citrate bicarbonate selective dissolution of the free iron oxide fraction of such soils (Jackson, 1965), it is noticeable that besides iron, rather large but variable amounts of aluminum are also solubilized. This occurs even in situations where no crystalline or amorphous aluminum oxide source can be detected (Juo et al 1974; Gallez et al 1975; De Alvis and Pluth, 1976; Fey and Le Roux, 1977). These results and one originating from more detailed but more punctual studies using techniques such as x-ray (Norrish and Taylor, 1961) and Mössbauer spectroscopy (Janot et Gibert, 1970), strongly support the idea that substitution of iron by aluminum in the structure of iron oxides is a common phenomenon in soils.

It was shown by Gastuche et al (1964) that the presence of Al cations in ferric solutions may inhibit the crystallization of iron oxides. Recent results by Taylor and Schwertmann (1978) nicely compliment these earlier observations by demonstrating that the presence of Al in solution during the oxidation of ferrous cations specifically favors formation of small, poorly crystallized goethites which resemble in particle size and morphology the natural alumino-ferrous goethite extracted from LAC soil. The consequences of the chemical heterogeneity in iron oxides are, at this time, far from being completely appreciated. This is not surprising since it is still difficult to identify aluminum-substituted iron oxides in soil samples. It is likely, however, that small and impure oxide particles shall exhibit a distinct solubility and a different reactivity during sorption and aggregation proces-

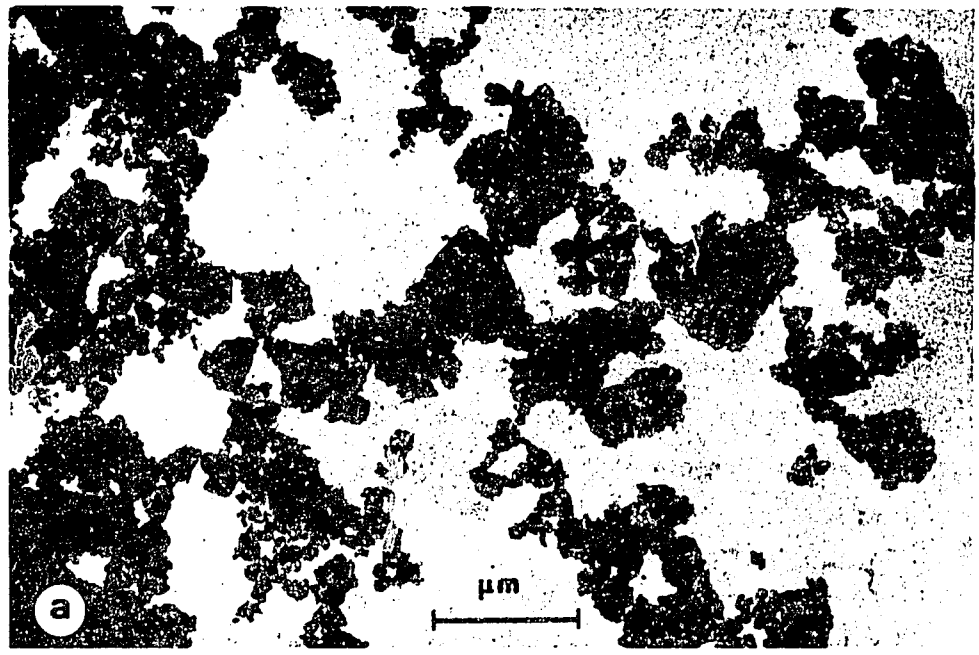

FIG. 5. Electron micrographs of : (a) an aluminum substituted goethite from Ndias, Sénégal; (b) a synthetic goethite prepared by aging of ferric hydroxide gel in boiling 2N KOH.

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ses. In the same way, the existence of aluminum occluded in and/or sorbed on ferric oxides shall be of interest for the numerous scientists studying the fate of aluminum in soil.

PROPOSALS

In the above comments, an attempt was made to show how the broad range of variability in structure, texture and composition exhibited by mineral colloids common to LAC soils makes the mineralogical inventory approach presently stressed in Soil Taxonomy of relatively poor predictive value.

As a possible alternative, we can briefly recall here some ideas developed elsewhere (Herbillon, 1978). Keeping in mind that many interactions taking place among colloids and between colloids and the soil solution are (or begin with) surface reactions, we are of the opinion that a more comprehensive appraisal of surface and charge properties are highly desirable at this stage. The parallelism existing between the clay mineralogical composition and the surface and charge characteristics due to these clays (Table 1), suggests indeed that an evaluation of these properties can generally serve as a convenient substitute to the mineralogical inventory. A further point which seems worth noting is that the parameters listed in Table 1 (nature and magnitude of the surface, nature and magnitude of CEC and AEC, position of ZPC) appear to be especially suitable for treatment in a hierarchical manner, and thus are well adapted for classification purposes.

It is clear that before making any firm proposal along this line, more data have still to be collected. The interest shown for this approach by several teams of scientists during the last few years, as well as the fact that charge properties are already differentia at various levels of the taxonomy, can be taken as an indication that the necessary information is being gathered.

Table 1. Parallelism between the mineralogical composition of clays and their surface and charge properties.

Mineralogical composition	Surface area	Charge properties
I. Smectites (also other 2:1 swelling clay minerals)	- Due to silicates - High - Internal (and external)	- Negative - High - Permanent (and nonpermanent)
II. Kandites + iron oxides	- Due to silicates and oxides - Intermediate - External	- Negative (and positive) - Low - Nonpermanent and permanent - Sensitive to the position of the ZPC
III. Gibbsite + iron oxides	- Due to oxides - Variable - External	- Positive and negative - Low - Nonpermanent - Very sensitive to the position of the ZPC

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MICROMORPHOLOGY OF ALFISOLS AND ULTISOLS WITH LOW ACTIVITY CLAYS

Hari Eswaran

ABSTRACT

The physical translocation of clay platelets from the upper part of the soils and their accumulation in the subsoil is a pedogenetic process entrenched in the concept of the argillic horizon. This article evaluates the micromorphological properties of Alfisols and Ultisols with low activity clays (LAC soils). LAC soils are those with a CEC of less than 16 me/100 g clay and which have characteristics of Oxisols except they also have an argillic horizon.

After a brief discussion of the clay translocation process, a review of the micromorphology of argillic horizons is made. The discussion of LACs attempts to show differences with non-LAC soils and draw limits with Oxisols. Finally the role of soil micromorphology in interpreting soil genesis is discussed.

INTRODUCTION

In the concept of Soil Taxonomy (USDA, 1975), Alfisols and Ultisols are soils which have an argillic horizon, or a horizon of illuvial accumulation of clays. It is apparent that a few pedologists still attempt to equate the previously termed "Podzolic soils" to these orders and employ a clay increase (as stipulated in Soil Taxonomy) to identify the soils. The reason for this has generally been the inability to identify the argillic horizon ss in the field (McKeague et al., 1978) coupled with the absence of reliable laboratory techniques to confirm the presence of illuvial

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clays. The ratio of fine to coarse or total clay is provided as an alternative test of an argillic horizon. However it is not emphasized in Soil Taxonomy that this is just a test and not conclusive proof, though it has been used in the latter sense by many. As a result of these problems, it is not incorrect to imagine that many soils may be misclassified.

Model profiles usually do not present difficulties for identification of the argillic horizon. Most problems are associated with soils which share properties of an Inceptisol or Oxisol. Another group of soils which present problems are those with an aquic soil moisture regime. In addition, unless the horizon is banded, argillic horizons in sandy or loamy-textured materials also present problems for field identification.

The technique of soil micromorphology was introduced by Kubiena (1938) and formalized by Brewer (1964). Since 1964, five international working meetings have been held, but it appears that these meetings have only served to create a new breed of pedologists whose basic interest is the microscopic and submicroscopic investigation of soils, without too much relation to the application of the technique to practical pedological problems. The consequence of this has been to divorce the rank and file pedologists from utilizing this valuable tool. In addition, older generation pedologists tend to shun away from the technique, as they have not kept pace with the development of that science.

Although the objective of this report is to review the micromorphological properties of the two orders of soils with low activity clays (LAC soils), soils with high activity clays are also considered to illustrate their differences. LAC soils are those with a cation exchange capacity (CEC) of less than 16 me/100 g clay. They also have mineralo-chemical properties of Oxisols, but in addition possess an argillic horizon. The 16-24 me soils frequently have a mixed mineralogy, though kaolinite may still be the dominant clay. Subordinate amounts of illite (more specifically commuted muscovite) and traces of vermiculite and chlorite may also be present. The

The mineralogy determines some of the micromorphological properties as will be shown later.

THE CLAY TRANSLOCATION PROCESS

Several conditions must be satisfied if clay is to accumulate in a subsurface horizon by vertical translocation. First the clay must be capable of movement. If clay platelets are cemented by sesquioxides, they must be dissolved prior to initiation of clay movement. In fact, this is a necessary process if a new phase of soil formation is to develop in oxic material. As has been indirectly shown by Lepsch et al (1977), organic acids are involved in reducing the iron, causing the cement to break up. If the platelets are not cemented then this process is not essential. This may be the case in a young soil or if recent material is deposited in older, weathered materials.

Clay in the surface horizon must be dispersed. The optimal pH conditions appear to be in the range 4.5 to 6.5 and dissolved electrolytes must be low to have a thick double layer. Conditions for dispersion are attained when the zero point of net charge (ZPNC) of the soil is distinctly different from the pH of the soil solution. These conditions need not prevail over the whole soil mass; frequently, they are only experienced in the immediate neighborhood of larger voids.

The media for clay translocation is water. Dispersion and translocation are favored if the moisture status of the soil alternates between wet and dry. Little or no dispersion and translocation occur if the soil is continuously wet or dry.

Ideal conditions for the formation of cutans or clayskins occur when the subsoil is dry or partly dry. The clay suspension moving down the profile stops in this part of the subsoil as the water is absorbed by the ped. During absorption of water, the ped surface acts as a filter and keeps clay out. The platelets are

then plastered on the ped surface or void walls. Clay films so formed must remain intact in order to be identified and this implied that ped- and bio-turbation processes must be minimal in subsurface horizons. If a layer of high pH and electrolyte concentration is present in the subsoil, clay accumulates by flocculation. Some clay plugs, papules etc., are formed by this process. 1/

Due to the number of processes which can retard development of the argillic horizon, soils with such a horizon have many physico-chemical and environmental properties in common. Like many pheonomena in nature, there is a modal condition and associated range. The modal profile is the one with the best expressed argillic horizon and presents few problems for identification; the problematic ones are those at the tail ends of the range.

MICROMORPHOLOGICAL EVIDENCE OF TRANSLOCATED CLAY

The most conclusive evidence for translocated clay is the presence of illuvation argillans in thin sections (Brewer, 1964). Many workers have employed this property either to show that clays have moved, or to place the soils in appropriate taxa.

In Canada, Coen et al (1966) showed that bands in certain sandy soils are due to translocated clay. Using micromorphological evidence, Acton and Arnaud (1963) separated the soils of the Weyburn Catena into those with and without translocated clay.

1/ The beta (β) horizon Bartelli and Odell (1960 a,b), a horizon of clay accumulation at the lowest part of the solum, where the solum is in contact with a calcareous substratum--is thought to be formed by this process. As clay accumulates by flocculation in the horizon, clayskins or cutans are not frequent and this has prompted a few workers to suggest other modes of formation.

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In the tropics, clay translocation has been shown by a number of workers (Laruelle, 1956, in the Congo; Rutherford, 1964 in New Guinea; Frei, 1964, in Ecuador; Bennema et al., 1970, in Brazil; Stoops, 1968, in the Congo; Eswaran, 1969; Eswaran & Sys, 1975; Eswaran & Banos, 1976, in Malaysia; Eswaran, 1972, in Nicaragua; Paramananthan et al, 1977 in Malaysia). Apart from this is a number of works published in other languages and local reports emphasize the relationship of the cutan to translocation.

In the United States, since the contribution of Allen (1930), many reports of argillans and their distribution in soils have been made (Frei & Cline, 1949; Hendricks et al, 1962; Grossman, 1964; Harpstead & Rust, 1964). Russian work includes those by Parfenova & Yarilova, 1958; Yarilova, 1963; Karpachevskiy and Shleynis, 1966.

Once it was established that clay moved in soils, the question was asked if the clay which moved was different from that which remained. Differences in color and texture between clayskin and soil material have been noticed by many workers (Mick, 1949; Kunze and Oakes, 1957; Frei, 1964). Buol and Hole, 1959, 1961; Rutherford, 1964; Grossman, 1964; Heil and Buntley, 1965, and Khalifa and Buol, 1968; reported differences in physical and chemical properties. Many of the differences in properties are related to the size of the clay which moves preferentially. This is essentially the fine clay (0.2 or 0.08 microns.). Consequently the relative amounts of fine clay in different parts of a profile is of importance as a parameter for identification of translocated clay. In Soil Taxonomy, it is now assumed that the argillic horizon is characterized by an accumulation of fine clay. Recent scanning electron microscropic observations (unpublished work of the author) however, suggests that this is not universally true. Argillans may be composed almost purely of coarse clay.

The amount of clay that has translocated is estimated from thin sections using a point count technique (Eswaran, 1969).

For statistical applications, composite thin sections are necessary (Grossman, 1964). As will be elaborated later, even this technique underestimates the amount of translocated clay in soils.

CONTRIBUTION OF TRANSLOCATION TO CLAY INCREASE IN ARGILLIC HORIZONS

This aspect of the argillic horizon has not received the attention it deserves, even though it is the basis of the argillic horizon concept Many indirect studies are reported and their conclusions range from those stating that all the clay increase is due to translocation, to those stating that the effect of translocation is minimal. The earlier opinions on this subject are unreliable since the soils were not defined with present day concepts. Simonson (1949) concluded that in the Red and Yellow Podzolic soils, the dominant process was one of clay formation, as the A horizon was too thin to have supplied the clay increase in the B horizon. The review of Simonson prompted studies on the genesis of these soils and experimental work was commenced at Earlham College, Indiana. Throp et al (1957), reporting on these studies concluded that they could demonstrate the movement of clay in soils columns. McCaleb (1959) disagreed with Simonson's findings and suggested that translocated clay formed a significant part of the clay increase. Bartelli and Odell (1960b) studying a related horizon--the beta horizon--concluded that a significant part of this horizon was made up of translocated clay. In addition to micromorphological evidence, they showed that clay in the beta horizon resembled, mineralogically, clay of the overlying B horizon and not the lower material. Allan and Hole (1968); Smeck et al (1968); Ranney and Beatty (1969); and Goddard et al (1973); all suggest that translocation could account for a significant part of the clay increase.

In all the above papers, no estimates have been made of the amount of translocated clay and *in situ* clay in the argillic horizon. Such estimates are necessary to decide if translocated clay is an important part of the total clay in the argillic horizon. Oertel (1968) analyzed the question and concluded that it is not. The first actual measurements were made by Brewer (1968) who concluded that translocated clay formed only an insignificant part of the total clay bulge. Some of these profiles may not have an argillic horizon as defined by Soil Taxonomy. Grossman and Fehrenbacher (1971) made similar studies and concluded that the amount of moved clay is sufficient to account for the computed decrements in clay for the eluviated horizons. Van Wambeke (1974), employing one of the profiles of Grossman and Fehrenbacher (1971), suggested--by purely mathematical computations--that the present-day eluvial horizon is too thin to account for the clay increase in the argillic horizon. Grossman and Fehrenbacher (1971) do not state if the moved clay would account for the clay increase in the B horizon.

The main difficulty with such computations is the uncertainty of the initial clay content of the present day A horizon prior to eluviation. As shown by Grossman and Fehrenbacher (1971) and Van Wambeke (1974), this may or may not resemble the present day C horizon. In order to arrive at estimates of moved clay in the argillic horizon, it is necessary to adopt assumptions and make computations as suggested by Van Wambeke (1972, 1974). Van Wambeke (*loc. cit.*) has several parameters which have great significance:

l = amount of clay lost from the A horizon per 100 g of parent material;

c' = clay content prior to eluviation; and

$k = l/c'$.

These parameters are derived from the present day A and B horizon values.

Calculations over a range of profiles give K values ranging from 0.1 to 0.8 and c' is always greater than C (C is the present-day clay content of the C horizon). Van Wambeke concluded that

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in a closed profile, c' should be equal to C; when this is not so, he explains the difference as being due to a much thicker A horizon, greater clay formation in the B horizon, or clay destruction in the A horizon, or all processes combined. These alternatives were considered because he assumes that the clay content prior to eluviation was uniform with depth. Many other workers who have dwelled on this problem have started with similar assumptions. This may be a source of error for later conclusions. The alternative is to assume an exponential decrease of clay with depth. In which case it follows that much of the clay increase can be allocated to the translocated clay from the A horizon which must have lost a tremendous amount of clay to attain the present-day value.

Micromorphological studies as employed by Brewer (1968) and Grossman and Fehrenbacher (1971) generally underestimate the amount of illuviation argillans. Translocated clay in microvoids are generally not recognized as argillans. Argillans (originally) which are assimilated into the matrix and today appear as plasma separations, are generally not estimated. Nettleton et al (1969) have discussed argillic horizons where the latter process is so active that morphological evidence of clay translocation has been obliterated. The process of obliteration is illustrated in the study of Osman and Eswaran (1973).

MICROMORPHOLOGY OF LAC ULTISOLS AND ALFISOLS

In the LAC soils, unlike those of mixed mineralogy as referred to earlier, the clay that moves is mineralogically not different from the clay of the s-matrix. This is because of the similarity of the mineralogical composition of all profile horizons. Consequently, the cutans in kaolinitic soils are invariably of kaolinite. However, thin section observations indicate that the cutans are generally paler in color and sometimes more brownish than the s-matrix. The pale colors may be due to two reasons. First a deferrification process in the A horizon is considered by Lepsch et al (1977) as a

necessary prerequisite to dissolve the iron cement and enable the clay to move. Secondly, it could be supposed that subsequent to cutan formation, water moving through the voids could remove some iron. The brownish coloration could be attributed to staining by organic matter. Pure kaolinite is white; so an argillan composed of only kaolinite without a sesquioxidic coating or organic matter staining is also white (Plate 1a). If hydromorphic conditions prevail, ferrous iron diffuses from the void wall into the cutan and later, perhaps, into the s-matrix. Oxidation of the iron causes staining of the cutan (Plate 1b).

Dissolution of the cement in the A horizon need not cause complete bleaching. The cutan may still have a reddish color (Plate 1c). The fact that deferrification may proceed subsequent to cutan formation is observed in some soils with reddish cutans. The mass of the cutans is red but there is a yellow layer adjoining the void wall. A more complex situation is where the cutan is composed of alternating layers of yellow and red material. Many kinds of interpretations have been given, but one cannot generalize on the origin of such forms in all soils.

Intensity of clay illuviation is indicated by the volume and thickness of the cutans. Soil Taxonomy requires 1% for an argillic horizon and there are few reasons to disagree with this value. In LAC soils especially, it is perhaps more relevant to determine if cutans indicate current translocation or not. This is particularly important in some soils which are polygenetic.

A good orientation of the cutanic material (Plate IIa,b) is generally an indicator that conditions favorable for destruction do not prevail in the soil. A loss of the orientation pattern--the extinction line becomes vague--is an indicator of cutan destruction. The cutan also develops a grainy aspect. Detailed studies of cutan destruction by ferrolysis has been made by Brinkman et al (1973). Consequently, one can make some statements on the state of illuviation from thin section observations.

Plate I.

a. Fabric of B2t horizon of Yasanthon series, Thailand. Most of the plasma is as argillans. X 80.

b. Higher magnification (x 120) of (a) to show the well-oriented nature of the cutans. The black line running across the argillans is the extinction line.

c. Fabric of the B2t horizon of Pak Chong series, Thailand. The matrix is clayey and most of the vughs have a coating of argillans. Some voids are completely filled and so there is an apparent continuity with the s-matrix. X 80.

d. As in (c) but with ordinary light. The contrast between cutanic and s-matrix plasma is more evident. Note the aggregated form of the plasma of the s-matrix, indicating an agglutinic SRDP of a former oxic.

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a
b
c
d

Many Oxisols in Central Africa and in the Amazon are formed on transported materials. Thin section studies of these reveal some interesting facts on cutans. Some of these soils have fragments of cutans incorporated in the s-matrix. This suggests that cutans may be well-cemented and during transport they move as an entity. Such forms in present-day Oxisols are one kind of papules and are interpreted as relict cutans. In some extreme cases there are other evidences for relict cutans. Gibbsite crystals on cutans is clear evidence that the cutan is relict (Plate Id). In some cases the cutan helps to cement the soil material. During transport, this moves as an entity. It is thus not strange to see pockets of soil material with cutans in a matrix of oxic material. Frequently the color and plasmic fabric of the cutan-cemented entity will indicate that it is foreign.

An interesting final question is if LAC soils can be differentiated from non-LAC soils from the morphology of the cutans. In some cases this is feasible, and if a scanning electron microscope (SEM) is available the nature of the cutanic material can be determined with some certainty. A cutan composed of illite generally shows high order interference colors. Other clays with a mica lattice show similar properties. Montmorillionitic cutans are more difficult to identify but can be differentiated with the SEM. For mixed mineralogy cutans, x-ray diffraction analyses are necessary to determine the composition.

S-Matrix

The optical properties of soils are largely a function of the mineralogy; consequently LAC soils can be differentiated from others. The plasmic fabric and the related distribution patterns are two of the parameters which may be used. It may be pointed out that the different macro-structural elements in the field are expressed as kinds of plasmic fabrics and related distribution patterns.

Plate II. (All at magnification X 80).

a. Fabric of B2t of Huai Pong series, Thailand. The white cutan is pure kaolinite.

b. Huai Pong series, Thailand. Clay plug (lower half of micrograph) stained with iron.

c. Laka series, Malaysia, showing argillan in sandy B horizon. The argillans bind the grains giving high stability to the soil material.

d. Oxic horizon from Zaire. The central void (black) with cutan is coated by a thin layer of gibbsite. Example of a relict argillic horizon.

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a
b
c
d

The normal related distribution pattern (NRDP) is a function of the texture of the soil (Eswaran and Banos, 1976) and consequently any kind of NRDP may be present in LAC soils. The specific related distribution pattern (SRDP) as defined by Eswaran and Banos (1976) is due to pedogenetic processes. In sandy soils, an intertextic and dermatic SRDP may arise through clay accumulation. The cutans occur as bridges between the sand grains in the former and as complete coatings in the latter. In the field, such argillic horizons have a friable consistence, and it is only with the use of thin sections that one can be sure if the intergranular plasma is due to illuviation. The Pina series in Puerto Rico has such a fabric. In sesquioxidic materials, the plasma tends to aggregate and a specific kind of DRDP (termed agglutinic) is formed. This SRDP is more frequent in Oxisols but as will be shown later, some Ultisols may also have this form. Non-LAC soils do not show this RDP.

The expression of the plasmic fabric is a function of the mineralochemical properties of the soil and it changes with evolution of the soil (Eswaran, 1972). Plasmic fabrics are morphological expressions of stresses within the soil mass and kaolinite-sesquioxidic materials have low COLE values and so stress orientations are weakly developed. In addition, free iron tends to mask the optical properties. As a result, asepic fabrics are frequent, and sometimes tend to isotic as the free iron content increases (Bennema et al, 1970 and Eswaran, 1972).

Other features

Plinthite, petroplinthite and lithoplinthic horizons may be present in LAC soils. All these have specific micromorphological properties and a brief discussion of them is included in this workshop.

Hydromorphic LAC soils have several features, most of which are not unique to LAC soils. The more frequent micropedological features are nodules and concretions and the properties of some of these are considered by Eswaran et al (1977).

MICROMORPHOLOGICAL INTERPRETATION OF THE GENESIS OF LAC SOILS

A study of the micromorphology of LAC soils in combination with other mineralo-chemical and physical properties, with an appreciation of the geomorphology of the area, provides some insight into the history of soils. Thin sections are most valuable in such studies as "soil formation leaves its imprints on the soil."

From micromorphological studies of the soils of Brazil, Malaysia, and Thailand, three situations may be envisaged with respect to soils with argillic horizons. The first case is where the profile is autochthonous and the argillic horizon lies above or continues into the saprolite. Profile BR6 (c.f. Brazil tour guide) is an example.

The second case is where an argillic horizon forms in an oxic material and generally the oxic material is reworked and transported. Many soils of the Khorat Plateau of Thailand are examples and the Pak Chong Series (c.f. Thailand tour guide) is perhaps the best. Plate IIc and d are micrographs of the argillic horizon in this soil and they show the excellent development of argillans. Under ordinary light (Plate IId) an agglutinic SRDP is clearly seen, which indicates that the material prior to clay translocation is oxic. Further, though the profile is deep with a "Pale" clay distribution pattern, horizons with argillans are not very deep. This is another indication that illuviation is recent and that the argillic horizon is forming in an oxic material.

The third case is where an oxic horizon overlies an argillic. The soil is bisequal and the Coto Series in Puerto Rico is a good example. Thin sections of the oxic show remnants of cutans while in the underlying argillic, good argillans are present. These kinds of interpretations can only be made with micromorphological studies in combination with other techniques.

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CONCLUSION

LAC soils have some distinct properties which differentiate them from their non-LAC counterparts. As in non-LAC soils, the degree of expression of the translocated clay varies. If a study is done on Bt horizons, as in the study of McKeague et al, (1970), the conclusions may be similar--only about 50% of the so-called argillic horizons may show identifiable cutans. The problem is not with identification of cutans or the definition of the argillic horizon, but is mainly related to application of the definition in the field. The subject of the argillic horizon will continue to be debated until pedologists learn to monitor them with micromorphology analysis.

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THE MEASUREMENT OF SURFACE CHARGE CHARACTERISTICS OF LOW ACTIVITY CLAY SOILS

G. P. Gillman and P. Bakker

Surface charge characteristics of soils containing significant quantities of kaolinite and/or iron and aluminum oxides are different from those where the clay fraction consists predominantly of 2:1 type minerals. In the former case, surface charge varies with such properties as pH, ionic strength, and ionic valency of the surrounding electrolyte, whereas in the latter case, the surface charge is relatively independent of such properties. Most soils contain variable amounts of both mineral types, currently referred to as constant surface potential and constant surface charge minerals, respectively, but many of the methods used for determining surface charge characteristics are suitable for the constant surface charge minerals only. This is particularly true for the ammonium acetate (pH 7) (Soil Survey Staff, 1972) method for estimating the cation exchange capacity (CEC), where results from this determination are used at a high level in the American Soil Taxonomy system to distinguish soils, some of which are dominated by constant surface potential minerals. This method estimates only the amount of surface negative charge which is capable of exchanging cations, and the estimation is performed at an artificially high pH, at an undefined ionic strength, using a monovalent cation, and an anion which probably causes an overestimation of actual negative charge by a specific adsorption mechanism.

An alternative procedure that is receiving an increasing use for estimating what is called the effective cation exchange capacity (ECEC), assumes that this quantity is the sum of the basic exchangeable cations and the hydrogen plus aluminum extracted by KCl. Unfortunately, as with the NH_4OAc method, there is no estimation of any

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positive surface charge which would be effective in exchanging anions. Also, all basic cations extracted are assumed to be exchangeable, which is not always the case, but more importantly, all of the acidic cations removed from the soil by 1N KCl are also assumed to be exchangeable, and there is evidence to show that such an assumption is not valid for oxidic soils.

It is the purpose of this paper to propose another method for examining the surface charge characteristics of soils, where both negative and positive surface charges are estimated in a simple and inexpensive manner, under conditions approximating those expected in the field. Results of using this method on 54 selected Alfisol, Ultisol, and Oxisol subsoils from Australia, Brazil, Malaysia, South Africa, Puerto Rico, and Colombia, are compared with those obtained by the ECEC method. It is proposed that the new method will be applicable to all soils, whether dominated by constant surface potential or constant surface charge minerals, and also to surface soils, so that a separate determination for classificatory and for agronomic purposes is obviated.

EXPERIMENTAL

Soil pretreatment

Since all soils entering Australia are heated overnight at 105°C to satisfy quarantine requirements, the Australian soils were treated in a similar manner.

Analytical procedures

Basic exchangeable cations were obtained by extracting 5 g of less than 2 mm soil with 5 x 20 ml portions of 1 M NH_4OAc (pH 7.0) using a centrifuge, and determining Ca, Mg, K, and Na on the combined extract by atomic absorption spectroscopy.

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The ECEC was determined by summing the basic exchangeable cations obtained above with the H + Al extracted with 1 N KCl. In the latter estimation, 10 g of less than 2 mm soil were placed in a filter funnel and leached with 100 ml of 1 N KCl over a 2-hour period. The extract was titrated to pH 8.5 with 0.1 M NaOH to obtain H + Al, then 10 ml of 1 M KF was added, followed by a back titration to pH 8.5 with 0.1 M HCl to allow estimation of extracted Al.

For the newly proposed method, 2 g of less than 2 mm soil was placed in a 30 ml preweighed plastic centrifuge tube with 20 ml of 0.1 M $BaCl_2$ and shaken end over end for 2 hours. After centrifugation, the supernatant solution was retained for analysis of Ca, Mg, K, Na, and Al. The soil was washed three times with 0.002 M $BaCl_2$, with a 1-hour shake between centrifugations. After the final centrifugation and decantation, the tubes were reweighed to estimate the volume of entrained 0.002 M $BaCl_2$. Then 10 ml of 0.005 M $MgSO_4$ was added and the tubes shaken for 1 hour. The conductivity of the suspension was then adjusted to that of a 0.0015 M $MgSO_4$ reference solution by the addition of more 0.005 M $MgSO_4$, or water, and this was repeated following overnight shaking. The tubes were reweighed to estimate the volume of extra 0.005 M $MgSO_4$ or water added and after centrifugation, Mg and Cl were determined in the supernatant solution. CEC was determined from the difference between the Mg added and that found in the final solution, and anion exchange capacity (AEC) estimated from the Cl found in this same solution, after allowing for the entrained 0.002 M $BaCl_2$. A full description of the development of this method is being prepared for publication. It is essentially a modification of Bascomb's (1964) compulsive exchange method, where Mg exchanges with Ba when the latter is precipitated as $BaSO_4$.

An estimate of variable charge was obtained in a simple manner by repeating the compulsive exchange method (without determining the basic exchangeable cations or extractable Al) with the modification that the pH of the final 0.002 M $BaCl_2$ was brought to pH 7 with a saturated $Ba(OH)_2$ solution before the final shake. This was readjusted before centrifugation, removal of the supernatant, and addition of the 0.005 M $MgSO_4$ solution.

For pH determination, 2 g of less than 2 mm soil were placed in a 30 ml plastic centrifuge tube with 10 ml of water and after a 1-hour end over end shake, the pH was recorded. After the addition of 0.5 ml of 2 M KCl and a further 1-hour shake, the pH was again determined. Δ pH was recorded as $pH_{KCl} - pH_{H_2O}$.

RESULTS AND DISCUSSION

As it is impractical to tabulate results for 54 soils, such results will be reported in the form of figures and regression tables.

The ECEC and compulsive exchange methods were highly correlated (Fig. 1) and this is not unexpected, as both of these methods give a realistic measure of the ability of soil to retain cations in the field.

The 1 M NH_4OAc and 0.1 M $BaCl_2$ reagents extracted similar amounts of basic exchangeable cations, and results for Ca, Mg, and K are shown in Fig. 2. This result is somewhat surprising in view of the simplicity of the $BaCl_2$ extraction procedure. In addition, the amounts of Al extracted by 1 M KCl and 0.1 M $BaCl_2$ were also well correlated (Fig. 3), and this makes the latter extractant an attractive reagent for removing basic and acidic metal cations in a single step.

Many soils possessed a significant amount of positive charge as measured by the proposed method. Most AEC values were greater than 1.0 milliequivalent per 100 g clay. When AEC values were plotted against CEC (Fig. 4), the samples lying to the left of the x=y line represent the highly oxidic samples of this study, i.e. where the clay mineral fraction is dominated by gibbsite/haematite/goethite.

When the variable charge, found by the difference in the compulsive exchange method measured at soil pH and pH 7.0, was expressed as a percentage of the former, the oxidic soils mentioned above showed increases of about 100%, whereas the remainder fell between

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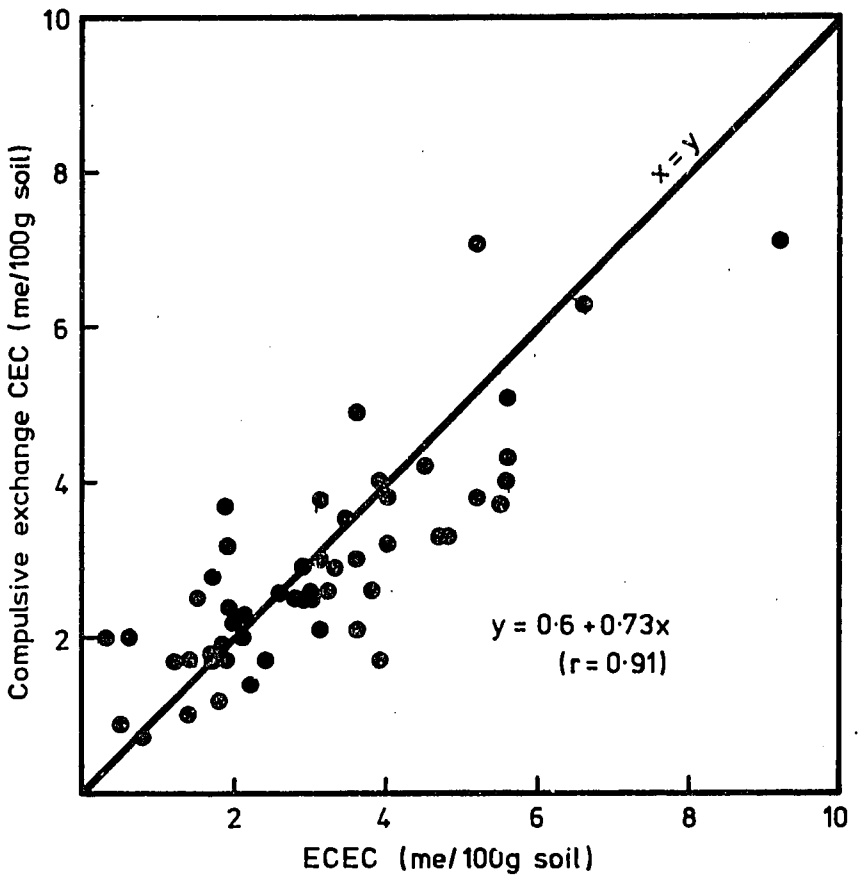

Fig. 1. Comparison between effective cation exchange capacity (ECEC) and compulsive exchange cation exchange capacity.

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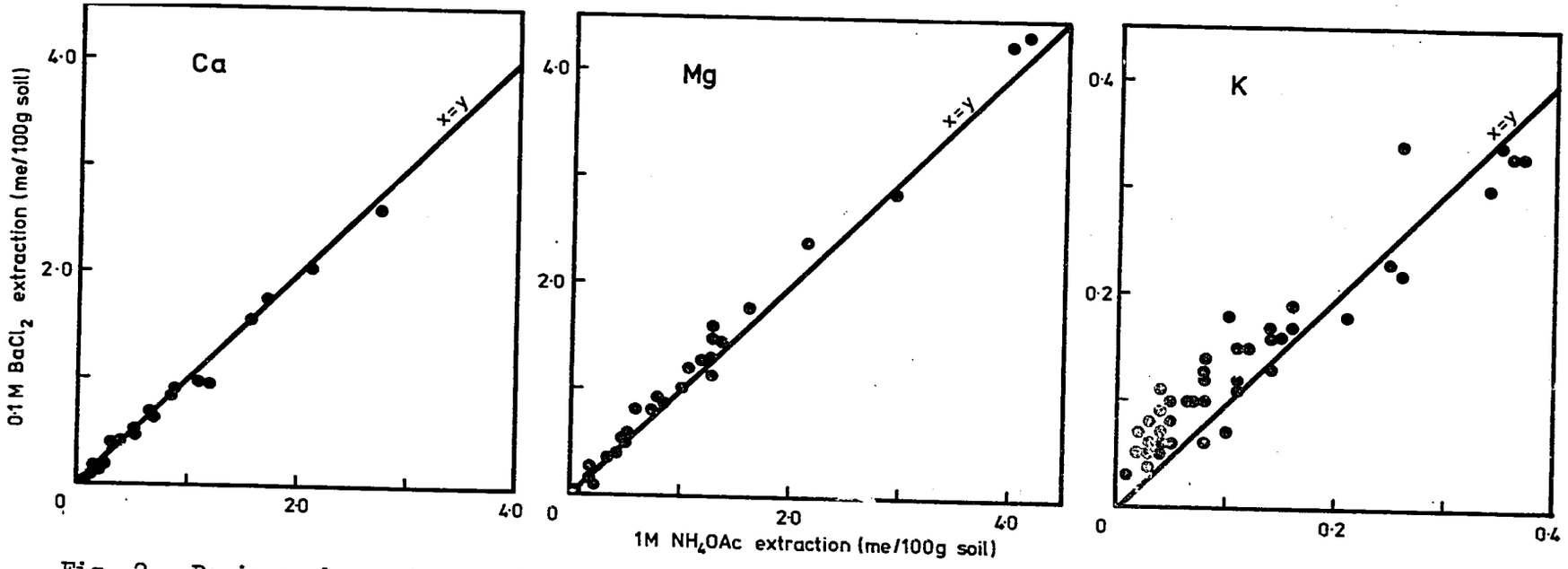

Fig. 2. Basic exchangeable cations extracted by 1 M NH_4OAc (pH 7.0) and unbuffered 0.1 M $BaCl_2$.

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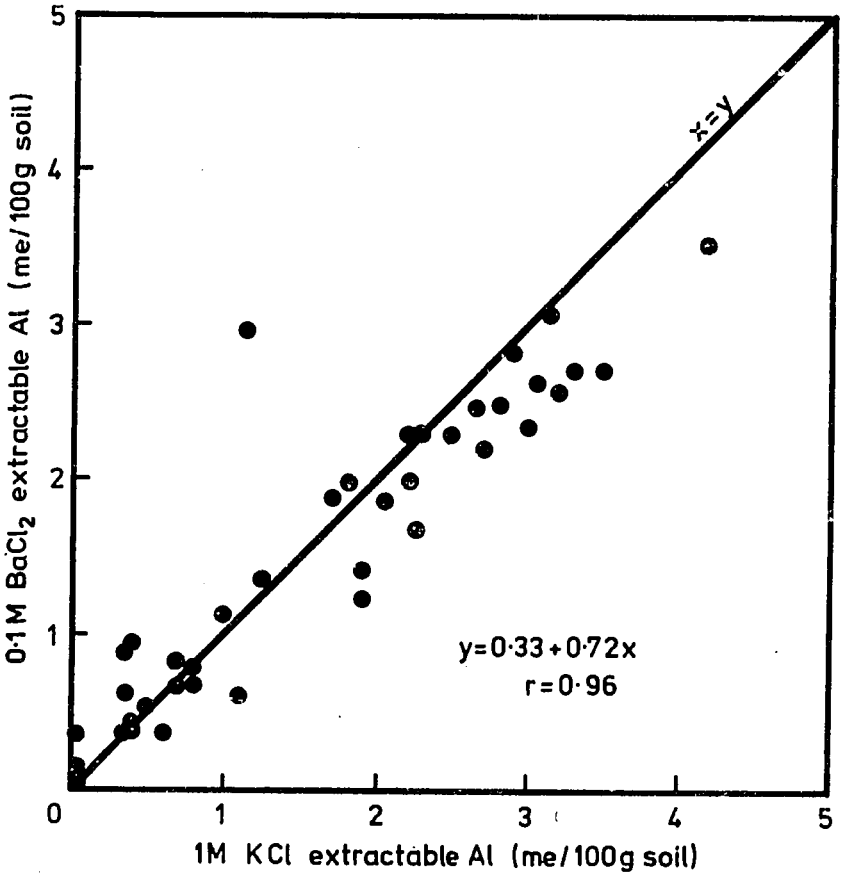

Fig. 3. Al extracted by 1 M KCl and 0.1 M $BaCl_2$.

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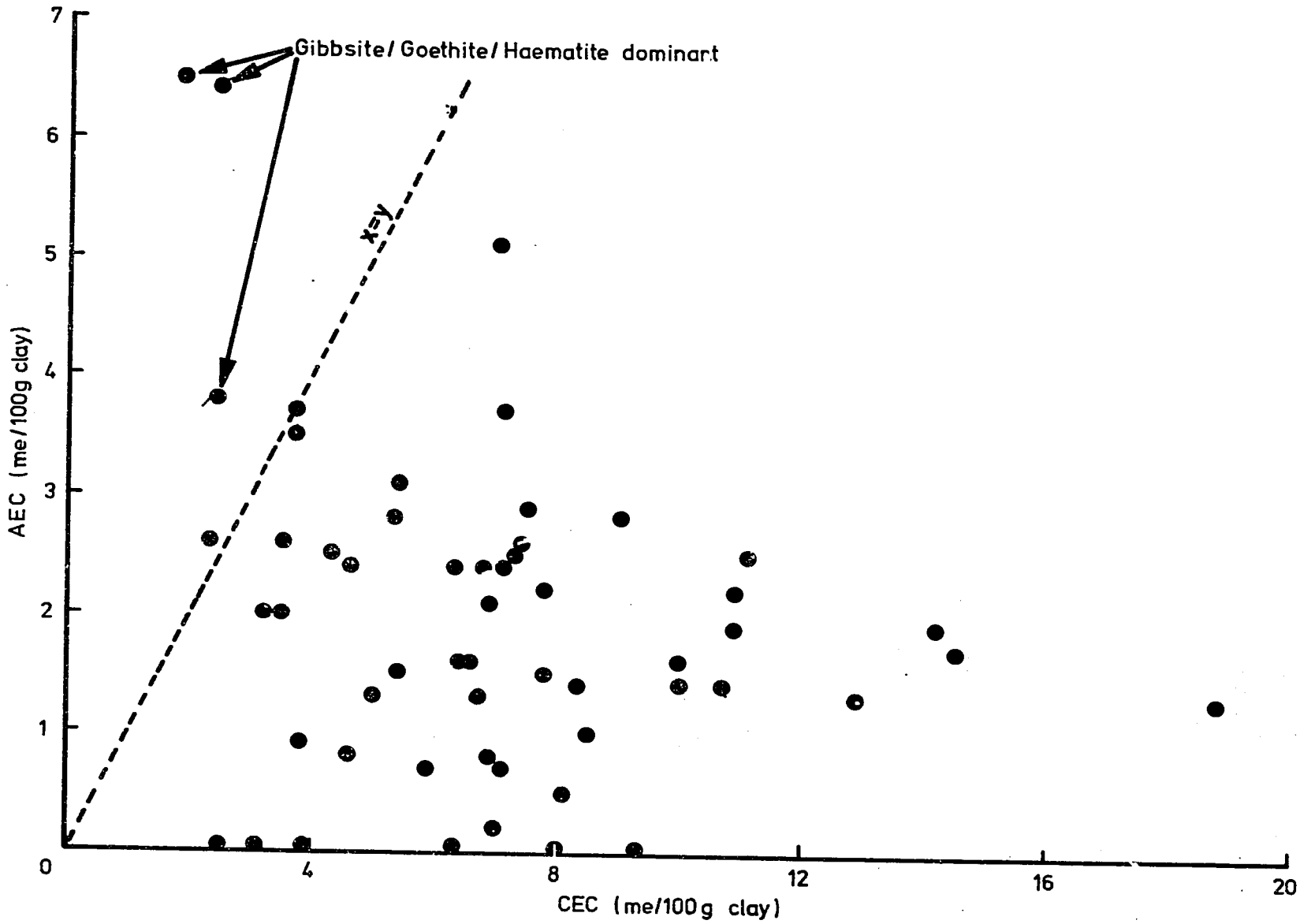

Fig. 4. AEC versus CEC as determined by the compulsive exchange method.

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3 and 50%. This is a useful result as it clearly distinguishes those soils dominated by oxide minerals from those consisting of predominantly kaolinitic material.

The plot of Al extracted by 1 M KCl versus pH_{KCl} (Fig. 5) showed a rapid increase in Al with decreasing pH. There was no Al extracted when the pH_{KCl} was greater than 4.5. An examination of data for a range of Brazilian low activity clay soils reveals the same relationship.

GENERAL DISCUSSION

The ECEC analysis obviously results in a more realistic analysis of measuring cation retention in that an attempt is made to estimate the cations actually present on the exchange complex. The difficulty is, however, that the basic cations extracted might not all be exchangeable. Tucker (1975), for instance, distinguishes primary and conditional basic exchangeable cations by using sequential extractions with various reagents. Also, in a saline soil, the soluble cations would have to be removed first, and there are objections to using solvents such as alcohol for doing this, when significant quantities of constant surface potential colloids are present. Such solvents tend to decrease surface charge which would cause some exchangeable cations to be removed. Removal of soluble cations with water allows the possibility of hydrolysis of exchangeable cations. These objections could be of minor importance, but a more serious consideration should be given to the assumption that aluminum removed from oxidic soils by 1 M KCl is exchangeable. Amedee and Peech (1976) showed that the aluminum extracted by KCl from Oxisols and Ultisols from Puerto Rico and Brazil was due in part to mineral solubility, and it therefore follows that the pH of the extraction medium would influence the amount of Al removed. In this present study, the soil pH values obtained were much lower than expected, and we now believe that this is due to sample history. In fact, closer inspection has shown that prolonged storage causes a decrease in pH, which is then further accentuated by heating at

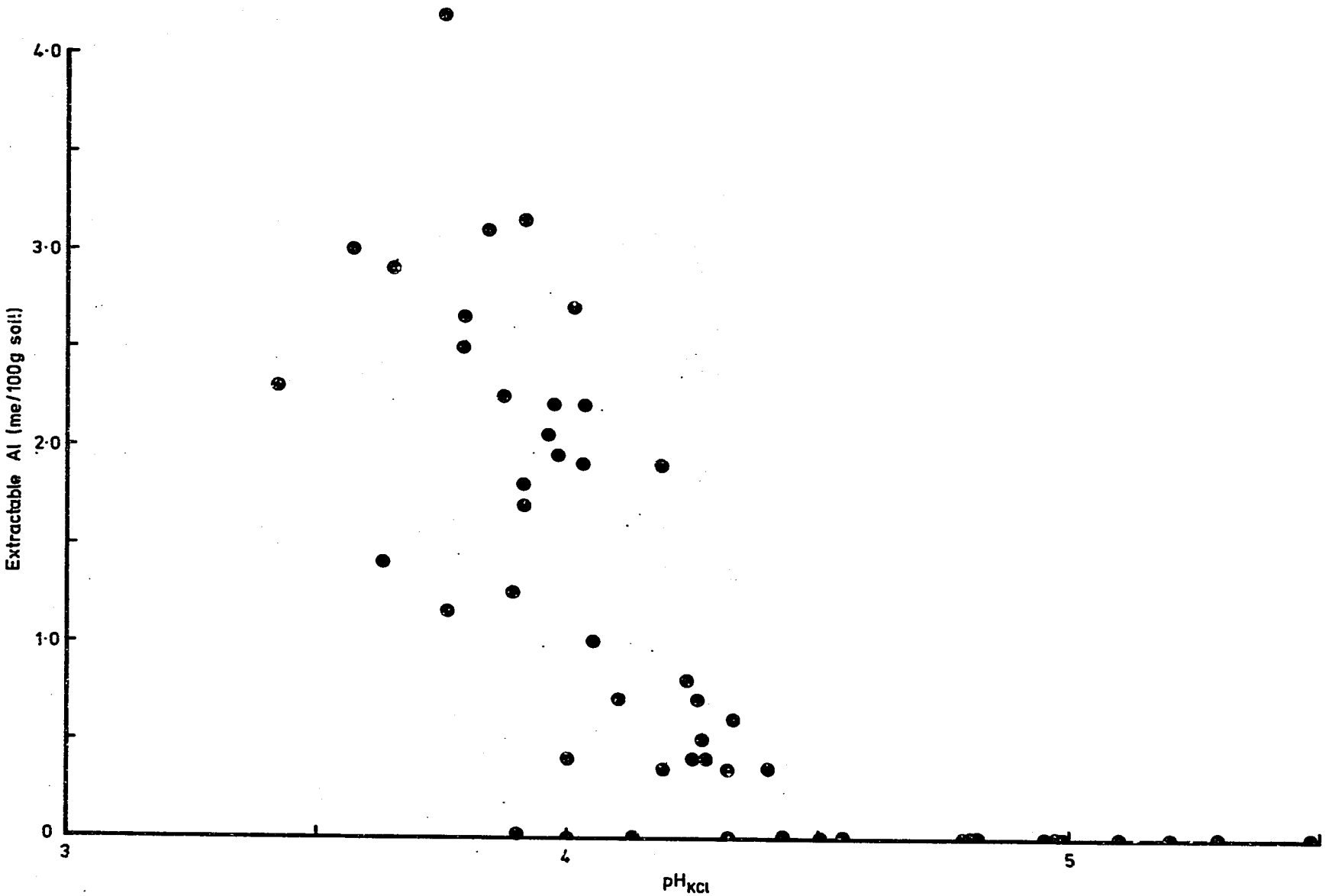

Fig. 5. Aluminum extracted by 1 M KCl versus pH_{KCl}.

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105°C. This is strikingly illustrated in Table 1, which summarizes the pH values for three surface and three subsurface soils before and after prolonged storage, and then followed by heat treatment.

The effect on pH of drying and heating has been reviewed by White (1969) where acid soils were usually found to decrease in pH following such treatments. It is interesting that the fall in pH is as severe in the subsurface as in the surface soils, indicating that organic matter is not involved. There is the intriguing possibility that there is a small but steady transformation of the oxide clay during prolonged storage, which is more rapid upon heating, causing an alteration to some particle surfaces. Such a change would be reflected in surface charge characteristics which regulate soil pH and the retention of ions. Also included in Table 1 are the amounts of Al extracted by KCl, and it is seen that as the pH fell, increasing amounts of Al were removed in solution. It is therefore suggested that these findings be further investigated in view of the obvious implications of comparing analytical results, such as ECEC for soils subjected to different storage and heat treatments.

In developing the proposed compulsive exchange method, the aim was to devise a simple and inexpensive method of determining meaningful surface charge characteristics which would be applicable to all soils. Such characteristics include the CEC and AEC, both determined under conditions approximating those present in the field. One should also have an estimation of the amount of negative charge generated, or positive charge neutralized by raising the pH, and it would be useful to predict the effect of salt concentration on surface charge. Not all of these values might be of immediate interest to the soil taxonomist, but the information is of interest to chemists and physicists, and a single method is more desirable than having to choose between a number of alternatives.

We believe that the proposed compulsive exchange method fulfills these objectives. The soil is equilibrated with a dilute, unbuffered electrolyte so that field pH is approximated. Then the ionic strength of the electrolyte can be made equal to that of the soil solution (I)

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Table 1. The effect of storage and heating (16 hours at 105°C) on pH and 1 M KCl-extractable Al for a range of north Queensland surface and subsurface soils.

Sample	Depth	Orig. pH	After storage pH		After storage Al	Storage + Heating pH	Storage + Heating Al
	(cm)				(me/100g)		(me/100g)
Acrohumox	0-10	5.4	(10 yrs)	4.8	0.94	4.3	5.60
Haplustox	0-10	5.7	(8 yrs)	5.0	0.59	4.5	1.10
Acrohumox	0-10	5.2	(9 yrs)	4.5	2.24	4.2	3.05
Acrohumox	90-120	5.0	(10 yrs)	4.7	0.07	4.5	0.35
Haplustox	105-120	5.6	(8 yrs)	4.9	0.37	4.4	0.70
Eutrustox	150-180	6.4	(8 yrs)	5.8	<0.05	5.1	<0.05

by measuring the electrolytic conductivity (EC) of a 1:5 soil:water suspension and applying the formula (Gillman and Bell, 1978)

$$I = 0.0446\ EC - 0.000173 \quad r = 0.980.$$

For routine determinations, we have proposed an ionic strength of 0.006, which is obtained by using 0.002 M $BaCl_2$ and 0.0015 M $MgSO_4$.

Thus CEC and AEC are determined under meaningful conditions, and their variation with pH and ionic strength is found by a simple alteration to the equilibrating solutions. In addition, basic exchangeable cations can be estimated in a simple extraction, though the objections raised above to the presence of soluble cations--objections common to all extractive methods--must be borne in mind. Our results show that 0.1 M $BaCl_2$ extracts amounts of Al similar to that extracted by 1 M KCl.

An interesting feature of this study was the generally small increase in CEC brought about by raising the pH to 7.0; as mentioned earlier, it was between 3 and 50% except for the three oxidic soils, where CEC was doubled. Only small increases should be expected for

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soils where the dominant clay mineral is kaolinite, and the proposed method has rightly identified this. The variable charge as measured by the difference between acetate CEC and ECEC (Sanchez, 1976), using calculated acetate CEC values obtained from the T-Value published in the Soil Study Tour Guide (1977), is much greater for the Brazilian soils, indicating that the acetate ion increases the surface negative charge by being chemisorbed.

CONCLUSION

In view of the failure of the ammonium acetate method to obtain meaningful CEC values for soils containing significant quantities of constant surface potential minerals, and of the limitations of the effective CEC method (as well as the NH_4OAc method) in measuring only negative charge, it is suggested that serious consideration be given to the proposed compulsive exchange method for measuring the surface charge characteristics of all soils.

We would expect that if a sufficiently representative selection of soils were assembled, those dominated by constant charge minerals would have high CEC and very low AEC values; those dominated by oxides (such as goethite, haematite and gibbsite) would have low CEC and relatively high AEC values; and those containing mainly kaolinitic minerals would have intermediate CEC and AEC values. Unfortunately, the heat treatment required for soils entering Australia precludes the assemblage of an international selection of soils in this country.

Although Sertsu and Sanchez (1976) have reported that heating to 200°C has no detrimental effect on soils, results reported here have shown that storage and heat treatment could have an important influence on the value calculated for ECEC.

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LOW ACTIVITY CLAY ULTISOLS AND ALFISOLS IN THAILAND

L. Moncharoen and P. Vijarnsorn

ABSTRACT

Ultisols are among the most common soils in Thailand. They developed in various parent materials, landforms, climates, and vegetation. Alfisols, in contrast, are restricted to a tropical savanna climate and basic parent materials. In upland areas, soils classified in the great group Paleudults are generally found in the Peninsula and Southeast coast regions, and those classified as Paleustults, Plinthustults, Haplustalfs, and Plaeustalfs are in other regions. In the lowland rice paddies, Paleaquults, Plinthaquults, Tropaqualfs, and Tropaquults are common soils. Natraqualfs are found in the Northeast Plateau, but in lesser extent.

According to morphological and pedogenic studies of most profiles in these orders, there is a distinct translocation of illuviated clay in the B horizon. Most Ultisols in Thailand are low in cation exchange capacity (CEC), percent base saturation (BS), pH, and available P and K. The most common clay mineral is kaolinite. Although the CEC and clay-type of Alfisols are almost the same as that of the Ultisols, they have a medium to high BS and relatively high pH. Many profiles of the Ultisols contain a lateritic or ironstone concretionary layer above a mottled clay or plinthite layer.

As far as Soil Taxonomy is concerned, better criteria should be developed and existing criteria revised to fill gaps in classification.

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INTRODUCTION

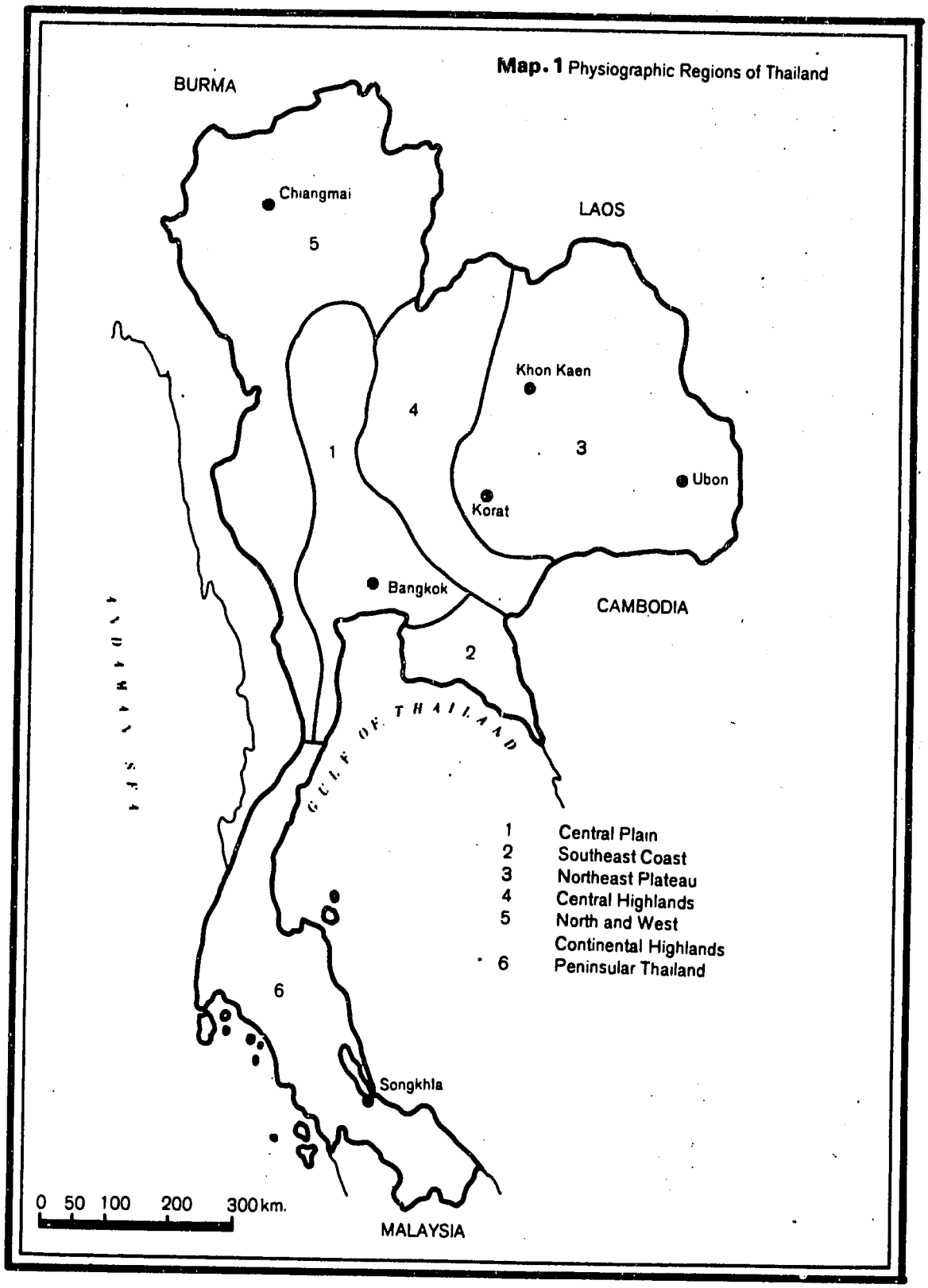
Soil classification in Thailand has initially followed the Great Soil Group system formulated by the Soil Conservation Service of the United States Department of Agriculture (Soil Survey Staff, 1975). This system was modified for tropical conditions by Dudal and Moormann (1964) and Rojanasoonthon (1966). It has worked reasonably well, but due to vague definitions of the groups there is some overlap and thus some soils are difficult to classify. An attempt has been made to apply the new soil classification system (7th Approximation and Soil Taxonomy) in Thailand. Early work concerned the classification of soils already mapped at the great group level and of individual profiles at the family level. As more information became available, we intended to apply the new system of soil classification to parallel the old one. At present, all the typifying pedons of soil series (about 300) have been classified for the family level. The correlation works and the revision of series descriptions to fit the new classification system continues.

Thailand lies in a tropical monsoon zone of Southeast Asia between latitudes 5° and 21° north. The total area of the country is approximately 513,982 sq km. It borders Laos to the north and east, Burma to the north and west, and Cambodia to the south and east. Peninsular Thailand is bounded to the south by Malaysia.

ALFISOLS AND ULTISOLS IN THAILAND

Distribution

Moormann and Rojanasoonthon (1968) proposed a broad physiography of Thailand to include six regions (Map #1): Central Plain, Southeast Coast, Northeast Plateau, Central Highlands, North and West Continental Highlands, and Peninsular Thailand. According to a general soil map at the suborder level (Map #2), the Ultisols and Alfisols occupy approximately 276,223 sq km or 53.7% of the country's total area. Based on these figures, Ultisols are the most extensive soils, occurring under



Map.1 Physiographic Regions of Thailand

(After Moormann and Rojanasoonthon, 1972)

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different climate conditions, geomorphic regimes, parent materials, and vegetation. Ultisols occupy approximately 221,125.6 sq km (43.03% of the total area). Alfisols are less extensive, and mostly occur on semi-recent terraces in the northern portion of the Central Plain, the Central Highlands, and the North and West Continental Highlands (in areas associated with limestone). Alfisols dominate the southern part of the Northeast Plateau where the area is also dominantly underlain by calcareous clastic rocks.

Occurrence and characteristics of LAC Ultisols and Alfisols

Although Ultisols and Alfisols are widespread throughout Thailand, they all do not consist of low activity clay (LAC), a clay which includes not much more than kaolinite and has a CEC of less than 16 me/ 100 g clay. The occurrence of LAC soils is mostly restricted to certain landforms, parent materials, and climatic conditions. I will describe the LAC Alfisols and Ultisols in order of physiographic regions, and I will discuss relationship of these soils to geomorphology, geology, climatic conditions, vegetation, and land use. Major characteristics of these soils at the great group level are summarized in Table 2.

Central Plain. The Central Plain is a large basin extending north 450 km from the gulf of Thailand. It occupies approximately 61,478 sq km (about 12% of the country). This basin started to form in the Tertiary period as the Northeast Plateau was uplifted. It has been filled with a very thick layer of Quarternary deposits. The major part of Central Plain consists of semi-recent and recent alluvial deposits. Recent and semi-recent fresh-water sediments are associated with deltas of major rivers, such as the Chao Phraya river system and Mae Klong system. Marine and brackish sediment are found near the gulf of Thailand and near Bangkok.

Alfisols are the most extensive soils in the Central Plain. However, LAC Alfisols are not so significant. Most of the soils contain a mixture of clay minerals derived from various types of rock.

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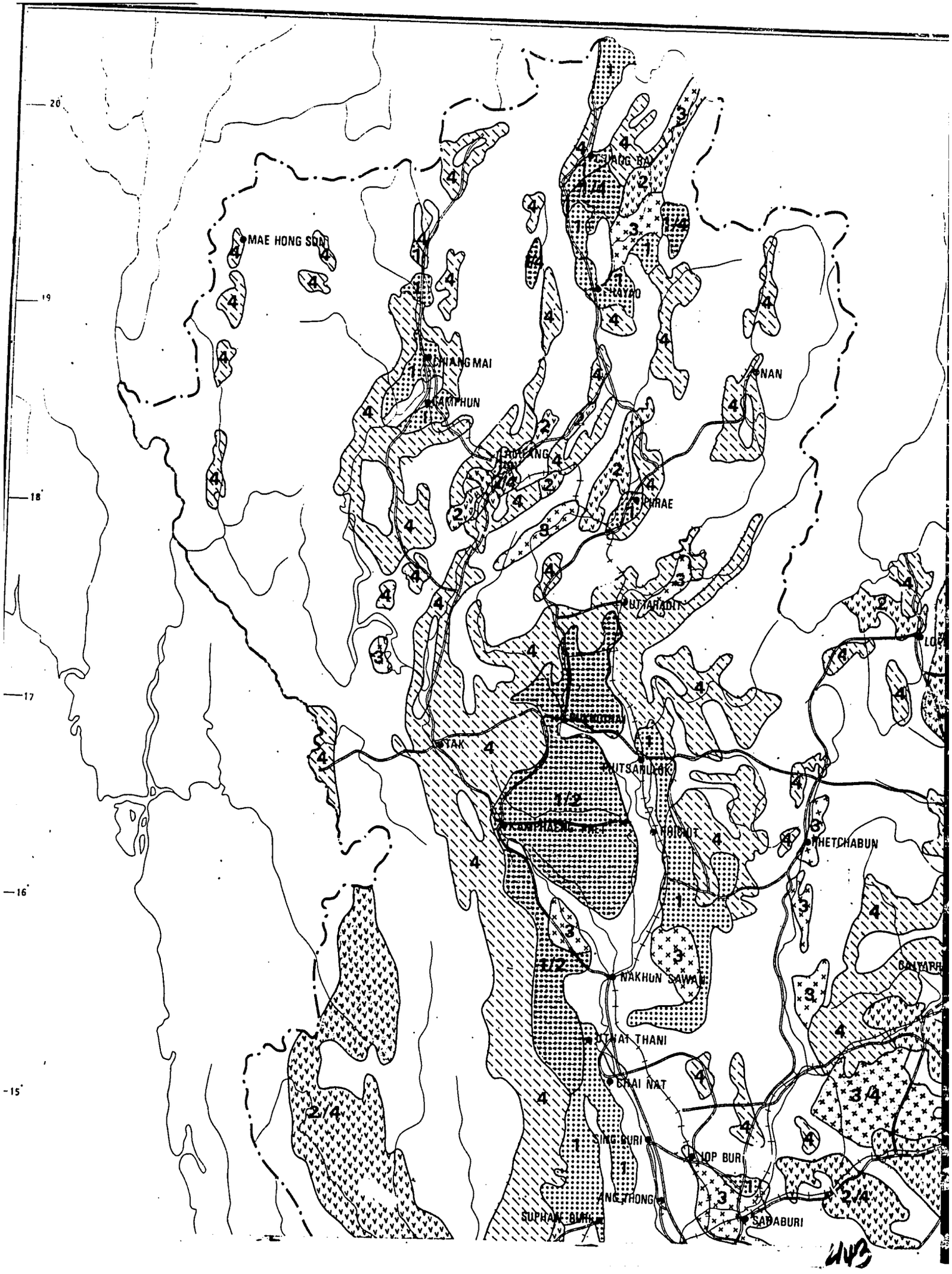
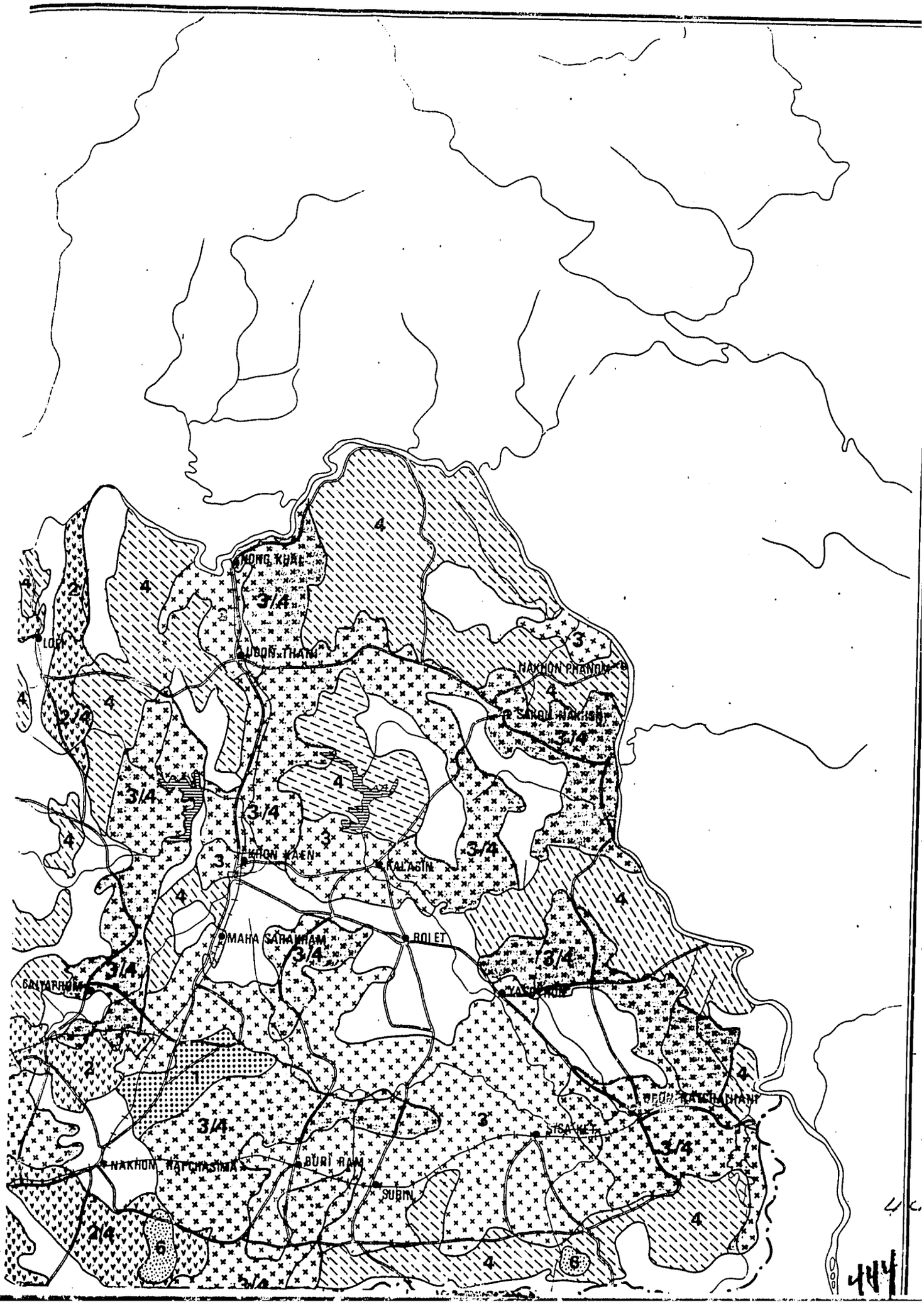

20
19
18
17
16
15
MAE HONG SON
CHIANG MAI
LAMPHUN
PHRAE
NAN
UTTARADIT
TAK
PHITSANULOK
PHETCHABUN
NAKHON SAWAN
UTHAI THANI
CHAI NAT
SING BURI
LOP BURI
SUPHAN BURI
SARABURI

443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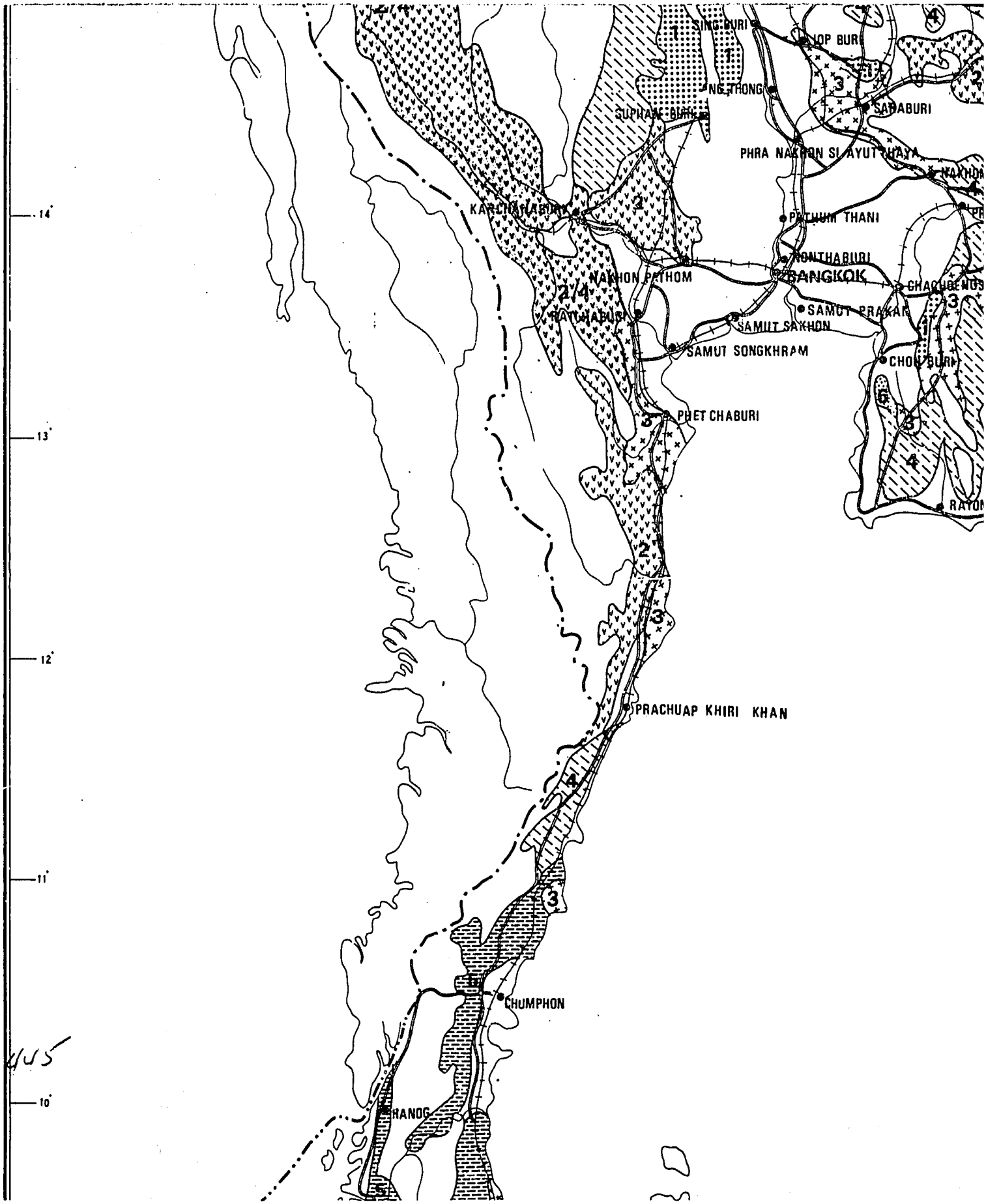
UBON THANI
NAKHON PHANOM
SAKON NAKHON
KHON KAEN
KALASIN
MAHA SARAKHAM
ROI ET
YASOTHON
UBON RATCHATHANI
SISAKET
NAKHON RATCHASIMA
BURI RAM
SURIN
4
3/4
3
2
2/4
1
6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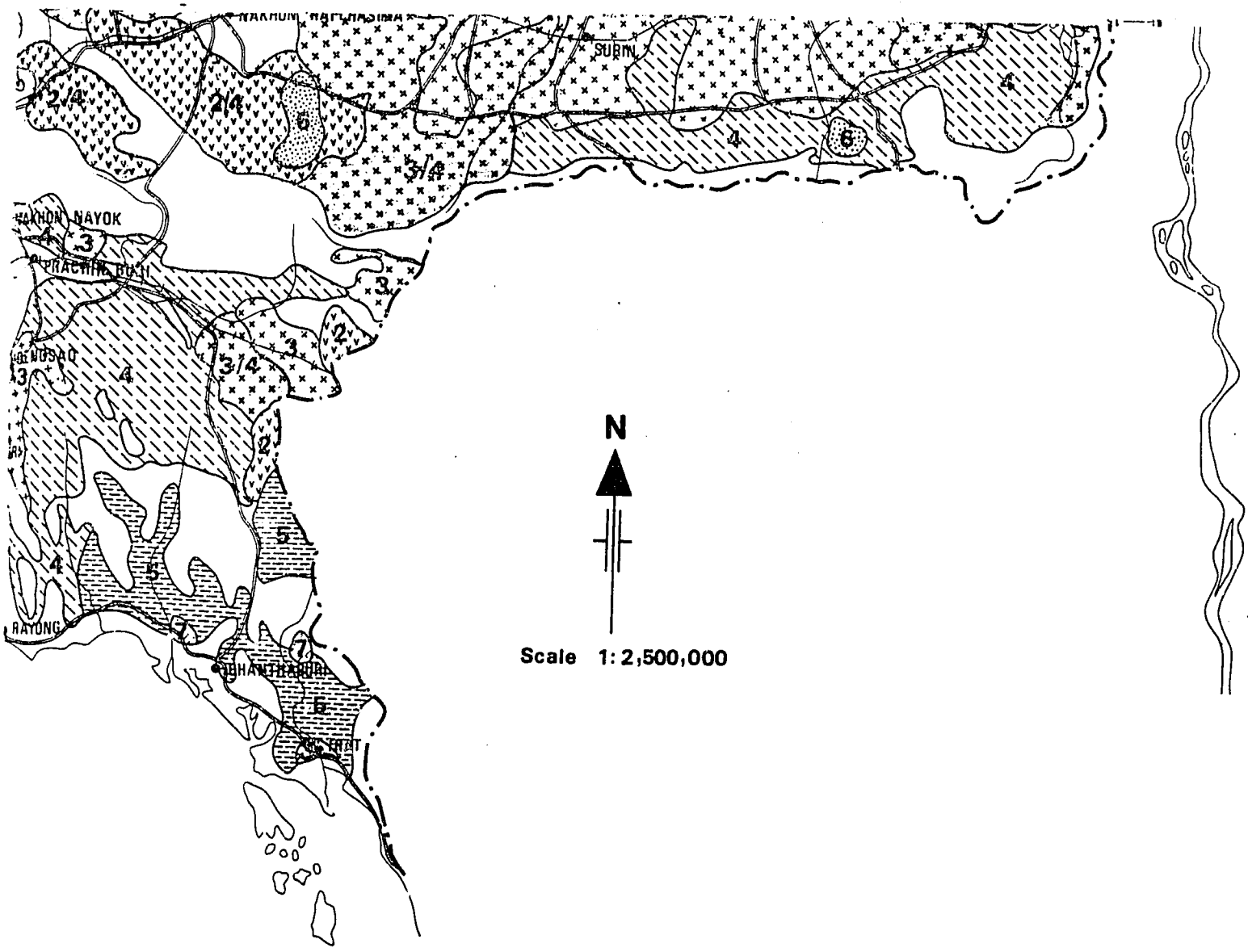
LOP BURI
ANG THONG
SUPHAN BURI
SARABURI
PHRA NAKHON SI AYUT HAYA
KANCHANABURI
PATHUM THANI
NONTHABURI
BANGKOK
NAKHON PATHOM
RATCHABURI
SAMUT PRAKAN
SAMUT SAKHON
SAMUT SONGKHRAM
CHON BURI
PHET CHABURI
PRACHUAP KHIRI KHAN
CHUMPHON
RANOG
14°
13°
12°
11°
10°

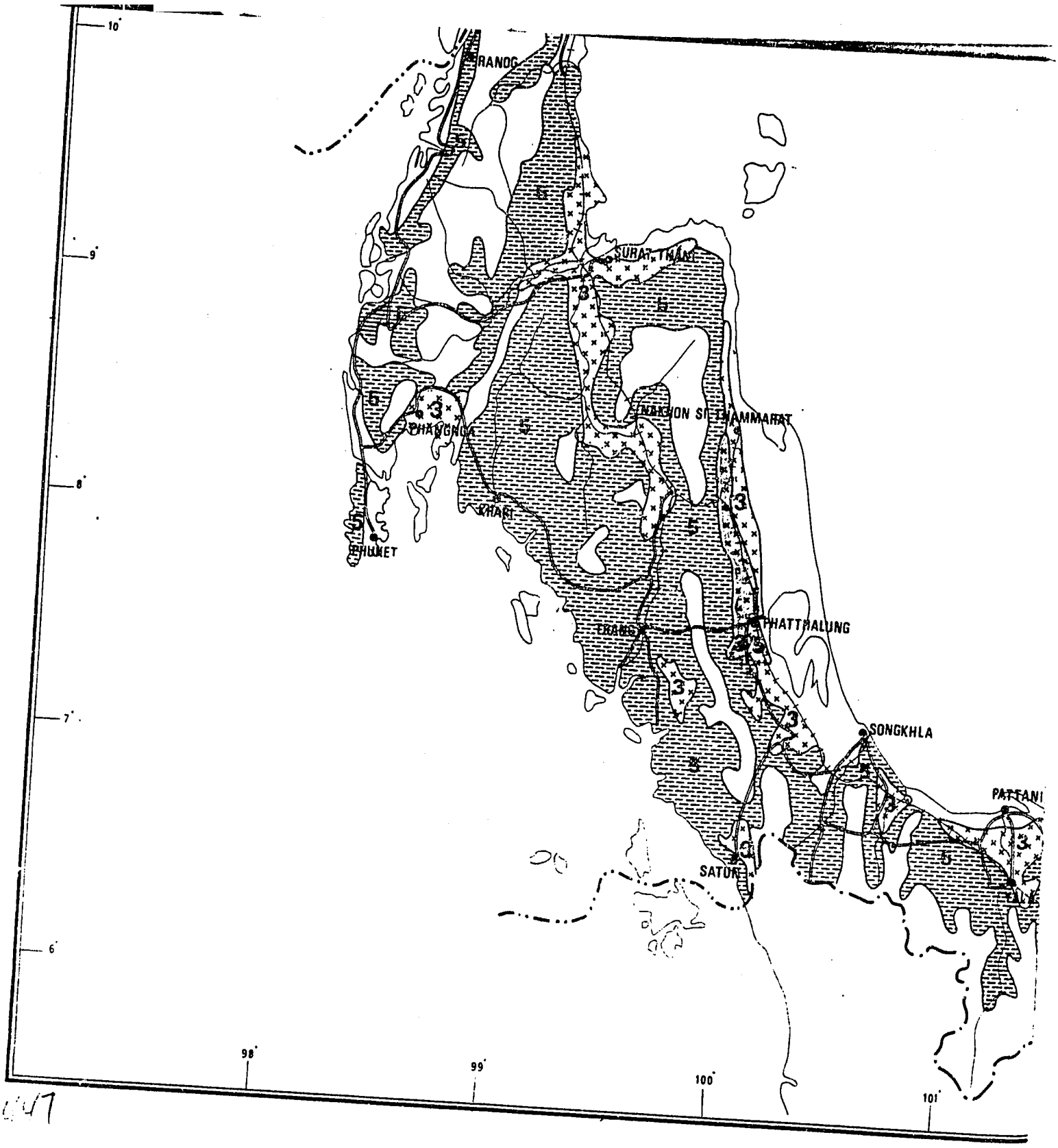
445

445



MAP SHOWING THE DISTRIBUTION OF ULTISOLS, ALFISOLS AND OXISOLS IN THAILAND

Mapping Unit No	Suborder
1	Aqualfs
2	Ustalfs
3	Aquults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SURAT THANI
NAKHON SI THAMMARAT
PHANGNGA
KHAO
PHUKET
TRANG
PHATTHALUNG
SONGKHLA
PATTANI
SATUN
10°
9°
8°
7°
6°
98°
99°
100°
101°

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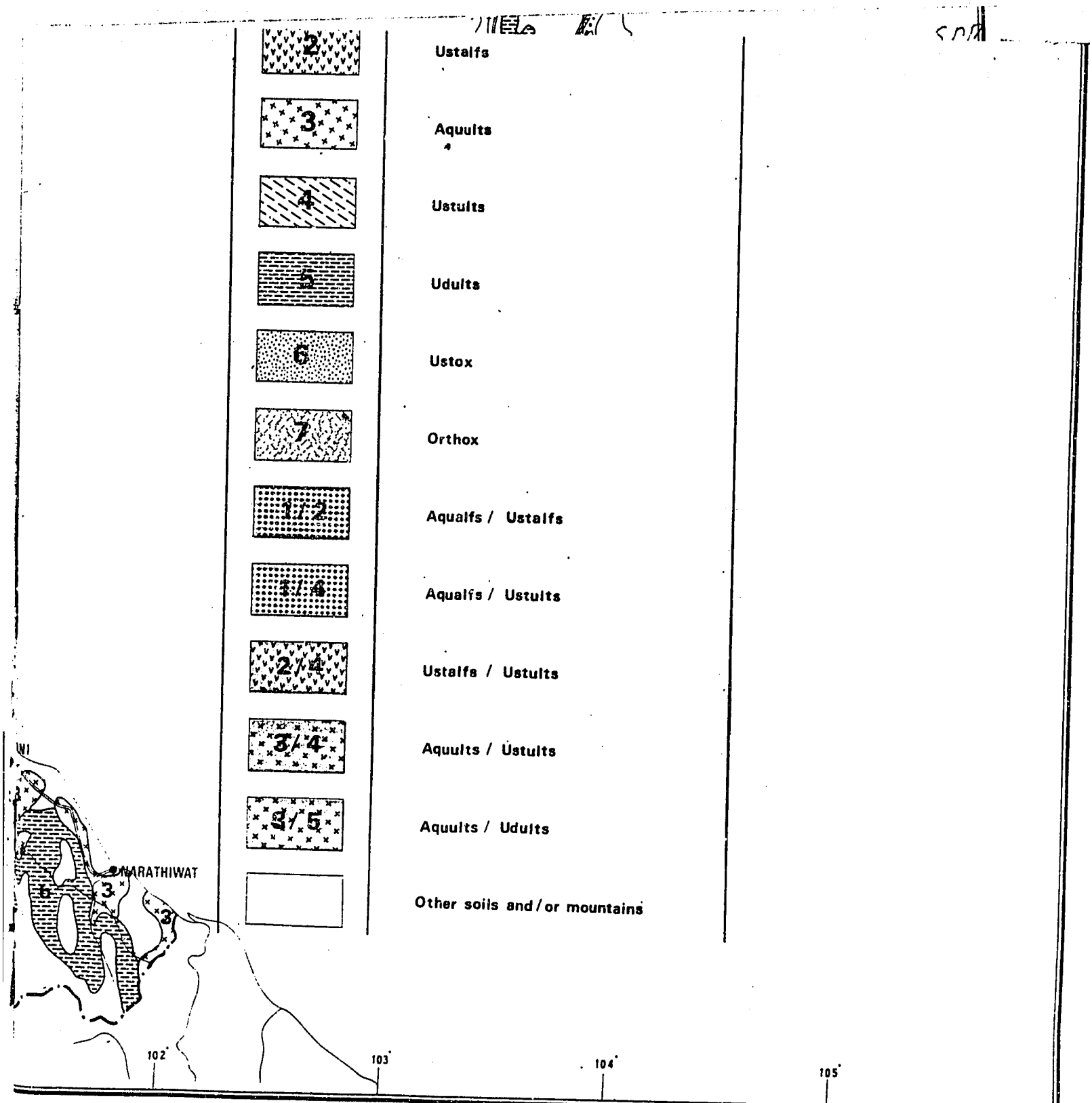
2
Ustalfs
3
Aquults
4
Ustults
5
Udults
6
Ustox
7
Orthox
1/2
Aqualfs / Ustalfs
1/4
Aqualfs / Ustults
2/4
Ustalfs / Ustults
3/4
Aquults / Ustults
3/5
Aquults / Udults
Other soils and/or mountains
NARATHIWAT
102°
103°
104°
105°

Table 1 Distribution of Alfisols and Ultisols in Thailand

Physiographic Regions / Mapping Units	Central Plain		Southeast Coast		Northeast Plateau		Central Highlands		North and West Continental Highlands		Peninsula Thailand		Total	
	Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%
1. Aqualfs	3,712.8	0.72	163.4	0.03	2,153.4	0.42	2,331.6	0.45	4,054.4	0.79			12,415.6	2.41
2. Ustalfs	2,918.2	0.57	371.3	0.07	1,841.5	0.36	2,301.9	0.45	4,173.2	0.81	274.8	0.05	11,880.9	2.31
3. Aquults	4,633.6	0.90	846.5	0.16	21,534.1	4.19	3,430.6	0.67	1,797.0	0.35	8,064.2	1.57	40,306.0	7.84
4. Ustults	11,309.1	2.20	6,111.2	1.19	31,580.9	6.14	15,868.4	3.09	23,954.8	4.66	972.8	0.19	89,797.2	17.47
5. Udults			4,455.3	0.87							33,385.3	6.50	37,840.6	7.37
1/2 Aqualfs/Ustalfs	9,772.0	1.90											9,772.0	1.9
1/4 Aqualfs/Ustalfs									1,240.1	0.24			1,240.1	0.24
2/4 Ustalfs/Ustults	1,188.1	0.23			2,561.8	0.50	4,344.0	0.85	11,695.3	2.28			19,789.2	3.86
3/4 Aquults/Ustults			467.8	0.09	48,793.3	9.49	2,970.2	0.58					52,231.3	10.16
3/5 Aquults/Udults											950.5	0.18	950.5	0.18
Other Soils	27,964.6	5.44	10,299.2	2.01	25,195.0	4.90	36,919.9	7.18	105,836.5	20.59	30,897.7	6.01	237,112.9	46.13
น้ำ					646.0	0.13							646.0	0.13
Total	61,498.4	11.96	22,714.7	4.42	134,306.0	26.13	68,166.6	13.27	152,751.3	29.72	74,545.3	14.50	513,982.3	100.00

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LAC Ultisols mostly occur on terrace and fan complexes adjacent to the West Continental Highlands where acidic rocks, quartzite-phyllite, granite, and gneiss are dominant. Such soils are classified as Paleustults and Haplustults. The native vegetation is mixed deciduous and develops under the tropical savanna climate. Many areas have been cleared for various upland crops such as sugarcane, corn, and beans.

Although the soils are derived from different parent materials, they show slight variation in chemical properties in the argillic horizon. They are low in base saturation (BS) (10-30%), CEC (1-12 me/100 g soil), pH (4.5-5.5) and nutrient status. Clay content of the soils is closely related to the parent materials. Fine grain clastic rocks seem to give a higher clay content to the soils than does Quarternary alluvium. These coarse-textured soils are mostly of alluvium origin and have a clay content that ranges between 15-24%. The coarse-textured soils show increasingly clay content with depth, but also have a weak argillic horizon which causes a problem for identification.

Paleaquults and Plinthaquults are great groups that dominate the southeast and northeast portions of the Central Plain. They formed on low terraces now covered by rice paddies. These soils are classified in the clayey family and have CECs ranging between 8-15 me/100 g soil.

Southeast Coast. This region is bordered on the north by mountains; on the south and west by the gulf of Thailand; and the east by the Banthad range, site of the Thai-Cambodian border. The region occupies an area of approximately 22,714 sq km (4.5% of the country). The east-central part of the region includes dissected highlands which are a continuation of the Cardaman mountains of southwest Cambodia. Quarternary sediments surround these highlands mainly in the western and southern part of the region. Shallow alluvial terraces are observed in the northern part of the region. Rock types are mostly granite and fine-grained sedimentary rocks.

In the northern and eastern parts of this region, where the average rainfall ranges between 1,300-2,200 mm, the moisture regime is classified

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as udic. LAC soils of the Ultisols are mainly classified as Paleustults and Haplustults, most of which develop from shale, phyllite and mudstone, are high in clay content, and contain thick layers of ironstone.

In the region's southern part, where average rainfall is greater than 3,000 mm, the moisture regime is classified as udic. Paleudults which developed from granitic rocks are the most extensive soils in this region. Some have a thin oxic horizon overlying an argillic horizon. On lowlying terrain, clayey families of the Paleaquults and Plinthaquults are dominant. Tropaqualfs are less significant, although they are particularly low in CEC (2-5 me/100 g soil).

The main problem in placing these soils according to Soil Taxonomy is the moisture regime. Within the region, rainfall varies between 1,300 to 4,000 mm per year. However, the overhead data of rainfall and potential evapotranspiration has no relation with the actual soil moisture regime. Annual records of actual soil moisture regimes from two sites in Chantaburi Province (average annual rainfall is 3,040 mm) indicate a udic soil regime, but from the formula used by Soil Taxonomy the ustic soil moisture regime is indicated. According to available data there are several factors that affect the soil moisture regime. Type of vegetation and land use patterns seem to be the most important. Since soil moisture regimes are used as a criterion for suborder categories, the rate of 4% per year deforestation in our country requires that classification of soil at that level change continually.

Northeast Plateau. The Northeast Plateau is composed mainly of broad terraces of the Meking river and its tributaries, the materials of which are derived from sandstone. Three important terrace levels have been recognized by Moormann and Rojanasoonthon (1968) and they are catchment areas of the Mun and Chi River systems. Paleaquults and Plinthaquults dominate this landform system. They are low in CEC (3-8 me/100 g soil) and are classified as the loamy family. The Plinthaquults are similar chemically to the Paleaquults, but they contain a plinthite layer under a hard lateritic gravel layer.

The northern part of the plateau is predominantly occupied by the middle terrace. Isolated remnants of the high terrace are also found here. Strings of these remnants seem to accompany the valley of the Mun and Chi rivers. Plinthustults, Paleustults, and Haplustults are dominant great groups on these two landform systems. Particle size classes of these soils are coarse loamy and fine loamy families (15-32% clay). Since the parent materials are derived from sandstone, the CEC is considerably low. This often presents a problem in identification of argillic horizons in the field. According to available analytical data, a significant number of pedons of these great groups are now considered to be Utlisols, but can also be classified as Alfisols. The fluctuation in base saturation of these soils is quite problematic. The precise determination of BS or CEC is quite critical in sandy textured soils, and any error would be amplified on a percentage basis. Furthermore, contamination in the field by termite activity, salt fusion, introduction of ash, etc., may affect analysis results.

Paleustalfs and Haplustalfs occupy a small extent of the high terrace but are restricted to the southwest portion of the plateau. They are similar in texture and CEC to the great groups described previously. The high BS in these soils is closely related to basic parent rocks. Calcareous sedimentary rocks with lime concretions are quite common under the soils of this region.

Central Highland. This region has a complex physiography that includes hills, plateaux, peneplains, and valleys. This landscape is mainly over basic rocks or transported material of basic origin. Representative rock types are andesite, basalt, limestone, and shale. Therefore, LAC Alfisols and Ultisols are not extensive. Most of the LAC soils occur in small patches within a mixed pattern that also includes Vertisols and Mollisols.

LAC soils of the Paleustults and Paleuquults have been mapped. Paleaquults occur to a small extent in low terraces adjacent to the Central Plain. Most of the Paleustults are developed from shale. They are developed mainly on old stable erosion surfaces in the southern

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Table 2 : Major characteristics of selected representative LAC Ultisols and Alfisols in Thailand

Physiographic Region	Great Group	Parent Material	Geomorphic position	range of some physico-chemical properties of argillic horizon					
				% clay	% Base saturation (by sum.)	C.E.C (NH_4OH)		pH 1:1	
						meq/100g. soil	meq/100g. clay (apparent)	H_2O	KCl
Central plain									
	Paleoquults	Old alluvium	semi-recent or low terrace	35—50	10—33	10—15	20—28	5.0—5.5	3.5—4.0
	Plinthaquults	Old alluvium	low terrace	40—55	10—25	8—12	14—20	5.0—5.5	3.5—4.0
	Paleustults	Old alluvium	higher terrace	15—24	20—30	1—4	4—26	4.5—5.0	3.0—4.0
	Paleustults	Shale & limestone	erosion surface	50—89	10—20	6—10	8—20	4.5—5.0	3.0—4.0
	Paleustults	Sandstone & quartzite	erosion surface	20—30	25—30	4—10	13—33	4.5—5.5	3.5—4.0
	Haplustults	Granite	erosion surface	16—30	10—20	3—7	8—33	4.5—5.5	3.0—4.0
South east coast									
	Tropequalts	Old alluvium	low terrace	20—30	10—60	2—5	10—18	5.0—6.0	4.0—5.0
	Paleaquults	Old alluvium	low terrace	35—45	10—25	3—8	6—23	4.5—5.0	3.5—4.0
	Plinthaquults	Old alluvium	low terrace	35—50	7—15	6—16	16—32	4.5—5.0	3.0—4.0
	Paleustults	Old alluvium	higher terrace	19—40	8—26	2—5	5—15	4.5—5.0	3.5—4.0
	Haplustults	shale, phyllite and mudstone	erosion terrace	40—60	5—30	5—10	8—17	4.5—5.5	4.0—4.5
	Paleudults	shale, phyllite and mudstone	erosion terrace	40—60	10—20	4—9	8—25	5.0—5.5	4.0—4.5
	Paleudults	granite	erosion terrace	20—50	3—25	3—8	6—25	4.5—5.5	3.0—4.0
	Paleustults	granite	erosion terrace	20—30	10—25	2—5	10—17	5.0—5.5	3.0—4.0
Northeast Plateau									
	Paleustalfs	Old alluvium	higher terrace	18—25	50—70	3—10	12—40	6.0—7.0	5.0—6.0
	Paleustalfs	Basalt	low plain	40—60	38—53	8—15	20—30	5.0	4.5
	[illegible]	[illegible]	low terrace	20—35	22—31	3—7	8—26	4.0—5.0	3.5—4.5

Plateau	Paleustalfs	Old alluvium	higher terrace	18—25	50—70	3—10	12—40	6.0—7.0	5.0—6.0
	Paleustalfs	Basalt	low plain	40—60	38—53	8—15	20—30	5.0	4.5
	Paleaquults	Old alluvium	low terrace	20—35	22—31	3—7	8—26	4.0—5.0	3.5—4.5
	Plinthustults	Old alluvium	higher terrace	20—32	10—25	8—11	31—55	4.5—5.0	3.5—4.0
	Paleustults	Old alluvium	higher terrace	16—25	16—32	2—6	9—36	4.5—5.0	3.5—4.0
	Plinthaquults	Old alluvium	low terrace	30—40	20—30	5—8	20—32	5.0—5.5	4.0—4.5
	Haplustults	Old alluvium	higher terrace	15—23	10—25	2—5	13—30	4.5—5.5	3.5—4.0
	Natraqualfs	Old alluvium	low terrace	16—35	64—85	5—12	14—31	6.0—8.0	5.2—7.3
Central Highland									
	Paleaquults	Old alluvium	low terrace	20—30	15—20	6—10	20—33	5.0—6.0	3.0—4.0
	Paleustults	granite	erosion surface	35—45	8—20	6—10	17—28	5.0—6.0	3.0—4.0
	Paleustults	shale	erosion surface	40—50	23—30	5—10	10—25	5.0—5.5	3.5—4.0
	Paleustults	shale	erosion surface	57—69	16—35	6—12	3—25	4.5—5.0	3.5—4.5
North + West Continental Highland									
	Tropaquults	alluvium	semi-recent terrace	40—50	65—80	10—16	20—32	6.0—7.0	5.0—5.5
	Paleaquults	alluvium	semi recent — low terrace	20—50	10—32	8—16	15—30	4.5—5.5	4.0—5.0
	Paleustults	alluvium	higher terrace + fans	20—35	14—30	6—12	17—34	5.0—5.5	3.0—4.0
	Paleustults	granite	erosion surface	40—50	5—6	7—9	14—23	5.0—5.5	4.0—4.5
	Paleustults	shale	erosion surface	40—60	5—15	5—12	12—25	5.0—5.5	4.0—4.5
Peninsula									
	Paleaquults	Old alluvium	low terrace fans	20—50	4—15	3—8	6—18	5.0—5.5	3.5—4.5
	Plinthaquults	Old alluvium	low terrace, all. plain	40—55	6—25	7—16	12—20	4.5—5.5	3.5—4.0
	Paleudults	Old alluvium	terrace fans	15—35	5—15	2—5	5—15	4.5—5.0	3.5—4.0
	Paleudults	shale, phyllite	erosion surface	40—65	10—25	8—15	20—38	5.0—5.5	3.5—4.5
	Tropudults	shale, phyllite	erosion surface	20—30	5—15	7—12	20—30	4.5—5.5	3.5—4.5
	Paleudults	granite	erosion surface	35—50	10—30	5—10	10—28	5.0—5.5	4.0

portion of the region. They are classified as the clayey family. In the great group of Ultisols, these soils have the higher CEC (6-12 me/100 g soils). In some areas near the Southeast Coast, the clayey family of Paleustults contains thick layers of unconsolidated ironstone nodules. The presence of high amounts of unconsolidated ironstone nodules causes problems in identification of argillic horizons in the field, in spite of increasing clay percentage with depth.

North and West Continental Highlands. This region is subdivided into two subregions, i.e. the Northern Hills and Valleys, and the Western Mountains. The Northern Hills and Valleys subregion is an area of parallel north to south oriented ridges, alternating with elongated intermontain basins which harbor four major rivers, namely the Ping, Wang, Yom, and Nan rivers. In the valleys small extents of the Tropaqualfs and Paleaquults occupy low and semi-recent terraces. Most Tropaqualfs are clayey textured, relatively high in CEC (10-16 me/100 g soil) and with a BS 65 to 80%. Some soils contain illite, but kaolinite is still the dominant clay mineral. These Paleaquults are mainly classified as the clayey family. They are relatively high in CEC (8-16 me/100 g soil).

Paleustults are dominant in the higher terraces and fan complexes, along the foothill slopes, and on low residual hills of granite and shale. Most are relatively higher in CEC than soils in the Northeast Plateau. In that region, there is also a limited occurrence of coarse-textured soils of this great group.

In the Western Hills and Valleys subregion the dominant rock types are basic, thus LAC Alfisols and Ultisols are less significant. The area is mainly of steep land and is mapped entirely as slope complexes.

Peninsular Thailand. Unlike the other physiographic regions, the soil moisture regime is classified as udic. Most of the terrain is occupied by LAC Ultisols, even though they are derived from different kinds of parent materials. This can be attributed to high rates of weathering under tropical monsoon and tropical rain forest climates.

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Paleaquults and Plinthaquults are dominant in the lowlying terrain of the eastern coastal plain. They are both low in CEC. Within these groups, the particle size class varies from loamy to clayey.

LAC Paleudults and Tropudults are the major great groups of this region. Paleudults in this region can be divided into two groups based on parent material. The coarse-textured soils with clay contents from 15-35% and with CEC of 2-5 me/100 g are mainly developed from transported material derived from various rock types. These types of Paleudults show an increasing clay content with depth. However, many have intergrade properties that can be observed in the field in the argillic, oxic, and cambic horizons. Other Paleudults are developed on shale, phyllite and granite, and typify this great group. They have a high clay content and a strongly developed argillic horizon. The CEC ranges between 5-15 me/100 g soil. On old stable land surfaces thin oxic horizons commonly overlie argillic horizons.

Soils of the Tropudults are shallow or moderately deep. In most instances the soils have argillic horizons of varying thickness overlying a weathered paralithic contact. They are classified under the loamy-textured family and have a CEC range of 8-12 me/100 g soil.

DISCUSSION

LAC soils of the Alfisols and Ultisols in Thailand generally contain kaolinite among the clay minerals. They are low in CEC, BS and nutrient status. These soils occur throughout the country under different physiographies, vegetation, parent materials, and climates. Problems concerning the classification of these soils according to the Soil Taxonomy system are summarized.

Identification of illuviated clay

In general, there are few problems in identification of the argillic horizon in paddy soils under aquic moisture regime. This hori-

zon is formed by the process of clay translocation favored by the alternate wetting and drying. However for loamy or sandy-textured upland soils the identification is often very difficult to make. Observations are rarely consistent from one person to another both in the field or in the laboratory. We feel that only 1 or 2% illuviated clay under cross niclos is not sufficient for identifying the argillic horizon.

Base saturation as a criterion to separate Alfisols from Ultisols

The criterion of 35% BS does not work well for soils that have very low CEC, especially in sandy-textured soils of the Northeast Plateau or in North Thailand. The BS is not known with certainty. Since the precise determination of CEC (the sum of cations and bases) is quite critical, small variations in these properties result in greater variation in BS. Many errors are amplified on a percentage basis. Also, different amounts of fusion, ash, and termite activity during different samplings or even different analyses may yield different results for BS. Therefore, it is proposed that the CEC should be considered with BS at the order level, or else the LAC soils separate into another group.

Oxic properties

Many LAC soils share some properties with either the Ultisols, Inceptisols, or Oxisols. Some soils have the micromorphological features of an oxic horizon, but due to a low clay content, they have an apparent CEC of more than 16 me/100 g clay. Therefore, they cannot be classified as Oxisols. This situation is often present for the loamy-textured LAC soils. Therefore for loamy soils, we should use the actual CEC instead of apparent CEC in order to eliminate this problem.

Identification of plinthite

There are always some problems concerning field identification of plinthites. In order to distinguish Paleaquults from Plinthaquults, we should have some quantitative way to identify plinthite both in the field and in the laboratory.

Needed subgroups

Subgroups of Paleustults, Plinthustults, Plinthudults, and Plinthaquults are not established, thus rendering the system incomplete. Some amendments should be made very soon if we desire international cooperation and agreement concerning these soils.

Soils with ironstones

Soils containing thick layers of ironstones should be set apart from those without. Without such distinction it is impractical to study some important criteria upon which the classification system is based, such as clay coatings and micromorphological features.

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ALFISOLS AND ULTISOLS WITH LOW ACTIVITY CLAYS IN MALAYSIA

Lim Jit Sai, Mohinder Singh Khalsi, and Hari Eswaran

The argillic horizon is one of the most important diagnostic horizons introduced by Soil Taxonomy. It is used extensively in soil survey and classification. This is particularly true in a humid tropical country like Malaysia, where most soils are deeply weathered and have rather homogeneous-looking profiles; consequently, they have few morphological properties that could be used as differentiating criteria. An additional feature in Malaysia, which may or may not be true in other parts of the world, is that soils with an argillic horizon have better physical properties, such as moisture retention, as compared with Oxisols. Consequently, the concept of the argillic horizon is adhered to in Malaysia.

This contribution deals with soils that have an argillic horizon and low activity clays. During discussions of the Committee on such soils (ICOMLAC), the debate has been on the limit of 16 or 24 me per 100 g clay. The decision from the Malaysian point of view is rather simple since there are very few soils with a cation exchange capacity (CEC) of more than 16 me per 100 g clay. Consequently, we wish to keep them apart (at least for their uniqueness), so we prefer a CEC limit of 16, which will be used in the rest of this paper.

The objective of this contribution is to report on the range and characteristics of low activity clay (LAC)Alfisols and Ultisols in Malaysia. Based on the data we have and our limited experience, we wish to present some suggestions to improve the Soil Taxonomy, or at least point to areas that are problematic to us.

FIELD IDENTIFICATION OF THE ARGILLIC HORIZON

The presence of clayskins in the field and their confirmation in thin sections is the main criterion used for identifying the argillic horizon. Soils with clayskins that do not meet the clay increment requirement (Soil Survey Staff, 1975) are still considered as having argillic horizons. This is because, especially on rolling terrain, cultivation practices have obliterated the A horizon and sometimes part of the B. On slightly hilly terrain terraces have been made by bulldozing, and since we do not wish to change the classification because of management practices, we pay less attention to the clay increment requirement. The logic here is the same as that employed for using a base saturation criteria at 1.5 m depth to separate Alfisols from Ultisols.

In the upland soils, we have most frequently misidentified soils high in sesquioxides and those belonging to loamy or lighter families. In clayey sesquioxidic soils, some of which resemble the Terra Roxa Estruoturada of the Brazilian classification, ped faces are very shiny, but thin sections show no cutans. Later we found that these were moisture films because on drying the soils the shiny surfaces disappeared. Putting a block of the B horizon in the sun for an hour is a quick test used to solve this problem. Continuing problems are experienced in loamy or lighter families, especially those approaching the Psamments. As structure is generally weak, the consistency is very friable and the B horizon feels like oxic. If textural requirements are met, the soils are classified as Ultisols, unless micromorphological studies show otherwise.

Perhaps we have made the most mistakes in identifying an argillic horizon in hydromorphic soils. When the soils are wet, we have great difficulty in identifying clayskins. Consequently, the final classification is made only after thin section studies. It is useful to point out that in the udic moisture regime of Malaysia, the best cutans are found in the Aeric Tropaquults and in some Aquic Tropudults. Further, cutans are better developed in loamy families and more specfically, in the northwest of Peninsular Malaysia where there is a slight ustic tendency.

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Frequently, it is necessary to decide if the argillic horizon is thick or thin. Depth to saprolite is important in Malaysia, since tree roots go deep into the soils. The "Pale" Great Groups in Soil Taxonomy are defined purely on the rate of decrease of clay with depth from the maximum clay content. In Malaysia, three situations occur with respect to this: (1) where there is a deep argillic horizon, and such soils are classified as Paleudults; (2) where there is a lithological discontinuity and the lower substratum is clayey; (3) where there is a saprolite in which the clay content does not decrease. It is appreciated that the latter two considerations are not according to Soil Taxonomy, but we have valid reasons for making this distinction. A soil on shale generally tends to show a "Pale" clay distribution, even if the saprolite appears at 1 m depth. However, as the saprolite has a higher nutrient retention, this is a better soil than a kaolinitic soil with a thick argillic horizon. The coastal marine clays are clayey to a depth of 60 m or more. The argillic horizon does not extend to more than 1 m. If these are placed in "Pale" Great Groups, we will need "Sulfic" subgroups, as there is pyrite in the subsoil. Since coastal marine clays have different management, it is unwise to group them together with the upland soils.

LAC SOILS

Alfisols

LAC Alfisols are rare in Malaysia and we do not have any pedon in our records that will qualify for this group. Well-drained Alfisols are frequently shallow profiles formed on easily weatherable rocks, such as ultrabasic rocks. The Mangkap, Sabor, Malawali, Beeston, Tingkaya, Kobovan, and Talid families are examples of such soils in Sabah. The Benta Series is perhaps the only soil in Peninsular Malaysia. Soils close to limestone hills have a calcium-rich substratum and the Perlis Series in Peninsular Malaysia is an example. Finally, Alfisols are also present in alluvium which receive a supply

of bases from adjoining limestone hills or ultrabasic intrusions. In practically all these soils, 2:1 clays dominate the mineralogy; therefore, they do not qualify as LAC soils.

Ultisols

Contrary to Alfisols, most Ultisols are LAC soils. They are present on a range of parent materials and under differing terrain conditions.

Distribution

Climatic changes are more significant with respect to elevation than to lateral distribution. Paramananthan (1977) has shown that isohyperthermic soil temperature regimes extend to an elevation 1,200 m (4,000 feet), above which it is isothermic or cooler. This is also the limit of the Ultisols. However, at this elevation, the soils are generally Tropohumults and these Humults may or may not qualify as LAC soils. The Ringlet Series in Peninsular Malaysia, which occurs at this elevation, has one horizon with a CEC of 15.8 me per 100 g clay; but as the horizon also has an ECEC of 12.2, it may be disqualified from LAC soils. LAC Ultisols only occur at elevations less than 2,000 feet. In isothermic and cooler areas, the moisture regime is perudic. Here an important soil formation process is accumulation of organic matter with associated podzolization.

Two areas in the lowlands with isohyperthermic soil temperature regimes and perudic moisture regimes, as estimated from climatic data (Van Wambeke and Eswaran, 1975), occur in Peninsular Malaysia. One is in the southeast of Peninsular Malaysia in the Penggarang Peninsula and the other is around Kuching in Sarawak. Conceptually, an argillic horizon should not be present in soils with perudic moisture regimes. This is so in the undulating terrain of the two areas where soils are Oxisols; in fact, the Gibbsiorthox is present in the Penggarang Peninsula. However, on steeper landscapes the actual moisture regime is udic due to considerable runoff (though the computed moisture regime is perudic) and so argillic horizons may

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form. This is the situation around Kuching, e.g. the Merit and Nyalau series. These Ultisols have two characteristic features: the argillic horizon is very weakly expressed and the soils show epiaquic characteristics, seemingly a good indicator of the perudic moisture regime. In general, Ultisols in the lowland perudic areas are Paleudults and have properties grading to Oxisols.

In Malaysia, there is no ustic moisture regime as computed from climatic data although there is ustic tendency on the Thailand border. An increase in the amount of termite mounds in northwest Peninsular Malaysia is an indicator of the drier conditions. It is in this area that soils with best developed argillans (in thin sections) have been found. This is the Laka series (Paramananthan et al, 1975).

Hydromorphic Ultisols are developed on alluvium. The degree of hydromorphism appears to govern formation of the argillic horizon. The horizon does not form when the soil is continuously wet. As stated before, clayskins are best developed in Aeric Tropaquults or Aquic Tropudults.

Physico-chemical, Mineralogical and Micromorphological Properties

As stated earlier, LAC Ultisols of Malaysia may or may not meet the clay increment. The fine clay ratios proposed in Soil Taxonomy may not be very practical and have only been attempted for a few soils. Table 1 shows the data for Langkawi Series (Hamdan et al, 1974).

Table 1. Granulometric composition of the Langkawai Series.

Horizon	% Sand	% Silt	% Coarse clay	% Fine clay	fine clay / Total clay
A_1	39.50	12.50	25.10	22.90	0.48
B_{21t}	29.00	6.00	25.40	39.60	0.61
B_{22t}	20.00	6.50	27.80	45.70	0.62
B_{23t}	21.00	6.00	27.80	45.20	0.62
B_3	20.50	7.50	31.00	41.00	0.57
BC	29.00	9.00	31.00	31.00	0.50
C	25.50	8.00	24.80	41.70	0.37

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In this particular case, the ratios meet the requirement for an argillic horizon. However, we question the use of this parameter, as it is implied that fine clay moves preferentially. Recent scanning electron microscope observations (unpublished work of the third author) indicate that some cutans may be composed of totally coarse clay. Moisture retention properties of some Ultisols are given in Table 2 (Lim, 1977).

Table 2. Moisture retention of some Ultisols.

Soil Series[a]	B.D. gm/cc	Moist. (Vol%) at pF					Moist. Between pF			
		0	1	2	2.54	4.19	0-1	1-2	2.00 2.54	2.54 4.19
HRU	1.52	63.4	56.6	28.9	24.5	21.9	6.8	27.7	4.4	2.6
LCG	1.20	68.9	54.0	50.6	45.2	41.4	14.9	3.4	5.4	3.8
CHT	1.15	66.0	56.0	47.9	47.4	40.0	10.0	8.1	0.5	7.4

[a]HRU = Harimau; LCG = Lancang; CHT = Chat. Data for the three soils are taken at 100 cm. The three soils are Typic Paleudults.

Comparing Ultisols and Oxisols of similar clay contents, Paramananthan (1977) showed that there is a greater amount of water in Ultisols. The Ultisols store in general 81.4 mm/m of water if 1/3 bar is used and 118 mm/m if 1/10 bar is used as compared to 78 and 105 mm/m for Oxisols with similar clay contents.

LAC Ultisols in Malaysia range in pH from 3.8 to 4.8. All the Ultisols studied to date have a net negative charge. The charge characteristics of some LAC Ultisols are summarized in Table 3. The permanent charge (PC), as determined by sum of NH_4OAc bases and KCl-extractable Al, ranges from 1 to 10 me per 100 g clay for LAC Ultisols. High Al saturation prevails in most LAC Ultisols.

Practically all LAC Ultisols have a kaolinitic mineralogy. Subsidiary amounts of goethite may be present and a few have 5-10% gibbsite. Many Ultisol clays show no peaks for iron minerals on X-ray diffraction. CEC (NH_4OAc) has been measured directly on the clays. The effect of free iron on CEC of clays was also investigated (Lim, 1977) and the data are presented in Table 4. Some Oxisols are also included. The relationship between the percent free iron and

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the change in CEC after iron removal is:

$$y = 11.6 - 1.17x;\ n = 23;\ r = -0.8217^{***}$$

Table 3. Charge characteristics of some Ultisols.

Soil/ Horizon	me per 100 g soil		me per 100 g clay		PDC/ PC	Aluminum Saturation%
	CEC (NH_4OAc)	Sum	PC	PDC		
Harimau						
A	2.48	4.51	13.9	46.2	3.30	54.9
B_{22t}	3.12	3.79	5.5	6.7	1.22	81.7
Chat						
A_1	7.72	13.90	14.1	35.1	2.49	74.6
B_{22t}	4.88	5.47	1.6	6.6	4.10	65.3
Lancang						
A	8.64	16.06	10.67	32.7	3.1	79.2
B_{22t}	4.72	7.09	3.10	8.1	2.6	88.9

The relationship indicates that when free iron is low, the removal of free iron results in an increase in CEC, and vice versa.

As stated earlier, thin sections are used to confirm the presence of the argillic horizon. A limit of 1% cutan is adhered to, to differentiate argillic from oxic horizons. The degree of development of cutans seems to be related to the moisture regimes and texture, and these relationships have been mentioned earlier.

LAC Ultisols in relation to land use

Experience indicates that these are good soils for oil palm. Yields of up to 13 tons FFB per acre a year are normal on these soils. In the wetter memebers, higher yields may be anticipated; of course, yields will decline if the soils are waterlogged.

LAC soils are also suitable for rubber, though Haplorthox seem to perform better. In the discriminatory use of our soils, we will

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recommend LAC Ultisols for oil palm. These are not the best soils for cocoa. The best soils for cocoa in Sabah are Alfisols. The well-drained LAC Ultisols are very suitable for peppers, as shown in Sarawak. Pepper plants also prefer non-arenic subgroups.

Table 4. CEC before and after iron removal.

Soil Series	Horizons	Free Iron %	CEC me/100 g clay Before	CEC me/100 g clay After	ΔCEC
Harimau	B21t	4.56	6.71	9.76	3.05
	B22t	4.90	7.40	10.88	3.48
	B3	4.94	6.70	11.44	4.34
	C1	5.24	5.10	10.24	5.14
Lancang	B21t	9.48	13.10	9.60	-3.50
	B23t	9.77	12.40	10.40	-2.00
	B25t	8.25	11.90	9.20	-2.70
	C(R)	9.48	11.70	9.20	-2.50
Chat	B21t	15.02	12.43	8.80	-3.63
	B22t	14.02	11.54	8.80	-2.74
	B26cnt	16.02	11.81	8.80	-3.01
Kening	B22ox	11.33	9.00	8.64	-0.36
	IIBC	11.33	9.00	8.64	-0.36
	IVBC	10.58	8.60	7.52	-1.08
Ulu Dong	B21ox	11.71	9.40	9.20	-0.20
	B23ox	11.71	9.40	9.28	-0.12
	B25ox	10.58	8.60	8.48	-0.12
Segamat	B22ox	16.10	12.90	6.56	-6.34
	B24ox	15.42	10.58	6.40	-4.18
	B26ox	15.09	9.40	6.88	-2.52
Sagu	B22ox	17.61	8.16	7.20	-0.96
	B24ox	17.25	8.90	4.80	-4.10
	B26t	16.61	11.13	9.48	-1.85

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APPLICATION OF SOIL TAXONOMY

Some problems in the application of Soil Taxonomy have been mentioned before. One recurring problem is scils with a thin oxic horizon underlain by an argillic horizon. These soils do show some problems for growing oil palm but none for rubber; so, we intend to make a distinction in the classification. Increasing the thickness requirement of the oxic horizon to 50 cm and including the additional condition that "if underlain by an argillic, the oxic should extend to 1.25 m" seems to solve part of our problems. Consequently, we wish to recommend this for consideration by ICOMOX.

Reasons for the 16 me limit for LAC Ultisols are given earlier. This is a good break for separating the better upland soils from the poorer ones. Mineralo-chemically, LAC soils are similar to Oxisols except that in general, they have better moisture retention properties.

We like the present concept of the "Pale" great groups. However, as discussed before, we would like a modification of the definition which would restrict the clay decrease to the "argillic horizon" and not to all the subsoil. A modified definition is given in the proposed key (Table 5) for the Udults. With this modification, the typic subgroup has a high CEC while the kandic subgroup has a CEC less than 16 me per 100 g clay in some subhorizon within 1.25 m of the soil surface.

LAC Ultisols with thin argillic horizons are the Kandi great groups. Non-LAC Ultisols with thin argillic horizons in the isotemperature regimes are Tropudults, with the Hapludults being non-isocounterparts.

Suggestions for subgroups include the following:

1. Allic - has a pH KCl of 3.5 less in some subhorizon within 1.25 m of the soil surface.
2. Plinthic, Petroplinthic, Lithoplinthic - as in Oxisols.
3. Batholithic - has a lithic or paralithic within 1.25 m of the soil surface.

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Table 5. Proposed key for the Udults

1.	Udults with a fragipan in or below the argillic horizon	FRAGIUDULTS
2.	Udults that have plinthite which forms a continuous phase or constitutes more than half the volume in some horizon within the upper 1.25 m of the soil	PLINTHUDULTS
3.	Udults that have an argillic horizon which has less than 10% weatherable minerals in the 20-200 micron fraction in the upper 1.25 m; and that have a clay distribution in the argillic horizon such that the percentage clay does not decrease from its maximum amount by more than 20% of the maximum found within 1.5 m of the soil surface.	PALEUDULTS
4.	Udults which have a Munsell Hue of 7.5 YR or redder in the top 1.25 m of the soil surface.	RHOUDULTS
5.	Udults have a CEC of less than 16 me per 100 g clay or less; or an ECEC of 12 me per 100 g clay or less in some subhorizon of the argillic within 1.25 m of the soil surface.	KANDIUDULTS
6.	Udults with an isothermic or isohyperthermic	TROPUDULTS
7.	Other Udults	HAPLUDULTS

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4. Kandic (in Paleudults) - has a CEC of less than 16 me per 100 g clay in some subhorizon of the argillic within 1.25 m of the soil surface.

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LAC ALFISOLS AND ULTISOLS OF SRI LANKA

K.A. de Alwis

ABSTRACT

Alfisols and Ultisols with low activity clays (LAC) constitute one of the more important unutilized soil resources of Sri Lanka. LAC Alfisols are Red-Yellow Latosols with high base saturation, which are all Paleustalfs. The LAC Ultisols consist mostly of Red-Yellow Latosols with low base saturation, which belong to the Paleustults. Other LAC Ultisols in Sri Lanka have been encountered only as isolated pedons belonging to the great groups: Tropudults, Plinthudults, Plinthaquults, and Paleudults.

The Paleustalfs and Paleustults have horizons which are considered argillic on the basis of pedogenic increases of clay content with depth, presence of weak void argillans and variation of the fine clay/coarse clay ratios with depth. Even though these soils do not have fine clay/total clay ratios specified as normal for argillic horizons, the evidence that clay has moved is clear enough to assign them to the Alfisols and Ultisols.

However, these argillic horizons show no cutans on field observation and possess all other characteristics of oxic horizons. If the surface horizons are truncated by erosion or thoroughly mixed with the B horizons by human or faunal activity, these soils would be indistinguishable from Oxisols. Difficulties also result during the separation of soils like these on old surfaces into Alfisols and Ultisols, according to base saturation at the order level.

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The low activity of the clays in the Paleustalfs and Paleustults could be attributed to the highly crystalline nature of the kaolinitic clays - even in the fine clay fraction - as evidenced by x-ray diffraction analysis and electron microscopy. The cation exchange capacity (CEC) per 100 g clay is in the range of 11 - 14 me in the B_{2t} horizons. In these soils, free Al oxides are practically absent and free Fe exists almost entirely as discrete particles of hematite rather than coatings of amorphous Fe oxides or hydrous oxides.

The LAC Alfisols and Ultisols of Sri Lanka have been classified at the family level according to Soil Taxonomy. The problem of finding a more comfortable niche for soils with B horizons having both argillic and oxic properties is discussed and a proposal is made for resolving this difficulty.

INTRODUCTION

All LAC Alfisols and most LAC Ultisols of Sri Lanka belong to the Red-Yellow Latosol Great Soil Group. These soils constitute one of the most important unutilized and underutilized soil resources of the country. They cover nearly 300,000 ha and occur as an arcuate belt in the coastal regions of northwestern, northern and northeastern Sri Lanka (Fig. 1). The Red-Yellow Latosols have remained largely unutilized owing to problems of inadequate water supply and low fertility.

Other LAC soils of Sri Lanka are of very limited occurrence. Isolated pedons of LAC Tropudults, Plinthudults, Plinthaquults and Paleudults have been described, but no sizeable extents have been mapped.

Red-Yellow Latosols are deep, reddish, loamy and clayey-textured soils which have developed on stable surfaces of the Red Earth Formation. This formation is derived from the weathering of beach-dune-ridge and/or near sea-shore deposits, probably of Upper Pleistocene or recent

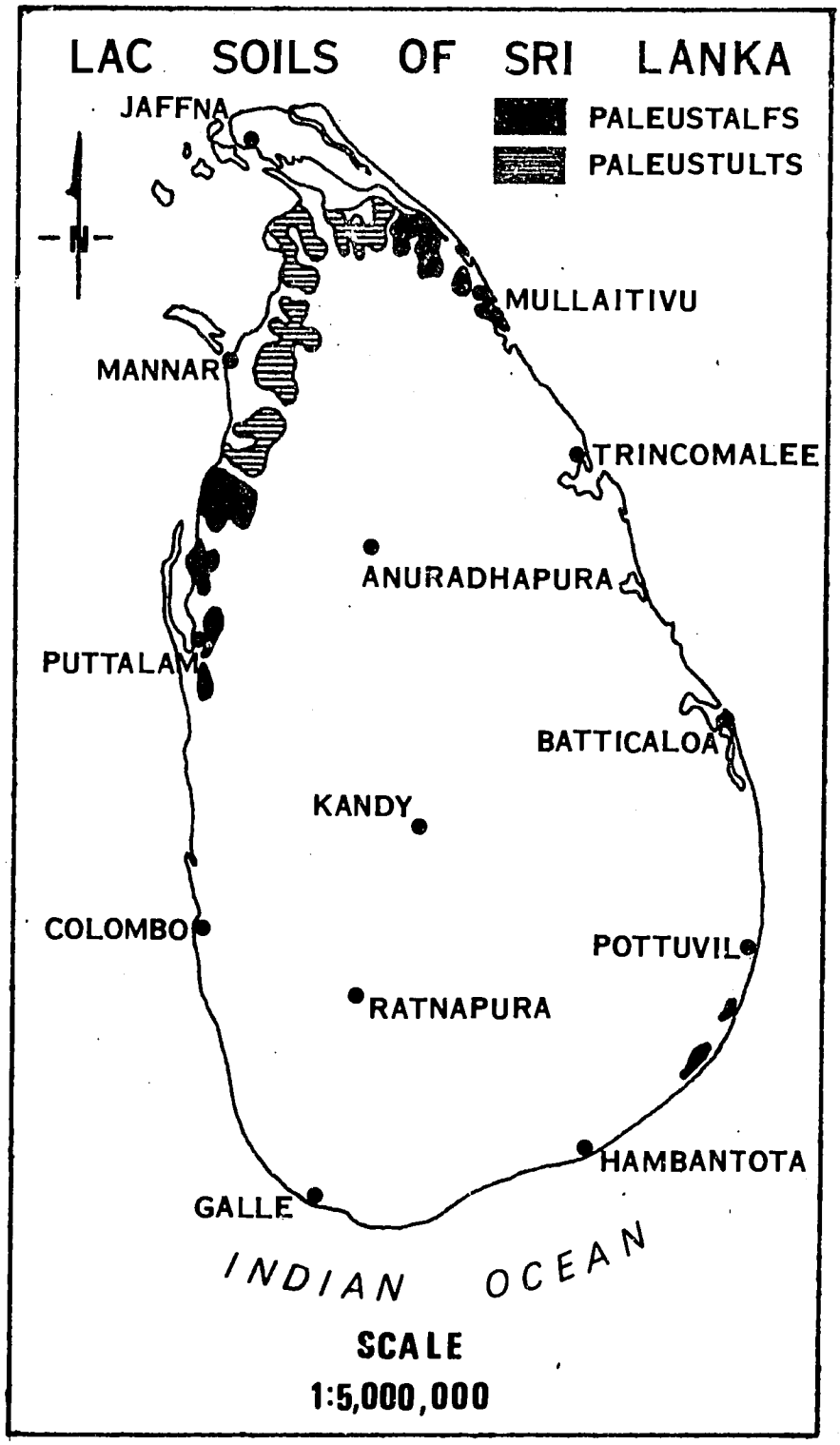

Fig. 1—The LAC Alfisols and Ultisols of Sri Lanka

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age. These deposits appear to have weathered partly at least *in situ*.

The climate under which soil formation had taken place appears to be not too different from that prevailing today. Certainly, much wetter phases have to be definitely ruled out on pedologic and other evidence. The present climate is characterized by a highly variable annual precipitation with a mean area ranging from 950 to 1450 mm. Most rain occurs during the period from October to January, and there is a prolonged dry spell from May to September. The mean annual temperature is 27 to 28°C.

The natural vegetation is dry, mixed evergreen and deciduous forest. The landscape is flat to gently undulating with the Red Latosols occupying the crests and upper slopes and the Yellow Latosols occurring in the valley bottoms.

NATURE OF THE LAC SOILS

The morphological, physical, chemical and mineralogical characteristics of Red Latosols have been described elsewhere (Alwis and Pluth, 1976). The Yellow Latosols are similar in most respects except for colors which are generally of 10 YR hue) and the occurrence of weak, fine mottles. Some morphological, physical and chemical characteristics of these soils which relate to the present discussions are given in Table 1.

The CEC/100g clay in the Red Latosols of Sri Lanka are in the range of 11 to 14 me. This is in accord with studies (Alwis and Pluth, 1976) of the clay mineralogy by chemical X-ray diffraction, differential thermal analysis and transmission electron microscopy which show that the clay fractions are dominated by highly crystalline (both in the morphological and X-ray sense) kaolinite. There are small but significant amounts of mica, almost exclusively present in the coarse clay (0.2 - 2.0 μ) fractions. The sandiest Red Latosols contain small amounts of a vermicullite-smectite intergrade.

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Table 1 Selected characteristics of two representative pedons of LAC Ultisols and Alfisols of Sri Lanka

Horizon	Depth	Colour moist	Structure	Particle size distribution: Sand 2000–50 µm	Silt 50–2 µm	Clay <2 µm	Fine clay / Coarse clay	Bulk density	15 bar H_2O vol/vol	PH 1:1 H_2O	PH 1:2 $CaCl_2$	Organic carbon	CEC-7/• 100g soil	Base/§ saturation	Extra Al	Cutans Field	Cutans Thin sec.	Clay # minerals
	cm			%	%	%		g/cm³	%			%	meq	%	meq 100g			
							Pedon No TP₁ Rhodic oxic Paleu tult											
A11	0–12	2·5YR3/4	1csbk	79	6	15	1·6	1·36	6·5	6·6	6·0	0·62	2·9	64	0·01	nil	nil	$K_3Mi_1O_1$
A12	12–25	2·5YR3/4	0–1csbk	69	5	26	2·5	1·40	9·7	5·7	5·1	0·38	2·6	42	0·02	nil	nil	
B21 t	25–55	2·5YR3/4	0–1csbk–m	54	5	41	3·0	1·42	14·8	5·1	4·3	0·27	3·2	26	0·06	nil	weak	$K_3Mi_1O_1$
B22 t	55–100	2·5YR3/5	0–1csbk–m	51	4	45	2·6	ND	ND†	5·3	4·2	0·18	3·3	23	0·08	nil	weak	
B23 t	100–145	2·5YR3/4	0–1csbk–m	45	4	51	2·5	ND	ND	5·4	4·3	0·18	3·9	27	0·03	nil	weak	
B24 t	145–235	2·5YR3/4	0–1csbk–m	50	3	47	1·3	ND	ND	5·5	4·4	0·11	3·6	30	0·03	nil	nil	
B24 t	235–345	2·5YR3/4	0–1csbk–m	43	7	49	1·6	ND	ND	5·7	5·0	0·12	4·2	44	0·02	nil	nil	$K_3Mi_1O_1$
							Pedon No MP₁ Rhodic oxic Paleustalf											
A11	0–5	5YR 4/4	0–1ccr	85	4	11	1·1	1·48	5·2	6·1	5·6	0·84	2·4	47	0·02	nil	nil	$K_3Mi_1O_1$
A12	5–18	5YR 3/3	1 msbk	80	4	16	1·3	1·50	7·2	5·8	5·0	0·68	2·3	31	0·03	nil	nil	
B21 t	18–48	2·5YR3/6	0–1csbk–m	70	4	26	1·5	1·50	11·3	5·3	4·4	0·48	2·2	18	0·09	nil	weak	$K_3Mi_1O_1$
B22 t	48–92	2·5YR3/6	0–1csbk–m	65	2	33	1·8	1·49	12·8	5·4	4·6	0·27	2·6	26	0·03	nil	weak	
B23 t	92–138	2·5YR3/6	0–1csbk–m	61	4	35	1·8	1·48	14·7	5·[illegible]	4·9	0·24	2·8	38	0·02	nil	weak	
B24 t	138–228	2·5YR3/6	m	60	4	36	1·6	1·53	15·0	5·6	5·2	0·15	2·7	40	0·02	nil	weak	
B25 t	228–400	2·5YR3/6	m	55	5	38	1·4	1·59	15·1	5·6	5·5	0·12	3·0	51	0·02	nil	weak	
B25 t	400–492	2·5YR3/6	m	53	5	35	1·5	ND	ND	5·7	5·3	0·07	2·8	53	0·01	nil	weak	$K_3Mi_1O_1$

• CEC by NH_4OAc.pH7 § Using CEC by summation † Not determined # K= Kaolinite, Mi = Mica, O = Others

Free iron oxides are present almost exclusively as discrete particles of hematite and not as coatings on the clays. Al oxides and hydrous oxides are present only as traces, if at all. The absence of free amorphous iron oxides gives these soils low reactivity with added phosphate fertilizer - which is a favorable factor.

CLASSIFICATION

The problems of classifying Red-Yellow Latosols according to Soil Taxonomy (Soil Survey Staff, 1975) are discussed below:

Argillic horizon or oxic horizon?

The Red-Yellow Latosols have B horizons which are considered argillic on the basis of pedogenic increases of clay content with depth, the presence of weak void argillans and the variation of fine clay/coarse clay ratios with depth. Even though these soils do not have fine clay/total clay ratios specified as normal for argillic horizons, the evidence is clear that clay has moved to assign them as Alfisols and Ultisols. Moreover, since the fine and coarse clays are both largely kaolinitic, and evidence indicates that some coarse clay has moved, the fine clay/total clay ratio may not be a sensitive indicator of illuviation in cases like this.

On the other hand, these B horizons show no cutans on field observation and possess all the other characteristics of oxic horizons: thickness > 30 cm, CEC < 16 me/100 g clay, < 10 me of NH_4OAc-extractable bases plus KCL-extractable Al per 100 g clay, only traces of weatherable primary minerals, > 15% clay and < 5% that shows rock structure. If the surface horizons are truncated by erosion or thoroughly mixed with the B horizons by human or faunal activity, the subsurface horizons of the Red-Yellow Latosols practically fit the criteria for oxic horizons and the soils would be classified as Oxisols.

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On the basis of their existing properties however, the Red-Yellow Latosols are regarded as Alfisols and Ultisols. They would however, also fit the original concept of oxisol and were in fact so classified by Moormann and Panabokke (1961).

Alfisols or Ultisols?

The Red-Yellow Latosols are divided into two orders in Soil Taxonomy, viz: Alfisols and Ultisols. However, some soil series belonging to these different orders occur side by side and have obviously developed under the same climate(s). For example, the Gambura Series is an Ultisol (on the basis of base saturation by summation of < 35% at 1.8 m depth) while the Mullaitivu and Wilpattu soils are Alfisols even though they are contiguous with the Gambura Series and occupy equivalent positions in the landscape.

A low base saturation in the lower B horizons of the Gambura Series as compared to the other two series, could have resulted from more efficient leaching of the former. All three soils have steady infiltration rates well in excess of the maximum storm intensities. Thus there is no run-off and maximum time for equilibration of percolating water with the exchange complex, and therefore maximum leaching efficiency, would be in the heaviest textured Gambura Series.

Separation of such obviously related, similar soils at the order level seems hardly justifiable. Obviously, base saturation of the argillic horizon is not an ideal criterion for separating soils developed on very old stable surfaces - like the Paleustalfs and Paleustults of Sri Lanka.

Classification into Families

The LAC Alfisols and Ultisols of Sri Lanka largely belong to the following families:

1. fine-loamy siliceous isohyperthermic Rhodic Oxic Paleustalf (proposed in recognition of the fact that properties of both Oxic and Rhodic Paleustalfs are combined in these soils)

2. fine-clayey kaolinitic isohyperthermic Rhodic Oxic Paleustult (proposed in recognition of oxic and rhodic properties)
3. fine-loamy siliceous isohyperthermic Aquic Paleustalfs
4. fine-clayey kaolinitic isohyperthermic Aquic Paleustult (proposed).

Additionally, families of arenic subgroups of the above great groups also occur.

PROPOSAL FOR IMPROVEMENT OF CLASSIFICATION

The possibility of both argillic and oxic properties occurring in the same horizon has to be recognized on the basis of evidence provided by these and numerous other LAC soils in different parts of the world. Automatically excluding these soils from the Oxisol order, not only results in shrinking of the order to absurd proportions, but also excludes many highly weathered soils on old stable surfaces around which the concept of Oxisols was originally formulated.

The following changes in the definition of t'.e oxic horizon and the Oxisol order are therefore proposed in order to overcome this difficulty:

1. In the summary definition of the Oxic Hroizon (p. 39, Soil Taxonomy) replace clause 1a by "1a. Have an oxic horizon either immediately below an epipedon up to 2m thick or at the surface."
2. My own preference is that clause 1b should be dropped altogether.

The existence of argillic properties in Oxisols could be appropriately recognized at great group level by having Argi-great groups (e.g. Argiustox, Argi-orthox, etc.) as much as we have Argi-great groups in the Mollisol order (Argiborolls, Argialbolls etc.).

This approach certainly makes sense in regard to the Sri Lankan soils, at least because their oxic properties far outweigh their prop-

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erties resulting from the presence of an argillic horizon, both from the genetic and management points of view. This will also de-fuse the arguments now raging among soil scientists in the tropics about the need to re-define the argillic horizon.

The only problem likely to arise from the two proposed changes, is that classification of soils of the Southern United States would undergo drastic changes at the highest levels. I wish such soils could be excluded from Oxisols from a practical, but not a scientific standpoint, by introducing a soil temperature limitation or by some other mechanism. But I don't yet see how this could be done without violating the fundamental principles of Soil Taxonomy.

In conclusion, it appears that we must definitely decide whether Soil Taxonomy is to be expanded to accommodate all soils of the world or serve as an instrument for soil surveys in selected regions only. If we accept the former objective as stated in Soil Taxonomy itself, that "the taxonomy should provide for all soils that are known, wherever they may be," we must be prepared to make bold changes where these are required by new knowledge. There can be no "vested interests" in science.

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LAC ALFISOLS AND ULTISOLS IN EASTERN AFRICA; SOME PROBLEMS TO THEIR IDENTIFICATION AND CLASSIFICATION

W. G. Sombroek and F. N. Muchena

Available data from Ethiopia, Kenya, Uganda, Tanzania, and Zambia (cf. "Sources of Information") indicate that low activity clay (LAC) Alfisols and Ultisols are common in eastern Africa. Their separation from other soils and their meaningful subdivision is sometimes problematic if the criteria of Soil Taxonomy are applied. Some of these problems are discussed in the following sections.

SEPARATION FROM OXISOLS

This is often difficult, in part, due to uncertain data on the cation exchange capacity (CEC) and textural analysis, and to scanty information on clay mineralogy and micromorphology. At the same time, it is apparent that there are many borderline cases of Oxisols--LAC Alfisols and Ultisols. With the present definitions of the *oxic horizon* versus the *argillic horizon*, many of the so-called Latosols of early soil studies in the region are excluded from the Oxisols of Soil Taxonomy. Even with the criterion of clay ratio B/A of 1.4 or less (Bennema-Comerma proposal, attached to ICOMLAC circular letter no 8), a substantial number of recorded latosolic pedons remain outside the Oxisols, both in areas with udic and ustic moisture regimes. Brammer's (1973) data on Zambia are a case in point (cf. ICOMLAC circular letter no 9, page 3.)

Many of these pedons do however fit the concept of a lixic horizon, as a weakly expressed variant of the argillic horizon on the oxic side (cf. Appendix 2 to ICOMLAC circular letter no 8). It may be recalled that this concept specifies a clay ratio B/A of 1.4 or more,

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while no or only few ped cutans would be present. It seems therefore worthwhile to further test the usefulness of the lixic horizon, or rather "lixo-argillic" horizon, and to refine its limits on both the oxic side and the argillic *sensu strictu* side. Weak macro structure, less than complete aggregate stability, low content of free iron, and relatively high bulk density would be important associated characteristics; they may even be used in the definition. In conjunction they would make the soils concerned liable to sheet erosion, induce rapid surface resealing after cultivation (or capping, hardsetting, surface shifting), and in general cause relatively poor moisture infiltration and storage.

BASE SATURATION

The percent base saturation (BS) (CEC calculated via sum of cations, pH 8.2 method; and NH_4OAc, pH 7.0 method) is used as criterion for high-level separation of soil taxa, in this case separation of Alfisols from Ultisols. This appears awkward especially in many eastern African areas with a ustic moisture regime. It would appear more appropriate to separate these two orders on the high acitivity clays (HAC) versus the low activity clays criterion, or a combination of CEC-clay and percent BS (cf. minority proposals in the various ICOMLAC circulars). In this connection Arnold's remark (this workshop) may be quoted:"... clay increase at LAC has not, or not the same, accessory properties as are common with clay increased with HAC," as well as Eswaran's observation (also this workshop) that clay coatings in HAC argillic horizons would be of different mineralogical composition from clay in the ped interiors, but essentially of the same composition in LAC argillic horizons.

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AL^{+++} SATURATION AND ALLIC SUBGROUPS

There exists mostly no separate determination of the exchangeable Al content in the countries concerned. The indirect data ($H^+ + Al^+$, or Hp value, of Mehlich, 1960) or the inferred data (low pH-KCl values) do however suggest that the percentages are often insignificant. This would only in part be due to some recent alkali-rich ash admixture (e.g. southwestern Kenya and northwestern Tanzania, west of the volcanic activity of the Eastern Rift Valley).

SEPARATION OF UDIC, USTIC AND ARIDIC SOIL MOISTURE REGIMES

The establishment of these regimes by the usual interpretation of overhead climatic data is often difficult and too broad to be of much practical use. In many surveyed areas the short distance variation in soil moisture regimes is quite large and of paramount importance for land use planning. In part this is due to a high degree of complexity of the rainfall/evaporation pattern (bimodal rainfall regimes, of varying reliability). There is however also a strong variation in soil infiltration rates, especially in areas of crystalline basement system rocks. The ensuing necessity to establish a dense pattern of monitoring of actual soil moisture regimes over a number of years, is virtually impossible to effectuate, at least where speedy soil resources inventories at reconnaissance level are required. For such cases the use of the soil moisture regime as a criterion for high-level separation of soils appears particularly impractical. The practice in Kenya therefore is to have on soil maps an "overprint" of agro-climatological zonification (based on interpretation of the few existing data from meteorological stations, with adjustments for local relief differences, and refinement by vegetational indications). At the same time, the differential soil moisture characteristics are assessed by one time infiltration/percolation rate determination, soil moisture storage capacity determinations, and estimates on runoff/surface sealing intensity. Soil moisture characteristics and rainfall characteristics are subsequently used as two distinct qualities in

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the process of (multipurpose) land evaluation

MOLLIC EPIPEDON CRITERION

Quite a few soils in eastern Africa would be LAC Alfisols and Ultisols but for their topsoils. Especially under forest-savannah or dry forest vegetation, at intermediate altitudes (1000-2000 m) and with ustic moisture regime, topsoils tend to just fulfill the requirements of a mollic epipedon as at present defined in Soil Taxonomy (cf. Nichols, 1978). They have clearly more than 0.6 % carbon, but just make the color, depth and base saturation requirements; they do not reach the exclusion criterion of "both massive and hard when dry," but are often very near to it (e.g. weak subangular blocky and hard; massive and slightly hard). These epipedons are a far cry from the soft, organic matter-rich topsoils of the traditional prairie soils of the U.S., Canada, Uruguay, Argentina, etc. Moreover, many of these marginal mollic epipedons would rather quickly deteriorate under cultivation, at the prevailing climatic conditions (see also McLelland's letter of March 1975, as attached to ICOMLAC circular letter no 1). It is proposed that the definition of a mollic epipedon be narrowed to exclude these borderline cases. A minimum of 0.9 % carbon is suggested (Walkley-Black) with a rider "not both hard-when-dry and with massive or weak subangular blocky structure."[1]

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[1] During the ensuing Thailand field tour Dr. Guy Smith mentioned that the 0.6 % carbon criterion had to be applied because of some sandy and winnowed soils of the Great Plains of the U.S., that for mapping reaons had to be included in the Mollisols. He agreed that the minimum carbon percentage can better be linked to the texture. Dr. Holzhey gave similar reasons for the broadness of the structure-consistence requirement with examples from Texas.

Well-developed mollic epipedons do occur in eastern Africa, for instance where some recent alkali-rich volcanic ash admixture has occurred (e.g. the Kisii area of southwestern Kenya). They are however often underlain by a trick (100-200 cm) subsurface horizon with LAC properties, of either high or low base status. This subsoil by itself is of considerable importance for moisture and nutrient storage. For these cases, it seems more appropriate to classify the soils systematically as Alfisols and Ultisols (Paletaxa) and to account for the presence of a mollic epipedon at a lower categoric level, as is in fact already allowed for in Oxisols.[2]

For the sake of completeness it should be mentioned that well-developed mollic epipedons with relatively thin subsoils of high base status do occur in eastern Africa as well. An example is the Rumuruti-Laikipia plateau over tertiary basalt/phonolite northwest of Mount Kenya, with ustic to aridic moisture regime and open savannah vegetation. There, the classification as Mollisols seems entirely appropriate.

SOILS WITH HIGH SPECIFIC SURFACE/HIGH CONTENT OF HYDROUS SESQUIOXIDES[3]

Dark red, deep LAC soils from permeable basic parent materials (metamorphic rocks rich in ferromagnesian minerals, basalts, some limestones, etc.) are of common occurrence in some of the eastern African countries (Kenya, Ethiopia, Northern Tanzania). These soils stand out for their favorable physical properties and fair-to-high

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2 Again, Dr. Guy Smith pointed out that at the present keying out in Soil Taxonomy not only Oxisols but also Ultisols can have a mollic epipedon.

3 ICOMLAC circular letter no 9, item 2.5, and others.

inherent fertility (micronutrients). They are intensively cultivated both for small landholders and estate farming. From the users' point of view, they are clearly different from other Alfisols and Ultisols, and this should be reflected in their classification. Their clay mineralogy is predominantly of the 1:1 type, with halloysite taking up not insignificant percentages. The same holds for amorphous or microcrystalline materials. Clay CEC values, corrected for % carbon, are often below 24 me, but not always. The content of non or microcrystalline hydrous Fe and Al oxides is high. Their specific surface and that of the total clay fraction is likely to be high. Morphometrically the soils often show a high structure stability, a gently clay bulge, and a shiny aspect to great depths.

The above properties, in conjunction, may be sufficient to define a nitic or nito-argillic horizon, as basis for separation of the soils concerned at a high categoric level in Soil Taxonomy. As suggested during the Brasil workshop, they may be keyed out as "Rhod" or "Nit-" taxa at group level, just before the "Kandi" taxa.

Elements that may be used for separation of these taxa for the definition of a nito-argillic horizon are the following:

a) well-drained, deep (more than 150/180 cm from surface)
b) high clay content throughout (more than 40, if not 50%), with fair to low percentage of silt (silt/clay ratio less than 0.35?)
c) gentle clay bulge, if any; no or only gradual increase in texture from A to B (ratio less than 1.2?) and no or only slight decrease from B to C (less than 20% within 50 cm)
d) only gradual decrease in organic matter content down the profile (little color change from A to B, no bleached sand grains)
e) well-defined blocky structure (moderate fine polyhedral)
f) friable when moist (but hard when dry)
g) high aggregate stability (practically no water-dispersible clay in the horizons with low organic matter content; structure index more than 90)
h) fair to high permeability and moisture storage per unit of volume, associated with rather low bulk density (lower than 1.4)

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i) many shiny ped faces throughout the B and the C horizons, which cannot or can only be partially associated with illuviation argillans in thin sections. The micromorphology would be essentially congelic (Eswaran), with many very thin coatings of weak birefringence in the voids and within the S matrix, in the latter occurring around the primary polyhedric structure elements (stress cutans, helped by electromagnetic orientation?)

j) high percentage of free iron (more than 5% if not 10%; dithionite extraction) and free aluminum (more than 1% if not 2%), and relatively high percentage of amorphous sesquioxides (more than 0.5% for both Fe and Al; oxalate extraction)

k) high specific surface of the sesquioxides (more than 100 if not 150 m^2/g) and of the total soil mass (more than 50 m^2/g?)

l) silicate clay minerals mainly kaolinitic, but metahalloysite and poorly crystallized materials often present (more than 20%?)

m) colors of low value and chroma (4/4 or less). Often hue 10R or 2.5YR, but sometimes yellower

n) CEC at pH 7 often between 16 and 24 me/100 g clay, but may be lower or higher

o) amount of weatherable minerals in the fine sand fraction usually rather small (less than 10%?)

Associated characteristics would be: distinct magnetism, H_2O_2 effervescence, relatively high Ti percentage (1-2%, or more). Note: these latter do also occur in Oxisols from basic parent materials (Latosol Roxo or Dusky Red Latosol), having progressed from Sys' intermediate stage of weathering to the final stage of weathering, with fluffy structure, clay CEC values below 16, and shiny faces only deep down the profile.

The separation of a nito-argillic horizon from a lixo-argillic horizon (see above) on the one hand, and from an oxic horizon and a well-developed argillic horizon on the other hand, will be discussed in a separate paper, to be presented at the end of the workshop if time permits.

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LOW ACTIVITY CLAY ALFISOLS AND ULTISOLS OF VENEZUELA

J. A. Comerma

In Venezuela, the argillic horizon is generally considered to be a very important pedogenic mark. Especially under our prevalent ustic moisture regime, the normal evolution of soils in Middle Pleistocene or younger alluvial plains goes from a cambic horizon in young landscapes toward an argillic in somewhat older landscape positions. This evolution in soil genesis is generally accompanied by a change in vegetation, i.e. forest toward savannah. Our explanation for this change is primarily related to an enhancement of the hydric contrast between the dry and wet seasons as shown in the argillic horizons, and secondly to a decrease in base saturation and available nutrients in the upper soil. In these kinds of landscapes the sequence from younger to older surfaces is from Alfisols to Ultisols, generally Pale-great groups and oxic subgroups. Associated soils in that maxima of pedogenesis are Hapl- and Plinth- great groups of Ultisols and a few patches of Oxisols.

In upper Pleistocene or older surfaces, whether in ustic or udic moisture regimes, the main soil associations are Ultisols and Oxisols. Most Ultisols are Pale- with oxic subgroups, and in these the significance of some argillic horizons in contrast to oxic is doubtful. There are no appreciable changes in native vegetation, bases, nutrient status, mineralogy, etc. The observable differences are mostly related to clay distribution with depth, and sometimes structural development.

With the purpose of studying the collective characteristics of these oxic subgroups of Alfisols and Ultisols in Venezuela, a review of soil survey reports and other publications was done.

RESULTS

From this review and information of previous soil maps of Venezuela, Figure 1 was prepared. It indicates the general areas where oxic subgroups of Alfisols and Ultisols are found. At present, an estimate of 10 percent of the country, or 9 to 10 million ha, is occupied by these soils.

The largest areas are associated with the Guiana Shield sediments or rock outcrops. In these areas the surfaces are thought to be of upper Pleistocene or older ages, and occur mostly as pediments or glacis and old alluvial plains. The major associated soils are Orthox in udic climates and Ustox and Psamments in drier climates.

Smaller areas in Western and especially North Central Venezuela occur as piedmont terraces of the Andes, and piedmont as well as high plains of the Northern Coastal Range. The surfaces are thought to be of middle Pleistocene ages. The major associated soils are Alfisols and Ultisols of higher clay activity.

Out of 50 selected pedons that have been well characterized and fit the definition of low activity clay (LAC) Alfisols and Ultisols, we can conclude through estimation of the main areas of occurrence, that in order of extension the predominant groups are: Paleustults, Paleudults, Paleaquults, Plinthustults, Haplustults, Plinthaquults, Paleustalfs, Haplustalfs, Tropaqualfs, Palehumults, and Rhodudults. Evidently LAC Ultisols are much more widespread and varied than LAC Alfisols.

LAC PALEUSTULTS, PALEAQUULTS, PLINTHUSTULTS, AND PLINTHAQUULTS

These LAC soils occur predominantly in savannahs of flat to very gentle slopes. Elevations are below 300 m above sea level, and rainfall commonly ranges between 1000 and 1500 mm. Base saturation in the subsoils varies from 5 to 40 percent, and the pH ranges between 4 and 5.5. The apparent cation exchange capacity (CEC) is

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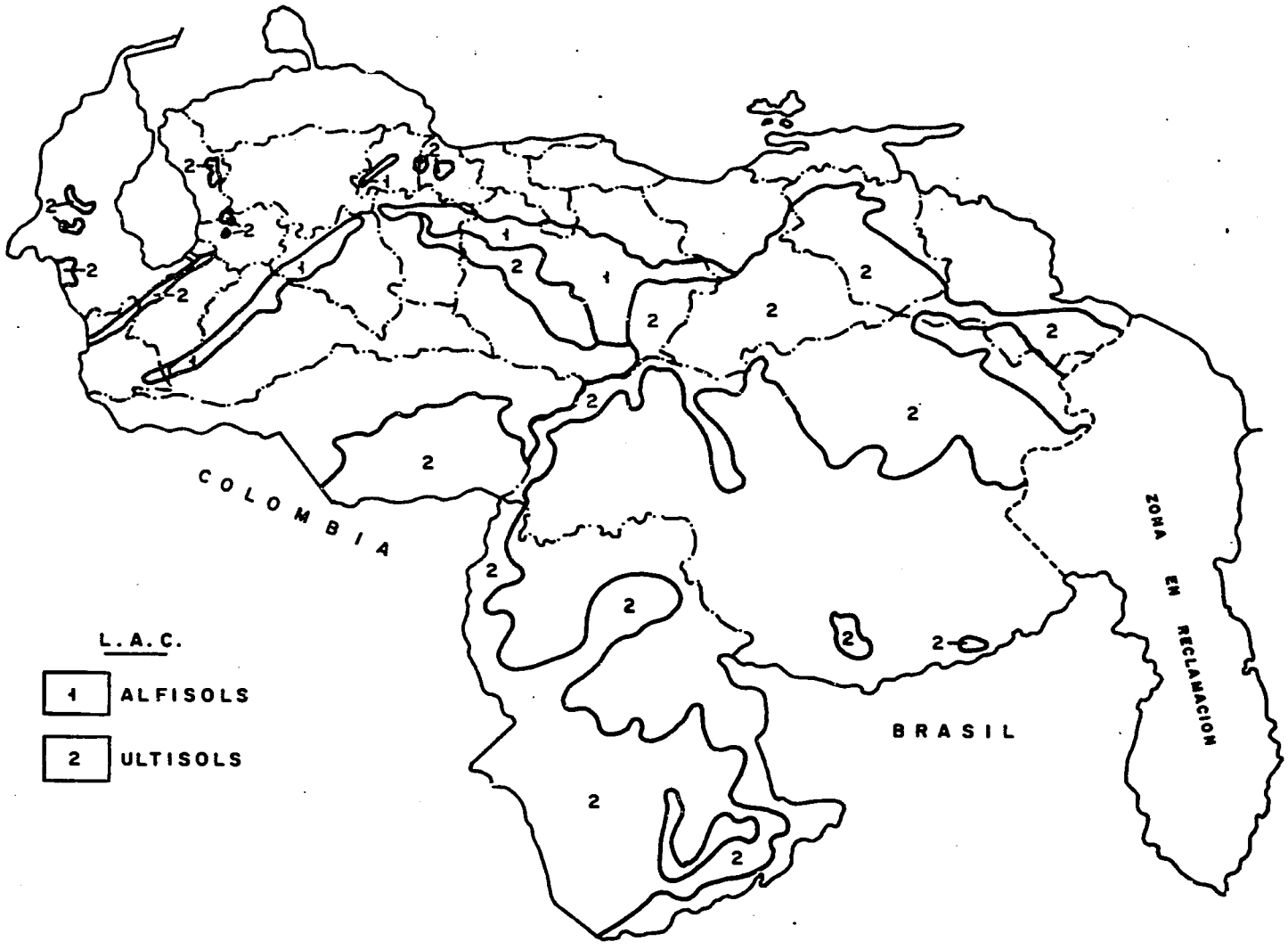
L.A.C. ALFISOLS AND ULTISOLS FROM VENEZUELA



below 16 me/in 75% of the cases; the most common values vary between 10 and 15 me/100 g of clay, especially for soils derived from sediments of the Guiana Shield.

Clay increase ratios from eluvial to the argillic are variable, but about 75 percent of the cases have ratios over 1.4, i.e. 1.4 to 1.8. These high ratios are especially noticeable in the Eastern Mesa soils, derived from the Guiana sediments in the southern portion, where sandy topsoils over sandy clay subsoils strongly predominate. It is also in this area especially in Paleustults, that we can describe oxic over argillic horizons at the base of the eluvial zone. As a general rule for these soils, we are able to observe clay films in the field when the texture is sandy clay loam or finer.

The most common subgroups, especially of Paleustults, are just oxic, while others are oxic combined with arenic, grossarenic, plinthic and proposed udic. In Plinthustults the aquic oxic and arenic oxic are common combinations, while in the Paleaquults the plinthic oxic is common.

LAC Paleudults

LAC Paleudults occur predominantly in moist evergreen forests, with 2000 to 2500 mm rainfall. The most common topography is gentle to rolling slopes. Base saturations in the subsoils in all cases are from 5 to 10 percent; pH values fall between 4 and 5. Apparent CEC's lies between 16 and 24 me/100 g of clay in 75 percent of the cases. Again, values of less than 16 me are associated with Oxisols and materials of the Guiana Shield, while higher values occur in soils derived from sediment of the Andes.

Clay increase ratios from the eluvial to the argillic are rather marginal for argillic horizons. The most common values are from 1.2 to 1.3 with rather gradual horizon boundaries.

The subgroups found are predominantly oxic, with one combination of rhodic oxic.

LAC Haplustults

LAC Haplustults collected in this review occur in various situations. Sometimes they are associated with Paleustults in similar landscape positions, under savannahs of flat-to-gentle slopes. In other cases they are located on piedmont terraces under a mixed forest-savannah vegetation. Finally, recent surveys in the Andes Mountains have located Oxic Haplustults derived from phyllites and mica schists on steep side slopes and undulated mountain tops, up to 1700 m above sea level. Base saturation of the subsoils generally range from 5 to 30 percent with pH from 4 to 5.5. Apparent CEC is dominantly over 16 me/100 g of clay.

Clay increase ratios with depth are in all cases 1.4 or higher. Subgroups are mostly just oxic, but there are also plinthic and arenic Oxic Haplustults.

LAC Paleustalfs and Haplustalfs

These LAC soils occupy similar positions along piedmont terraces and fans of alluvial material from the Andes and the Northern Coastal Range. Both have mostly savannah vegetation in many cases mixed with trees. Rainfall and elevation are similar to those for LAC Ustults, although they seem to dominate in the drier climates, and if together with Ustults, they occupy somewhat lower terraces. Base saturation in the subsoils are commonly between 20 and 60 percent with pH values from 4 to 6.5. Apparent CEC values are dominantly over 16 me, most values being between 19 and 22 me/100 g clay.

The subgroups are in all oxic, except for the combinations of aquic oxic.

Mineralogical analyses were conducted for some horizons of only 10 of 50 pedons; therefore it is risky to try reaching conclusions on this matter. Nevertheless, the tendencies observed from these analyses are: (1) In all cases the predominant clay mineral is kaolinite. (2) Second in dominance are micas. These commonly reach levels of 10 percent or less in the clay fraction, but there are three cases where the levels are even higher, one of them reaching

about 40 percent of the clay fraction and still the apparent CEC is around 13 me/100 g of clay. (3) Third in dominance are 2:1-2:2 interlayered silicate clays or gibbsite. These tendencies raise some doubts on the mineralogical significance of the CEC values used to describe the oxic character.

SUMMARY

At present an estimated 10% (9-10 million ha) of the area of Venezuela has LAC Ultisols and Alfisols (less than 24 me, apparent CEC). The largest areas occur around the Guiana Shield, either from its derived sediments or from rocks *in situ* of Upper Pleistocene and older ages; its main associated soils are Orthox, Ustox, and Psamments. Smaller areas in western and North Central Venezuela occur as piedmont terraces of the Andes; the main associated soils are Alfisols and Ultisols of higher clay activity.

From soil surveys and other sources, mostly at the north of the Orinoco river, 50 reported pedons that fit the definition of LAC Alfisols and Ultisols were selected. In order of extent the following groups were found: Paleustults, Paleudults, Paleaquults, Plinthustults, Haplustults, Plinthaquults, Paleustalfs, Haplustalfs, Tropaqualfs, Palehumults, and Rhodudults.

LAC Ustults occur mostly in savannahs of flat-to-gentle slopes, with 1000 to 1500 mm rainfall, base saturations of 10-50%, and pH values of 4-5.5. Clay increase is variable but ratios greater than 1.4 (1.4-1.8) strongly predominate. About half of them have apparent CEC of less than 16 me. Most subgroups are oxic alone; others are combined with plinthic, arenic, grossarenic, udic and plinthaquic.

Paleudults are found mostly under forest with gentle-to-rolling slopes, with 2000 to 2500 mm rainfall, very low base saturations (10-15%) and pH values of 4 to 5. Most soils have a gradual clay increase with marginal ratios of 1.2 to 1.3, and an apparent CEC

generally between 16 and 24 me. Most subgroups are oxic alone (typic ?); others are combined with plinthic, rhodic, and arenic.

Paleustalfs have similar characteristics to Paleustults except that the base saturations are somewhat higher (20-50%); pH values range from 4 to 6.5; and most subgroups are ultic oxic and aquic oxic. Haplustults are also similar to Paleustults except for clay distribution.

Some problems related to clay mineralogy, apparent CEC, and transitional oxic horizons above the argillic are also discussed.

OCCURRENCE OF SOILS WITH LOW ACTIVITY CLAYS IN THE U. S. AND PUERTO RICO

S. W. Buol

With the exception of Oxisols, the activity of the clay fraction in soils in the U. S. has not been used as a criterion for soil classification, except as it relates to associated properties. However, many data are available from pedons that have been sampled as representatives of the approximately 14,000 soil series recognized in the U. S. At present many of these data are being placed in automatic data and retrieval facilities so that in the future they will be more readily available to researchers.

In preparing this paper as much data as possible has been reviewed, however, it is certain that more is available. An attempt has been made to focus on three aspects of identifying low activity clay (LAC) soils in the U. S. First, the taxonomic identification of LAC soils will be examined. Second, the genetic factors responsible for LAC soils will be discussed. And, third, the geographic distribution of LAC soils within the U. S. will be described.

TAXONOMIC PLACEMENT OF LAC SOILS

The only clear entry into the taxonomic placement of LAC soils appears to be through the family level of Soil Taxonomy (Soil Survey Staff, 1975). Family criteria (p. 387) state that kaolinitic families, used only in soils containing more than 35% clay in their control section, shall have "more than half kaolinite, tabular halloysite, dickite and nacrite by weight, smaller amounts of other 1:1 or nonexpanding 2:1 layer minerals or gibbsite, and less than 10% montmorillonite."

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By using a cation exchange capacity (CEC) value for each mineral species, a CEC value for a mixture can be calculated. There are several values reported for the CEC at pH 7 (CEC_7) of the different clay minerals (because of isomorphic substitution, particle size, etc.), and the ranges published by Grim (1968) appear acceptable (Table 1).

In developing the calculated CEC_7/100 g clay values in Table 2, the values of Table 1 were assigned to mixtures that could be expected to form the kaolinitic family limit in Soil Taxonomy. Vermiculite and montmorillonite were both considered as meeting the less than 10% montmorillonite definition in a kaolinitic family, and no consideration has been given to the possible presence of illite or chlorite. This simplification is probably valid since chlorite is almost never found in the clay fraction of soils approaching the kaolinitic family placement, and although illite is commonly present, its content is low and its CEC/100 g clay is not much greater than that of kaolinite. From the calculated values it can be seen that it should not be possible to get more than 28.5 me/100 g clay apparent CEC_7 values, if the content of montmorillonite is less than or equal to 10% of the clay mixture (Using the highest value of Grim, 1968). If the lowest values presented by Grim are used, the 10% montmorillonite mixture should give 10.7 me/100 g clay; and a mean value would give 19.6 me/100 g clay apparent CEC_7 for a 90% kaolinite and 10% montmorillonite mixture.

It has been a common practice to place soil series in taxonomy using the interpretation of x-ray diffractograms of clay samples from the control section. Figure 1 consists of a series of x-ray diffractograms for soil clays that exhibit apparent CEC_7 values in the 12-28 me/100 g clay range. All of these data are from the upper coastal plain area of North Carolina, and the x-ray traces were made of samples prepared in the author's laboratory. Thus, variations in x-ray diffractograms caused by different preparation techniques and instrument settings are not present. Such

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Table 1. Clay mineral CEC_7 ranges (Grim, 1968).

Clay	me/100 g clay
Kaolinite	3-15
Smectite group	80-150
Illite	10-40
Vermiculite (not interlayered)	100-150
Chlorite	10-40

Table 2. Calculated CEC_7/100 g clay values using $\geq$ 90% kaolinite and $\leq$ 10% montmorillonite mixtures.

Soil clay	Assigned CEC values
CEC/100 g	(me/100 g clay)
$\leq$ 10.7	Mont = 80 Kaol = 3
$\leq$ 17.7	Mont = 150 Kaol = 3
$\leq$ 21.5	Mont = 80 Kaol = 15
$\leq$ 28.5	Mont = 150 Kaol = 15
$\leq$ 19.6	Mont = 115 Kaol = 9 (mean)

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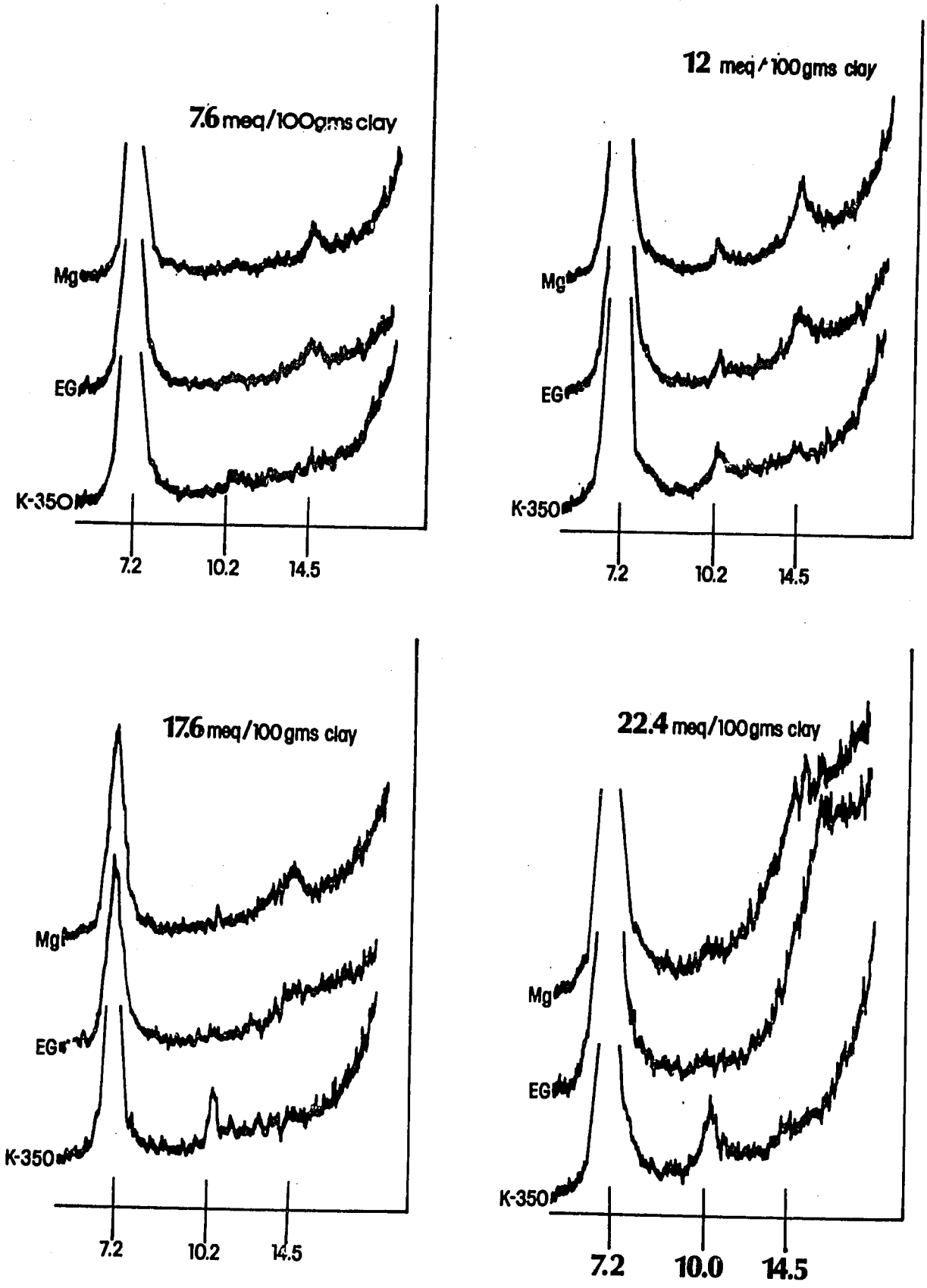

Figure 1: X-ray diffractograms and apparent clay CEC_7 values of selected Ultisol argillic horizons

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variations in diffractograms from this source can be substantial and cannot be overlooked when comparing data from other sources.

Recently Hajek (1978) published characterization data for a number of soils in Alabama (Table 3). These data have been developed from samples sent to his laboratory by scientists in the field during the course of their soil mapping operations. The placement into mixed or kaolinitic families was made by the interpretation of x-ray data. The apparent CEC_7/100 g clay was calculated during the preparation of this paper, from the CEC/100 g soil and percent clay content data reported by Hajek (1978). Note that except for some overlap in the CEC_7/100 g clay values (between 17 and 21 me) there is reasonably good agreement between the two methods.

Proceeding on this demonstrated relationship between clayey kaolinitic families and low activity clays, the most recent placement of soil series (August, 1977) was searched for those soil series that could be considered as having low activity clays. Table 4 lists all those series found in the 9 orders, excluding the Ultisols, which are placed in clayey kaolinitic families. Oxidic families are also included because the oxidic criteria preclude a kaolinitic placement and may include some LAC soils.

The series name is given and also the state that has the administrative responsibility for defining the series. Although not always, this is usually the state that has the most extensive occurrence of that soil.

It can be seen that there presently are no potential LAC series in the Vertisol or Aridisol orders. All the clayey-textured Oxisols are presently in kaolinitic or oxidic mineralogical families. All of the Spodosol, Mollisol, Inceptisol, and Histosol series with potential LAC mineralogy are located in Hawaii. One potential LAC Entisol (Chastain) is present on the east coast of the U. S. and two are in Hawaii. There are 15 series in the Alfisol order that potentially fit a LAC classification. Again, it should be noted that Table 4 contains only those series having both clayey-textured control sections and kaolinitic or oxidic

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Table 3. Apparent CEC/100 g clay for clayey B22t horizons in Alabama Alfisols and Ultisols (Hajek, 1978).[a]

Mixed Families	Kaol. Families
32	20
26	12
23	21
40	20
50	13
40	15
49	13
31	15
26	11
18	14
17	17
19	13
26	16
25	13
49	18
35	18
42	15.5 (11-21)
32 Ave (17-50)	

[a] Procedure of Hajek *et al* (1972). Equivalent to NH_4OAc pH 7.

Table 4. Series in clayey[a] families with kaolinitic or oxidic mineralogy.

Classification	Series	State
Alfisols		
Aeric Ochraqualf: fine, kaol., thermic	Percilla	TX
Glossic Cryoboralfs: fine, kaol.,	Sielo	UT
Mollic Hapludalfs: fine, kaol., thermic	Trawick	TX
Typic Paleudalf: fine, kaol., thermic	Alto	TX
	Meth	LA
Typic Paleudalf: very fine, kaol., mesic	Swimley	VA
Rhodic Paleudalf: fine, kaol., thermic	Coronaca	SC
	Nacogdoches	TX
Udic Haplustalf: very fine, kaol., mesic	Martinez	AZ
Oxic Paleustalf: fine, oxidic, isothermic	Kanepuu	HI
Oxic Rhodustalf: fine, oxidic, isohyperthermic	Kemoo	HI
Abruptic Durixeralf: fine, kaol., thermic	Chesterton	CA
	Redding	CA
Ultic Palexeralf: fine, kaol., thermic	Red Bluff	CA
Typic Rhodoxeralf: fine, kaol., thermic	Guenoc	CA
Aridisols - None		
Entisols		
Typic Fluvaquent: fine, kaol., thermic	Chastain	SC
Tropic Fluvaquent: very fine, oxidic, non-acid, isohyperthermic	Hanalei	HI
Typic Torrifluvents: fine, kaol., non-acid, isohyperthermic	Mala	HI
Histosols		
Terric Troposaprist: clayey, kaol., dysic, isomesic	Alakai	HI
Inceptisols		
Typic Placaquepts: fine, oxidic, acid, isothermic	Hulua	HI
Typic Tropaquept: very fine, kaol., nonacid, isohyperthermic	Kalihi	HI
Plinthic Tropaquept: fine, halloysitic, acid, isothermic	Koolau	HI
Ustoxic Humitropept: fine, kaol., isohyperthermic	Kunia	HI
fine, kaol., isothermic	Haliimaile	HI
fine, oxidic, isohyperthermic	Kolekole	HI
fine, oxidic, isohyperthermic	Pohakupu	HI
Andic Ustic Humitropept: fine, oxidic, isohyperthermic	Ainakea	HI
Oxic Humitropept: fine, oxidic, isothermic	Hihiman	HI
Fluventic Ustropepts: fine, oxidic isohyperthermic	Pakala	HI

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Table 4 continued

Classification		Series	State
Oxic Ustropept:	fine, kaol., isohyperthermic	Hoolehja	HI
Oxic Ustropept:	very fine, kaol., isohyperthermic	Uwala	HI
Vertic Ustropept:	very fine, kaol. isohyperthermic	Waipahu	HI
Mollisols			
Lithic Haplustoll:	clayey, kaol., isohyperthermic	Mamala	HI
Oxic Haplustoll:	fine, kaol., isohyperthermic	Makaweli	HI
Oxic Haplustoll:	fine, kaol., isohyperthermic	Paia	HI
Vertic Haplustoll:	very fine, kaol., isohyperthermic	Waialua	HI
Oxisols:	All kaol., oxidic (or other)		
Spodosols			
Histic Lithic Tropaquod:	fine, oxidic, isomesic	Waialeale	HI
Ultisols:	See further breakdown - Table 5		
Vertisols:	None		

[a]Fine and very fine textural names are used in some orders to define 35 to 60% and more than 60% clay, in the control section, respectively.

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mineralogy. We should expect that several other series with fine-loamy or coarser control section texture could have apparent clay CEC values low enough to meet proposed LAC criteria.

Most of the potential LAC series in the U. S. classify in the Ultisol order. Table 5 lists subgroups with series in one of three combinations of taxonomic families: a) subgroups with both clayey, kaolinitic (oxidic) and clayey mixed families; b) subgroups with only clayey, kaolinitic (oxidic) families; c) subgroups with only clayey mixed families. About 200 series are involved. No climatic or geographic patterns appear from this listing.

POSSIBLE RELATIONSHIPS OF LAC SOILS

It appears clear that most LAC soils in the U.S. are classified in the Ultisol order. Also, by definition all Oxisols fit the criteria. However, it is clear that not all Ultisols have LAC. A further examination of the Ultisols was made to determine if a causative factor or factors could be related to the presence of low activity clays.

Gamble and Daniels (1974) found an area dominated by LAC Paleudults in the upper and middle coastal plain soils of North Carolina. They state "....within the solum kaolinite is always present but generally diminishes in relative quantity toward the surface where other minerals may dominate" (Gamble & Daniels, 1974). They point out that a 2:1-2:2 intergrade-clay mineral (Al-interlayered) occurs in the solum at all sites, and it decreases in relative quantity with depth as mica (illite) becomes relatively more abundant. They hypothesize that the abundance of 2:1-2:2 intergrade nearer the surface may result from the alteration of micaceous eolian material to vermiculite, to 2:1-2:2 intergrade. Kaolinite appears to be inherited from parent material in these coastal plain terraces. The apparent CEC values they found (Table 6) clearly show that low activity clays are present well below the soil solum.

Table 5. Ultisol subgroups with clayey families.

A. Subgroups with clayey, mixed and clayey kaolinitic families	
Typic Albaquults	Typic Hapludults
Typic Ochraquults	Aquic Hapludults
Typic Paleaquults	Typic Paleudults
Aeric Paleaquults	Rhodic Paleudults
Plinthic Paleaquults	Typic Rhodudults
Xeric Haplohumults	Typic Tropudults
Typic Tropohumults	Typic Haploxerults
Typic Fragiudults	
B. Subgroups with only clayey kaolinitic (oxidic) families	
Typic Fragiaquults	Aquic Fragiudults
Typic Palehumults	Arenic Paleudults
Plinthic Palehumults	Arenic Plinthic Paleudults
Epiaquic Orthoxic Tropohumults	Fragic Paleudults
Humoxic Tropohumults	Plinthic Paleudults
Orthoxic Tropohumults	Oxic Haplustults
Ustoxic Tropohumults	Plinthic Haplustults
C. Subgroups with only clayey, mixed families	
Aeric Ochraquults	Humic Hapludults
Oxic Plinthaquults	Aquic Arenic Paleudults
Typic Umbraquults	Aquic Tropudults
Typic Haplohumults	Dytropeptic Tropudults
Andeptic Haplohumults	Orthoxic Tropudults
Aquic Haplohumults	Plinthic Tropudults
Epiaquic Palehumults	Vertic Tropudults
Aquic Tropohumults	Typic Haplustults
Epiaquic Tropohumults	Arenic Haplustults

Table 6. Apparent CEC of the clay in coastal plain sediments in North Carolina (after Gamble and Daniels, 1974).

Depth	Horizon	Effective CEC	pH 8.2 CEC	Clay
		(me/100 g clay)	(me/100 g clay)	(%)
Upper Coastal Plain (Arenic Plinthic Paleudult)				
168-274	B21	4.8	21	33.3
274-427	B22	3.3	26	20.7
427-503	B23	3.6	30	17.7
579-670	C	3.3	12	17.1
731-884	C	2.7	20	27.2
(Arenic Paleudult)				
229-274	B2	7.9	18	11.1
335-427	B3	9.7	23	9.2
488-579	C	7.9	25	22.6
670-792	C	7.2	22	9.5
(Plinthic Paleudult)				
46- 69	B12t	8.6	23	29.2
86-107	B22t	7.8	21	34.7
127-148	$A^1 2?$	4.5	18	31.4
201-239	$B^1 3^1 p^1$	4.1	16	33.9
305-343	C	10.8	16	41.6
427-488	C	6.4	13	26.7
518-579	C	7.5	15	23.4
732-884	C	9.3	17	17.3
1006-1036	C	9.3	21	10.3
1036-1158	C	8.2	19	15.3

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Table 6 continued

Depth	Horizon	Effective CEC	pH 8.2 CEC	Clay
		(me/100 g clay)	(me/100 g clay)	(%)
Middle Coastal Plain (Plinthic Paleudult)				
51- 69	B22t	8.7	26	34.4
89-109	B24	6.0	21	31.5
137-162	B26pl	5.7	17	24.4
229-274	C	7.2	15	17.9
274-335	C	5.7	14	18.3
427-488	C	17.7	26	2.4
579-671	C	11.8	20	5.4
(Typic Paleudult)				
56-171	B22	11.6	30	29.7
94-137	B24	10.1	23	22.2
173-211	B3t	16.5	20	26.5
244-274	C	11.8	15	10.6
366-411	C	22.1	32	8.6
411-488	C	20.5	43	12.4
(Aquic Hapludult, tenative)				
61-107	B21t	27.5	61	5.2
107-183	B22	18.5	65	4.7
274-335	B3	9.4	22	13.9
457-579	C	11.7	26	9.2
732-853	C	14.0	19	15.3
1036-1158	C	115.0	208	1.3

In another study Calvert (1978) examined a Typic Hapludult, clayey, kaolinitic, thermic profile in the piedmont of North Carolina. His study extended to hard granitic rock at a depth of over 5 meters. He found LAC values in the saprolite material well below the soil solum (Table 7). Other observations indicated alternation of the feldspars to kaolinite of characteristic low apparent CEC well below the solum. From these and other observations it was suspected that within the Ultisols, LAC soils may be related to acidic parent material. In an attempt to check this assumption, information recorded for the series description for clayey, kaolinitic (oxidic) and clayey mixed series of certain Udults in the southern U. S. was tabulated (Table 8). Where one tends to find a greater frequency of reference to basic rock in mixed families the results are inconclusive, perhaps in part due to the very brief nature of statements describing parent material commonly found in most series descriptions.

Table 7. Clay CEC in a Typic Hapludult in North Carolina (after Calvert, 1978).

Depth	Horizon	Clay	Apparent CEC_7	Direct clay CEC pH 4	Measure (ca/mg) pH 7
(cm)		(%)	(me/100 g clay)	(me/100 g clay)	(me/100 g clay)
16-67	Bt	60.7	6.3	4.9	6.6
102-137	C1	30.4	10.5	4.4	6.4
217-252	C21	12.0	15.8	4.1	5.1
327-367	C22	12.0	13.3	3.0	4.2
482-522[a]	CR	(6.3)[a]	28.5	2.5[a]	3.8[a]

[a] Average of 4 intermediate depths.

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Table 8. Parent material of Udult soils in the southern U.S.

Typic Hapludults - Clayey, kaolinitic, thermic	
Soil	Parent Material
Appling	Residium from acid igneous and metamorphic rock
Aragon	Cherty limestone, interbedded sandstone, siltstone and shale
Cecil	Acid igneous and metamorphic rocks
Chestatee	Granites, gneisses, schists and quartzite
Georgeville	Phyllites or Carolina slates
Herndon	Phyllites or Carolina slates
Hulet	Acid metamorphic rocks
Madison	Acid micaceous metamorphic rocks
Mayodan	Shales, sandstones, siltstones
Nankin	Coastal Plain
Pacolet	Acid crystalline rocks
Spotsylvania	Granite gneiss and shists
Wedowee	Acid crystalline rocks
Typic Hapludults - Clayey, mixed, thermic	
Albertville	Shale or interbedded shale and sandstone or siltstone
Arundel	Marine deposits of acid clays overlying sandstone, shale & siltstone
Brockroad	Mantle of silty and clayey sediments overlying material from mica, shist and gneiss
Carnasaw	Sandstone and shale
Cullen	Basic and acid igneous and metamorphic rocks
Cunningham	Acid shales with limestone or siltstone in places
Cuthbert	Acid stratified loamy and clayey sediments (coastal plain)
Enders	Shales or interbedded shale and sandstone
Endsaw	Shale
Galilee	Clayey shales and sandstone
Gritney	Coastal Plain
Kirvin	Coastal Plain
Luverne	Coastal Plain
Masada	Alluvium from felsic rocks
McQueen	On stream terraces from alluvial sediments high in mica
Nason	Sericitic shist, phyllites or slates
Remlap	Interbedded limestone and shale
Sweatman	Shaly clays of upper coastal plain
Tatum	Sericite shist
Townley	Shale or interbedded shale and sandstone
Vance	Acid crystalline rock
Williamsville	Glauconitic marine sediments

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Table 8 continued

Typic Hapludults - Clayey, kaolinitic, mesic	
Christian	Residium or old alluvium of interbedded shale, siltstone & limestone
Typic Hapludults - Clayey, oxidic, mesic	
Bradson	Acid crystalline alluvium and colluvium
Hayesville	Granite, gneiss or schist residium
Typic Hapludults - Clayey, mixed, mesic	
Agnos	Clayey residium over shale siltstone and limestone
Boden	Sandstone bedrock
Braddock	Colluvial material or old alluvium over saprolite (acid igneous)
Gassville	Limestone, siltstone, shale
Groseclose	Cherty, dolomitic limestone
Muse	Acid shales and siltstone
Pervina	Sedimentary rocks
Sequoia	Acid shales and siltstones
Trappist	Acid shales and siltstones
Unison	Basic or basic and acidic crystalline rocks
Typic Paleudults - Clayey, kaolinitic, thermic	
Collegedale	Clayey residium from limestone or limestone and shale
Dewey	Old alluvium over residium from limestone
Esto	Sediments on the coastal plain
Faceville	Coastal plains sediments
Fullerton	Residium from limestone
Henderson	Coastal Plain
Marlboro	Clayey coastal plain sediments
Summerton	Old alluvium in the coastal plain
Waynesboro	Alluvium from sandstone, shale and limestone
Typic Paleudults - Clayey, mixed, thermic	
Butusha	Coastal plain
Caroline	Coastal plain marine sands, silts and clays
Shubuta	Coastal plain sediments
Turbeville	Old alluvium from acid igneous rocks
Typic Paleudults - Clayey, kaolinitic, mesic	
Dunmore	Residium from dolomitic limestone
Frederick	Clayey residium from dolomitic limestone

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Table 8 continued

Typic Paleudults - Clayey, mixed, mesic

Doniphan	Clayey shales and cherty dolomite or limestone
Macedonia	Clayey shales and cherty limestones

LOCATION OF LAC SOILS IN THE U. S.

Figure 2 is a small scale map showing the locations where low activity clays are most prevalent. It is likely that most soils in these areas have low activity clays. Three states (Georgia, North Carolina, and South Carolina) appear dominated by low activity clays. Areas excluded in these states are the Inceptisol-dominated mountain areas, the Alfisol-dominated band of volcanic slates, and the lower (younger) coastal plain terraces. A rather small area of LAC soils is present in a band immediately west of the Appalachian Mountains in eastern Tennessee. The LAC soils appear to extend only a few kilometers into the northern most counties of Florida. Little evidence is available to fix a northern boundary in Virginia. Some evidence in Alabama (Hajek, 1978) indicates that the LAC soils are limited to the eastern Mississippi in the upper coastal plain sediments. This western boundary may be considered in part related to the prevalence of eolin mica from glacial sediments in the Mississippi river basin. No LAC pedons have been found in Ultisols west of Mississippi river.

LAC Ultisols are estimated to dominate 35.8 million hectares (88.5 million acres) in the U. S. This is approximately 41% of the Ultisol areas mapped (Buol, 1973). Only the 48,000 hectares (119,000 acres) of Oxisols and 176,000 hectares (437,000 acres) of Humults in Puerto Rico appear dominated by low activity clays. Tropudults in Puerto Rico appear to generally have more active clays.

S.W. Buol: Occurrence of Soils with Low Activity Clays in the US and Puerto Rico

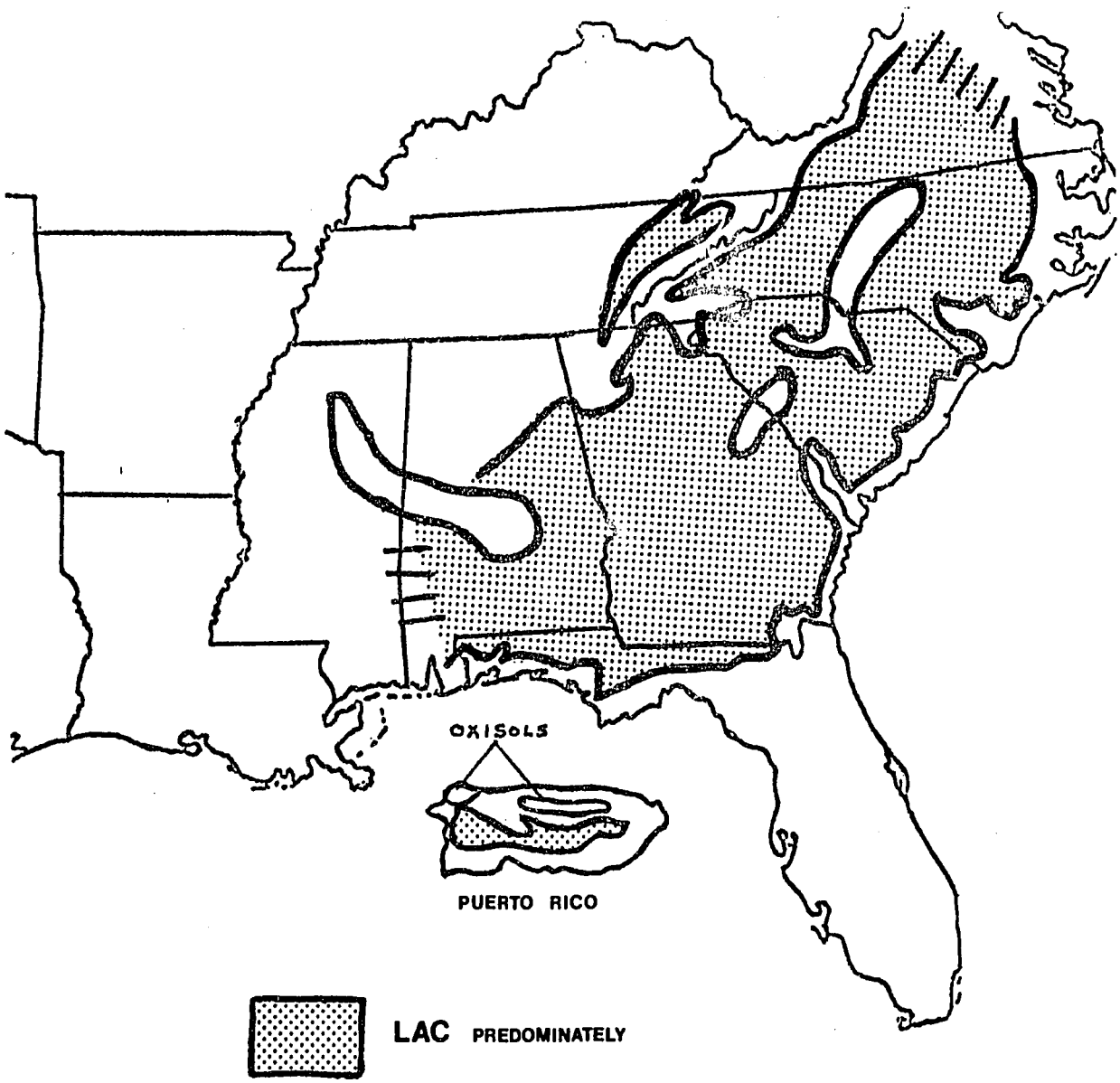

Figure 2: Approximate areas in the US and Puerto Rico where soils with apparent CEC_7 values less than 16 meq/100 g clay apparently dominate

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CONCLUSIONS

It appears reasonable to equate low activity clays with the kaolinitic mineralogical families as used in clayey soils of the U. S. Some apparent CEC_7/100 g clay value of 16-21 me seems a most appropriate criterion for defining low activity clays. Other than Oxisols which have low activity clays by definition, most LAC soils in the U. S. classify as Ultisols. LAC soils occur mainly in the states of Georgia, North Carolina, South Carolina and adjacent areas, with perhaps a Xerult area in California and some Humults in Puerto Rico. The data available suggest that their occurrence can be related to the direct formation of kaolinite from feldspar in acid saprolite regimes, and the absence of significant admixtures of eolian mica to the soil solum. The almost complete Al interlayering of any clay-sized vermiculite appears to be present in many LAC soils. Where this interlayering is not complete the vermiculite component of the clay mixture imparts enough CEC to raise the apparent CEC value above what would be considered a LAC range.

ACKNOWLEDGEMENTS

Appreciation is expressed to Mr. Joe Nichols, SCS, Ft. Worth for data presented in Table 8.

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CONCEPTS FOR THE CLASSIFICATION OF ALFISOLS AND ULTISOLS WITH LOW ACTIVITY CLAYS

F.R. Moormann

The ultimate goal of ICOMLAC is to produce a comprehensive revision of Soil Taxonomy, in which the taxa of Alfisols and Ultisols dominated by low activity clays will be upgraded as regards the categorical level at which they are distinguished. While most members of ICOMLAC are agreed on this goal, the several years of verbal discussions and written communications have made it clear that such a revision is a multifaceted enterprise and that it is well-nigh impossible to reach a general agreement about changes to be introduced in Soil Taxonomy. The best that ICOMLAC can hope for is a majority consensus on useful and relevant revision of the present structure and text of Soil Taxonomy, which can be used by the field surveyor (with the aid of his colleagues in the laboratory) to make better soil maps. Not one single proposal in this paper is agreed upon by all members of ICOMLAC, or, for that matter, by even a large majority of soil scientists conversant in the use of Soil Taxonomy. Nevertheless, the conceptual proposals that follow seem to come closest - within our present knowledge - to give workable answers to a number of controversies, elaborated in "Taxonomic Problems of Low Activity Clay Alfisols and Ultisols" by F.R. Moorman, this volume.

The tasks ahead are now more clear: the concepts have to be tested in the real world, i.e. in the fields, and have to be translated into keys to be proposed for introduction in Soil Taxonomy.

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CONCEPTS OF LIMITS FOR KANDI TAXA

Concept of kandi taxa

The concept of kandi taxa in Alfisols and Ultisols is based on the dominance in subsurface horizons of "low activity clays," mainly kaolinite, with or without considerable amounts of free (Fe) oxides in the clay fraction. The kandi taxa belong to Alfisols and Ultisols because they have, apart from other properties, an argillic horizon, or a clay increase from the surface horizon to a subsurface horizon which, from a taxonomic viewpoint, can be equated with the presence of an argillic horizon, and which is not due exclusively to anisotropy of the parent materials (Soil Taxonomy, page 26). Many of the pedons belonging to kandi taxa have one or more properties that are characteristic for Oxisols, and they may be "mixtures of quartz, kaolin, free oxides, and organic matter," the central concept of Oxisols (Soil Taxonomy, p. 323). The boundaries between such kandi pedons and Oxisols are extremely vague, and defy clear taxonomic separation using the present "diagnostic tools" of Soil Taxonomy. Definition of these boundaries was and is a key problem to be solved by ICOMLAC.

Other pedons belonging to kandi taxa have, apart from one or more Oxisol properties, characteristics which are transitional to Inceptisols, e.g. a higher weatherable mineral content than admitted for an oxic horizon, while at the same time having a low or very low clay activity. Definition of the boundary of such pedons with Inceptisols, is, therefore, another of the problems of ICOMLAC.

A third problem, which had to be solved when defining the kandi concept, is the boundary between kandi great groups and the Alfisols-Ultisols, which either have a higher activity of the clay or another property that, in the keys of great soil groups, is given priority over the kandi-characteristics (e.g. plinth- and fragi- great groups).

When presenting the proposals which follow in the next three paragraphs, I want to insist on the "taxonomic character" of these proposals. In the first place, they are meant to facilitate the task of the field-

man-soil surveyor to make decisions as to which taxon a specific LAC pedon belongs. Less attention had to be given to the pedogenetic uniformity of the kandi taxa, which range from highly weathered to "not-so-strongly weathered," with or without weatherable minerals in the 20-200 μm fraction, from very deep to not-so-deep pedons, etc. The proposed separations are, therefore, pragmatic; they should be tested in the field in order to see whether they give separations into useful groupings.

Limits between kandi taxa and Oxisols

The conceptual definition of this limit is: "To distinguish kandi taxa of Alfisols and Ultisols with a CEC of $\leq$ 16 me/100 g clay by NH_4OAc at pH 7 in the major part of all subhorizons between 25 and 125 cm from Oxisols, the kandi great groups have one or both of the following:

a) a distinct argillic horizon with at least a moderate grade of blocky structure in the moist soil, having clayskins discernable both in the field, using up to 60 power magnification, and in thin sections in at least 40 cm of some subhorizon(s) at a depth of less than 125 cm.

b) an epipedon with less than 40% clay after mixing of the upper 18 cm and an increase in clay within 30 cm vertical distance to underlying horizons, as follows:
   - if the epipedon has less than 20% clay, the absolute clay increase should be at least 7%;
   - if the epipedon has 20-40% clay the clay ratio between a subsurface horizon at less than 100 cm and the epipedon should be $\geq$ 1.4."

The following footnotes regarding this concept can be given:

i. The limit of 16 me/100 g clay (NH_4OAc_7) is not necessarily the limit of all kandi pedons. In fact, for kandi taxa of Alfisols, an upper limit of 24 me is proposed. Moreover, the 24 me limit is proposed for all kandic subgroups. A conse-

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quence is that "oxic" subgroups would become redundant in Alfisols and Ultisols.

ii. No equivalent ECEC (sum of bases + 1N KCl-extractable Al) is, as yet, given here. Tentatively, the value of 12 me seems most appropriate but, because of the pH dependency of the ECEC, a sliding scale may be more appropriate.

iii. The expression "in major part of all subhorizons between 25 and 125 cm" may mean either that the low CEC horizons should together be more than 50 cm thick, or that the weighed average CEC of all horizons between 25 and 125 cm should be less than 16 me. Note that the presence of a lithic, paralithic, petroferric contact or a lithoplinthic horizon is not (yet) taken into account. When the concept is translated in actual definitions and keys, this has to be done, of course.

iv. The alternatives a) and b) are the core of the proposed concept. While in alternative a) we mention the "argillic horizon," alternative b) does not speak of an argillic (though there <u>may</u> be one). The purpose of this proposal is to give a reasonably easy taxonomic tool to the field man for making a decision as to whether or not a low activity clay soil should go with Oxisols. In this respect, the concept touches directly on the mandate of ICOMOX and should, therefore, be tested also by that committee. In the first instance, the concept here proposed would not require changes in the definitions and listing of properties of the argillic and oxic horizons, although it might easily accommodate eventual changes. It does, however, require changes in the order definitions of Alfisols (<u>Soil Taxonomy</u>, page 95, sub 1) and Ultisols (page 349, sub 1), because a good proportion of pedons, falling under (b) of the concept may not have an argillic horizon as presently defined. Such a change in order definition will, of course, have its repercussions on other pages of <u>Soil Taxonomy</u>. The concept proved very useful to make a reasonable separation between new style Oxisols, and kandi taxa of Alfisols and Ulti-

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sols in the profiles we studied in Brazil and the Far East but much more testing is needed.

v. Under (a) of this concept, the "normal" kandi Alfisols and Ultisols can be accommodated, i.e. those for which the presence of clayskins is clear. It should be noted that a pedon falling under (a) does not have to have a specified clay increase, or the clay increase may be in the range now used in the definition of the argillic horizon (page 27, sub 1). The notion of a "distinct" argillic horizon therefore pertains to the indisputable presence of clayskins over 40 cm thickness and within a depth of 125 cm.

vi. The requirement under (a) for a "moderate grade of blocky structure" may or may not be necessary. It is, however, a reinforcement of the notion of a "normal" kandi taxon. In fact the poor visibility of clayskins frequently goes together with a weakly pronounced structure of the argillic horizon.

vii. The depth requirement mentioned under (a) of discernible cutans is multipurpose. First, it could serve to admit the presence of a subsurface horizon with all properties of an oxic horizon overlying an argillic horizon. This would circumvent the problem we have had with the so-called "thin oxic horizon." Secondly, it may serve to leave classified as Oxisols certain uniformly, fine-textured Oxisol pedons in which, under certain circumstances, a thin argillic horizon has formed. However, this has to be tested by ICOMOX.

viii. Pedons which fall under (b) are distinguished on their clay increase only; they may or may not have clear illuviation cutans, as specified under (a). Specifically this concept is introduced to accommodate those pedons with a clear clay increase ("textural B"), but which do not show clear clayskins on field and/or thin section examination. The clay increase required is commensurate with previous proposals by Guy Smith and by Bennema/Comerma.

Pedons which have more than 40% clay in the epipedon and which do not show distinct illuviation cutans as specified under (a) will fall "automatically" in Oxisols, provided the additional requirements for an oxic horizon are present.

ix. The requirement that the clay increase should occur within 30 cm vertical distance is introduced to exclude pedons (quite common) having a very gradual clay increase.

x. It is assumed that LAC pedons with 40% clay or more in the epipedon and which do not have a distinct argillic horizon as defined under (a) of the concept, may for all practical purposes be considered Oxisols if they meet the other requirements for this order. Some may show a clay increase, but from descriptions and analytical data available to us at this time, none showed an increase from A to B of 16% clay, within a vertical distance of 30 cm. Even if the present Soil Taxonomy requirement of an 8% increase is used, almost all LAC pedons with very fine-textured epipedons would fall outside Alfisols and Ultisols.

Because we are mostly working with poorly dispersible clays an alternative limit of 2.5 times water retained at 15 bars tension may have to be introduced in keys and definitions (see Soil Taxonomy, footnote 2, page 325). Note that the 40% clay limit would be equated with 16% water at 15 bars tension.

Guy Smith added the following footnote: When we compare measured clay from Thailand and Lincoln, it would seem we need to retain the 15 bar water. The Thai lab did not get the same dispersion as the Lincoln lab. In some horizons the Thai ratio approached 0.6 while the Lincoln ratio was 0.4.

xi. The requirement to mix the upper 18 cm of the epipedon was made to exclude pedons with a very thin coarser textured upper part of the epipedon. Originally, a depth of 20 cm was proposed, but, since the "18 cm mixing requirement" is used elsewhere in Taxonomy (Mollisols, Vertisols, p. 92), it was introduced here

also.

xii. Schargel proposed that clay increase in pedons as defined under (b) in the concept should be limited to a maximum depth, as follows:

- if the epipedon has 20-40% clay, the clay increase should occur at less than 100 cm. This limit has been introduced already in the conceptual definition.
- if the epipedon has less than 20% clay, but does not meet the requirements of a grossarenic subgroup, the clay increase should occur at less than 125 cm, and finally
- if the epipedon meets the requirements for a grossarenic subgroup, the clay increase should occur between 100 and 200 cm.

It should be noted that no specific solution is given for pedons where the clay increase is due partly or completely to stratification and lithological discontinuities. This problem, which is still under lively discussion in the U.S. Soil Survey staff, will remain with us, unchanged by the concept definition of kandi.

xiii. I am sure that many more footnotes will be forthcoming regarding the conceptual definitions. So be it, but let me, for your elucidation and moral support, quote the following from Charles E. Kellogg's "A Lament for B" (1957, privately printed at the Twelve Oaks Press):

> "The old podzolic texture B
> Has clay-skins now to make it B
> And if there are no skins to see
> It still may be a clayey B."

Limits between kandi taxa and Inceptisols

These limits were not extensively discussed at the Brazil and Southeast Asia workshops, nor have they received much attention in the circular letters. Border cases are either less frequent, or the limits are easier to determine, or both. In various discussions and letters, however, the problem was raised, hence this paragraph.

In fact there are two kinds of border cases, partially overlapping, as follows:

- pedons, which have a CEC/100 g clay (NH_4OAc-pH 7) between 16 and 24 me;
- pedons, which have a CEC/100 g clay of less than 16 me, but which are excluded from Oxisols because of the presence of weatherable minerals (more than 3% in the 20-200 micron fraction, or more than 6% if occluded by iron (cf. Soil Taxonomy, p. 38, and footnote 13).

As in the case of transitions between kandi pedons and Oxisols, we do have border cases with Inceptisols, where we run into trouble in the determination of whether or not there is an argillic horizon. We therefore need a conceptual definition of the limit between kandi taxa and Inceptisols. For practical purposes, this would be approximately parallel to the conceptual definition of the limit between kandi taxa and Oxisols.

Limits between kandi taxa and high activity clay (HAC) Alfisols and Ultisols

In correspondence, in several circular letters, and during both the Brazil and Southeast Asia meetings the subject has been extensively discussed. The diagnostic "key property" has been, and still is, the CEC by NH_4OAc at pH 7, in me per 100 g clay. The diagnostic depth was proposed to be the upper 50 cm of the argillic horizon, the weighted average CEC to be determinant. In principle, to this depth requirement should be added the weighted average CEC of the upper 50 cm of the subsurface horizon replacing the argillic horizon in the conceptual definitions above.

The diagnostic limits of CEC now recommended are as follows:

- Between kandi great groups of Ultisols and HAC Ultisol taxa: 16 me/100 g clay (NH_4OAc), as specified above for depth.
- Between kandi great groups of Alfisols and HAC Alfisol taxa: 24 me/100 g clay (NH_4OAc), as specified above for depth.

- For kandic subgroups in relevant taxa: a maximum of 24 me/100 g clay (NH_4OAc), as specified above for depth.

Depending on the place which the kandi great groups ultimately are given in the key, kandic subgroups can occur in various great groups. Two examples may serve here:

(i) In Ustalfs, provided the kandi great groups key out (Soil Taxonomy, page 138) after HCC, Natrustalfs, we may expect a kandic subgroup in HCB, Plinthustalf. The introduction of kandic subgroups in HCA, Durustalfs, and HCC Natrustalfs appears redundant.

(ii) In Udults (Soil Taxonomy, page 360) all present great groups may have kandic subgroups but not, of course, the kandi great groups if they are introduced. If the kandi great groups key out after FCB, Plinthudults, this great group and also FCA, Fragiudults may have kandic subgroups throughout the whole range of CEC values, less than 24 me per 100 g clay.

On the contrary, the kandic subgroups of FCC, Paleudults, FCD, Rhodudults, FCE Tropudults and FCF, Hapludults (may) have kandic subgroups where the diagnostic CEC value is confined by 16 and 24 me per 100 g clay. A grave inconvenience is that the latter subgroups are defined by a very narrow CEC range, i.e. from 16-24 me, which in practice may prove difficult to use. This can be overcome by introducing 16 me CEC as the exclusive diagnostic limit for the kandic subgroups in Ultisols. This, however, would split a number of already established subgroups of Ultisols in Soil Taxonomy, because the present "oxic" subgroups use 24 me as a diagnostic limit. Part of the pedons now belonging to oxic subgroups within the Ultisol order would hence go with kandi great groups or kandic subgroup, but another part would loose the identity.

The examples given may serve as an indication of the repercussions which our effort is going to have on other taxa; as I said before, rewriting the keys is not something that can be quickly done!

The use of ECEC (sum of bases plus 1N KCl extractable aluminum), as an additional or alternative diagnostic property has been extensively discussed. For the kandi taxa in Ultisols, there is a consensus that 12 me per 100 g clay should serve as an alternative diagnostic limit as follows:

> . . . . have a CEC (NH_4OAc-pH 7) of < 16 me or an ECEC of < 12 me clay in most subhorizons. . . .

In view however of the dominance of the pH-dependant charge in low activity clays, the use of ECEC as a diagnostic property is difficult. For the kandi taxa in Alfisols, using the ratio 16:12 between the two CEC values, the diagnostic ECEC would become 18 me. Insufficient data are available to confirm or reject this value. A "sliding" diagnostic ECEC limit depending on pH may be required, but needs more work.

ICOMLAC is well aware that the diagnostic limits based on CEC values calculated on 100 g clay are subject to several sources of error. More work is required on these and alternative determinations, including quantitative or semi-quantitative determinations of the mineralogical composition of the clay fraction. Much is known, but it has to be "translated" into taxonomic terms, requiring continuing and concerted efforts of soil chemists/mineralogists, and soil taxonomists.

KANDI GREAT GROUPS

Separation of two great groups according to depth

The original trend in defining the typic subgroups of the kandi taxa was that they should have an attenuated transition between B and C horizons. In common with the "Pale" great groups of Ultisols, they would have a textural profile such that the clay content would not diminish from its maximum by 20% or more of that maximum at a depth of 150 cm, or (clear) clayskins should be present at that depth. Thinner pedons would fall in leptic, lithic, paralithic or petroferric subgroups.

Against this trend, two objections were made:

- In certain regions (e.g. Malaysia) virtually all better drained Ultisols would fall under one great group, those of the Kandiudults. This was deemed undesirable from a geographic and possibly from a soil management point of view.
- By keeping the deep and shallower kandi subgroups together in one great group, a proliferation of subgroups, frequently with double or triple names, would occur.

Added to this, the "lumping" of kandi pedons, irrespective of their depth, would require considerable regrouping of Paleudults and Hapludults with LAC in the Southeast United States, and thus would be less acceptable. (CL No. 9, appendix 2). Basically, therefore, two kandi great groups are to be distinguished in most suborders of Alfisols and Ultisols as follows:

- kandi great groups: "...have a lithoplinthic horizon[1] within 1.5 m of the surface or have a clay distribution such that the percentage of clay does not decrease from its maximum amount by more than 20% of that maximum within 1.5 m of the soil surface, or the layer in which the percentage of clay is less than the maximum has skeletans on ped faces or has 5% or more plinthite by volume."
- kanhaplo great groups: "...have a clay distribution such that the percentage of clay decreases from its maximum amount by more than 20% of that maximum within 1.5 m of the soil surface and have no skeletans on ped faces at 1.5 m depth, or have a lithic, paralithic, or petroferric contact within 1.5 m of the soil surface."

The following footnotes should be made:

i. The above definitions are conceptual; they are not definitions to be used as such in the keys.

[1] Guy Smith added the provision of a (yet to be recognized) lithoplinthic horizon here, because "it is impractical to determine clay percentage in it." In his experience, it is always a II horizon.

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ii. The depth criteria of the kandi great groups follow those of the pale great groups of Ultisols in most respects, but differ from them in not requiring the percentage of weatherable minerals in the 20-200 micron fraction in the upper 50 cm of the argillic horizon (or its "equivalent") to be less than 10. This will be dealt with below.

iii. The depth criteria of the kandi great groups follow those of the Paleudalfs, Paleustalfs and Palexeralfs, but differ from these great groups in all other aspects, mentioned in Soil Taxonomy (keys, pp. 125, 138, and 147). The definition of Paleboralfs is irrelevant in this respect; it may moreover be expected that kandi taxa in Boralfs are redundant. Aqualfs have, at present, no pale great group, but it appears probable that kandi taxa should be foreseen.

iv. The requirement "or the layer in which the percentage of clay is less than the maximum has skeletans on ped faces..." in the above conceptual definition of the kandi great groups may have to be dropped, because of the basic assumptions discussed under "Limits between kandi taxa and Oxisols" above. If so, only those pedons in which the clay does not decrease as specified in the definition would remain kandi. All pedons in which the clay content diminishes sufficiently with depth would be kanhaplo, and the mention of skeletans at 1.5 m depth would be dropped also.

Weatherable minerals

For the present Pale great groups of Ultisols, the lack of weatherable minerals in the 20-200 micron fraction (less than 10% in the upper 50 cm), is one of the diagnostic properties. Discussions on this topic have resulted in omitting this property as diagnostic for kandi taxa in Ultisols. For Alfisols the weatherable mineral content was never a diagnostic property at great group level; hence the Pale great groups of Alfisols are not required to have a low content in weatherable minerals.

The basic reason to drop any mention of weatherable minerals from the "kandi concept" is that there is no good correlation between the dominance of low activity clays and the absence or presence of weatherable minerals in the 20-200 micron fraction. While it is true that among kandi pedons in Ultisols most have a low content of weatherable minerals, there are important exceptions which tend to occur in well-defined geographic patterns, dependent mainly on origin of soil-forming materials. For instance, among Kandiudults and Kanhapludults in Southern Nigeria, those formed on materials derived from intermediate crystalline rocks mostly have over 10% weatherable minerals at the specified depth. On the other hand, not all kandi pedons of Alfisols have a high content of weatherable minerals as can be seen in Kandiustalf pedons on old sediments along the coast of Western Nigeria, Benin, and Togo. These examples were confirmed during the Southeast Asia workshop by others from e.g. Venezuela. Content of weatherable minerals in kandi taxa of Alfisols and Ultisols would, therefore, be relegated to the subgroup level. (See SUBGROUPS OF KANDI TAXA below.)

The "Trop" great groups, and their relation to kandi taxa

The question was raised if, under these circumstances, the trop great groups in Alfisols and Ultisols would still remain relevant. These great groups are:

- for Alfisols: Tropaqualfs and Tropudalfs;
- for Ultisols: Tropaquults, Tropohumults, and Tropudults.

The following tentative review could be given, based on the assumption that kandi and kanhaplo great groups would be keyed out before trop great groups.

- Tropaqualfs: LAC pedons would be excluded from this taxon; the others remain. In my experience, many of the present Tropaqualfs are dominated by high activity clays, while a minority would go to kandi taxa.
- Tropudalfs: This already rare taxon would diminish in importance, because LAC pedons would be excluded. There will remain, however,

Tropudalfs, e.g. those on relatively young materials, derived from basic volcanic rocks. The most extensive areas I have seen were on Luzon, in the Philippines, and they would remain in this taxon.

- Tropaquults: This great group, already rarely found (Soil Taxonomy, p. 355) will undoubtedly diminish in importance when kandi taxa are introduced. They would be limited to Aquults, which apart from the temperature regime requirement, would have to be dominated by "high activity clays," and which should not have properties diagnostic for the Pale great group (Soil Taxonomy, p. 351). Personally, I do not know of such pedons. However, Guy Smith writes: "To the best of my recollection, I found these in the West Indies, Guyana, and Venezuela, mostly on late Pleistocene alluvium."
- Tropohumults: Interpreting the section of Soil Taxonomy dealing with Tropohumults (Soil Taxonomy, p. 358-360), one might conclude that high activity clay pedons are common in this taxon (see e.g. pedon 116 in Soil Taxonomy). However, it is possible that the higher CEC in these pedons is determined by the high content of O.M., while, at the same time, the clay activity may be low.
- Tropudults: There is no doubt that the introduction of kandi taxa will diminish the importance of this great group considerably, but interpretation from the data given in Soil Taxonomy (p. 367-369) would indicate that they do exist, even if the low activity clays are excluded. Guy Smith writes that these soils are common in Puerto Rico, with vermiculite and montmorillonite dominant.

In conclusion, ICOMLAC, within its present mandate, could not propose to "do away" with the trop taxa on the basis of redundancy.

"Plinth" great groups

The Malysian-Thai workshop did not give a definite view on the relevancy and placing of plinth great groups. Hence, ICOMLAC will leave the present definitions and placing in the keys of these great groups as

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they are now in Soil Taxonomy. Kandi and kanhaplo great groups would key out after the plinth great groups, and low activity clays in the latter would be distinguished on the subgroup level (kandic subgroup).

SUBGROUPS OF KANDI TAXA

During the Malaysian-Thai workshop, attention to subgroups was mainly given during the field tours. Because the records of the discussions are, as to date, not in my possession, only a few remarks can be given at present, of subgroups discussed during the workshop.

- The allic subgroups of kandi taxa in Ultisols. In continuation of discussions during the Brazil workshop (CL No. 9, p. 23/24 and CL No. 9, p. 16), the allic subgroup was again discussed. The key question, i.e. the depth at which high Al^{3+} saturation should be diagnostic, was not resolved. Tentatively, it therefore was decided not to introduce an allic subgroup.

  The chemist-mineralogists, more specifically Goro Uehara, pointed out that possibly the Al^{3+} saturation is less important than the nature and amounts of other adsorbed cations. Both when defining an allic, and eventually an acric, subgroup, this parameter should be taken into account. More specifically, a lack of adsorbed Ca^{2+} may be of more importance than a concomittant high Al^{3+} saturation. As example, Pedon No. 11 from Thailand (Phangnga series) was cited, where extractable Ca is well below 0.1 me in most of the B_{2t} horizon. Further info on relevant diagnostic values were promised.
- The acric subgroups in kandi taxa of Ultisols. The proposed diagnostic ECEC boundary for this eventual subgroup is < 2.5 me per 100 g clay. Again, however, as in the case of the allic subgroup (now defunct), the lack of cations, more in particular Ca^{2+}, may be more important than the ECEC value per se. This too is a subject to be pursued further.
- The vadic subgroup (connotation: vadose water; vadosus (L) =

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shallow; vadum = a shallow or ford). A subgroup is desired by some for such pedons which are not hydromorphic enough to be considered as an aquic subgroup, but which show moderate to strong iron segregation, frequently due to interflow-water saturation during part of the year. The pedons which were called "ferric" in the Brazil meeting and at least two pedons in Thailand (Nos. 11, Phangnga and 18, Ban Bung series) have similar characteristics. This subgroup should be distinguished from the typic subgroups on the basis of distinct (rusty) mottling at less than 100 cm depth. In defining vadic subgroups care should be taken to exclude the properties of the present epiaquic subgroups.

- Subgroups respectively rich and poor in weatherable minerals. As was discussed above, the content of weatherable minerals in the 20-200 micron fraction in kandi and kanhaplo great groups would not be used as a diagnostic characteristic at this level. From my own experience it appears that this content, especially of minerals that provide K upon weathering, is important from a soil management point of view both in Ultisols and Alfisols. Moreover, since it is in most cases related to composition and age of the soil-forming material, there appears a sound geographical basis for making the distinction between "rich and poor" in weatherable minerals.

This characteristic cannot be relegated to the family level, since the mineralogical composition of the 20-200 micron fraction is not used as a criterion in the clayey and clayey-skeletal families. Hence, it appears opportune to introduce "rich and/or poor" subgroups.

In this respect, a note from Richard Schargel is relevant, and his proposal should be tested: "To separate kandi and kanhaplo pedons as regards their content of weatherable minerals, the 1.5% K_2O content in the fine earth (less than 2 mm) might be used (tested) as a limit. Possibly, the sum of K_2O, CaO, MgO and Na_2O gives a better separation, also at 1.5% or at a relatively higher percentage. The first 50 cm of the argillic horizon (or

equivalent finer textured horizon) would be diagnostic in this respect." Richard adds as justification that it is easier for most labs to get the total elemental analysis than the mineralogical data. For Venezuela, the 1.5% K_2O seems to work well, but the critical K_2O content might be as low as 1%. I think that this alternative limit certainly is worthwhile to be tested.

In terms of nomenclature, it can be suggested that the characteristic "less than 10% weatherable minerals in the 20-200 micron fraction" should be included in the list of properties of all typic subgroups. The pedons with more than 10% weatherable minerals would require a separate subgroup for which we may use "caric" (carus (L) = rich; the mnemonicon should be "cher," for those who have not forgotten all their French).

Other subgroups. Most of the existing subgroups in various taxa of the present pale great groups can and should be applied in the new kandi and kanhaplo taxa, where appropriate. Lack of available data makes it an impossible task to make an even approximately complete list of subgroups under the kandi and kanhaplo taxa. Part has been described, others may be inferred, but, in order to define the typic subgroups, more data should be forthcoming from the field.

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SOIL TAXONOMY IN TROPICAL AMERICA

R. Guerrero

In the last decade important efforts have been made to evaluate the methodology and achievements of national soil survey and classification programs in Tropical America on a regional basis (Costa de Lemos, 1971; Van Wambeke, 1971). For instance, a seminar on systematic land and water resources appraisal was held in Mexico in 1971 under the sponsorship of the Food and Agriculture Organization (FAO), and twenty Latin American countries participated. The conclusion obtained at this seminar indicated that considerable progress has been made in soil survey and classification during the last ten years. Costa de Lemos (1971) showed that there has recently been a development of national regional programs; the application of more modern techniques such as cartography and photo-interpretation studies; the implementation of a more appropriate terminology; the use of advanced systems of soil taxonomy such as the "7th approximation, the FAO legend, and national systems; and the utilization of soil maps in other disciplines.

At present, soil survey and classification programs have great differences in goals, methods, and achievements from country to country. Important differences are related to methodologies followed in soil surveys, systems of soil classification used, training of personnel, effectiveness of teaching, utilization of soil classification, ability to apply it to practical purposes, and the appraisals of benefits or inadequacies of the systems. Some of these were mentioned in previous works by Van Wambeke (1971) and Costa de Lemos (1971). The study reported in this article has been prepared to identify similar problems and evaluate the current situation.

The fundamental goals and specific objectives of this study may be summarized as follows:

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Goals

1. To prepare an authoritative, informative document for governmental agencies, national experts, and foreign advisors on the status, applications, and limitations of soil classification in Tropical American countries.
2. To make critical evaluations of present objectives and achievements of the systems of soil classification used in Tropical American countries.
3. To motivate governmental and agricultural agencies in less developed countries (LDCs) to reorganize, support, or reinforce projects on soil resources inventory, particularly in relation to the development of soil survey and classification programs.
4. To permit the extrapolation and intrapolation of adequate techniques and management practices for modern agriculture, so that crop production can be increased through the process of agrotechnology transfer.
5. To enhance the utilization of Soil Taxonomy (Soil Survey Staff, 1975) as a system to classify tropical soils, to transfer agricultural technology and to exchange technical communication.
6. To establish the suitability of Soil Taxonomy over other systems for classifying tropical soils.
7. To identify the main accomplishments and limitations of agronomy schools and other official institutions which carry out teaching, research and complementary support for the soil survey program--with respect to regular courses, training abroad, physical facilities, staff conditions, cooperative work, and budget allocations.

Objectives

1. To identify, examine, and evaluate the utilization of Soil Taxonomy in Tropical American countries.

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2. To identify, analyze, and evaluate the advantages and deficiencies of the utilization of Soil Taxonomy in the tropics.
3. To draw conclusions and make recommendations on matters related to Soil Taxonomy which should be investigated or proposed.

METHODOLOGY OF THE STUDY

This SOTA (state-of-the-art) report is an analytical review and critical compilation of information obtained by research on the application and adequacy of the USDA Soil Taxonomy system for classifying soils of the tropics. The study intends to prepare a guide for diagnosis and solution of soil classification problems in the tropics by extracting and summarizing concepts on the use of the system. Hopefully, the information obtained will come an important tool for experts and governmental agencies in the decision-making process for development planning.

Most information was collected through questionnaires sent by airmail to soil scientists in Tropical American countries. After several tentative schemes, the final model included the suggestions by Babbie (1975), Eckardt and Ermann (1977), and personal ideas.

The questions were indicated as either "closed questions," in which the correspondent was asked to select among several options, or "open questions," in which the correspondent was asked to comment at length. On many questionnaires only the closed questions were answered.

Unfortunately, it was almost impossible to express the results as percentages of the total sample, because within a particular table or set of questions the number of answers was not uniform. In other words, for some questions some correspondents omitted some answers; for others, they selected more than one option.

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There were two model questionnaires. The first model was primarily directed to heads, directors, or officers of national programs in each country; the second was sent to individual soil scientists. The first questionnaire had three sections and a total of 427 questions: I-Structure, procedures, and specifications of the soil survey and classification systems used (151 questions); II-Evaluation of Soil Taxonomy (220 questions); III-Human and Physical Resources (56 questions).

The second questionnaire had a total of 116 questions. The first questions were focused on the utilization of Soil Taxonomy and other systems of soil classification, and the later ones were on the adequacy and limitations of the system. For the first inquiry, fifteen questionnaires were received from ten countries.

The second set of 209 individual questionnaires was mailed on October 1, 1977 to soil scientists of 25 countries. By the final deadline of January 31, 1978, 48 questionnaires were received from 17 countries. An English version of the Spanish questionnaire had been prepared and sent to Guyana, French Guyana, Surinam, Trinidad-Tobago, Jamaica, Martinique, and Haiti. No answers were obtained from the following eight countries: French Guyana, Surinam, Trinidad-Tobago, Jamaica, Martinique, Haiti, Cuba, and Paraguay (Table 1).

Table 1. Distribution and responses to the questionnaire.

	Distribution		Responses	
	Countries	Number	Countries	Number
1st Questionnaire	20	53	10	15
2nd Questionnaire	25	209	17	48

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CONCLUSIONS AND RECOMMENDATIONS

The information collected shows that the Soil Taxonomy classification system is usually adequate to classify tropical soils and that this system is being used in Tropical America to a varying extent. The answers were discussed in specific sections and summarized in tables within the text of the complete study. In addition, some soil scientists made specific remarks on particular aspects of the system either as individuals or as representatives of national programs.

In this section, important conclusions and recommendations are summarized briefly.

National soil survey programs

Methodology presently used to carry out national soil survey programs is rather variable but fairly adequate. Differences and deficiencies of soil surveys come from the absence of a standard, uniform methodology. Actually, terminology and procedures currently used in most Tropical American countries are those proposed by the Soil Survey Manual (Soil Survey Staff, 1951). However, since detailed definitions (objectives, descriptions and specifications) of the different orders of soil surveys (types or kinds of surveys) are omitted or not specified in the present edition of the manual, many differences exist from country to country.

Therefore, depending upon the objectives of the work and the available resources of personnel, equipment and facilities, the future methodology should indicate the "soil survey order" such as "general" or "exploratory," as in the old terminology. The future methodology should also show appropriate procedures and specifications for each "soil survey order" and for all sections and steps of the respective work, such as photo-interpretation support, cartography, scales, soil units, sampling, delineation, etc. In this way the procedures will fall within international standards, the quality of the final soil survey report will improve and, con-

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sequently, its utilization value will be increased.

Use of different systems of soil classification

Information on the type of soil survey and soil classification system used indicated that the Soil Survey Manual (Soil Survey Staff, 1951) and Soil Taxonomy (Soil Survey Staff, 1975) are commonly used in Tropical America. Fortunately, only a very few countries are not presently carrying out soil classification programs (Table 2).

Table 2. Use of taxonomic systems in 17 countries sampled.

Taxonomic System	Number of Countries	Percentage of the sample
No taxonomic system	2	11
Other (exclusive)	1	6
Soil Taxonomy and others	4	24
Soil Taxonomy (only)	10	59
Total	17	100

Some specific conclusions on systems other than those of the Soil Survey Manual and Soil Taxonomy refer to:

1. *Manuals of soil survey.* Since the FAO and CIAF Manuals follow the terminology and procedures indicated in the Soil Survey Manual to a large extent, there are not strong discrepancies among countries with respect to general or particular points.
2. *Equivalencies to other systems* (Table 3).

Table 3. Equivalencies of other systems to Soil Taxonomy.

Name of System	Number of Opinions
Baldwin, Kellogg and Thorp	10
FAO - UNESCO Legend	9
French Classification	8
Brazilian, Canadian, Australian, Kubiena classifications	1 each

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Answers to the questionnaire reinforced some previous studies (Beinroth et al, 1974; Beinroth, 1975; Name-Tuñón, 1976) and showed that equivalencies of other systems to Soil Taxonomy are possible only for a small proportion of the total population, such as some higher categories and selected classes, and only for a few systems. For other systems the correlation has not been indicated and appears to be difficult or impossible to attain. As a consequence, the problem remains to find good correlation and reliable equivalencies among Soil Taxonomy and other systems. However, it is desirable to at least broaden the present, tentative correlations in order to ease the international communication problem in pedology.

3. *Reasons to use other systems.* Although Soil Taxonomy was the system used by most correspondents, three reasons were given why Soil Taxonomy was not used:
   a. Lack of facilities - the proper application of the system requires some minimal facilities and equipment.
   b. Lack of command - occurs when the soil specialists have received training in countries in which Soil Taxonomy is not taught.
   c. Lack of support - the system is not followed and has not received enough diffusion and importance in the country.

Utilization of Soil Taxonomy

Evaluation of answers to the questionnaire clearly indicated that Soil Taxonomy is the most common system of soil classfication in Tropical America (83% of the sample; Table 2). However, it is worthwhile to note some of the comments collected from several correspondents regarding the advantages, disadvantages, constraints, gaps and problems of the system and, consequently, to draw some specific recommendations. Hopefully, this will strengthen and widen the utilization of Soil Taxonomy in Tropical America.

Table 4. Present utilization of Soil Taxonomy.

Frequency of Use[a]	Actions or Projects	Number of Opinions
Very frequent (40-30)	Soil classification	40
	Soil survey, field work	38
	Communication	33
	Soil survey, interpretation	32
	Meeting and lectures	31
Frequent (30-20)	Teaching	27
	Generalized maps	26
Infrequent (20-10)	Technology transference	19
	Extensive land use	17
	Intensive land use	15
	Up-dating old surveys	15
	Making specialized maps	13
Very infrequent (10-1)	Land taxation	3
	Thesis work	2
	Ultra-detailed surveys (Exp. Stations)	2
	Ecology classes, Soil correlation	1

[a]Arbitary Scale: 40 most, 1 least.

Soil Taxonomy is mostly used for soil classification, field work, soil survey interpretation, written communication, lectures and other technical meetings. Surprisingly, however, it is only moderately used for transfer of technology, extensive and intensive land use, and practically not at all for ultra-detailed (1st order) soil surveys by agricultural experimental stations and for thesis work. In other words, the system is being properly applied for some purposes which *per se* are within the main goals of the classification; but at the same time, it is being much less utilized for other objectives which supposedly are also in the nature of the taxonomy -- such as transfer of technology, extensive land use, and ultra-detailed survey and thesis work (Table 4).

Admittedly, the lack of use of Soil Taxonomy in soil teaching, agricultural extension, and experimental research on the one side, and the inefficient utilization of the information obtained on the other, have to a large degree limited the transfer of agrotechnology by pedologists and edaphologists. In fact, it is still common to extrapolate or interpolate soil data in the same country or abroad. This is because ultra-detailed (1st order) soil surveys and the taxonomy for soils of agricultural experimental stations have not been published; because experimental results have been expressed only for local soils series; because data have not been correlated for soils with similar or different characteristics in the same or different areas of the country or finally, because most edaphologists are not familiar with Soil Taxonomy. In addition, the present categories of Soil Taxonomy (with the exception of the soil series) are not thought to be suited for practical purposes. Therefore, it is necessary to conduct and to publish ultra-detailed soil surveys and classifications at the subgroup and family levels for the agricultural experiment stations of Tropical America. This information should be distributed among local researchers and they should be asked to publish their results on plant-soil relationships, soil management, soil use, and soil potential, with reference to Soil Taxonomy. Then it will serve as a common language among native and foreign researchers and allow them to use the data obtained more efficiently.

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An overall estimation of the general feeling indicates that, at present, many LDCs are not able to efficiently apply Soil Taxonomy because they have substantial limitations in knowledge of the system, personnel, equipment, and facilities. It should be recognized that for many countries in which the regular physical facilities are largely inadequate or in which the personnel has not been well-trained, the current adoption of Soil Taxonomy as an official system might be inadvisable. Accordingly, comments received on these and other related matters are grouped in two broad categories: informative limitations and governmental constraints.

Informative limitations. These deal with those conditions which make application of the system less feasible, less systematized, and more haphazard. These limitations are related to: a) poor knowledge and lack of contacts; b) pragmatic approaches of agricultural officers; and c) lack of diffusion. Deficiencies in communication have been caused by lack of knowledge, lack of command of the system, and lack of contacts. Most agricultural agencies are more interested in soil survey than in soil classification, and they are more ready to support massive and preliminary projects focused on the so-called "practical land classifications," such as "land capability" and "irrigation." Traditionally, they have considered these immediately applicable for practical purposes, but much less sophisticated than true soil survey and classification.

Governmental constraints. Several correspondents emphasized that development of a strong national soil survey program depends on government action. For countries in which the government is conscious of their importance, the programs are relatively well-supported; but in a few countries their role in the evaluation of national resources inventory is, unfortunately, underestimated or ignored.

So, according to the information collected, different methodologies for soil survey and soil classification are used in tropical countries. Less emphasis is given to problems of taxonomic classification; knowledge of Soil Taxonomy as a natural system is insufficient; logistic support to carry out the soil survey is inadequate. "Practical" land classification projects are now encouraged and, as a con-

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sequence, regular programs are permanently weakened. Therefore, official concerns in national soil survey programs should be primarily focused on three main aspects: technical policies, official support, and teaching programs.

National governments can make a substantial contribution to technical policy by making public statements of official support to specific programs on national soil resources inventories; by indicating long-term goals, short-term objectives, priorities of the projects, and benefits expected; by pointing out advantages and problems of the system used; by explaining the system adopted and correlation procedures for the whole country; by improving the functioning and budget of national, regional and local organizations which have technical projects under their responsibility; by increasing the number of pedologists, their salaries, and their opportunities for advanced graduate studies; and by improving equipment, techniques, facilities and the logistic support required to carry out regular programs.

Suitability and limitations of Soil Taxonomy for classifying tropical soils

Several soil scientists indicated both general and specific comments on the advantages, benefits, constraints problems, disadvantages or gaps in applying Soil Taxonomy for the classification of tropical soils. The main conclusions and recommendations on those matters are:

Suitability. Comments expressed on the adequacy of the system were essentially considered in three main areas: fundamentals, structure, and practical utilization and implications (Table 5).

Technical inadequacy. The opinions and suggestions of several soil scientists on the adequacy of the system as a whole or on differentiating criteria and definitions to classify tropical soils were enumerated. In summary, the main technical disadvantages, problems or gaps of Soil Taxonomy are related to the necessity:

a. to strengthen the tendency to make the system more dependent on field conditions and, consequently, less subordinated to laboratory determinations;

b. to review the nomenclature (such as it has been mentioned for "trop," "iso," "rhod," etc.);

Table 5. Adequacy of Soil Taxonomy categories for classifying soils of the tropics (adapted from the originals).

Categories	Very Adequate	Adequate	Partially Adequate	In-adequate	Very In-adequate
Orders	8[a] (19)	28 (67)	6 (14)	0	0
Suborders	9 (21)	23 (55)	10 (24)	0	0
Great Groups	7 (16)	27 (61)	9 (20)	1 (2)	0
Subgroups	4 (10)	21 (53)	11 (28)	4 (10)	0
Families	5 (12)	19 (45)	12 (29)	6 (14)	0

[a] Numbers are opinions; percentages are in parentheses.

c. to review definitions of some differentiating criteria (such as plinthite, color with chromas less than 2, cracks, etc.);

d. to review the definitions of some diagnostic horizons (such as mollic, cambic, argillic, etc.); and

e. to review some classes already keyed, at different categories. Specific remarks were indicated in the questionnaires, for instance:

i. For orders: Andosols, to replace Andepts. To review Inceptisols, Alfisols, Ultisols, and Histosols.

ii. For suborders: To review the methodology of determination and the application of the soil climatic regimes criteria.

iii. For great groups: to exclude from Alfisols soils having a high percentage of base saturation but low CEC.

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iv. For subgroups: to narrow the definition of the typic, and to prepare guidelines on how to use soil units in generalized maps.

v. For families: to consider the possiblity of using other criteria (such as slope, texture of the surface horizon, fertility status of the plow layer, drainage, erosion, etc.) to prepare soil maps for land use.

In general, Soil Taxonomy is being used to indicate the predominant properties, main limitations, and land potential of tropical soils and, also, as a reference for exchanging technical information.

However, since the system cannot contain all the information required for land use, some divisions among taxonomic units might be redefined for practical needs. Therefore, it might be necessary to modify some definitions, to allow interpretative groupings, to develop some practical interpretations, and to eliminate the lack of bridges among pedologists, researchers, extension agents, and planners. A new project should be implemented to classify soils of the agricultural experimental stations, to coordinate the revision of Soil Taxonomy, and to cooperate in the characterization of selected representative pedons of tropical countries.

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RECOMMENDATIONS OF THE WORKSHOP

In the Summary Session held at the Asia Hotel in Bangkok, Thailand on 9 September 1978, chairman F. H. Beinroth proposed twelve subject matter areas for consideration by the workshop participants as recommendations for future action. All motions were discussed, duly seconded and carried unanimously.

Not necessarily in order of importance or priority, the resolutions of the workshop are that:

1. The International Committee on the Classification of Oxisols (ICOMOX) be formalized by the Soil Conservation Service of the U.S. Department of Agriculture in analogy with the constitution of the International Committee on the Classification of Alfisols and Ultisols with Low Activity Clays (ICOMLAC).

2. The International Committee on the Classification of Alfisols and Ultisols with Low Activity Clays (ICOMLAC) submit a final proposal to the Soil Conservation Service on or before 1 July 1979 so that official testing can be initiated. The proposal should include definitions, keys, supporting data, and a review of the repercussions of the proposed changes relative to other taxa of Soil Taxonomy.

3. The rationales and concepts basic to Soil Taxonomy but not explicitly stated in the text of the book be recorded and published. The Soil Science Society of America should solicit relevant questions and topics for discussions through "Agronomy News".

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4. An International Committee on Soil Climatic Regimes, tentatively named ICOMCLIM, be established and that Professor Dr. A. Van Wambeke serve as chairman of this committee.

5. A Third International Soil Classification Workshop be held in the Near East in 1979 or 1980. The general theme of this workshop should be the taxonomy of soils of dry places in the lower latitudes and should address the mandate of ICOMCLIM.

6. A meeting of key members of the International Committee on the Clasisification of Oxisols (ICOMOX) be held in early 1980 to discuss progress, formulate proposals and outline action plans.

7. A Fourth International Soil Classification Workshop be held in Africa in 1981. The workshop should concern the mandates of ICOMLAC, ICOMOX and ICOMCLIM. In addition, it should relate management practices and crop performance to the soils to be studied in the field.

8. An International Committee on the Classification of Andisols, tentatively named ICOMAND, be established and that Dr. M. Leamy serve as its chairman. The 1981 ISSS conference in New Zealand should provide a first opportunity for some members of ICOMAND to meet.

9. The laboratory methods for soil characterization in various parts of the world be cross-checked, correlated and, if possible, standardized and that the International Soil Museum in Wageningen, The Netherlands assume an active role in this matter.

10. The development of worldwide data banks for important and representative soils and for soil resource inventories be pursued, possibly by the International Soil Museum.

11. Mechanisms to effectuate international soil correlation be studied with the objective to arrive at uniform identification of quantified soil properties as an aid to the transfer and utilization of soil-related research.

12. The discussions regarding an International Soils Center be actively continued and the nature, structure, scope and functions of the Center be conceptualized.

THE TASK AHEAD

F. H. Beinroth

As Dr. Dudal has pointed out so eloquently, this workshop has accomplished a great deal and has made significant progress relative to the objectives and mandates of ICOMLAC and ICOMOX.

However, it also transpired during the last two weeks that there are many more problems with Soil Taxonomy that remain to be resolved. While some of these are minor in nature, others are rather fundamental. Obviously, the need for changes will prevail in the forseeable future as more is learned about soils -- particularly those of the tropics -- and the new experience must be incorporated into the pool of knowledge that is Soil Taxonomy. It is also clear that coordinated international efforts are needed to attain this goal.

In pursuit of this endeavor and to keep alive the dialogue and action initiated in Brazil and continued at this workshop, the University of Puerto Rico has suggested to AID that similar activities be held in other parts of the world and will be requesting the necessary funds. In particular, we have proposed workshops in the Middle East and in Africa for 1980 and 1981, respectively. At this point in time we don't know what the fate of our proposals will be, but we have reason to be cautiously optimistic.

Let me mention here that the degree of consideration our proposal will be given by AID will depend in large measure on your reaction to the present workshop. I have mentioned earlier that we have been able to convince AID to fund this workshop mainly on the strength of all the wonderful

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things you said about the Brazil meeting. By analogy, it should greatly enhance the prospects of our new proposal if you could again bring your reactions and feelings about this workshop to the attention of AID. I believe that this small effort on your part may help open up exciting avenues for future activities.

That said, let me look at some of the more distant tasks ahead. It is, of course, of paramount importance that we have a functional soil classification system of sound scientific standards. But the mere existence of such a scheme does not solve any practical problems; it must also be used. Consequently we should encourage the use of Soil Taxonomy as the universal system for the reasons I have pointed out in my keynote address in Kuala Lumpur. I believe that a common and universally applied system of soil classification is a conditio sine qua non for effective transfers of agrotechnology and agricultural development in the LDC's. Soil Taxonomy has come a long way in this regard, but it still has a considerable distance to go. Pedologically speaking, many countries of the Third World are still incomunicado.

This brings me to another task ahead: How can we assure the proper and uniform use of Soil Taxonomy on a worldwide scale? In the U.S., this is achieved through soil correlation at a national level, which is really a system of quality control. It should also be possible to correlate soils at an international level. And FAO has, in fact, demonstrated that when it prepared the Soil Map of the World. So how can the same be done for Soil Taxonomy? What we need is an authoritative international entity that can arbitrate the discrepancies that surely will emerge in worldwide correlation. We have thought of this in our discussions with AID and we hope that eventually a suitable mechanism and funds can be found to accomplish this task.

Finally, I must mention again that, from a practical point of view, soil classification is just one element of a more comprehensive system of land evaluation. And as I see it, the most challenging task ahead for pedologists is land evaluation. We must address the question of what do all these taxa mean in terms of land qualities, soil productivity, crop

suitability, inputs, outputs, etc. Under the able leadership of FAO, a conceptual framework for modern land evaluation has recently been developed. However, enormous and interdisciplinary efforts are required to translate these concepts into practically feasible terms and to formulate a standardized methodology. This may well have repercussions on the kind of differentiae we should use in soil classification. Land evaluation is an exceedingly complex undertaking. But I believe it is the most challenging task that lies ahead.

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I. PHYSICAL ENVIRONMENT

Location

The Kingdom of Thailand is located centrally in the Indochainese Peninsula of Southeast Asia between 5°40' and 20°30' north latitude and 97°70' and 105°45' east longtitude. The total area of the country is 513,985 square kilometers (approximately 185,000 square miles). Thailand is about three-fourths the size of Texas or approximately equal to the size of France. The country is axe-shaped, with a long panhandle extending southward along the Malay Peninsula. The longest north-south span is about 1,620 kilometers (1,000 miles) and the widest part is 750 kilometers (500 miles) from east to west. It has common frontiers with Laos on the north and east, with Burma on the north and west and with Cambodia on the southeast. Peninsular Thailand is bounded on the south by Malaysia.

Population

The figures of the Ministry of Interior 1977 census indicated a Thailand population of 44,272,693 which signified a relatively high increase of 2.7 percent per year for the last decade. The 1960 population was only 26,258,000 (Thailand, Central Statistic Office, 1962). The present population density is 85.5 per km^2. About 80 percent of the population is engaged in certain forms of agriculture, predominantly as rice farmers.

Climate

Thailand like all Southeast Asia, is dominated by the monsoon. General climatic characteristics of the six physiographic regions are summarized in the Table 1. Thailand average annual rainfall, and mean annual temperature

Table 1 Generalized climatic data for the six physiographic regions of Thailand

	Central Plain	Southeast Coast	Northeast Plateau	Central Highlands	North and West Continental Highlands	Peninsular Thailand	
						West coast	East coast
Annual rainfall (mm)	1220-1592	1312-4456	1089-2163	1352	1045-1744	2177-5106	1018-2568
Annual mean humidity (%)	64-76	74-78	68-73	70-73	71-75	77-83	78-82
Annual mean temperature (° c)	27-29	27	26.7-27	26-28	24-28	27	27-28
Absolute maximum temperature (° c)	39-44	38	42-43	41-43	40-43	35.5	38-39
Absolute minimum temperature (°c)	5-12	9	2-4	2-7	2-6	19	14-18

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are shown in Figure 1 and 2.

Most of continental Thailand and part of Peninsular Thailand can be classified as Tropical Savanna (Koppen- "Aw"). In the northern mountain areas, higher elevations produce sufficient cool temperature to place most of the area in the Humid Subtropical Zone ("Cw"). In the eastern most section of the Southeast Coast, the western mountains and Peninsular Thailand where rainfall is very heavy, the area can be classified as Tropical Monsoon climate ("Am"). On the west coast of the Peninsular Thailand, although vegetation reaches the true rain forest type, it fails to fit Koppen Tropical Rain Forest. ("Af") type, because there are two or three months of dryer winter when rainfall is under 60 mm.

Broadly speaking the climate of Thailand includes a rainy season from May to October, a cool dry season from November to February and a hot dry season or intermonsoon period from March to May, except in the south and part of Southeast Coast where there is no pronouced dry season. The Southwest Monsoon blows steadily from May to September, when it gives way to the cool, drier Northeast Monsoon. Annual temperature ranges are small throughout the country, with somewhat wider ranges in the northern part at higher altitudes. The hottest month is generally April and the coolest month is January.

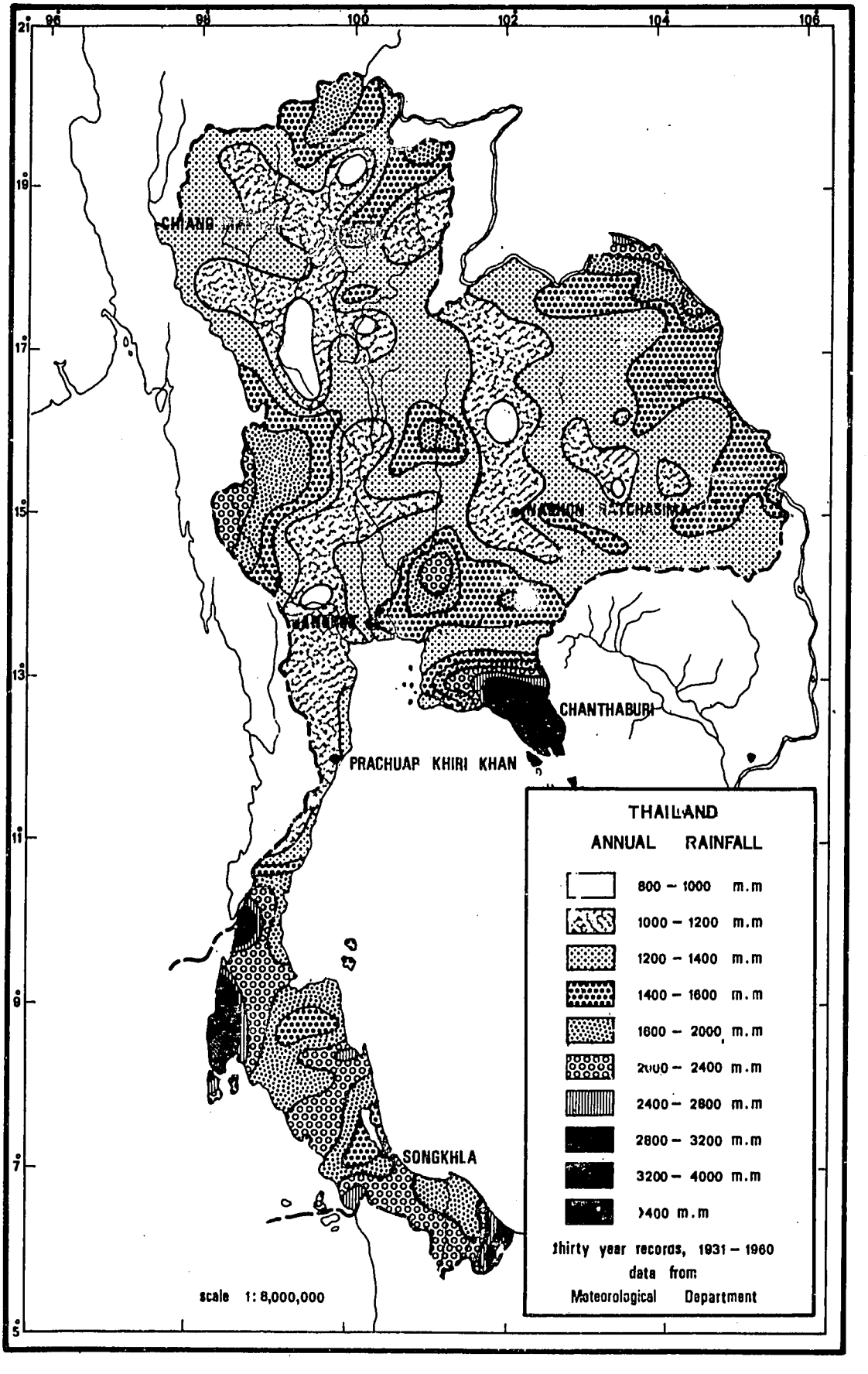

Fig.1 ISOHYETAL MAP OF THAILAND

(After Royal Thai Survey Division, 1969)

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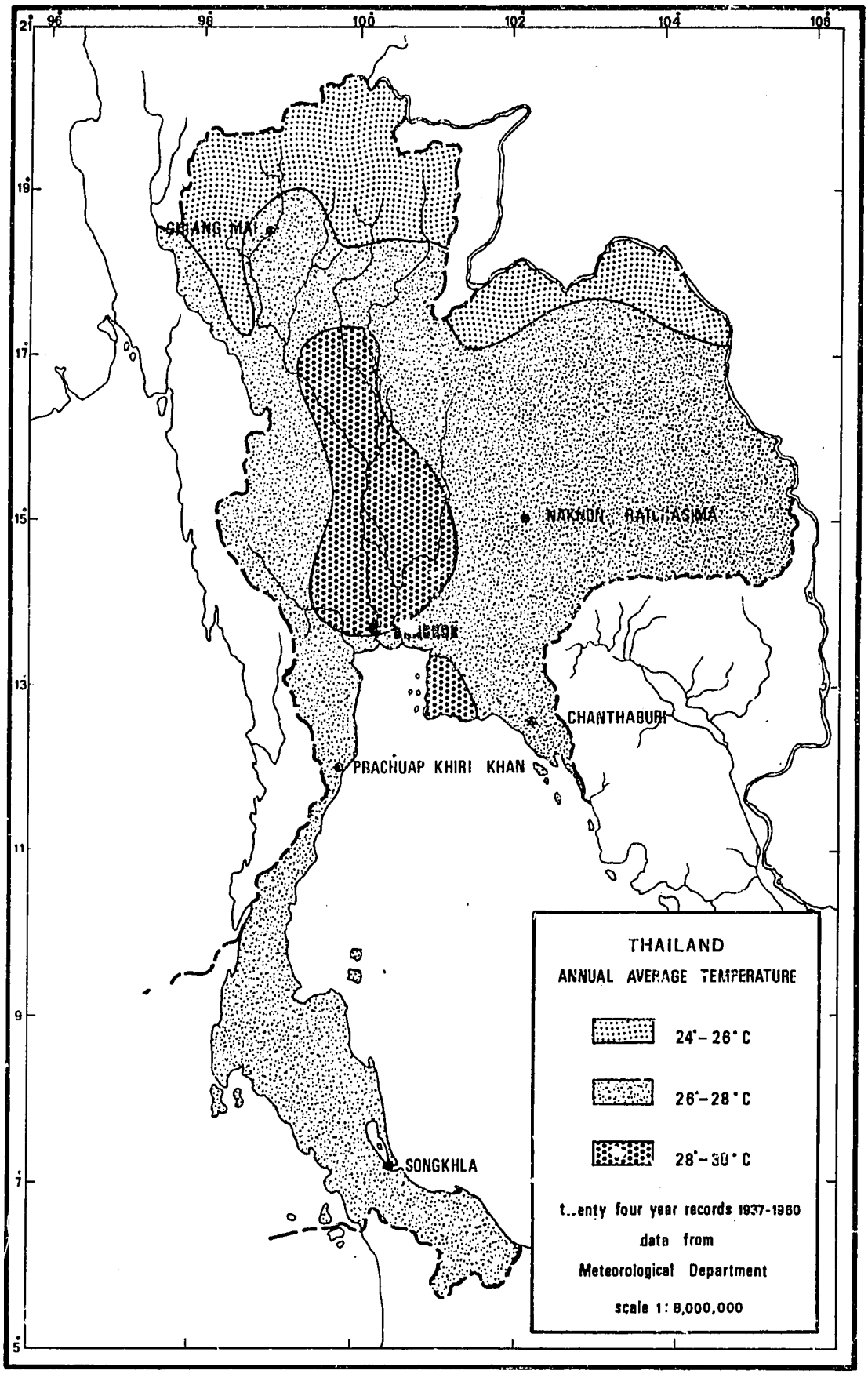

Fig 2 MEAN ANNUAL TEMPERATURE OF THAILAND

(After Royal Thai Survey Division, 1969)

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Soil Climate

Soil moisture and temperature regimes are very significant to soil classification. Unfortunately little work has been done on this subject in Thailand. The moisture-strength of soil samples had been studied in 1976 to predict soil trafficability. The Soil Survey Division began working on soil moisture and temperature regimes in 1978.

An attempt has been made to estimate soil moisture and temperature regimes for soil classification and mapping. Figure 3. shows the inferred soil moisture regimes of Thailand. This results are from combining and estimating presently available data. The aquic moisture regimes dominantly occur in rice paddies which cover low lying lands throughout the country. The udic moisture regime dominates the Southern Peninsula, the Southeast Coast and the North and West Continental Highlands. (Where there is hill evergreen vegetation and where the total amount of rainfall exceeds 2,000 mm. per year). The rest of the areas are classified under the ustic moisture regime.

In 1969, O.W. Rice used Moisture-strength data (for a depth of 16.5 inches) to predict the soil temperature regimes in Thailand. It appears that most soils in Thailand fall into the isohyperthermic class and that a significant number of soils with impeded drainage are classified as hyperthermic. A comparison of air and soil temperature differences in the dry season with the rainy season shows that in the rainy season temperature differences were not related to soil drainage conditions. In the dry season, the poorly drained paddy fields clearly had larger positive temperature differences. However, informations about soil moisture regimes should be confirmed since the 16.5 inch depth is short of the control section as defined in the Soil Taxonomy.

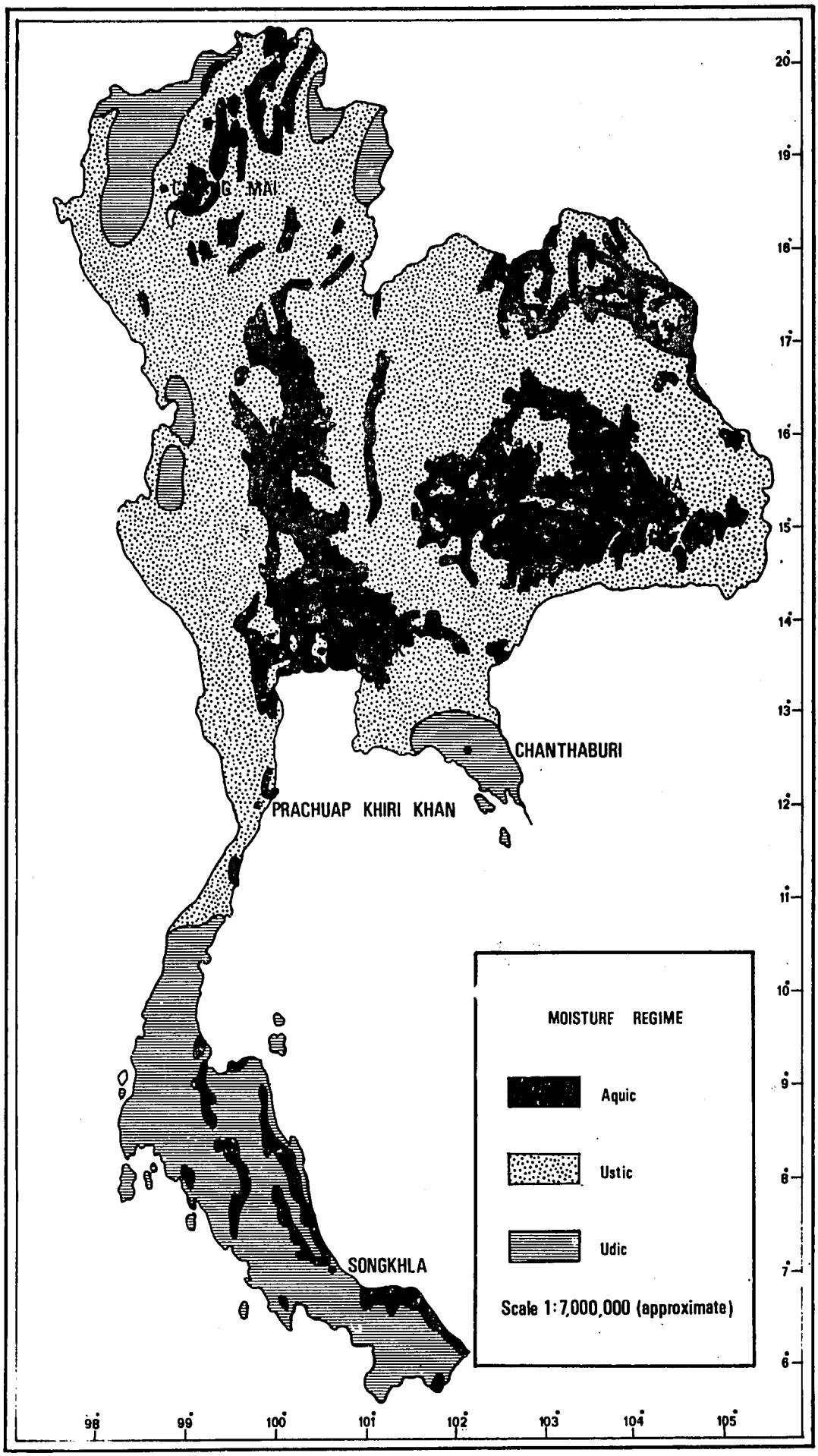

Fig 3 INFERRED SOIL MOISTURE REGIME OF THAILAND

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Main Landforms

Brown et al (1951) and Pendelton (1953,1962) had proposed five physiographic regions for Thailand. From our cuttent work in soil survey since 1961, it was found that nessary to add another broad physiographic region namely "Central Highland" (Moormann and Rojanasoonthon, 1966). These physiographic regions are shown in Fig.4. Each of these regions in turn is Characterized by various type's of landforms. The latest and most thoroughly attempt to classify landforms of Thailand is by Scholten and Siriphant (1973), accompanied by a map at a scale of 1 : 2,500,000 (Fig.5). The following is an abbreviated account of landform types of Thailand according to the nomenclature of these authors.

1. Beach and Dune Formations - they are found along shores of coastlines. They sometimes grade landward into a terrace landscape. Their relief is undulating with slopes ranging from 2 to 4 %.

2. Active and Former Tidal Flats of Recent Marine and Brackish Water Deposits-they are found extensively in the southern Central Plain along the Gulf of Thailand. They are also found locally on the eastern shore of the peninsular region.

3. Former Tidal Flats of Older Brackish Water Deposits-these areas occupy a large area in the southern part of the Central Plain.

4. Flood Plains of Recent River Alluvium-they can be seen along all major rivers. They are quite flat.

5. Low Alluvial Terraces of Semi-Recent and old Alluvium-they occur extensively in all parts of the country, usually flat.

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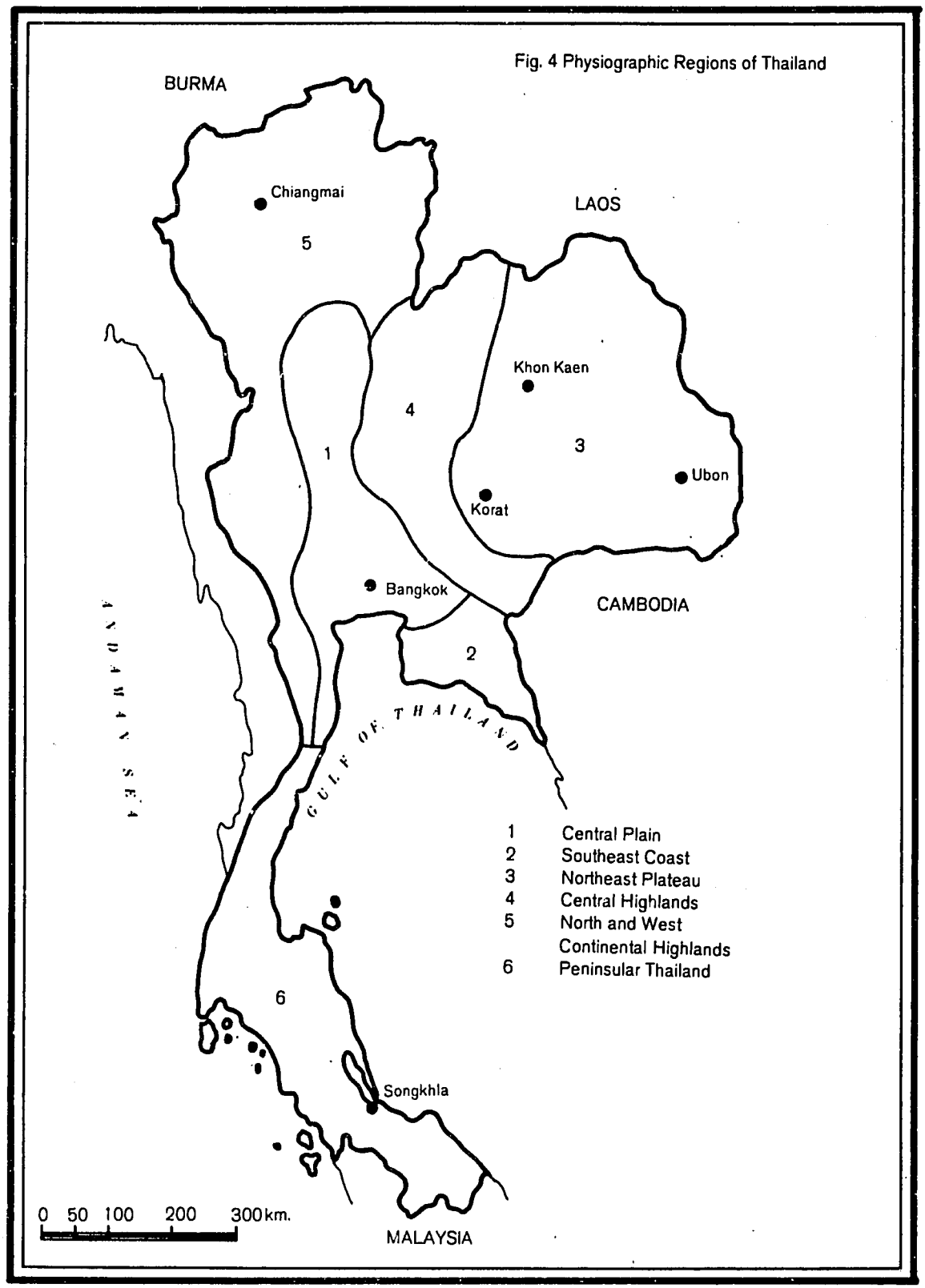


Fig 4 Physiographic Regions of Thailand

(After Moormann and Rojanasoonthon, 1972)

6. High Alluvial Terraces and Fans of old alluvium and colluvium-they are found frequently in positions above low terraces. Generally, the relief is undulating to rolling, with 2-16 % slope. They are especially significant on the Northeast (Khorat) Plateau.

7. Landforms in Organic Matter-there are peat and muck deposits, usually form in depressions, found especially in Peninsula.

8. Landforms in Residual Materials-they are found throughout the country, mostly adjacent to hills and mountains, bordering alluvial terrains, and they have been observed to form on nearly all rock types in Thailand.

9. Lava Plateau and Volcanic Remnants-these landforms are not especially common in Thailand. Slopes may be as great as 16 % on dissected terrains, however usually do not exceed 16%

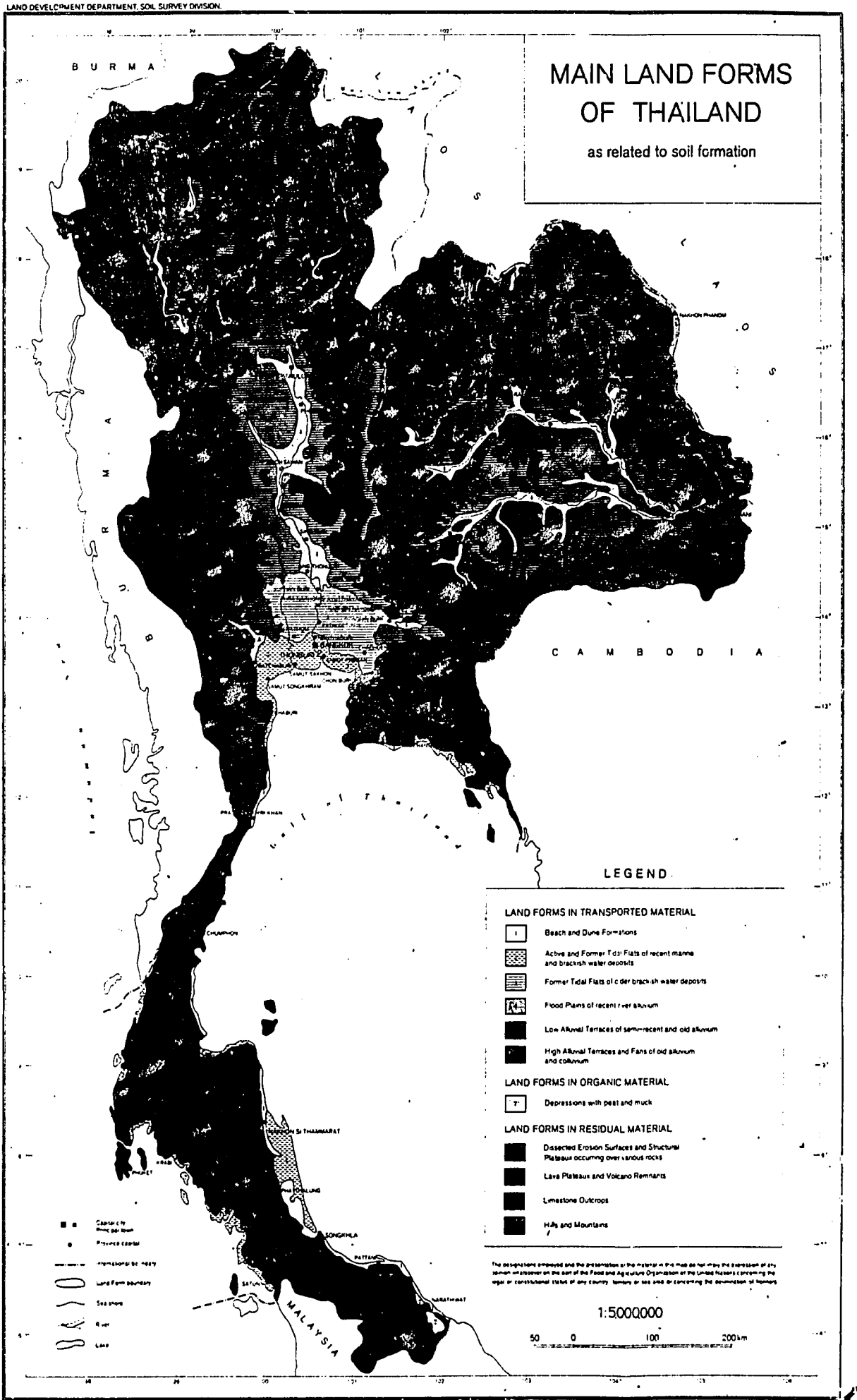
10. Limtstone Outcrops-since limestone weathers exclusively by chemical solution its outcrops produce craggy vertical sided forms of distinctive appearance. They are found everywhere but on the Northeast Plateau.

11. Hills and Mountains-these landforms occur throughout the country with the exception of Nottheast Plateau and most of Central Plain. They are formed on many different kinds of rocks and usually have a North-South trend. Slopes generally exceed 20 %

Geology of Thailand

Occurence of major rock types in Thailand ranges in age from Precambrian, probably through every geological are to the present. The following is on abbreviated account of the geological history of Thailand. It must be

LAND DEVELOPMENT DEPARTMENT, SOIL SURVEY DIVISION.



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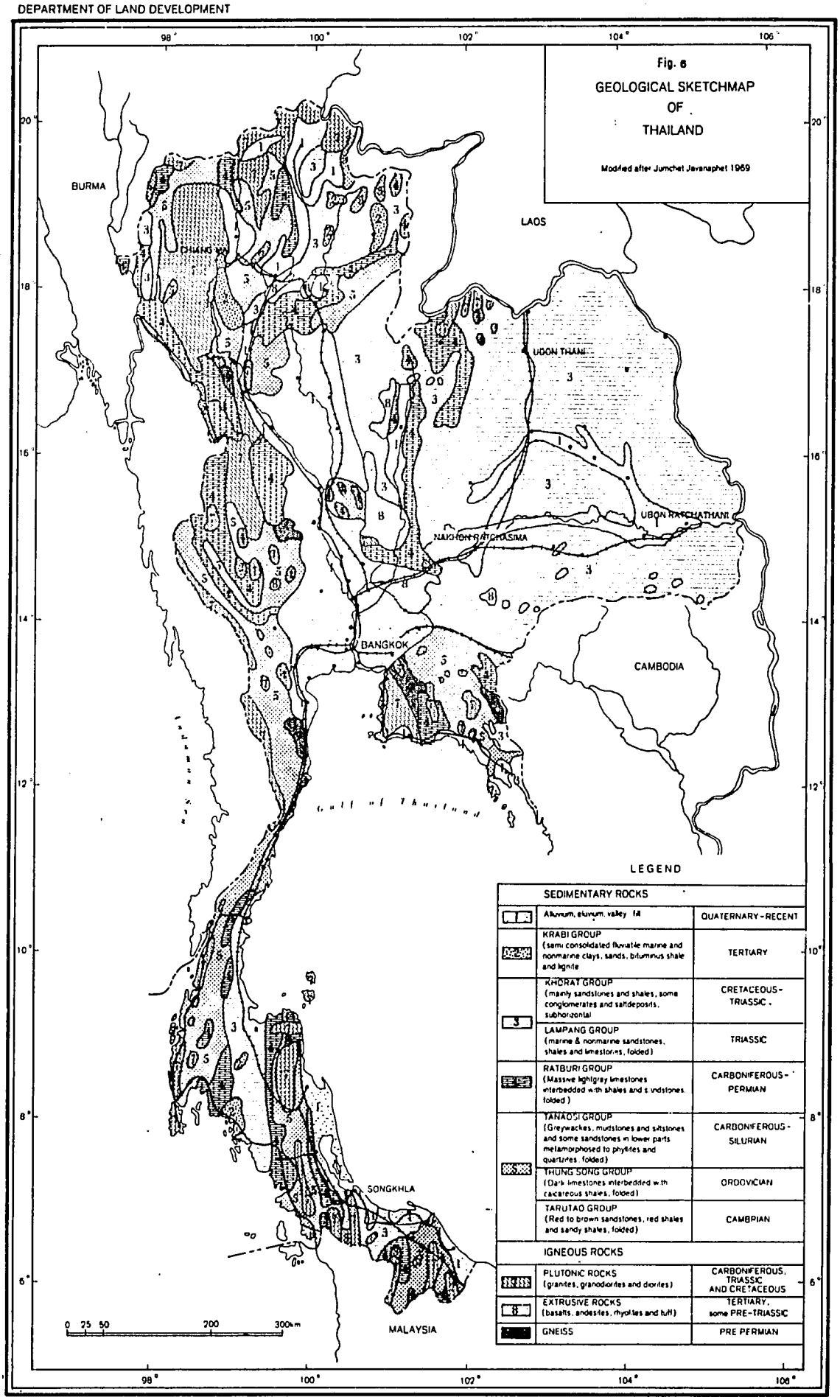
Fig. 6
GEOLOGICAL SKETCHMAP
OF
THAILAND
Modified after Jumchet Javanaphet 1969
BURMA
LAOS
CHIANG MAI
UDON THANI
UBON RATCHATHANI
NAKHON RATCHASIMA
BANGKOK
CAMBODIA
SONGKHLA
MALAYSIA
Gulf of Thailand
0 25 50 200 300km
LEGEND
SEDIMENTARY ROCKS
Alluvium, eluvium, valley fill
QUATERNARY-RECENT
KRABI GROUP
(semi consolidated fluviatile marine and nonmarine clays, sands, bituminus shale and lignite
TERTIARY
KHORAT GROUP
(mainly sandstones and shales, some conglomerates and saltdeposits, subhorizontal
CRETACEOUS-TRIASSIC
LAMPANG GROUP
(marine & nonmarine sandstones, shales and limestones, folded)
TRIASSIC
RATBURI GROUP
(Massive lightgray limestones interbedded with shales and sandstones folded)
CARBONIFEROUS-PERMIAN
TANAOSI GROUP
(Greywackes, mudstones and siltstones and some sandstones in lower parts metamorphosed to phyllites and quartzites, folded)
CARBONIFEROUS-SILURIAN
THUNG SONG GROUP
(Dark limestones interbedded with calcareous shales, folded)
ORDOVICIAN
TARUTAO GROUP
(Red to brown sandstones, red shales and sandy shales, folded)
CAMBRIAN
IGNEOUS ROCKS
PLUTONIC ROCKS
(granites, granodiorites and diorites)
CARBONIFEROUS, TRIASSIC AND CRETACEOUS
EXTRUSIVE ROCKS
(basalts, andesites, rhyolites and tuff)
TERTIARY, some PRE-TRIASSIC
GNEISS
PRE PERMIAN

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kept in mind, however, that even the most major point are still in dispute.

Many geologists feel that Thailand has a Precambrian basement complex exposed in the West of Thailand and overlain unconformably by sediments and metasediments, many of which are geosynclinal in origin. They range in age from Cambrian to Triassic. The high point of deposition in this sequence was probably in Silurian-Devonian time when the approximately North-South trending paired geosynclines developed. An orogeny possibly took place in the lower Carboniferous when the underlying sediments were folded and metamorphosed. Triassic was also intrusion of the rocks by ingneous rocks and much volcanic at this time. The major trend of structures produced was North-South. Volcanic activity, shelf deposits, and then marine sedimentation followed until the upper Triassic when perhaps another orogeny occurred. Stable continental type sediments were laid down from The Jurassic until the Tertiary when there was possibly renewed orogenesis. The Khorat plateau was uplifted in the Tertiary and sedimentation took place in isolated structural basins including the Central Plain. Volcanic activity was also important during this time.

Stratigraphy Although the stratigraphic nomenclature for Thailand has not been firmly established, the following system is probably most widely known. See the map also for particular lithologies.

Group :

Tarutao (Cambrian) Many coarse elastic shallow-water shelf deposits, particulary sandstone and quartzite metamorphosed in many places. Found in the western mountains, eastern gulf and the southern peninsula.

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Thung Song (Ordovician) Some elastic shallow water shell deposits, but predominantly limestone. Found in some areas as Tarutao, Also metamorphosed.

Tanaosi (Silurian, Devonian, Lower Carboniferous (?))

Made up of lower Kanchanaburi and upper Kaeng Krachan formations. Diverse, but principally clastic rock types mainly geosynclinal in origin. Highly folded and metamorphosed to greenschist facies (low grade) in many places. Extensive everywhere but on the Khorat Plateau.

Ratchaburi (Permian) - diverse clastic marine sediments. Known mainly in Western Thailand.

Khorat (Triassic, Cretaceous) - principally clastic sediments (redbeds). Continental especially alluvial in origin. Found on Khorat Plateau.

Krabi (Tertiary) - many clastic rocks, also lignite deposits. Seen in isolated basins throughout Thailand.

Igneous Rocks

Granite is the most common igneous rock in Thailand and has intruded in the Carboniferous, the Triassic-Jurassic, and the Cretaceous-Tertiary. Ultramafic and mafic plutonic rocks are far less common and occur in only a few places in the North of Thailand.

Volcanic rocks occur interbedded with sediments from the geosynclinal sequences. They also occur as flows, plugs and pyroclastic rocks from Carboniferous through quarternary times. The sapphire and ruby placers in Thailand are associated with the basalts of the Chanthaburi and Kanchanaburi areas.

Metamorphic rocks

Precambrian (?) para and orthogneisses are found widespread but not extensively throughout Thailand as part of the basement complex. They have been metamorphosed to the amphibolite (medium to high grade) facies and are of diverse rock type including calc-silicate rock, marble, quartzofildsparthic gneisses, quartzites and also interlayered granite and pegmatite. They have undergone many changes and as a reseult are structurally complex.

Metasedimentary rocks of the greenschist facies (Low grade) are very extensive in Thailand. They occur from the Cambrian to at least the Devonian. They are usually highly folded and include argillites, phyllites, metavolcanics, quartzites and states derived from geosynclinal sediments. Contact metamorphic aureoles occur around many granite plutons, particulary those of the Cretaceous-Tertiary. Dynamic metamorphism is also common but not extensive.

Geology of Northeast Plateau (Khorat Plateau)

The ascension from the west onto the Khorat Plateau is marked in part by out crops of the Permo-Carboniferous Ratchaburi Limestone. Here, according to some experts, it forms an erosional surface of the so called-terra rosa soils.

The Khorat Plateau is held up mainly by the semi-horizontal Khorat group of continental type sediments (red beds). The lowest member, an upper Triassic bassal conglomerate overlies the Permo-Carboniferous Ratchaburi group unconformably. The upper most salt member contains gypsum, anhydrite and rock salt and somes suggested the occurrence of desert like conditions in the cretaceous. Below is a short stratigraphy of Khorat.

Stratigraphic Subdivision of Khorat Group

Era	Period		Formations
Mesozoic	Creataceous	Upper	Salt Formation Ban Na Yo or Khok Kruat
	Jurassic	Middle	Phu Phan Phra Wihan (including Sau Kua).
	upper Triassic	Lower	Phu Kradung (including Nam Phong, Huai Hin Lat)

Much of the Khorat Plateau has been overlain by a series of terraces; the origin and correlation of which has not been determined. Some geologists feel that the causes of the terraces formation are mainly tectonic falling base level associated with the rise of the plateau and others believe that it may be climate. A formerly drier climate would imply flash floods and associated deposition of enormous volumes of sediment. This would evidently be followed by a change in stream regimes with decreased discharge and cutting of the terraces.

The basalt 30-40 km. southeast of Nakhon Ratchasima is similar deep weathering profiles and are apparently the same age. However, there are not gem bearing as in Chanthaburi basalt.

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Geology of Southeast Coast

Major rock types in this region normally arrange themselves in strips elongated along the north-south trend. Along the eastern flank of the gulf of Thailand, thin strip of quartzite-phyllite and/or argillite hills of Kanchanaburi formation are found, interspaces with the large area of granite. This granite is Carboniferous in age, usually porphyritic in nature and often shows strong flow structure orientation. Quartz veins and apatite dykes commonly cut through this granite body. Further north, this granite area grades into gneiss and schist of Pre-permian age. West of Rayong, Permian limestone crags and steep side hills are commonly occurred near and along the coastal area. Kanchanaburi formation of quartzite and phyllite occupies west of the eastern half of the entire region. Along the coastal portion however, outcrops of granite in low curves hillocks are common throughout. This kind of terrain has often been called erosional surface, in which there is much local deposition on this surface and therefore, the soils often certain a great deal of coarse sand fragments and grit. Radiometric investigation in 1969 concluded that the age of this granite was late Carboniferous, the rock itself can be called a gneissic granite (or adamellite), the foliation in this rock is due to the alignment of the micas. The so-called erosional surface whether it will be on granite or quartzite-phyllyte or limistone will grade into terrace, tidal flat and coastal plain. Distinction between these landforms is made with difficulty. Plinthite and ironstone (laterite) are found on these materials, the ironstone is usually vesicular in nature and has incorporated many quartz pebbles and grit.

At Amphoe Tha Mai, 5 to 10 km. west of Chanthaburi, a small but singnificant gem bearing Tertiary basalt is outcropped. It is the source of

the renounced star sapphires and rubies exclusively found in Thailand. Southeast of Chanthaburi (e.g. in Pliu Agricultural Experiment Station), Triassic granite is commonly found, it is probably more correctly called a granodiorite. With high rainfall, there is a deep red weathered profile over granite and many incipient development of plinthite profile. This Triassic granite, is more mafic than other older granite and contains large amount of biotite and hornblende. Further north along this border strip, important areas of limestone and gneiss and schist of similar age as indicated earlier are located.

Land Use

The existing land use program of Thailand has been started in 1971 by Land Classification Division of the Land Development Department. The 1 : 1,000,000 scale land use map was completed in 1976 by using aerial photograph and landsat imergary interpretation with field check. The results of this investigation are summarized in Table 2, and in the simplified land use map (Fig. 7).

Table 2 Types of Land Use in Thailand

(After Land Classification Division 1976)

	sq.km.	%
1. Horticultural crops	315	0.07
2. Perennial crops	31,150	6.06
Orchard	793	
Rubber	25,929	
Coconut	2,386	
Orchard + rubber	1,375	
Orchard + coconut	667	
3. Field crops	38,822	7.55
Corn	16,344	
Sugarcane	6,626	
Cassava	2,345	
Others(fibre crops,banana,pineapple etc.)	6,771	
Sugar cane + cassava	6,736	
4. Paddy field	113,995	22.18
5. Paddy field + field crops (50 - 50 %)	29,635	5.77
6. Field crops + forest (70 - 30 %)	78,668	15,31
7. Forest	212,324	41.31
8. Idle land	457	0.09
9. Salt pan, shrimp + fish pond	1,103	0.21
10. Marsh	1,169	0.23
11. Water	2,492	0.48
12. Urban area	2,487	0.48
13. Highway + roads	1,329	0.26
Total	513,982	100

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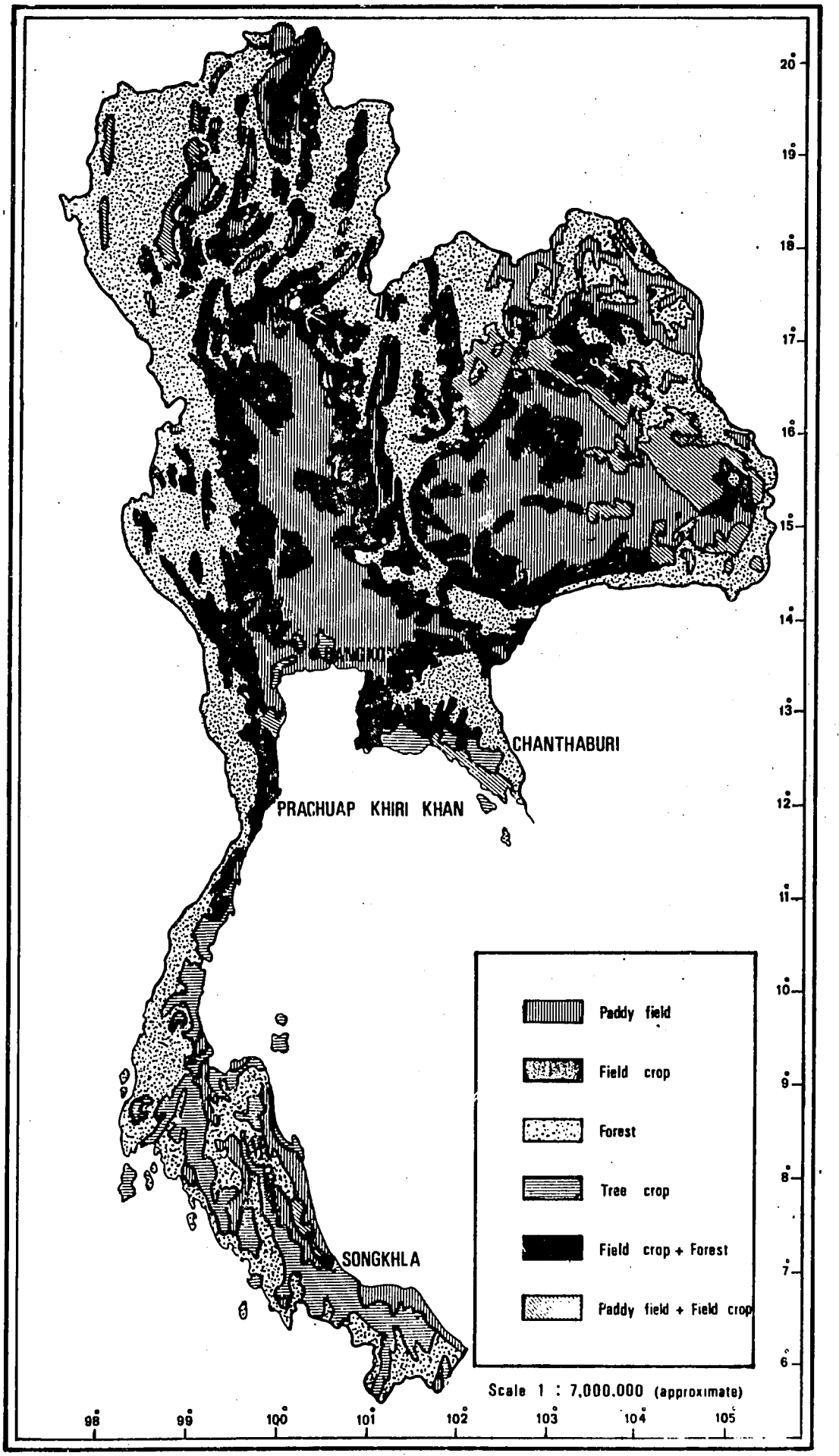

Fig 7 SIMPLIFIED LAND USE MAP OF THAILAND

(Modified after Manu Omakupt, 1976)

Based on this investigation it is reported that 41.31 % of Thailand is forest, 56.94 % is agriculture and the remaining 1.75 % consists of swamps, idle land, urban centers, high way and other miscellaneous areas. Cultivated lands are wide-spread in Thailand. The lower flood plains, with prolonged, deep flooding, support direct-seed "floating rice". Higher flood plains, and lower terraces support transplanted rice with the help of low dikes to retain rainwater. Higher terraces, plateaus and foot hills throughout Thailand support upland tilled crops, grazing and varieties of shrubs and trees for food and fibre. Cultivated crops typical of the region rubber, coconut, oilpalm and fruit-trees are in the South and Southeast; cassava in the Southeast and Northeast, beans and cotton in the Central Plain and shifting cultivation in the mountaineous area of the North and West. Merely all villages and cities intensive cultivation of vegetable gardens and fruit orchards (such as of coconut and banana) is practiced on natural levees and other high grounds such as ridges.

Natural Vegetation

In 1955, the Royal Thai Forestry Department reported that about 70 % of the total area was covered with forest vegetation. According to the study of existing land use in 1976 by the Department of Land Development, about 41 % of the area is classified as the forest land. According to recent information of the Royal Thai Forestry Department, this percentage of the forest land is reduced to 37.1 %. The estimated rate of deforestration in Thailand is about 4 % per annum. The relatively high rate of deforestration is caused by the increase in population, arable land and economic motivation during the last two decades.

The natural vegetation of Thailand reflects the climatic conditions. Figure 8. is the modified version of forest types in Thailand based on reports of the Royal Thai Forestry Department and the Land Development Department.

Tropical rain forest is the dominant type among the evergreen forest types. It is concentrated in the highest rainfall zones, i.e. the Southeast coast, the east of Chanthaburi and Peninsular Thailand. Dry evergreen forest and hill evergreen forest dominate in the Southeast coast and in the higher ranges of the Central Highlands and North and West Continental Highlands. The other evergreen types are much less significant in extent. Coniferous (pine) forest is found in patches on the plateau of Central Highlands and North and West Continental Highlands, mainly at elevation from 600 to 1,300 meters.

The various subtypes of Mixed Deciduous forest dominate in the Northern part of the Central Highlands and in hills and adjacent terrace areas of the North and West Continental Highlands. The higher hilly areas of the Northeast plateau also are mainly under this forest type.

Dry dipterocarp forest is the main type of the terrace formations and the low sandstone ridges of the Northeast plateau. It also occurs extensively on the terrace formations of the Northern part of the Central Plain. In other physiographic areas it is less wide spread; in the lower rainfall zones it occurs mainly on sandy, leached terraces and low hills of acidic rocks.

Mangrove swamp forest is found in the most coastal areas, but most extensively on the "drowned" West Coast of Peninsular Thailand.

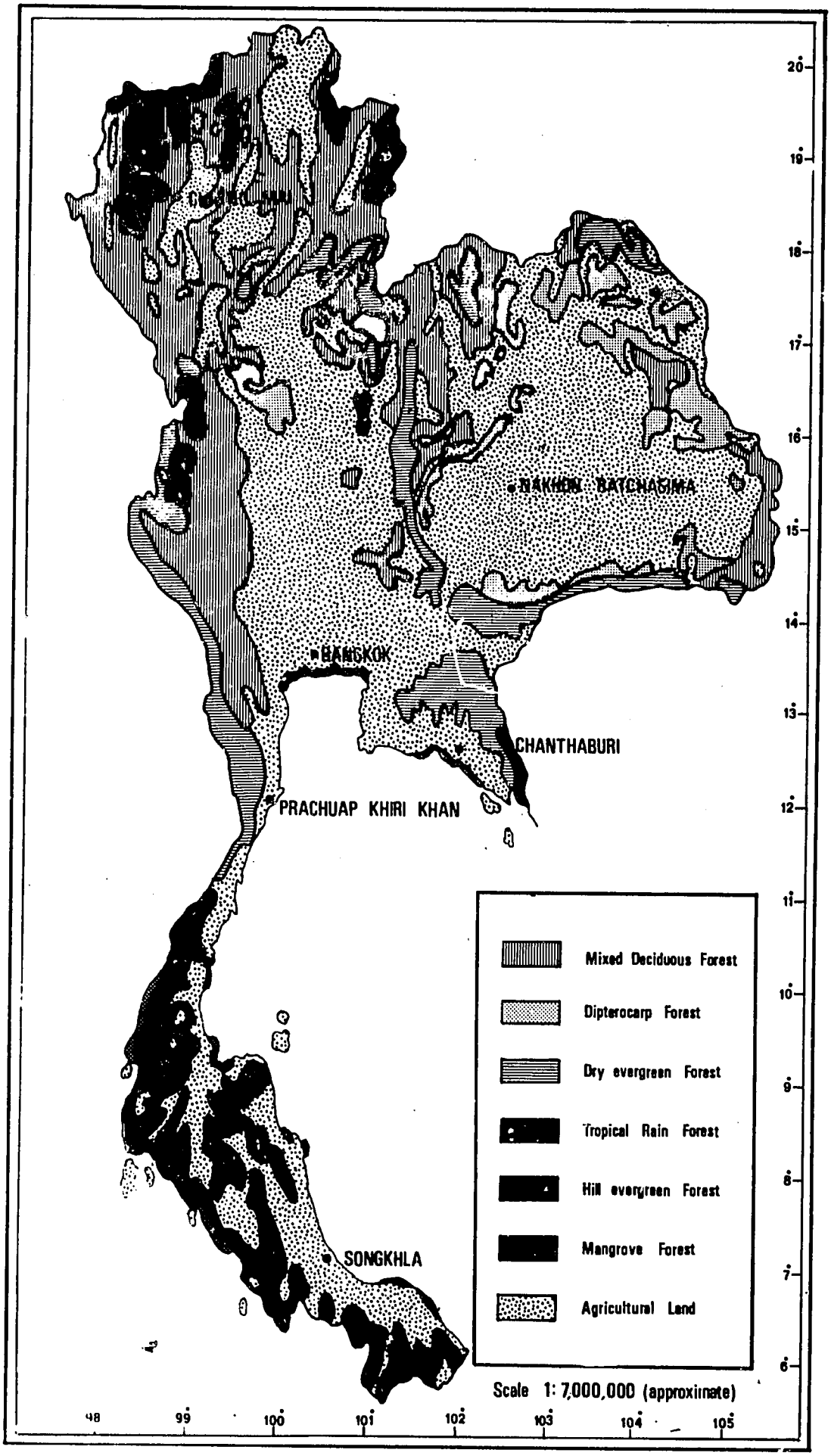

Fig 8 NATURAL VEGETATION OF THAILAND

(Modified after Royal Thai Fovestry 1967 and Land Development Department, 1976)

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II. SOILS OF THE EXCURSION AREA

The area of the excursion route has already been covered by detailed reconnaissance soil surveys. The great group soil units are shown in the General Soil Map of the Excursion Area (Fig.9).

9 Orders recognized :-

Ultisols This is the most common unit in the north-eastern and eastern part of the excursion area. Apart from beach sand and swamps it occurs on all landforms and on a wide range of parent materials. The Ultisols include three major and four minor great groups, namely the Paleustults, Haplustults, Paleudults, Plinthaquults, Plinthustults, Tropudults and Rhodustults are present.

Inceptisols are the next most extensive soil unit of the area. The unit occupies the large area in the Central Plain, and a small extent in the Northeastern plateau and the Central Highlands. The unit usually occurs on former tidal flats of old brackish water deposits, flood plains of recent alluvium and on low alluvial terraces of semi-recent deposits. The unit is differentiated into six great groups such as the Tropaquepts, Ustropepts, Sulfaquepts, Dystropepts, Eutropepts and Halaquepts.

Mollisols are found in the Central Highlands and are generally formed on very calcareous materials, such as marl, weathered fragments of limestone and weathered products of basalt. These soils are medium to fine textured and show high base saturation. Three great groups, Calciustolls, Haplustolls and Haplaquolls are recognized.

5%

Entisols show little or no profile development. The unit occupies not only beach and dune sands but also active tidal flats of recent marine and brackish water deposits. Undeveloped profiles that formed on recent water-deposited materials or on old alluvium from sandstone or granite are also described as Entisols. The soil texture varies from sand to clay. The unit is very often found along river levees of the Central Plain and occassionally on old alluvium derived from sandstones of the north-eastern plateau. The Entisols are differentiated into Hydraquents, Sulfaquents, Ustifluvents, Quartzipsamments, Ustipsamments, Tropaquents and Troporthents.

Alfisols This unit is wide spread in the northern and north-eastern parts of the north-eastern plateau. They occur a smaller extent in the plateau's Southern end. The soils have a loamy to clayey texture and a medium to high base saturation that is the highest in the subsoil. There are four great groups of Alfisols, namely the Paleustalfs, Haplustalfs, Natraqualfs and the Tropaqualfs.

Vertisols This unit is a limited extent only in the southern part of central highlands and found on rich, clayey material associated with limestone, marl and limestone derived alluvium. Less important in extent are Vertisols on materials derived from basic igneous rocks (basalt and some andesite). Vertisols found in this area can be differentiated into Pelluderts, Pellusterts, Chromuderts and Chromusterts.

Oxisols have a limited distribution. They occur on basalt formations and old alluvial terraces. In some places the Oxisols, if present, occupy too small an area to be mapped. The soils are deep, clayey, and porous. They are differentiated into the Haplustox, Umbriorthox and Haplorthox.

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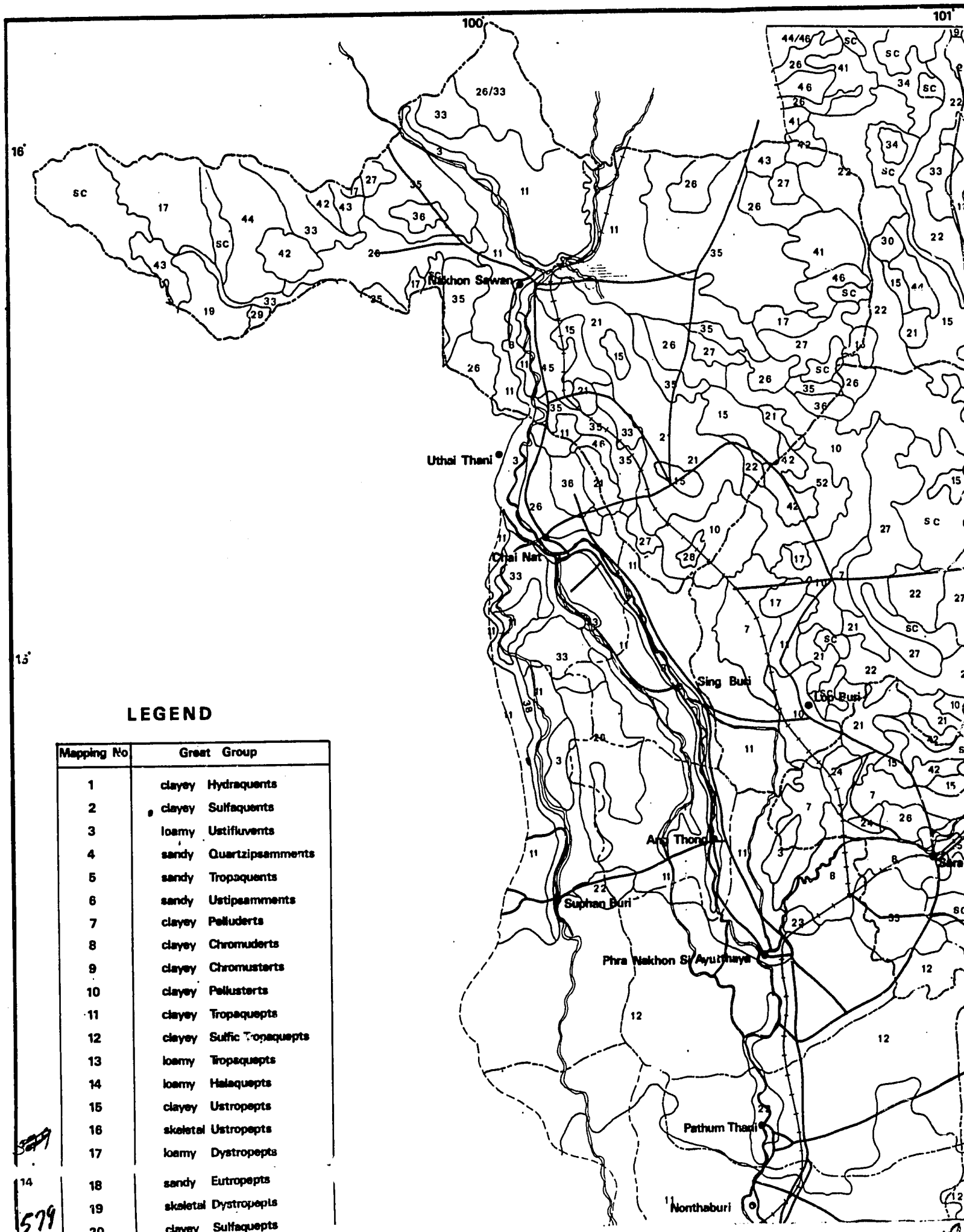
Spodosols This unit is of very limited extent. Only the great group Tropaquods are found only small places in northern part of the Central Plain. The other Spodosols namely Tropohumods are restricted to shore lines along southeast coast in strips so narrow that they cannot be mapped.

Histosols These organic soils occur in only one area, the South Eastern shore line of Rayong Province. They occupy swampy depression of river mouths and are thus situated only slightly above sea-level. Only one great group, Tropofibrists, is recognized.

578

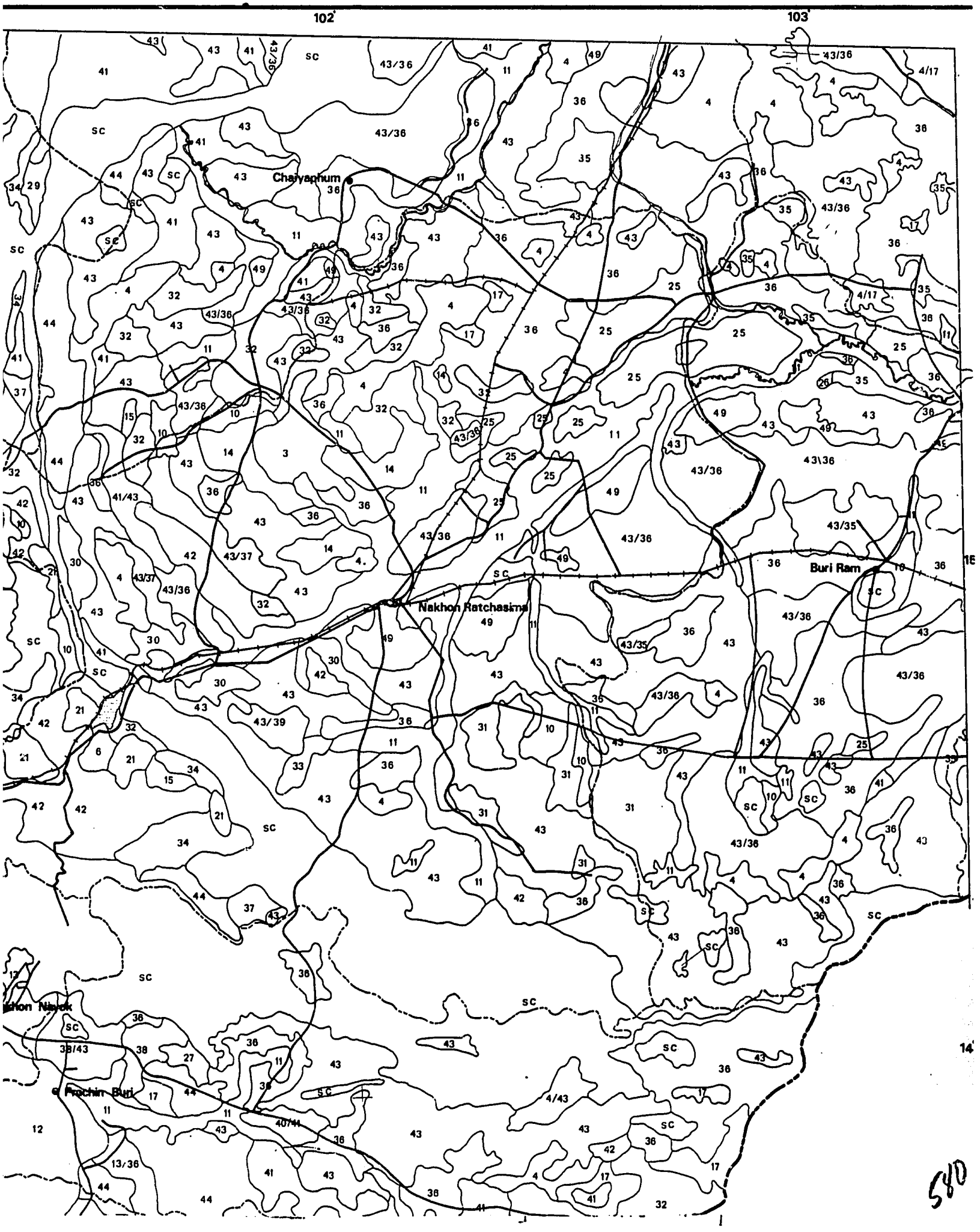


LEGEND

Mapping No	Great Group
1	clayey Hydraquents
2	clayey Sulfaquents
3	loamy Ustifluvents
4	sandy Quartzipsamments
5	sandy Tropaquents
6	sandy Ustipsamments
7	clayey Pelluderts
8	clayey Chromuderts
9	clayey Chromusterts
10	clayey Pellusterts
11	clayey Tropaquepts
12	clayey Sulfic Tropaquepts
13	loamy Tropaquepts
14	loamy Halaquepts
15	clayey Ustropepts
16	skeletal Ustropepts
17	loamy Dystropepts
18	sandy Eutropepts
19	skeletal Dystropepts
20	clayey Sulfaquepts

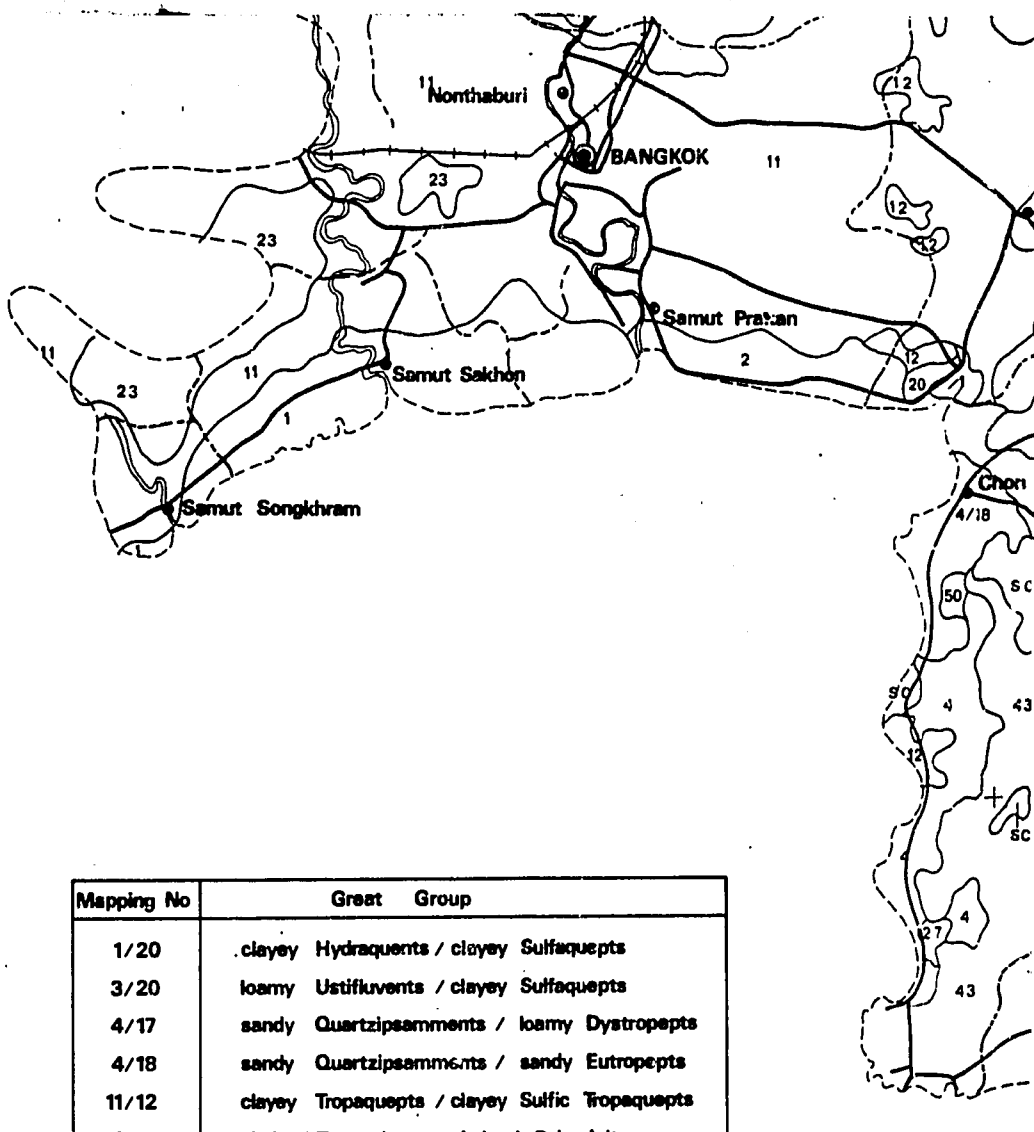
579

579


102
103
Chaiyaphum
Nakhon Ratchasima
Buri Ram
Prachin Buri

580

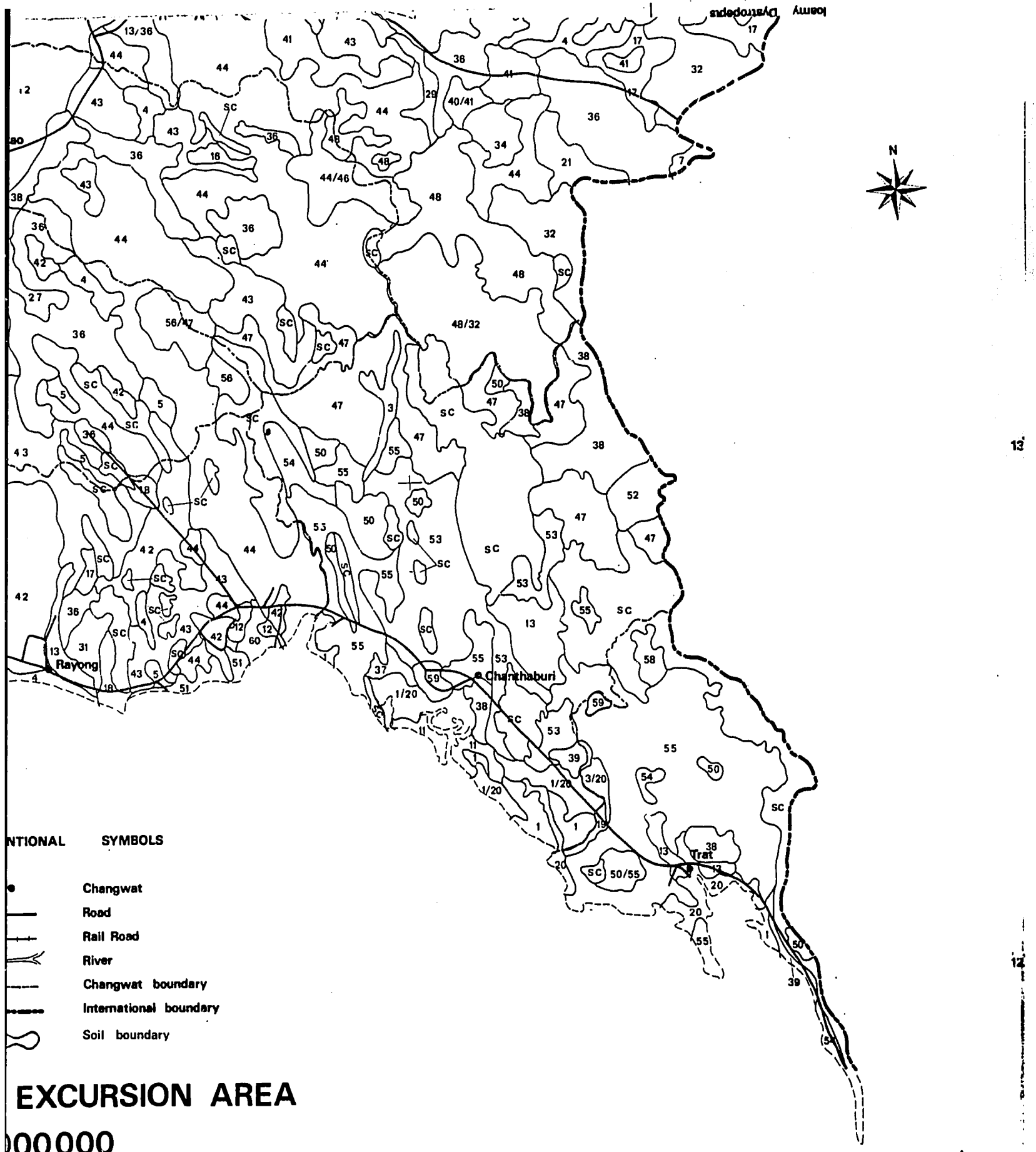
18	sandy	Eutropepts
19	skeletal	Dystropepts
20	clayey	Sulfaquepts
21	clayey	Calciustolls
22	clayey	Haplustolls
23	clayey	Haplaquolls
24	loamy	Tropaquods
25	clayey	Natraqualfs
26	clayey	Tropaqualfs
27	loamy	Tropaqualfs
28	skeletal	Tropaqualfs
29	clayey	Paleustalfs
30	loamy	Paleustalfs
31	skeletal	Paleustalfs
32	clayey	Haplustalfs
33	loamy	Haplustalfs
34	skeletal	Haplustalfs
35	clayey	Paleaquults
36	loamy	Paleaquults
37	skeletal	Paleaquults
38	clayey	Plinthaquults
39	loamy	Plinthaquults
40	skeletal	Plinthaquults
41	skeletal	Plinthustults
42	clayey	Paleustults
43	loamy	Paleustults
44	skeletal	Paleustults
45	skeletal	Rhodustults
46	skeletal	Haplustults
47	loamy	Haplustults
48	clayey	Haplustults
49	loamy	Haplustox
50	skeletal	Troporthents
51	sandy	Tropohumods
52	clayey	Tropudalfs
53	clayey	Paleudults
54	loamy	Paleudults
55	skeletal	Paleudults
56	loamy	Tropudults
57	skeletal	Tropudults
58	clayey	Umbriorthox
59	clayey	Haplorthox
60		Tropofibrists



Mapping No	Great Group
1/20	clayey Hydraquents / clayey Sulfaquepts
3/20	loamy Ustifluvents / clayey Sulfaquepts
4/17	sandy Quartzipsamments / loamy Dystropepts
4/18	sandy Quartzipsamments / sandy Eutropepts
11/12	clayey Tropaquepts / clayey Sulfic Tropaquepts
50/55	skeletal Troporthents / skeletal Paleudults
48/32	clayey Haplustults / clayey Haplustalfs
56/47	loamy Tropudults / loamy Haplustults
44/46	skeletal Paleustults / skeletal Haplustults
40/41	skeletal Plinthaquults / skeletal Plinthustults
4/43	sandy Quartzipsamments / loamy Paleustults
38/43	clayey Plinthaquults / loamy Paleustults
41/43	skeletal Plinthustults / loamy Paleustults
13/36	loamy Tropaquepts / loamy Paleaquults
43/36	loamy Paleustults / loamy Paleaquults
43/35	loamy Paleustults / clayey Paleaquults
43/37	loamy Paleustults / skeletal Paleaquults
26/33	clayey Tropaqualfs / loamy Haplustalfs
SC	Hills and mountains with miscellaneous soils

GENERAL SOIL MAP

appr. scale



EXCURSION AREA

)00,000

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III. DESCRIPTION OF EXCURSION ROUTE

As shown in Figure 10, soil pedons are identified by numbers. The stops are discussed in order of their occurrence as we proceed from Thailand's central plain to the northeastern plateau and then to the southeastern coastline.

Stop 1. The Ancient City of Phra Nakhon Si Ayutthaya

The tour route first passes along the Bangkok, or Central Plain on the so called "the Chao Phraya Delta" where wetland rice is grown extensively. The Bangkok plain consists of thick Quaternary alluvial deposits that are more than 400 m. deep. Saline and nonsaline marine sediments occupy the Southern most portion of the Bangkok plain. Vast brackish water deposits occupy a wide zone in the central part of the plain where acid sulphate soil is formed.

The first stop will be at Phra Nakhon Si Ayutthaya, once the capital of the country (for a period of 417 years). This old capital was invaded and destroyed beyond repair by the Burmese in 1767. However, numerous magnificent ruins still exist in this old city. All these ruins, such as the big images of Buddha, the huge pagodas or chedis, and the fine architectural foundations and structure;, indicated that Phra Nakhon Si Ayutthaya was one of the most properous cities on the Indo-China peninsula during the 13th century. At this stop, we spend about 45 minutes for pictures and relaxation before the long ride and hard work begins.

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* Bonus pedon No.1 representative of the acid sulphate soil in this area. Unfortunately however we are unable to observe it due to deep flooding.

Stop 2. Profile of Pedon No.1 : Pak Chong series.

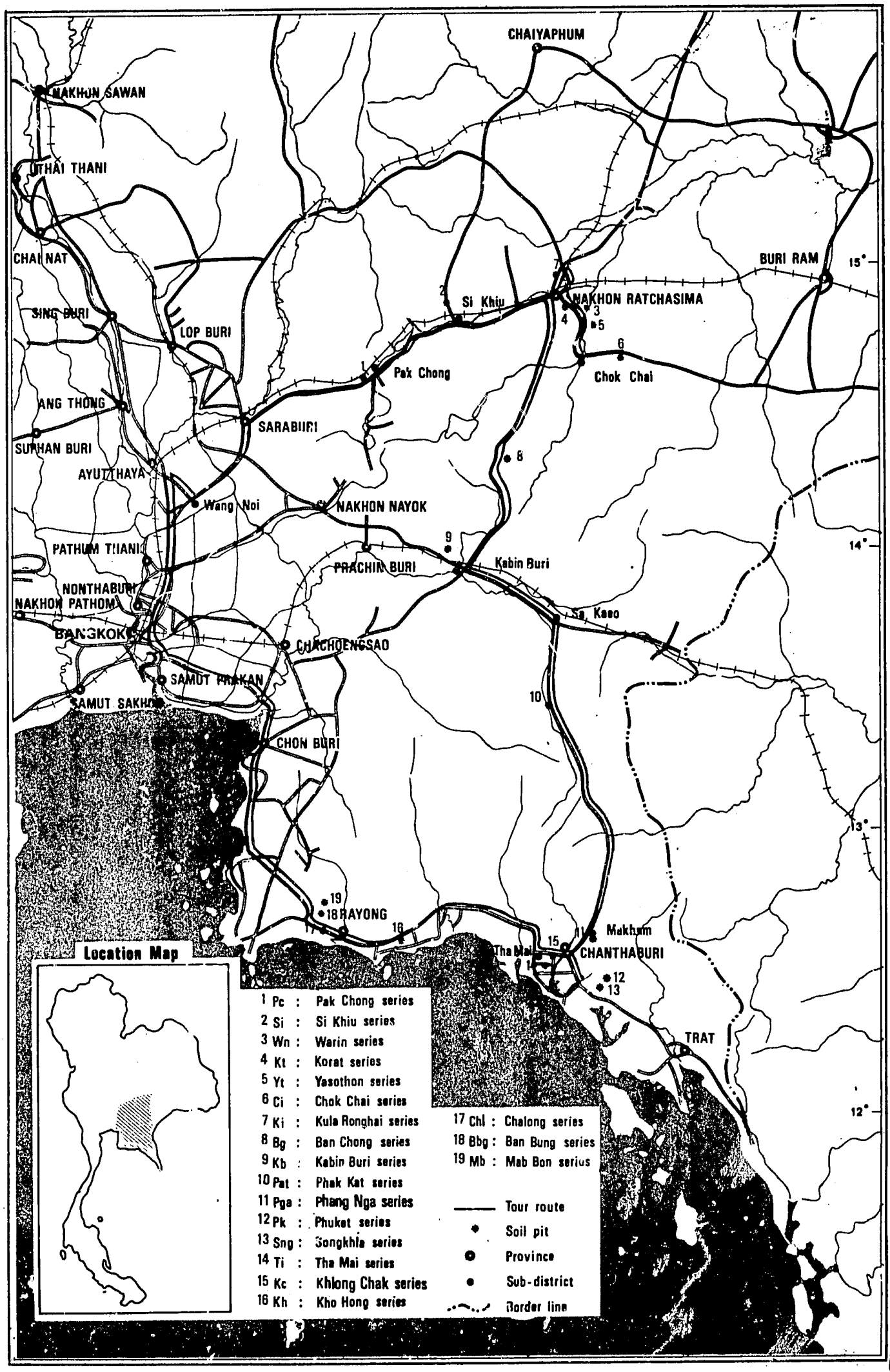
At about 154 km. northeast of Bangkok on Mitraparp (Friendship) Highway, is an area of red clayey soil developed from shale associated with Carboniferous and/or Permian limestone. The profile of Pedon No.1 is named the Pak Chong series. These soils commonly occur on erosion surfaces. This particular surface is terraced and covered by a deep weathering profile (i.e., it is "etched"). It's planated form is thought to result from the backwasting of near by slopes. Alternate descriptive terminologies are "strath terrace", "etch plain", "Karst corrosion plain", and "partial peneplain" The Pak Chong series is most widespread in the Central Highlands and in the country's northwest region. With the Pak Chong soils, which dominate on relatively higher, well drained lands, the Tha Kli soils (Typic Calciustolls) and the Lop Buri soils (Typic Pellusterts) are commonly found in association.

Stop 3. Profile of Pedon No.2 : Si Khui series.

The tour route continues northeast on the same highway, then turns north after 6 km. into the district of Si Khui by now we are on the Khorat Plateau.

At this stop, we will observe the profile of pedon No.2 so called the "Si Khui Series". This soil is developed from old alluvium (that overlies calcareous sandstone) and occurs on an undulating alluvial terrace. The principal associated soils include those classified as Paleustults and Ustoxic Dystropepts.

Mixed diciduous forest dominated by bamboo is the native vegetation on this soil. Again, however, parts are cleared for various upland crops


CHAIYAPHUM
NAKHON SAWAN
UTHAI THANI
CHAI NAT
SING BURI
LOP BURI
BURI RAM
15°
Si Khiu
NAKHON RATCHASIMA
Pak Chong
Chok Chai
ANG THONG
SARABURI
SUPHAN BURI
AYUTTHAYA
Wang Noi
NAKHON NAYOK
PATHUM THANI
PRACHIN BURI
Kabin Buri
14°
NONTHABURI
NAKHON PATHOM
BANGKOK
Sa Kaeo
CHACHOENGSAO
SAMUT PRAKAN
SAMUT SAKHON
CHON BURI
13°
RAYONG
Makham
Tha Mai
CHANTHABURI
TRAT
12°
Location Map
1 Pc : Pak Chong series
2 Si : Si Khiu series
3 Wn : Warin series
4 Kt : Korat series
5 Yt : Yasothon series
6 Ci : Chok Chai series
7 Ki : Kula Ronghai series
8 Bg : Ban Chong series
9 Kb : Kabin Buri series
10 Pat : Phak Kat series
11 Pga : Phang Nga series
12 Pk : Phuket series
13 Sng : Songkhla series
14 Ti : Tha Mai series
15 Kc : Khlong Chak series
16 Kh : Kho Hong series
17 Chl : Chalong series
18 Bbg : Ban Bung series
19 Mb : Mab Bon serius
Tour route
Soil pit
Province
Sub-district
Border line

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namely cassava, kenaf, and castor bean.

Stop 4. Profile of Pedon No.7 : Kula Ronghai series.

From pedon No.2, the tour retraces back to the Mitraparp Highway, then proceeds northeast to the vicinity of Nakhon Ratchasima province. In a paddy field, about 4 km. north of the town. Pedon No.3 known as the Kula Ronghai series is observed.

The Kula Ronghai soils are formed from old alluvium and commonly occur on low alluvial terraces of the Khorat basin. They occupy a moderate extent in the Khorat Plateau, particularly in its southern part. Major associated soils are those classified in great group Paleaquults and Halaquepts. This soil is mainly used for transplanted rice and natural grazing during the dry season.

Stop 5. Profile of Pedon No.4 : Khorat series.

Pedon No.3 is seen in a suburban area of Nakhon Ratchasima province. The Khorat soils are developed from old alluvium and occur on higher alluvial terraces. They are found in a moderate to large extent on the Khorat Plateau and also in the northern region of the country. The principal associated soils include those in the great groups Plinthustults, Quartzipsamments and Paleaquults.

The native vegetation consists of dry dipterocarp forests and mixed-diciduous forests. After clearing of climax forests, most areas are used for growing cassava, kenaf, water melon, beans, and castor beans.

Stop 6. Profile of Pedon No.3 : Warin series.

About 1 km. south of pedon No.4 on Khorat-Chokchai Highway, we pass undulating terrain of medium textured soils that also develops from the old alluvium. The tour stops at Pedon No.5 which has been mapped as the Warin series. This soil occurs on a similar physiography as the Khorat series, but at a slightly higher elevation. The major associated soils are not much different from those of the Khorat Series. They are similar by way of native vegetation and present land use.

Stop 7. Profile of Pedon No.6 : Yasothon series.

After going south about 4 km. from stop 6, we turn left and travel about 400 m. on a dirt road. At the next stop we study pedon No.6 the Yasothon series. This soil, in general also occurs on high alluvial terraces in the Khorat Plateau. The relief of the soilscape ranges from undulating to rolling. They are commonly found in association with Pedon No.4 and No.5.

The natural vegetation is dipterocarp forest and mixed-deciduous forest. Much of the area was cleared for a large variety of upland crops namely kenaf, cassava, corn,castor bean, and some fruit trees - banana, mango, and jackfruit.

Stop 8. Profile of Pedon No.6 : Chok Chai series.

From stop 7, we return to the Highway and head about south to Chok Chai district. Then, we proceed east on Chok Chai-Dejudom Highway until we arrive at Pedon No.6

Physiography that is different from the alluvial terraces to previous stops. Most of this area is occupied by fine-textured soils which are developed from tertiary basalt. We stand on a lava plain that has been etched, laterized, and slightly modified by dissection.

The profile that is examined is named the Chok Chai series. It represents a soil that is typical in basalt terrain. The original native vegetation is mixed diciduous forest, but much of it has been cleared for cultivation. Chili, corn, cotton, cassava, castor bean, pine apple, jackfruit, banana, and mango are grown on Chok Chai Soils, It is believed that this is one of the most productive soils on the Northeast plateau.

Stop 9. Profile of Bonus Pedon No.2 : Surin series.

If we have enough time, we will observe a pedon of the Surin series. This pedon is located about 1 km. west of Stop 8. The soil occurs on the same lava plain as the Chok Chai soil, but at a lower elevation and where the surface materials are now most likely locally derived from sedimentary deposits. The original vegetation is mixed deciduous forest, but parts of it are cleared for cassava, castor bean, and kenaf growing and also for road construction.

Stop 10. Profile of Pedon No.8 : Ban Chong series.

From Nakhon Ratchasima province, the tour proceeds south towards and above an escarpment of the Khorat Plateau. About 45 km. from the town of Nakhon Ratchasima, we pass undulating terrain of an alluvial terrace. Then, we enter a complex of soils developed from residuum and colluvium of Jurassic sedimentary rocks (such as sandstone, shale and siltstone). Low hills with

strongly convex slopes, which is common to dissected nonlaterized etchplain. The original planated form of this surface is considered to be structurally controlled.

We stop to study Pedon No.8 which has been mapped as the Ban Chong series. This soil is developed from residuum and colluvium derived from shale. They are commonly found in association with soils of the great group Haplustults and often with ironstone gravels.

This soil occupies moderate extents in North Thailand. On gently sloping land, this soil is mainly used for permanent cultivation of upland crops such as upland rice, corn, and cassava. On steep slopes mixed deciduous forest is still dominant.

Stop 11. Profile of Pedon No.9 : Kabin Buri series.

We now enter the eastern border of the Central plain as we leave the Khorat Plateau behind. At the next stop we examine the Kabin Buri series, a shallow, gravelly, clayey soil. This soil develope from residuum of shale on a slightly dissected erosional surface or "laterized etchplain". This soil occurs moderately in this area and also in North Thailand. It usually is covered by low secondary shrubs which are now partly cleared for cassava planting. Many cultivated lands have been abandoned recently due to unexpected unfavorable soil conditions.

Stop 12. Profile of Pedon No.10 : Phak Khat series.

The tour turns southeast and then travels southward parallel to the Cambodian border. We will pass through gently sloping land where the climax forest has been recently cleared. Several new towns or villages are

scattered along both sides of the highway. Corn, cotton, upland rice and bananas are principal cash crops in this area.

Most of the soils are fine textured and underlain by layers with secondary lime. At a stop we observe Pedon No.11 which represents the Phak Khat series. The soil is well developed and derived from a thin veneer of alluvium on micaceous mudstone or shale. Physiographically, the general region here appears dominated by high alluvial terraces and erosion surfaces, that surrounds entrenching and encroaching alluvial plains or "accumulation glacies" (upon which you stand). Since Phak Khat Soils occupy relatively low elevations, the water table always fluctuates within 1 m. from the soil surface during the rainy season.

Stop 13. Profile of Pedon No.11 : Phangnga series.

This part of the tour enters the vicinity of Chanthaburi province. As we pass through, we can feel the atmosphere changing from that of a tropical savanah climate into tropical monsoon climate. Because of increasing rainfall (about 3000 mm./year), and relative humidity (80 to 85 %), the vegetation and present land uses are different except in the rice paddies. Tropical evergreen forests, fruit trees and para-rubber trees occur here.

The profile of Pedon No.11 is located about 10 km. northeast of the town of Chanthaburi where we will stay overnight. This represented soil is called the Phangnga series. The soils commony occur in granitic areas in this region as well as in the Thai Peninsula. Rubber (*Hevea braziliensis*) and various kinds of tropical fruit trees such as rambutan (*Nephelium lappaceum*), durian (*Durio Zibethinus*), lansa (*Lansium domesticum*), and mangosteen (*Garcinia mangostana*) are commonly grown on the Phangnga soils.

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Stop 14 and 15 . Profile of Pedon No.12 and 13 : Phuket and Songkhla series.

Just about 18 km . southeast of the Chanthaburi town, we visit Pliu Agricultural Station. Research here is conducted by the Department of Agriculture and it concerns the growth of tropical fruit trees such as durian, rambutan, coconut and pepper . This station is located close to a foothill slope of a granitic mountain (location of Pedon No.2) and on top of a small alluvial fan (location of Pedon No.3).

The soil in this area is representative of the Phuket and Songkhla series. The Phuket soil develops from residuum and colluviated materials of granite and occur on the foothill slopes. The Songkhla soil occupies lower elevations adjacent to the Phuket soil and are formed from transported materials of granite.

Originally, most of the area was under tropical evergreen forest consisting of tall, dense stands and was complex in composition and structure. The Dipterocarpaceae family was numerous among the forest stands. On the floor of this forest the foliage of herbs, shrubs, tree shoots and young trees grew continuously. Rattan, beaker-shaped palms, lianas and bamboos were abundant. Mosses, orchids and tree ferns are commonly found. Except for the mountaineous terrain, the area has been cleared for para-rubber and fruit trees.

Stop 16 . Profile of Pedon No.15 : Khlong Chak series.

We retrace back on the same highway and then return to the vicinity of Chanthaburi. About 8 km. east of Chanthaburi, we stop at Pedon No. 15, the Khlong Chak series. This soil developed from shale and occurs on a laterized

etch plain or partial peneplain that 's dotted with subaccordant residual hills. The soils are found to a moderate extent in Southeast and Peninsular Thailand. They commonly occur in association with soil of the same great group but which are different in effective soil depth and with soils of the great group Plinthudults.

The native vegetation is tropical evergreen forest. Parts have been cleared for planting rubber crees. Also, much of the area has been quarried for road building material.

Stop 17. Profile of Pedon No.14 : Tha Mai series.

About 10 km. east of stop 16, we enter another system of residual hills and planeted surfaces with dark reddish brown, fine textured soils that develop from Tertiary basalt. The profile that is examined is located about 5 km. east of Tha Mai district.

The native vegetation is tropical evergreen forest again but most of it is replaced by pepper (*Piper nigrum*), rubber and various kinds of fruit trees (such as rambutan, durian and citrus). Gemstone are being mixed in this area. With enough time, we can visit the mines.

Stop 18. Profile of Pedon No.16 : Kho Hong series.

The tour route goes eastward on Sukumvit highway, along the southeast coast. About 75 km, east of the town of Chanthaburi, we stop to study Pedon No.16, the Kho Hong series. This soil formed from deposits of coalescing fans. (which, incidently overly a wave-cut terrace of marine sediment). The relief is undulating. These soils occur moderately in Southeast and Peninsular Thailand. The native vegetation, in general, is tropical

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evergreen forest but mixed deciduous forest exists in a transition zone between the tropical savannah and the tropical monsoon climates. Principal crops grown on the soils are cassava, para-rubber and fruit trees.

Stop 19. Profile of Pedon No.17.: Chalong series.

We enter Rayong province and pass the provincial capital which is situated on an old sand bar. About 14 km. east of the capital, we stop at Pedon 17, the Chalong series. This soil seems to be developed from materials transported a very short distance from laterized granite and contact metamorphic rock. The relief is undulating. The series occupies a moderately large area in this region and is exclusively used for cassava growing.

Stop 20. Profile of Pedon No.18 : Ban Bung series.

From stop 19, we take another road and go about 3 km. north of Pedon No.17. We stop on a narrow flood plain to examine the profile of Pedon No.18, the Ban Bung series. Transported material derived from granite is the parent material of this soil which occupies a moderate extent in the region. Relief is nearly flat or flat. The soil commonly occurs in association with soils of great group Quarzipsamments and with the soils of the same great group that lie in higher elevations. They occupy a moderate extent in this region and are mainly used for cassava and sugar cane cultivation. In areas of suitable water supply, vegetables are commonly grown.

Stop 21. Profile of Pedon No.19 : Mab Bon series.

This is the last profile of the field trip. It is located about 11 km. north of stop 20. The profile is on dissected etch plain or peneplain in carboniferous grainite. The Mab Bon soil is repersentative for

uppermost elevations of this undulating relief. It occupies a moderate extent in this region and is used for cultivation of cassava, sugar cane, pineapple and some friut trees such as jackfruit (*Artocarpus heterophyllus*) and mango (*Mangifera indica*).

IV. DESCRIPTIONS OF SELECTED PEDONS

This part contains descriptions of pedons, tables of laboratory data and results of micromorphological study. For quick reference the medhods are listed below :-

1. Particle size analysis by pipette method as described by method of Analysis Part I (Black, C.A.; 1965). Using dispersing agent as described in Soil Bulletin No.10 (FAO, 1976).

2. Separation of sand fraction by dry sieving.

3. The quantity of gravel by wet sieving after soaking with dispersing agent. Using the sample after bulk density determination.

4. Bulk density by core method.

5. Soil air dried moisture content by gravimetric method.

6. Water content at saturation by gravimetric method (Sample was soaking wet over 2 nights weighed, then oven-dried over 2 nights weighed again and calculated the moisture content).

7. Moisture retention by pressure plate apparatus.

8. Saturation Percentage by method described in Saline and Alkali Soils Agriculture Handbook No. 60.

9. Electrical Conductivity by method described in Saline and Alkali Soils Agriculture Handbook No. 60.

10. Organic Carbon by Walkley and Black wet oxidation method (6A 1a).

11. Nitrogen by Kjeldahl digestion method (6B1)* and Ammonia distillation method (6 B 1a).

12. Calcium carbonate ($CaCO_3$) by acid neutralization method to give an approximate measurement (6E 1c).

13. Extractable iron (Fe) by Dithionite-citrate-bicarbonate extraction (6C3).

14. pH determined with a glass electrode and KCl reference electrode in 1 : 1 Soil : water and 1 : 1 Soil : Normal KCl suspension (8C 1a, 8C 1c).

15. Extractable bases by NH_4OAc extraction (5 B1).

16. Extractable acidity by $BaCl_2$ - triethanolamine 1 method (6 H1) and back - tritration with HCl method (6H 1a).

17. Cation Exchange Capacity determined by ammonium acetate at pH 7.0 (5 A 1) and direct - distillation of adsorbed ammonia Kjeldahl (5 A 1a) and determined by ammonium chloride unadjusted pH followed the method 5 A 1 and 5 A 1 a.

18. Aluminum by KCl extraction I 30 min. (6G1) and aluminon colorimetry I., hot color development (6G1a).

* The references between parentheses and based on the methods described in Soil Survey Laboratory Methods and Proceedures far Collecting Soil Samples, Soil Survey. Investigation Report No.1. Soil Conservation Service, USDA.

19. Available phosphorus Bray's No. 2 method to determine "available P". Soil is extracted with a solution containing 0.03 N. ammonium fluoride and 0.1 N. Hydrochloric acid. P is determined by Colorimetry (Watanabe, F.S. and S.R. Olsen. 1959. Soil Science Society of American Proceeding. 29 : 677-78).

20. Available potassium by NH_4OAc 1 N. at pH 7.0.

21. Mineralogical analysis

a) Preparation of sample by combined methods described by Kilmer and Alexander (1949), Jackson (1956), Mehra and Jackson (1960), Theisen and Harwards (1962), and Bunting (1955).

b) Sample analysis by Phillips X-Ray diffractometer using CoK_{α} radiation, a Fe-filter and with scanning speed of 2° per minute.

c) Estimation of the clay mineral composition by determination of the relative areas of diffraction peaks from $20 = 6^{\circ}-15^{\circ}$.

22. Micromorphological study

a) Preparation of soil thin section.

Thin section of undisturbed oriented soil material were prepared by impregnating them under vacuum with a mixture of plastic resin and monostyrene. A catalyst (benzoyl peroxide) and an accelerator (cobaltoctoate) were added for hardening. The subsequent detailed procedure is given by STOOPS (1969).

b) Micromorphological description

Thin sections were studied and described by using a Reichert polarizing microscope. The micromorphological descriptions were made according

to the terminologies proposed by BREWER (1976), STOOP and JONGERIUS (1975), BECKMANN and GEYGER (1976) and ESWARAN and BANOS (1975).

The micromorphological studies of Pedons No. 1, 2, 3, 4, 5, 6, 8, 12, 13 and 16 were made by H.ESWARAN, State University of Ghent. The remaining pedons were studied by the Soil Micromorphological Section, Soil Analysis Division, Department of Land Development.

INDEX TO METHODS

U.S. DEPT. AGR., SOIL CONS. SVC., NAT. SOIL SURVEY LAB., LINCOLN, NEBRASKA, U.S.A.

CONVENTIONS

2A1 All data reported on <2mm (LT 2MM) size fraction base
2B Data sheet symbols
.0 not detected
TR detected, less than minimum reported amount

PARTICLE SIZE ANALYSIS

3A1 Pipette analysis, alkaline sodium polyphosphate (hexametaphosphate) dispersant
8D1 Ratio of 15-bar water to measured clay

WATER RETAINED AT 15-BARS (1500 KILOPASCALS)

4B2 Crushed sample, saturated and desorbed on membrane

ION-EXCHANGE ANALYSES

5A7A Cation exchange capacity, unbuffered ammonium chloride, syringe extractor, direct distillation
5A6A Cation exchange capacity, ammonium acetate, pH 7, syringe extractor, direct distillation
5A3A Cation exchange capacity, sum of cations (bases + acidity at pH 8.2)
5B4A Extractable bases from 5A6A extraction
6N2E Ca, atomic absorption
6O2D Mg, atomic absorption
6P2B Na, atomic absorption
6Q2B K, atomic absorption
6H1A Acidity, $BaCl_2$-TEA, pH 8.2
6G1E Al, N KCl extractable, syringe extraction, atomic absorption
8D1 Ratio ammonium acetate CEC: clay
8D3 Ratio extractable Ca: extractable Mg
5F1 Percent extractable Ca/ammonium acetate CEC
5C1 Base saturation, ammonium acetate CEC
5C3 Base saturation, sum of cations CEC

OTHER CHEMICAL ANALYSES

8C1A pH in water, 1:1 soil:water
8C1C pH in N KCl, 1:1 soil:solution
8C1E pH in 0.01 N $CaCl_2$, 1:2 soil solution
8C1B pH in saturated paste
6A1A Organic carbon, acid-dichromate digestion
6B1A Total nitrogen, Kjeldahl
6C2B Fe, dithionite-citrate extractable, atomic absorption
8E1 Resistivity of saturated paste (corrected to 15.6°C)

SAND MINERALOGY

7B1 Mineral counts of sand or silt (grain mounts in petropoxy, petrographic analysis). FNES = Fine sand, VFNS = Very fine sand, COSI = Coarse silt.

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Pedon No.1
Pak Chong series

Location : Km. 154 on Mitraparp Highway (from Bangkok to Nakorn Ratchasima), Ban Pang Sok, Amphoe Pak Chong, Nakhon Ratchasima Province.

Parent material : Shale associated with limestone.

Physiography : Erosion surface (recently proposed "karst corrosion plain")

Relief : Nearly flat

Slope : North-facing slope of 2 percent.

Elevation : Approx. 350 m.

Drainage : Well drained.

Climate : "Tropical Savanna"; annual rainfall 1181.2 mm.; mean temperature 26.2 °C.

Vegetation : Corn (approx. yield 1.5 m. ton/ha) and cassava (approx. yield 22 m. ton/ha).

Limitations effecting plant growth : Low nutrient status.

Horizon	Depth (cm.)	Horizon Description
Ap	0-12	Dark reddish brown (2.5YR3/4), clay, dark red (2.5YR3/6) dry; moderate fine subangular blocky breaking to granular structure; slightly hard, friable, sticky, plastic; many fine roots; slightly acid (pH 6.5); clear, smooth boundary.
B_{21t}	12-53	Dusky red (10R3/4) clay, dark red (2.5YR 3/6) dry; moderate medium subangular blocky structure; hard, friable, sticky, plastic; broken moderately thick cutans on ped faces; common fine roots; very

		strongly acid (pH 4.5); diffuse, smooth boundary.
B_{22t}	53-137	Dusky red (10R3/4) clay, dark red (2.5YR3/6) dry; moderate medium subangular blocky structure; hard, friable, sticky, plastic; patchy moderately thick cutans on ped faces; common fine roots; very strongly acid (pH 4.5); diffuse, smooth boundary.
B_{23t}	137-200	Dark red (10R3/6) clay; weak fine subangular blocky structure; friable, sticky, plastic; patchy thin cutans on ped faces; few fine roots; very strongly acid (pH 4.5).

Remark : colors are for fully moist soil unless otherwise stated.

SOIL Pedon No.1 : Pak Chong series **LOCATION** Amphoe Pak Chong, Northern Ratchasima-province

SOIL LABORATORY Soil Analysis Division, Department of Land Development. **LAB. Nos.** 6929 — 6935

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm. of whole Soil Pct.	Bulk Density g/cc.		Water Content: Water at Saturation	1/3 bar	15 bar	Saturation Percentage	Electrical Cond. mmhos /cm.	
													←Pct.→					
0-12	A_p	5.6	40.8	53.8						0.6	1.01		90.64	29.12	23.38	63.0	0.29	
12-30	B_{21t}	5.3	23.5	71.2						0.18	1.17		84.03	29.31	24.02	77.2	0.07	
30-53		5.4	14.8	79.8									87.23	29.05	24.70	85.6	0.18	
53-90	B_{22t}	3.2	12.2	84.6						0.28	1.08		89.67	34.33	26.01	69.7	0.04	
90-137		2.3	14.5	83.2									89.13	33.00	25.49	58.2	0.08	
137-160	B_{23t}	2.4	11.0	86.6						0.80	1.20		100.23	29.67	24.56	60.9	0.11	
160-200		2.2	15.2	82.6									99.41	29.34	24.48	61.4	0.16	

Depth (cm.)	Organic Carbon	Nitrogen	C/N		Carbonate as $CaCO_3$	Ext. Iron as Fe		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases: Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	NH_4OAc pH7
	←Pct.→				←Pct.→						←meq/100 g→							
0-12	2.10	0.16	12.88		1.02	8.11		6.2	5.3	-0.9	7.78	2.02	0.22	0.10	10.12	9.36	19.48	13.18
12-30	1.13	0.04	32.28		0.89	8.61		5.0	4.2	-0.8	5.05	1.23	0.07	0.00	6.43	9.62	16.05	9.86
30-53	0.62	0.06	10.88		0.71	8.70		4.4	3.8	-0.6	1.84	0.65	0.04	0.05	2.58	11.67	14.25	8.60
53-90	0.37	0.01	37.00		0.70	8.82		4.4	3.7	-0.7	0.55	0.34	0.03	0.03	0.95	11.83	12.78	8.68
90-137	0.40	0.03	12.64		1.65	7.44		4.4	3.7	-0.7	0.45	0.42	0.03	0.04	0.94	11.78	12.70	8.52
137-160	0.40	0.03	11.62		0.67	9.30		4.1	3.7	-0.4	1.59	0.77	0.04	0.04	2.44	12.70	15.14	8.61
160-200	0.29	0.24	1.20		0.60	9.53		4.1	3.7	-0.4	1.49	0.67	0.05	0.00	2.57	12.29	14.86	8.68

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Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay: CEC NH_4OAc	Ratio to clay: CEC NH_4Cl	Ratio to clay: Ext. iron	Ratio to clay: 15 bar water	Base Saturation: Sum Cations	Base Saturation: NH_4OAc	Available: P (Bray No.2)	Available: K NH_4OAc pH7.1N			
	←meg/100 g→		meg/100g clay					←Pct→		←PPm→				
0-12	10 68	tr	—	0 24	0 20	0 15	0 43	51 95	76 78	6	78			
12-30	7 06	0 44	9 65	0 14	0 10	0 12	0 34	40 06	65 21	3	23			
30-53	6 31	3 90	8 12	0 11	0 08	0 11	0 31	18 11	29 32	3	12			
53-90	5 11	5 03	7 07	0 11	0 06	0 11	0 31	7 43	10 58	6	12			
90-137	6.30	4 31	6 31	0 10	0 08	0 09	0 31	7 40	11 03	2	12			
137-160	6 01	3 84	7 02	0 10	0 07	0 11	0 28	16 12	28 34	2	12			
160-200	6 05	3 58	7 45	0.11	0 07	[illegible]	0 30	17 29	29 61	2	12			

Depth (cm.)	Mineralogy (X- ray Diffraction): Clay fraction	Silt fraction
0-12	Kaolinite	
12-30		
30-53	Kaolinite	
53-90	Kaolinite	
90-137	Kaolinite	
137-160		
160-200		

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SOIL CLASSIFICATION-

SERIES - - - - - - - -PAK CHONG (PC)

SOIL NO - - - - - - - S78PN-000-01 COUNTY - - - THAILAND

GENERAL METHODS- - -1A,1B1B,2A1,2B SAMPLE NOS. 78P1713-781719

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, NTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

APRIL 1979

DEPTH CM	HORIZON	SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFES .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	SAND 2-.10	INTR 1I .2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	RATIO 8D1 15-BAR TO CLAY
		PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B (PCT LT 2MM)																
0-12	AP	5.3	11.4	83.3		.5	.8	.8	1.6	1.6	3.3	8.1		3.7				.26
12-30	B21T	4.6	10.3	85.1		.9	.6	.5	1.3	1.3	4.8	5.9		3.3				.27
30-53	B21T	3.4	7.0	89.6		.7	.5	.4	.9	.9	4.1	2.9		2.5				.27
53-90	B22T	2.0	4.3	93.7		.5	.2	.2	.6	.6	2.6	1.7		1.4				.27
90-137	B22T	2.1	5.6	92.3		.4	.4	.2	.6	.6	1.4	4.2		1.5				.27
137-160	B3	2.7	5.2	92.1		.6	.3	.3	.8	.8	1.4	3.8		1.9				.26
160-200	B3	2.5	5.0	92.5		.5	.4	.2	.8	.8	1.6	3.4		1.7				.26

DEPTH CM	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2) VOL. GT 2 PCT	WEIGHT GT 75 PCT	75-20	20-5	5-2	LT .074	20-2 PCT LT20	(BULK DENSITY) 4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	(WATER CONTENT) 4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 HRD CM/CM	CARBONATE 6E1B LT 2 PCT	3A1A LS .002 PCT	(PH) 8C1A 1/1 H2O	8C1B 1/2 CACL
0-12													21.9				6.3	5.6
12-30													23.1				5.1	4.5
30-53													28.1				4.6	4.0
53-90													25.3				4.7	4.0
90-137													25.3				4.7	4.0
137-160													24.3				4.4	4.0
160-200													24.4				4.4	4.0

DEPTH CM	(ORGANIC MATTER) 6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	(EXTRACTABLE BASES 5B4A) 6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	ACTY 6H1A BACL TEA	AL 6G1E KCL EXT	(CAT 5A3A EXTB ACTY	EXCH 5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA 5F1 SAT NHAC PCT	(BASE SAT) 5C3 EXTB ACTY PCT	5C1 NHAC PCT
						(MEQ / 100 G)													
0-12	1.64			7.4		8.7	2.0	TR	.2	10.9	8.1		19.0	16.1	.19	4.4	54	57	68
12-30	.97			8.2		5.2	1.1	.1	.1	6.5	9.9	.6	16.4	12.6	.15	4.7	41	40	52
30-53	.56			6.6		2.1	.6	TR	.0	2.7	13.1	3.7	15.8	11.7	.13	3.5	18	17	23
53-90	.28			8.0		.6	.3	.1	TR	1.0	13.7	5.9	14.7	12.4	.13	2.0	5	7	8
90-137	.23			7.7		.4	.4	.1	TR	.9	12.1	4.9	13.0	10.9	.12	1.0	4	7	8
137-160	.23			8.1		.9	.7	.1	TR	1.7	11.6	4.1	13.3	10.7	.12	1.3	8	13	16
160-200	.20			7.8		1.3	.4	.1	.0	1.8	11.2	4.0	13.0	10.3	.11	3.3	13	14	17

DEPTH CM	PH 8C1C KCL	CEC 5A7A NHCL MEQ / 100 G
0-12	5.2	13.2
12-30	4.1	8.4
30-53	3.6	
53-90	3.7	
90-137	3.7	7.3
137-160	3.7	
160-200	3.7	

SAND MINERALOGY (7B1) PLACEMENT: SILICEOUS.
053-090 FNES - RE99 QZ95 OP4 PO1 ZR (369 GRAINS). COS1 - RE99 QZ87 PO7 FE1 OP2 TH2 ZR1.
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS OP = OPAQUE PO = PLANT OPAL QZ = QUARTZ TH= TOURMALINE ZR = ZIRCON.

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Micromorphological description of Pak Chong series.

30 cm.depth

The NRDP is plasmic. The plasma is bright reddish and is not distributed continuously. It is aggregated to form coalescing microaggregates which are more evident under plain light (Fig.11a). This type of related distribution pattern is agglutinic specific related distribution pattern which is typical of an Acrustox. Plasmic fabric is insepic, argillasepic and in some places is isotic. There are only very few, fine sand-sized quartz grains (Fig.11b). No other minerals are present.

A complex system of interconnected ortho-vughs form the voids (Fig.11b). Under plain light it is clear that the voids are formed by the packing of the microaggregates. The voids are coated by a thick layer of very well oriented ferri-argillans which occupy about 15% of the area (Fig. 11b). The presence of the argillan may be detected even under plain light (Fig.11a), by its homogenous waxy texture compared to the spongy aspect of the soil material. In some voids, a thinner layer of yellow argillan coats the reddish ferri-argillan (Fig.11c). Some of the finer voids are completely infilled with translocated clay, resulting in clay-plugs or papules.

100 cm.depth

The NRDP is plasmic. The plasma is less aggregated in this horizon (Fig.12b,c). Plasmic fabric is argillasepic, insepic. An ooidsepic fabric accentuates the presence of microaggregates locally. Grains are dominantly fine sand-sized quartz. Few medium sand-sized runiquartz are also present.

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The matrix is very compact. Voids are few and are fine orthovughs. Illuviation argillans are much fewer (1-2%) and are confined to the larger voids. Few, fine papules are also present.

There is some evidence of biological activity. Few, large aggrotubules (Fig.12a) are also present.

Interpretation

There is little doubt regarding the presence of an argillic horizon. Clay translocation and accumulation in the upper part of the profile is an active, current process. Comparing the sample at 30 cm. and 100 cm, it seems that the latter layer has very much less argillans. Indirectly, this suggests a recent accumulation process, the translocated clay reaches a maximum at shallow depths.

The material at the 30 and 100 cm. depths is similar indicating that there is no discontinuity between the two. The soil material is preweathered and deposited. The agglutinic SRDP which is displayed in the 30 cm. sample and to a lesser extent in the 100 cm. sample, clearly indicated that the material had reached an oxic stage and even an acric stage in soil formation prior to clay illuviation.

Clay translocation took place subsequent to deposition of this oxic material. The profile is an example of an argillic horizon developing in oxic material. Detailed sampling will show that the subsoil has an oxic horizon.

What caused the change in soil formation? The large scale deforestation in the early part of this century with associated changes in climate are contributory.

Classification : a) Soil Taxonomy.

Oxic Paleustults.

b) FAO/UNESCO

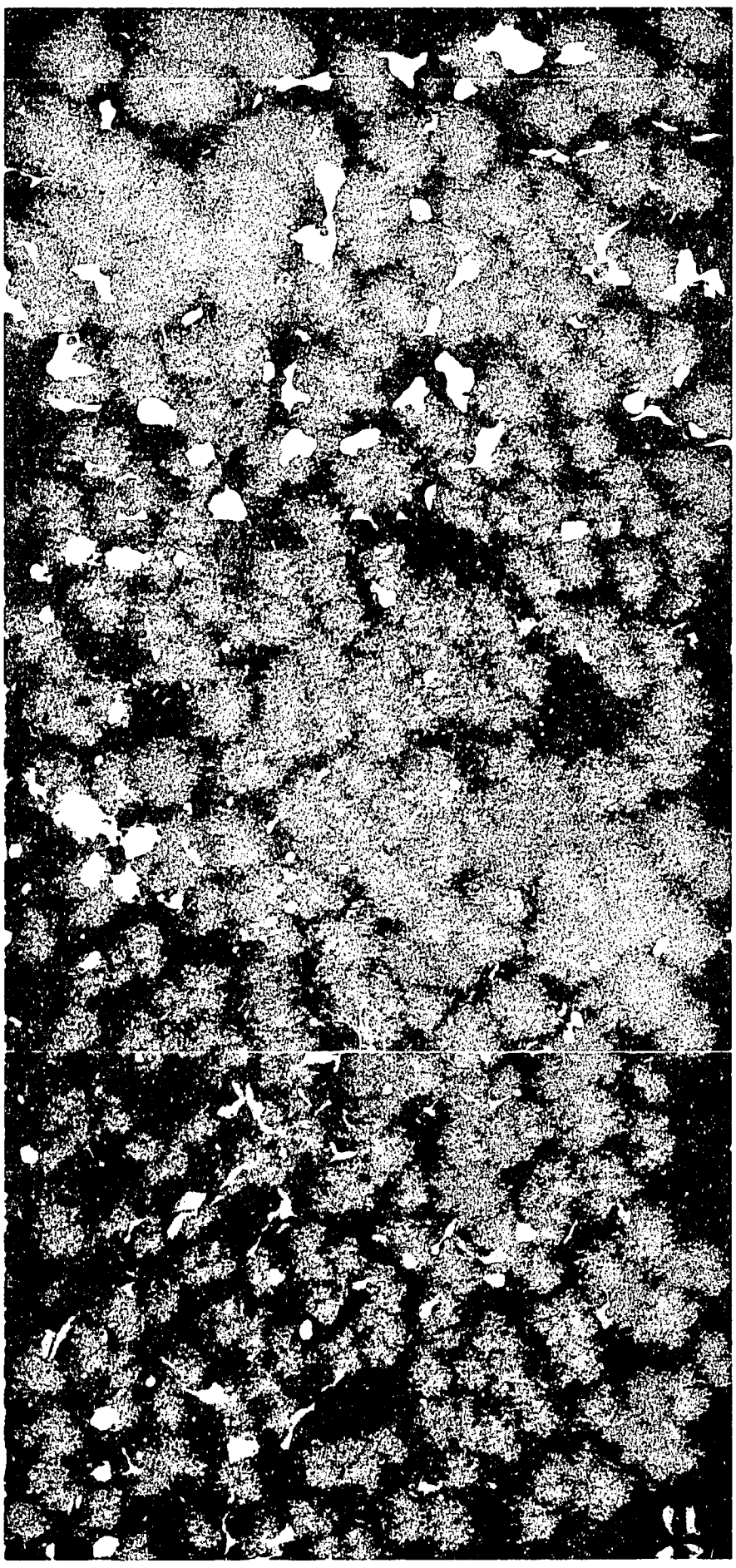
Deptric Nitrosols.

c) French Classification

Sol Ferralitic Forlement

desature Lessivic modal

Comments : Since a) this soil has CEC 24 meq per 100 g clay (by NH_4OAc) and has a cation-retention capacity from NH_4Cl of 12 meq per 100 g clay in the major part of the argillic horizon and b) has an argillic horizon that has a color value, moist of less than 4 and has a color value, dry less than 1 unit higher than the value, moist, in all part of the soil within 1 m. of the top of the argillic horizon. Subgroup Oxic Rhodic Paleustults may be established for classification of this pedon.



x 40

Plain Light

(a)

x 40

Crossed Nicols

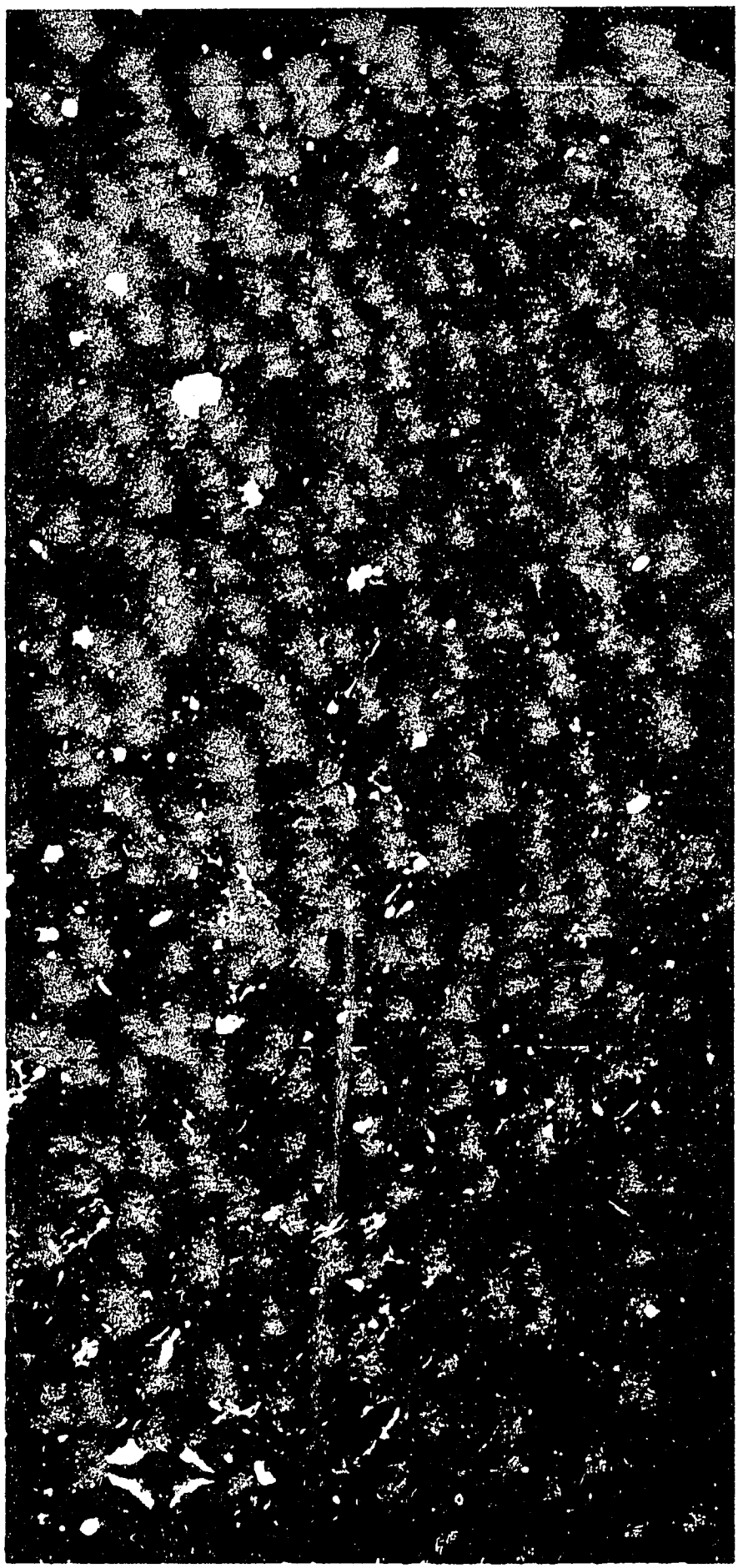
(b)

x 80

Crossed Nicols

(c)

Fig. 11. Pak Chong series at 30 cm. depth.



x 40

(a)

x 40

(b)

x 80

(c)

Fig. 12. Pak Chong series at 100 cm. depth.

Pedon No. 2
Sikhiu series

Location : Approx. 700 m. West of Km. 5.9 on Sikhiu-Chaiyaphum Rd, Amphoe Sikhiu, Nakhon Ratchasima Province.

Parent material : Old alluvium on calcareous sandstone.

Physiography : Alluvial terrace.

Relief : Gently undulating. Slope : Northwest-facing slope of 2-3 percent.

Elevation : Approx. 270 m. Drainage : Well drained.

Climate : "Tropical Savanna"; annual rainfall 1181.2 mm; mean temperature 26.2 °C.

Vegetation : Bamboos and thorny shrubs

Limitation effecting plant growth : Low nutrient status, prone to erosion.

Horizon	Depth (cm.)	Horizon Description
A_1	0-13	Dark brown (7.5YR3-4/2) sandy loam; weak medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; many fine roots; slightly acid (pH 6.5); gradual, smooth boundary.
B_{21t}	13-53	Dark red (2.5YR3/6) loam; weak coarse subangular blocky structure; friable, slightly sticky, slightly plastic; patchy thin cutans on ped faces; common fine and coarse roots; strongly acid (pH 5.5); diffuse, smooth boundary.

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B_{22t}	53-94	Dark red (2.5YR3/6) loam; weak coarse subangular blocky structure; friable, sticky, plastic; patchy thin cutans on ped faces, few medium and coarse roots; strongly acid (pH 5.5); diffuse, smooth boundary.
B_{23t}	94-125	Dark reddish brown (2.5YR3/4) loam; moderate medium and coarse subangular blocky structure; friable, sticky, plastic; continuous thin cutans on ped faces; common medium and coarse roots; slightly acid (pH 6.5); diffuse, smooth boundary.
B_{24t}	125-185/190	Dark reddish brown (2.5YR3/4) loam; moderate coarse subangular blocky structure; friable, sticky, plastic; continuous thin cutans on ped faces; common medium and coarse roots; many termite holes; neutral (pH 7.0); clear, wavy boundary.
B_{3cn}	the soil surface.	Dark reddish brown (2.5YR3/4) gravelly loam; weak fine subangular blocky structure; friable, sticky, plastic; strongly effervescent; gravels composed of ironstones and quartz; mildly alkaline (pH 7.5).

<u>Remark</u> : Layer of calcareous sandstone bed rock occurs below 210 cm. from the soil surface.

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SOIL Pedon No.2 : Sikhiu series **LOCATION** Ampoe Sikhiu, Nakhon Ratchasima Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development **LAB. Nos.** 6943 – 6951

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm of whole Soil Pct.	Bulk Density g/cc.		Water Content: Water at Saturation (Pct.)	1/3 bar (Pct.)	15 bar (Pct.)	Saturation Percentage	Electrical Cond. mmhos/cm.	
0-13	A_1	58.0	33.1	8.9	0.5	0.4	2.4	28.0	26.7	0.11	1.58		57.00	9.55	6.10	32.4	0.20	
13-33	B_{21t}	47.6	32.9	19.5	0.1	0.5	2.1	24.2	20.7	—	1.35		59.99	15.04	9.48	38.6	0.11	
33-53		45.9	33.4	20.7	0.3	0.5	1.7	22.7	20.7				64.97	14.65	9.31	38.2	0.10	
53-75	B_{22t}	45.3	31.8	22.9	0.3	0.4	1.8	24.5	18.3	0.13	1.54		65.21	15.93	10.02	40.3	0.10	
75-94		44.9	35.0	20.1	0.3	0.4	1.6	23.0	19.6				61.53	15.79	9.15	47.8	0.09	
94-125	B_{23t}	44.5	35.8	19.7	0.4	0.4	1.7	23.4	18.6	0.27	1.54		53.36	15.97	9.84	43.6	0.09	
125-152	B_{24t}	38.6	34.6	26.8	0.9	0.4	1.5	21.0	14.8	0.55	1.52		58.47	19.08	12.16	52.0	0.11	
152-185/190		39.0	39.0	22.0	1.3	0.5	1.3	22.1	13.8				59.90	20.14	11.89	43.6	0.28	
185/190-210	B_{3cn}	43.6	42.0	14.4	7.0	3.2	3.0	17.3	13.1	63.25	1.71		49.07	35.64	11.38	35.7	0.29	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N		Carbonate as $CaCO_3$ (Pct.)	Ext. iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	CEC: NH_4OAc pH7
0-13	0.60	0.04	14.28		0.58	0.62		5.9	4.6	-1.3	3.75	0.74	0.21	0.05	4.75	3.80	8.55	5.13
13-33	0.56	0.01	56.00		0.62	0.84		5.2	3.9	-1.3	3.25	0.95	0.17	0.08	4.45	6.13	10.58	6.60
33-53	0.51	0.04	13.78		0.52	1.16		5.3	3.8	-1.5	3.38	0.63	0.13	0.08	4.22	6.17	10.39	6.36
53-75	0.37	0.04	8.81		0.73	0.89		6.4	5.2	-1.2	6.00	0.74	0.16	0.06	6.96	3.83	10.79	6.62
75-94	0.39	0.03	13.93		0.63	0.88		5.8	4.5	-1.3	5.66	0.62	0.13	0.06	6.47	4.23	10.70	6.25
94-125	0.34	0.05	6.54		0.64	0.86		5.5	4.3	-1.2	5.86	0.64	0.15	0.06	6.71	4.22	10.93	6.82
125-152	0.32	0.05	6.04		0.82	0.94		6.0	4.7	-1.3	7.57	0.66	0.20	0.08	8.51	4.29	12.80	8.48
152-185/190	0.31	0.05	5.85		0.88	0.78		7.3	6.0	-1.3	10.13	1.06	0.25	0.08	11.5	3.11	14.65	9.53
185/190-210	0.33	0.05	6.87		0.88	0.67		7.6	6.8	-0.8	23.42	1.27	0.31	0.13	25.13	0.78	25.91	9.15

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Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay				Base Saturation		Available				
				CEC NH_4OAc	CEC NH_4Cl	Ext. iron	15 bar water	Sum Cations	NH_4OAc	P (Bray No.2)	K NH_4OAc pH7.1N			
	←meg/100 g→		meg/100g clay					←Pct→		←PPm→				
0 – 13	4.32	tr	—	0.48	0.49	0.07	0.6[illegible]	55.56	92.59	2	74			
13 – 33	5.33	0.44	25.33	0.34	0.27	0.04	0.49	42.06	67.42	2	59			
33 – 53	4.99	0.59	44.49	0.31	0.24	0.05	0.45	40.62	66.35	2	39			
53 – 75	6.30	tr	—	0.29	0.28	0.04	0.44	64.50	100	2	51			
75 – 94	5.30	tr	—	0.31	0.26	0.04	0.46	60.47	100	2	39			
94 – 125	5.75	tr	—	0.35	0.29	0.04	0.50	61.39	92.30	2	43			
125 – 152	7.59	tr	—	0.32	0.28	0.04	0.45	65.48	100	2	66			
152 – 185 190	9.21	tr	—	0.43	0.42	0.04	0.54	76.77	100	4	94			
185 – 210 190	8.74	tr	—	0.64	0.61	0.05	0.70	96.98	100	15	105			

Depth (cm.)	Mineralogy (X – ray Diffraction)	
	Clay fraction	Silt fraction

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SOIL CLASSIFICATION-

SERIES - - - - - - -SIKHIU (S1)

SOIL NO - - - - - - - S78PN-000-003 COUNTY - - - THAILAND

GENERAL METHODS- - -1A,1B1B,2A1,2B SAMPLE NOS. 78P1727-78P1735

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, NTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

APRIL 1979

DEPTH CM	HORIZON	PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B: SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	SAND VCOS 2-1	SAND COBS 1-.5	SAND MEDS .5-.25	SAND FNES .25-.10	SAND VFNS .10-.05	SILT COSI .05-.02	SILT FNSI .02-.002	SILT VFSI .005-.002	SAND 2-.10	INTR II .2-.02	FINE CLAY TO CLAY PCT	NON-CO3- CLAY PCT	RATIO 8D1 15-BAR TO CLAY
		PCT LT 2MM																
0-13	A1	61.5	25.0	13.5		.7	.4	1.6	25.0	33.8	18.9	6.1		27.7				.37
13-33	B21T	53.2	23.3	23.5		.1	.4	1.4	22.5	28.8	16.3	7.0		24.4				.34
33-53	B21T	51.7	24.4	23.9		.4	.6	1.4	20.0	29.3	15.8	8.6		22.4				.33
53-75	B22T	52.1	24.9	23.0		.4	.5	1.4	21.3	28.5	16.7	8.2		23.6				.36
75-94	B22T	52.1	25.8	22.1		.3	.4	1.3	19.8	30.3	18.0	7.8		21.8				.35
94-125	B23T	51.1	26.3	22.6		.5	.5	1.2	20.7	28.2	18.1	8.2		22.9				.36
125-152	B3T	46.4	25.6	28.0		.9	.4	1.0	16.5	27.6	18.2	7.4		18.8				.35
152-190	B3T	46.4	26.3	27.3		.7	.4	1.1	17.6	26.6	16.8	9.5		19.8				.37
190-210	B3CN	50.0	26.0	24.0		8.9	2.4	1.6	13.5	23.6	16.1	9.9		26.4				.40

DEPTH CM	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2) VOL. GT 2 PCT	WEIGHT GT 75 PCT	75-20	20-5	5-2	LT .074	20-2 PCT LT20	BULK DENSITY 4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	WATER CONTENT 4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	CARBONATE 6E1B LT 2 PCT	3A1A LT .002 PCT	(PH) 8C1A 1/1 H2O	8C1E 1/2 CACL
			(PCT LT 75)															
0-13													5.0				5.9	5.0
13-33													8.0				5.3	4.4
33-53													7.9				5.3	4.4
53-75													8.2				6.8	6.1
75-94													7.7				5.7	5.0
94-125													8.1				5.6	4.9
125-152													9.9				6.1	5.5
152-190													10.1				7.7	7.1
190-210													9.5		3		8.3	7.8

DEPTH CM	(ORGANIC MATTER) 6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	(EXTRACTABLE BASES 5B4A) 6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	ACTY 6H1A BACL TEA G	AL 6G1E KCL EXT	(CAT EXCH) 5A3A EXTB ACTY	5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA 5F1 SAT NHAC PCT	(BASE SAT) 5C3 EXTB ACTY PCT	5C1 NHAC PCT
						(MEQ / 100 G)													
0-13	.56			.9		4.1	.8	TR	.2	5.1	3.0		8.1	6.5	.48	5.1	63	63	78
13-33	.60			1.4		3.9	1.0	.1	.2	5.2	2.9	.7	11.1	8.9	.38	3.9	44	47	58
33-53	.47			1.5		4.0	.7	.1	.1	4.9	5.7	.9	10.6	9.5	.40	5.7	42	46	52
53-75	.31			1.4		7.1	.7	TR	.1	7.9	2.6		10.5	8.3	.36	10.1	86	75	95
75-94	.25			1.4		5.0	.7	.1	.1	5.9	3.4		9.3	6.3	.38	7.1	60	63	71
94-125	.25			1.4		5.4	.6	.1	.1	6.2	3.2		9.4	8.5	.38	9.0	64	66	73
125-152	.25			1.6		7.0	.8	.1	.2	8.9	2.5		11.4	10.6	.39	9.8	74	78	84
152-190	.24			1.4		10.5	.9	.1	.2	11.7	.9		12.6	11.7	.43	11.7	22		
190-210	.21			2.5			1.6	.1	.3		.0			11.9	.50				

DEPTH CM	PH 8C1C KCL	CEC 5A7A NHCL MEQ / 100 G
0-13	4.8	
13-33	4.0	
33-53	4.0	
53-75	5.4	
75-94	4.5	
94-125	4.5	
125-152	4.9	
152-190	6.3	
190-210	7.2	

SAND MINERALOGY (7B1) PLACEMENT: SILICEOUS.
053-075 FNES - RE100 QZ99 OP1 FK VFNS - RE98 QZ96 TM1 ZR1 FK2.
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS OP = OPAQUE QZ = QUARTZ TM = TOURMALINE ZR = ZIRCON FK = POTASSIUM FELDSPA

Micromorphological description of Sikhiu series.

100 cm. depth

The NRDP is plasmi-granic. The grains are medium to fine sand-sized quartz, very angular and heavily fractured; runiquartz is frequent. The plasma within the cracks of the runiquartz is goethitic. The plasma of the s-matrix is reddish brown with a high sesquioxide content. Plasmic fabric is weakly developed skel- insepic, argillasepic.

Illuviation argillans (Fig.13a,b) are thin but strongly oriented; they occupy about 1-2% of the area.

Few, large lateritic nodules with well formed goethite bands are present. These are bright reddish and have sharp boundaries. They are relict features and are indicative that the soil material is of transported origin.

130 cm. depth

S-matrix only differs slightly from the overlying horizon. There appears to be a larger amount of fine sand in this horizon. There is also a higher amount of runiquartz and fragments of laterite. The amount of illuviation argillans is however much less (Fig.13c,d). The plasma shows clear oxic properties. These are indicated by the weak expression of oriented domains, the microaggregation tendency and some goethite droplets.

Interpretation

The soil material is pre-weathered prior to deposition. It has reached the oxic stage of soil formation. The presence of the runiquartz and

the rounded laterite fragments indicate that this is transported material. The weak plasmic fabric and the agglutinic tendency indicate the oxic nature of the soil material.

An argillic horizon is developing in this highly weathered and transported material. Cutans though present are not well expressed.

Compared to Pak Chong series (P1), this soil must be on a much younger surface. It may be safe to suppose that clay illuviation is just commencing. The good orientation and general fabric of the argillans indicate that they are not relict features.

<u>Classificatior</u> : a) Soil Taxonomy.

Rhodic Paleustalfs.

b) FAO/UNESCO

Eutric Nitrosols.

c) French Classification.

Ferralitic.

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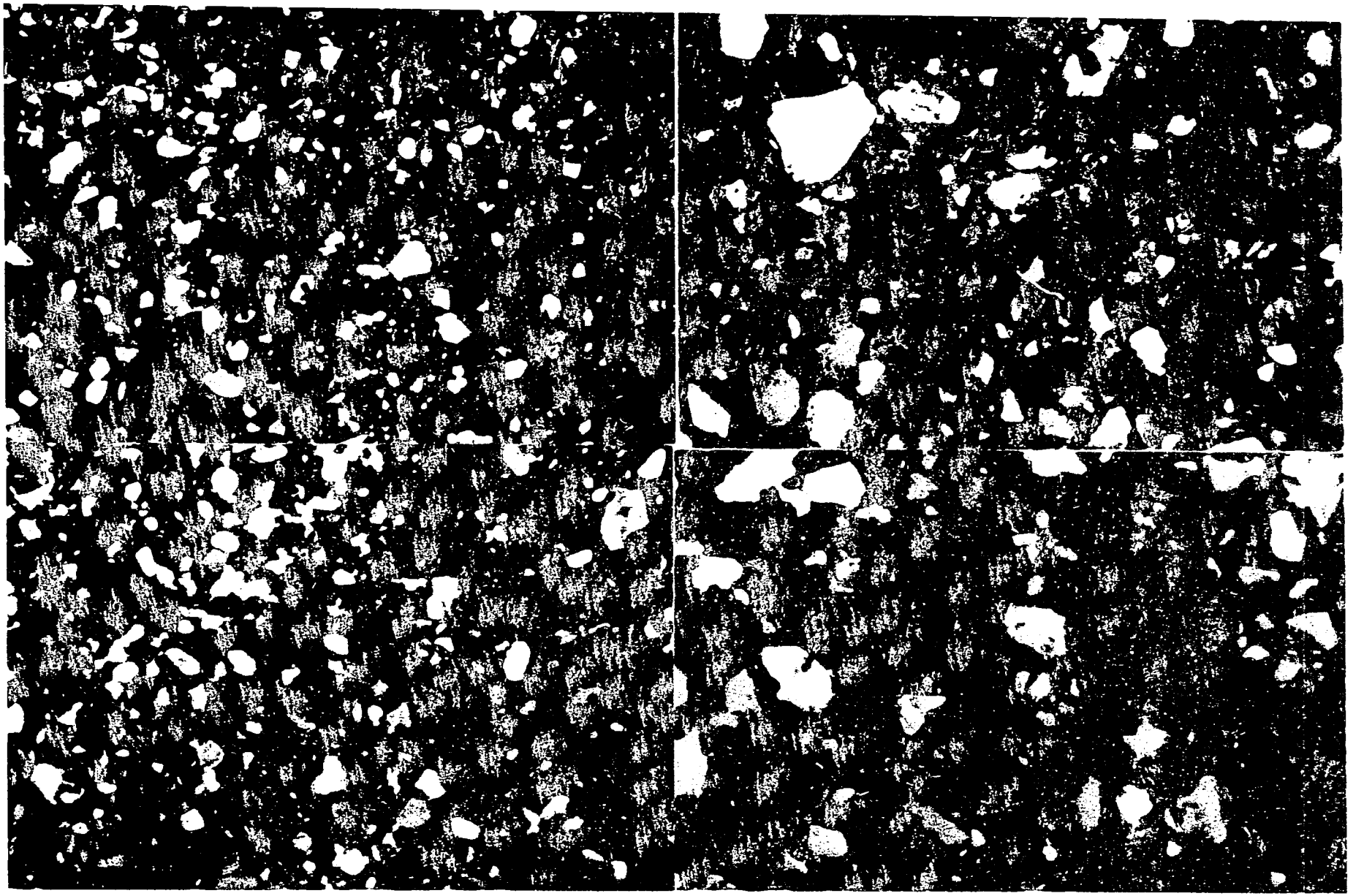
(a) (b)



(c) (d)

Pedon No. 3
Warin series

Location : At km. 4, last side of Korat-Chokchai Rd, Amphoe Muang, Nakhon Ratchasima Province.

Parent material : Old alluvium,

Physiography : Alluvial terrace.

Relief : Undulating. Slope : 2-3%

Elevation : Approx 205 m. Drainage : Well drained.

Climate : "Tropical Savanna", annual rainfall 1181.2 m., mean temperature 26.2 °C.

Vegetation : Cassava (approx yield 18 m. ton/ha), mango, jack fruit.

Limitation effecting plant growth : Low nutrient status, prone to erosion.

Horizon	Depth (cm.)	Horizon Description
Ap	0-18	Dark brown (7.5YR4/2) fine sandy loam; weak fine and medium subangular blocky structure breaking to fine granular structure; slightly hard, friable, slightly sticky, slightly plastic: many very fine and fine roots; common charcoal pieces; medium acid (pH 6.0); abrupt, smooth boundary.
A_2	18-29	Brown (7.5YR5/4) sandy loam; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; few very fine roots; strongly acid (pH 5.5); clear, smooth boundary.

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B_1	29-41	Brown to strong brown (7.5YR5/4 to 7.5 YR5/6) sandy loam; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; patchy thin cutans on ped faces; few very fine roots; common termite holes; very strongly acid (pH 4.5); gradual, smooth boundary.
B_{21t}	41-63	Yellowish red (5YR5/6) sandy loam; moderate medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic, broken thin cutans on ped faces and in pores; few very fine roots; common termite holes; very strongly acid (pH 4.5); gradual, smooth boundary.
B_{22t}	63-110	Yellowish red (5YR5/6) sandy clay loam; moderate medium and coarse subangular blocky thin cutans on ped faces and in pores; few very fine and some decayed coarse roots; common termite holes;very strongly acid (pH 4.5); gradual, smooth boundary.
B23t	110-162	Yellowish red (5YR5/8) sandy clay loam; few fine distinct light gray (10YR7/2) mottles; moderate medium and coarse subangular blocky structure; friable,

		sticky, plastic; broken thin cutans on ped faces and in pores; few very fine and few decayed medium roots; very strongly acid (pH 4.5); gradual; smooth boundary.
B_{3t}	162-210	Red (2.5YR5/6) sandy clay loam; common medium and coarse prominent light gray (10YR7/2) mottles;weak medium and coarse subangular blocky structure; friable, sticky plastic; few very fine and fine

Micromorphological description of Warin series

50 cm. depth

The NRDP is granic. Plasma is very scarce (Fig.14a) and is present mainly associated with grains or as fine aggregates in the intergranular voids. Due to the low amount of plasma, plasmic fabric is not easily discernable The pattern of the association of the plasma to the grains gives the s-matrix some spodic characteristics. This is however accidental and is purely because of the low amount of plasma relative to the grains.

Grains are fine to medium sand-sized quarts. Runiquartz is very abundant (Fig.14a).

Few ($\angle$ 1 %), thin, illuviation argillans are present. They are mainly associated with the grain surfaces. In some of the larger grains, only part of the surface is coated suggesting stripping off of the cutanic material.

100 cm.depth

The s-matrix differs slightly from the overlying horizon. There is much more plasma, giving rise to a plasmi-granic NRDP. Under high magnifications, the plasma is aggregated together to form an agglutinic SRDP. There is also a slightly higher amount of finer-sized grains. Illuviation argillans (Fig.14b), form 2-3% of the area. They are well oriented though thin. The clay increase from the A to the B horizon cannot be attributed to clay translocation alone.

150 cm.depth

The s-matrix (Fig.14c) is similar to the overlying horizon. There is little change in the size and shape of the quartz grains. Illuviation argillans occupy about 1 % of the area. They are similar to the overlying horizon.

SOIL Pedon No.3 : Warin series **LOCATION** Amphoe Muang, Nakhon Ratchasima Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development **LAB. Nos.** 7022 – 7031

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm of whole Soil Pct.	Bulk Density g/cc.		Water Content (Pct.): Water at Saturation	1/3 bar	15 bar	Saturation Percentage	Electrical Cond. mmhos /cm.	
0-18	A_p	67.5	27.4	5.1	0.7	4.5	15.6	32.0	14.7	0.41	1.40		40.81	9.22	3.77	22.4	0.47	
18-29	A_2	65.6	26.6	7.8	0.4	4.6	16.0	29.8	14.8		1.65		40.27	8.36	4.17	22.1	0.25	
29-41	B_1	61.6	26.0	12.4	0.5	4.5	14.6	29.3	12.7		1.58		42.31	8.77	5.29	27.0	0.16	
41-63	B_{21t}	57.6	25.9	16.5	0.6	4.6	13.9	29.6	8.7		1.39		46.03	11.10	7.03	32.2	0.10	
63-85	B_{22t}	54.7	21.4	23.9	0.6	5.4	16.0	25.0	7.7		1.49		53.40	12.16	8.27	32.3	0.08	
85-110	B_{22t}	55.2	24.1	20.7	0.6	4.2	15.7	25.3	9.2				52.40	11.35	7.95	29.4	0.06	
110-135	B_{23t}	54.0	26.2	19.8	0.5	4.2	13.0	24.7	11.6		1.47		52.22	11.10	7.42	29.9	0.08	
135-162	B_{23t}	53.4	27.0	19.6	1.0	5.1	13.6	24.1	9.6				52.53	11.24	8.13	30.6	0.07	
162-195	B_{3t}	52.6	26.0	21.4	1.0	4.7	12.2	24.3	10.4		1.58		53.72	12.02	8.58	40.0	0.06	
195-210	B_{3t}	50.3	27.5	22.2	0.9	3.5	11.1	23.4	11.4				48.06	14.06	9.51	42.3	0.07	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N		Carbonate as $CaCo_3$ (Pct.)	Ext. iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	CEC: NH_4OAc pH7
0-18	0.55	0.04	15.39		0.40	0.73		5.5	5.2	-0.3	2.46	0.73	0.22	0.02	3.43	1.89	5.32	3.10
18-29	0.31	0.03	9.69		0.46	0.69		5.4	4.9	-0.5	1.66	0.73	0.13	0.03	2.57	2.27	4.84	2.92
29-41	0.22	0.03	6.97		0.26	0.58		4.2	3.9	-0.3	0.86	0.67	0.10	0.05	1.68	4.55	6.23	3.41
41-63	0.22	0.02	13.12		0.20	0.38		3.8	3.6	-0.2	0.42	0.88	0.09	0.02	1.41	3.82	5.23	4.33
63-85	0.21	0.02	12.35		0.35	0.50		4.0	3.7	-0.3	0.26	0.90	0.10	0.03	1.29	5.77	7.06	5.19
85-110	0.18	0.02	7.67		0.35	0.77		4.0	3.7	-0.3	0.36	0.90	0.08	0.02	1.34	4.21	5.55	5.77
110-135	0.19	0.04	4.74		0.27	0.48		4.0	3.6	-0.4	0.31	1.32	0.05	0.03	1.71	5.39	7.10	4.54
135-162	0.21	0.01	16.15		0.25	0.65		4.0	3.6	-0.4	0.62	1.38	0.05	0.03	2.08	4.62	6.70	5.20
162-195	0.47	0.03	13.43		0.35	0.53		4.0	3.6	-0.4	1.09	1.27	0.05	0.05	2.46	4.62	7.08	6.36
195-210	0.16	0.04	4.08		0.41	0.52		4.0	3.7	-0.3	2.52	1.65	0.04	0.03	4.24	3.84	8.08	9.32

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Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay: CEC NH_4OAc	Ratio to clay: CEC NH_4Cl	Ratio to clay: Ext. iron	Ratio to clay: 15 bar water	Base Saturation: Sum Cations	Base Saturation: NH_4OAc	Available: P (Bray No.2)	Available: K NH_4OAc pH7.1N			
	←meg/100 g→		meg/100g clay					←Pct→		←PPm→				
0-18	2.87	tr	-	0.81	0.56	0.14	0.74	64.47	100	6	86			
18-29	2.12	tr	-	0.37	0.27	0.09	0.53	53.10	86.01	4	43			
29-41	2.12	0.87	18.95	0.28	0.17	0.05	0.43	26.97	49.27	2	35			
41-63	2.67	1.88	19.94	0.26	0.16	0.02	0.43	26.96	32.56	2	31			
63-85	4.00	2.57	16.15	0.22	0.17	0.02	0.35	18.27	24.86	2	35			
85-110	4.06	2.37	17.92	0.28	0.20	0.04	0.38	24.14	23.22	3	20			
110-135	3.85	2.02	18.84	0.23	0.19	0.02	0.37	24.08	37.67	2	12			
135-162	3.85	2.08	21.22	0.27	0.20	0.04	0.41	31.04	40.00	1	16			
162-195	4.16	1.91	20.42	0.30	0.19	0.02	0.40	34.75	38.68	1	12			
195-210	4.83	0.79	22.68	0.42	0.22	0.02	0.43	52.48	45.49	1	12			

Depth (cm)	Mineralogy (X-ray Diffraction): Clay fraction	Silt fraction
0-18	Kaolinite, possibly trace amount of poor crystallins 14 A° group of clay minerals, appreciable amount of quartz.	Mainly quartz
18-29	Mostly kaolinite; 5-10% rather poor crystalline 14 A° group of clay minerals appreciable content of quartz.	Mainly quartz
29-41	Mostly kaolinite; 5-10% rather poor crystalline 14 A° group of clay minerals, some quartz.	Mainly quartz
41-63	Mostly kaolinite ~5%, montmorillonite; some quartz.	Mainly quartz
63-85		
85-110	Mostly kaolinite; ~5% rather poor crystalline montmorillonite; small amount of quartz.	Mainly quartz
110-135		
135-162	Mostly kaolinite; ~5% rather poor crystalline montmorillonite; small amount of illite, some quartz.	Mainly quartz
162-195		Mainly quartz
195-210	Mostly kaolinite; 5-10% of 14 A° group of clay minerals presumably montmorillonite, some quartz.	Mainly quartz

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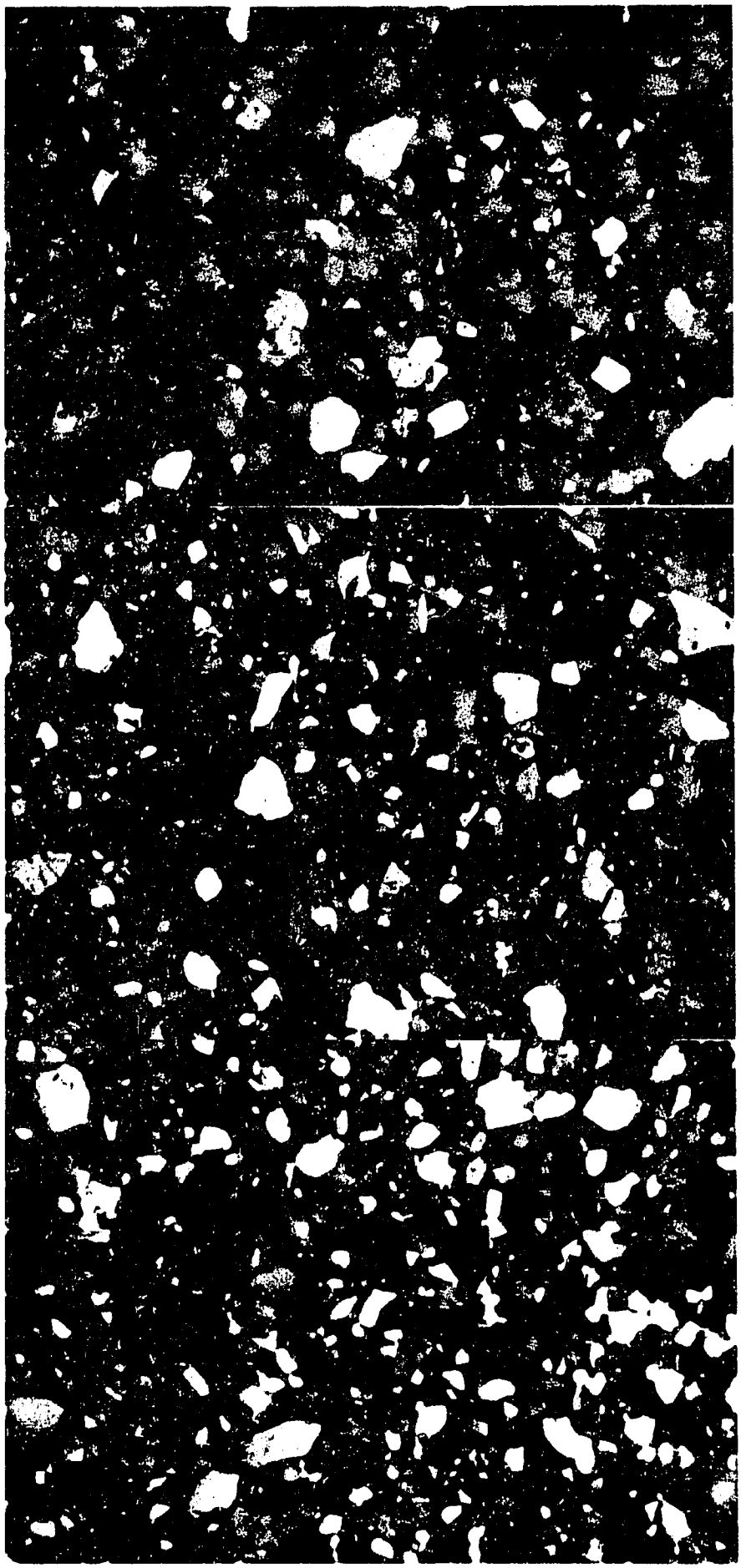

x 40

50 cm depth

(a)

x 40

100 cm depth

(b)

x 40

150 cm depth

(c)

Fig. 14. Warin series.

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Interpretation

The clay increase observed in the profile is not pedogenetic and relicts the depositional conditions. As in the previous profiles (P1, P2) the soil material is pre-weathered.

In this pre-weathered and transported material, present day soil formation results in translocation of some clay leading to formation of an argillic horizon. The amount of identifiable illuviation is small but significant.

This is another example of an argillic horizon formation in an essentially oxic material.

Classification : Typic ? Paleustults.

Comments : Presumably, the definitions of the subgroups of Paleustults are more or less the same as those of Haplustults. This pedon might be a representative profile for Typic Paleustults.

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Pedon No. 4
Khorat series

Location : Near Pa Satharam Temple, about 3 km. South of Nakhon Ratchasima, Amphoe Muang, Nakhon Ratchasima Province.

Parent material : Old alluvium

Physiography : Alluvial terrace.

Relief : Slightly undulating. Slope : West-facing slop of 2.3 percent.

Elevation : Approx. 192 m. Drainage : Well drained.

Climate : "Tropical Savanna", annual rainfall 1181.2 mm, mean temperature 26.2 °C.

Vegetation : Low secondary shrubs; many areas have been used for growing cassava (approx.yield 18.3 m. ton/ha) and kenaf (approx. yield 1.2 m. ton/ha).

Limitations effecting plant growth : Low nutrient status, prone to erosion.

Horizon	Depth (cm.)	Horizon Description
Ap	0-20	Dark grayish brown (10YR4/2) sandy loam; weak medium and coarse subangular blocky structure; friable, slightly sticky, non plastic; many fine roots; strongly acid (pH 5.5); abrupt, smooth boundary.
A_2	20-58	Brown (7.5YR5/4) sandy loam; weak fine subangular blocky structure; friable, non sticky, non plastic; common fine and coarse roots; very strongly acid (pH 5.0); clear, smooth boundary.

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B_{21t}	58-100	Brown (7.5YR5/4) sandy loam; moderate coarse subangular blocky structure; friable, slightly sticky, slightly plastic; few fine and coarse roots; very strongly acid (pH 4.5); gradual, smooth boundary.
B_{22t}	100-134	Brown (7.5YR5/4) sandy loam; few medium and coarse distinct light brownish gray (10YR6/2) mottles; moderate coarse subangular blocky structure; friable, slightly sticky, slightly plastic; few fine and coarse roots; very strongly acid (pH 4.5); gradual, smooth boundary.
B_{23t}	134-180	Brown (7.5YR5/4) sandy loam; many medium and coarse faint light brownish gray (10YR6/2) mottles; few medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; patchy thin cutans on ped faces; very strongly acid (pH 4.5); gradual, smooth boundary.
B_3	180-210	Pinkish gray (7.5YR6/2) sandy loam; many medium distinct strong brown (7.5YR5/6, 5/8) mottles; moderate coarse subangular blocky structure; friable, slightly sticky, slightly plastic; few medium roots;

few medium soft and slightly hard iron-manganese oxide concretions; very strongly acid (pH 4.5).

Micromorphological description of Khorat series

60 cm. depth

The NRDP is granic (Fig.15a). Plasma forms a small fraction of the soil mass, is brownish yellow in colour under plain light and is present as aggregates associated with the grains or in the intergranular voids. Angular quartz in two size classes--fine and medium--are the only kind of grains present. Voids are dominantly intergranular.

Only remnants of argillans, as thin partial coating on a few large quartz grains, are present. Some accumulation of translocated clay had taken place in this layer, but it appears that even this is being stripped out.

Runiquartz is very abundant. Comparison of the nature of the plasma which is reddish within the quartz grains and brownish in the s-matrix, clearly indicates the transported nature of the sediment.

130 cm. depth

The s-matrix is very similar to the previous sample as shown in Fig.15b. Illuviation argillans are minimal. They do not occupy even 1% of the total area.

Interpretation

This pedon presents problems in classification. It is sandy textured and there is a definite increase in clay with depth. Due to the texture, the structure is weak. Some patchy clay skins were observed in the field.

SOIL Pedon No.4 : Khorat series **LOCATION** Amphoe Muang, Nakhon Ratchasima Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development **LAB. Nos.** 6999 – 7007

Depth (cm)	Horizon	Size class and particle diameter (mm) Total Sand (2-0.05)	Total Silt (0.05-0.002)	Total Clay (<0.002)	Sand Very Coarse (2-1)	Sand Coarse (1-0.5)	Sand Medium (0.5-0.25)	Sand Fine (0.25-0.1)	Sand Very fine (0.1-0.05)	Coarse fragments >2 mm of whole Soil Pct.	Bulk Density g/cc.		Water Content Water at Saturation (Pct.)	Water Content 1/3 bar (Pct.)	Water Content 15 bar (Pct.)	Saturation Percentage	Electrical Cond. mmhos/cm.	
0–20	A_p	67.4	25.6	7.0	0.2	4.2	17.8	31.5	13.7		1.47		42.26	6.59	3.43	21.1	0.36	
20–38	A_2	75.4	20.6	4.0	0.6	12.0	6.2	44.0	12.6		1.52		47.18	7.49	2.01	22.3	0.09	
38–58	A_2	69.7	25.0	5.3	0.1	1.1	7.2	30.2	31.1				41.64	4.65	2.10	22.9	0.10	
58–76	B_{21t}	68.1	14.3	17.6	0.1	2.0	8.8	29.7	27.5		1.58		45.29	5.60	2.52	22.7	0.07	
76–100	B_{21t}	63.2	23.5	13.3	0.6	5.0	14.7	30.1	12.8				57.53	8.02	4.63	25.0	0.10	
100–134	B_{22t}	62.8	24.2	13.0	0.2	3.9	16.2	32.9	9.6		1.55		55.20	9.31	4.68	19.4	0.07	
134–155	B_{23t}	61.9	24.9	13.2	0.2	4.7	16.1	29.3	11.6		1.66		55.38	7.67	4.91	25.5	0.07	
155–180	B_{23t}	62.4	26.4	11.2	0.4	4.9	15.3	28.7	13.1				43.27	10.29	5.13	24.5	0.09	
180–210	B_3	60.8	26.3	12.9	0.4	4.0	14.7	29.5	12.2		1.59		43.46	10.48	5.03	23.9	0.08	

Depth (cm)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N	Carbonate as $CaCo_3$ (Pct.)	Ext. iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases Ca (meq/100 g)	Mg	K	Na	Sum of bases	Extract. Acidity	CEC Sum Cations	CEC NH_4OAc pH7
0–20	0.55	0.04	13.44	0.51	0.07		4.6	3.8	−0.8	1.10	0.67	0.06	0.02	1.85	2.63	4.48	2.28
20–38	0.15	0.01	18.87	0.51	0.11		4.6	3.6	−1.0	0.11	0.05	0.03	0.02	0.21	2.63	2.84	1.38
38–58	0.11	0.02	6.47	0.49	0.65		4.3	3.6	−0.7	0.07	0.13	0.02	0.02	0.24	2.63	2.87	1.10
58–76	0.18	0.01	15.08	0.57	0.10		4.3	3.7	−0.6	0.06	0.10	0.02	0.03	0.21	3.02	3.23	1.41
76–100	0.15	0.03	6.08	0.43	0.12		4.1	3.4	−0.7	0.09	0.32	0.02	0.03	0.47	3.43	3.90	2.62
100–134	0.13	0.02	7.76	0.45	0.09		4.2	3.4	−0.8	0.10	0.44	0.03	0.03	0.60	3.81	4.41	3.03
134–155	0.15	0.03	6.08	0.52	0.13		4.1	3.4	−0.7	0.09	0.48	0.03	0.03	0.63	4.56	5.19	3.01
155–180	0.13	0.02	7.76	0.58	0.17		4.0	3.3	−0.7	0.10	0.60	0.03	0.03	0.76	3.80	4.56	2.92
180–210	0.11	0.05	2.12	0.64	0.15		4.0	3.3	−0.7	0.18	0.70	0.03	0.03	0.94	4.17	5.11	3.55

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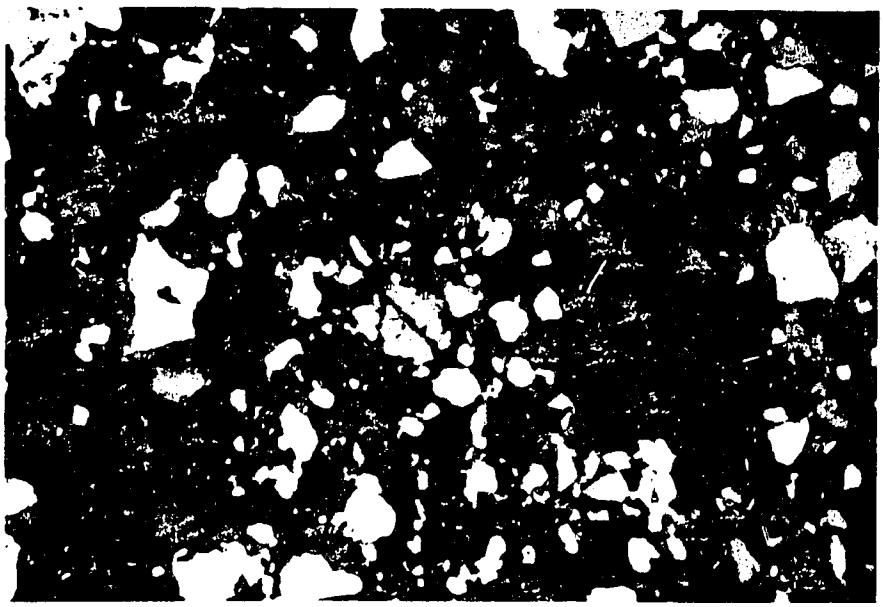
Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay: CEC NH_4OAc	Ratio to clay: CEC NH_4Cl	Ratio to clay: Ext. iron	Ratio to clay: 15 bar water	Base Saturation: Sum Cations	Base Saturation: NH_4OAc	Available: P (Bray No2)	Available: K NH_4OAc pH7.1N			
	←meg/100 g→		meg/100g clay					←Pct→		←PPm→				
0–20	1.65	0.25	30.00	0.33	0.24	0.01	0.49	41.29	81.14	5	16			
20–38	0.86	0.59	20.00	0.34	0.22	0.03	0.50	7.39	15.44	2	4			
38–58	0.94	0.68	17.36	0.21	0.18	0.12	0.40	8.36	21.82	3	4			
58–76	1.38	1.02	6.99	0.08	0.08	0.01	0.14	6.50	14.89	2	8			
76–100	2.38	1.84	17.37	0.20	0.18	0.01	0.35	12.05	17.04	1	8			
100–134	2.47	1.81	18.54	0.23	0.19	0.01	0.36	13.61	19.80	2	4			
134–155	2.69	1.80	18.41	0.23	0.20	0.01	0.37	12.14	20.93	1	4			
155–180	2.60	1.80	22.86	0.26	0.23	0.02	0.46	16.67	26.03	2	8			
180–210	2.76	1.57	19.46	0.28	0.21	0.01	0.39	18.40	26.48	1	8			

Depth (cm)	Mineralogy (X-ray Diffraction): Clay fraction	Silt fraction
0–20		
20–38	Kaolinite, 5-10% rather poor crystalline montmorillonite, some quartz	Mainly quartz
38–58	Kaolinite 5-10% rather poor crystalline montmorillonite, some quartz	Mainly quartz
58–76	Kaolinite 5-10% rather poor crystalline montmorillonite, some quartz	Mainly quartz
76–100		
100–134	Kaolinite, 5-10% poor crystalline 14 A group of clay mineral presumable montmorillonite some quartz	Mainly quartz
134–155	Kaolinite, 5-10% poor crystalline montmorillonite, some quartz	Mainly quartz
155–180		
180–210	Kaolinite, 5-15% poor crystalline montmorillonite some quartz.	Mainly quartz

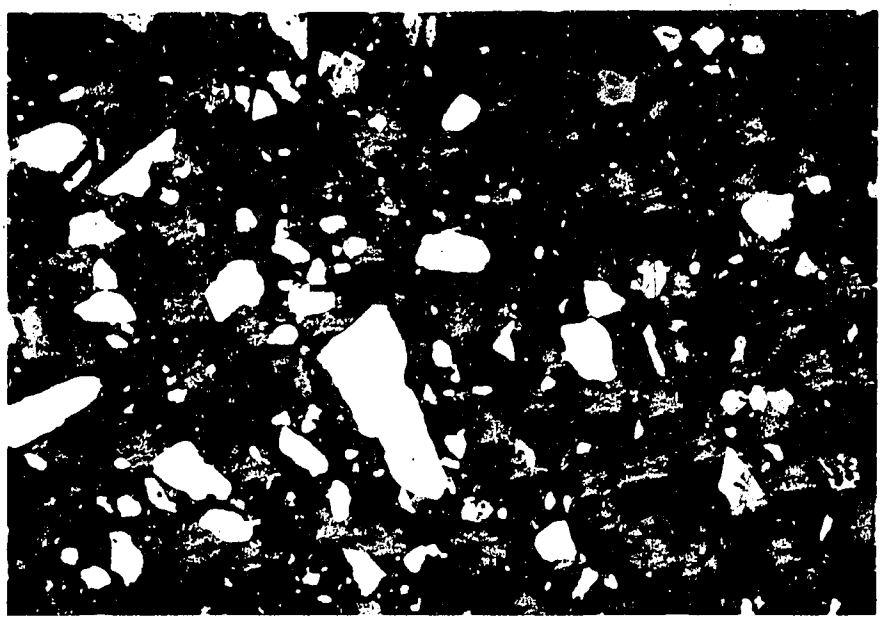
6-31



x 40

60 cm depth

(a)



x 40

130 cm depth

(b)

Fig. 15. Khorat series.

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The micromorphological study, however, indicates that clay translocation and accumulation is an insignificant process, either in the past or current. There are no weatherable minerals and the nature of the plasmic fabric and other micromorphological features indicates that the subsoil is oxic.

Based on the micromorphology, the soil is classified as a Haplustox. From the use point of view, an Ultic subgroup would be appropriate but due to the nature of the definition of this subgroup, it cannot be classified as such. Consequently, it is proposed that the definition of the Ultic subgroup be modified to include all soils which show the necessary clay increase for an argillic horizon.

The pedon also grades from Quartzipsamments. The following classification is proposed for discussion.

Ultic Quartzipsammentic Haplustox.

<u>Classification</u> : Ustoxic Dystropepts.

<u>Comments</u> : Most parts of the subsoil have a fine earth fraction that retained $\neg$ 10 meq. NH_4^+ per 100 g. clay and have apparent cation-exchange capacity of $\neg$ 16 meq. per 100 g clay. Hence, they can not fit in oxic horizon although the micromorphological features indicates that the subsoil is oxic.

<u>Classification</u>

a) Soil Taxonomy.

Oxic Paleustuults.

b) FAO/UNESCO

Dystic Netosol

c) French Classification.

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Pedon No. 5
Yasothon series

Location : About 400 m. East of Khorat-Dejudom Rd. (at km.7th)
Amphoe Muang, Nakhon Ratchasima Province.

Parent material : Old alluvium

Physiography : Alluvial terrace.

Relief : Nearly flat Slope : 1 percent.

Elevation : Approx. 200 m. Drainage : Well drained.

Climate Type : "Tropical Savanna"; annual rainfall 1181.2 mm, mean temperature 26.2 °C.

Vegetation : Cassava (approx. yield 13.83 m. ton/ha).

Limitations effecting plant growth : Low nutrient status, prone to erosion.

Horizon	Depth (cm)	Horizon Description
A_1	0-14	Dark brown (7.5YR3/2) loamy sand; dark reddish brown (10YR4/2) dry; weak medium and coarse subangular blocky structure; soft, very friable, non sticky, non plastic; many fine and common coarse roots; medium acid (pH 6.0); clear, smooth boundary.
A_3	14-34	Reddish brown (5YR4/4) sandy loam, yellowish red (5YR4/6) dry; weak medium and coarse subangular blocky structure; soft, very friable, non sticky, non plastic; many fine and medium roots; strongly acid

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		(pH 5.5); gradual, smooth boundary.
B_1	34-62	Red (2.5YR4/8) sandy loam, yellowish red (5YR5/6-8) dry; weak medium and coarse subangular blocky structure; slightly hard, very friable, nonsticky, nonplastic; many fine medium and few coarse roots; strongly acid (pH 5.5); gradual, smooth boundary.
B_{21t}	62-115	Red (10R4/8) sandy loam, red (2.5YR4/8) dry; moderate medium and coarse subangular blocky structure; slightly hard, very friable, slightly sticky, slightly plastic; patchy thin cutans on ped faces; common fine and medium roots; very strongly acid (pH 4.5); diffuse, smooth boundary.
B_{22t}	115-200	Red (10R4/8) sandy loam, red (2.5YR4/8) dry; moderate medium and coarse subangular blocky structure; slightly hard, very friable, slightly sticky, slightly plastic; patchy thin cutans on ped faces; few fine roots; very strongly acid (pH 5.0).

Remark : Colors are for fully moist soil unless otherwise stated.

SOIL Pedon No.5: Yasothon series **LOCATION** Amphoe Muang, Nakhon Ratchasima Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development **LAB. Nos.** 6958 – 6965

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2 0 05)	Silt (0 05 0 002)	Clay (0 002)	Sand: Very Coarse (2 1)	Coarse (1 0 5)	Medium (0 5 0 25)	Fine (0 25 0 1)	Very fine (0 1 0 05)	Coarse fragments >2 mm of whole Soil Pct.	Bulk Density g/cc.		Water Content (Pct.): Water at Saturation	1/3 bar	15 bar	Saturation Percentage	Electrical Cond. mmhos/cm.	
0-14	A_1	76 6	20 9	2 5	0 5	5 0	19.0	32 7	19 4		1 46		35.69	6.27	2.60	21.7	0 04	
14-34	A_3	74 4	18 3	7 3	0 7	5 7	20 5	32 3	15 2		1 49		39 51	4 42	2 82	22 9	0 13	
34-62	B_1	73 4	20 1	6.5	0 5	4 9	17.2	38 1	12.7		1 55		36 97	4 85	2 88	20 7	0 13	
62-85	B_{21t}	67 7	16 8	15.5	1.2	6.2	19 2	34.4	6.7		1.46		42 58	8.00	6.57	28.7	0 09	
85-115		64 8	16 3	18.9	0.7	5.3	17.1	30.5	11 2				47.05	9.42	11.21	32.3	0.05	
115-150	B_{22t}	65 4	21.3	13.3	1.1	5.1	17.4	34 2	7 6		1.64		34 88	8 09	5.21	26.6	0.05	
150-175		65.8	21 3	13.1	0.7	4.6	16.2	32.7	11.4				42.26	7.89	4.85	24.8	0.06	
175-200		65 4	21.3	13.3	1.0	5.2	19.3	33.0	6 0				35 46	7.21	4.99	20.5	0.04	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N		Carbonate as $CaCo_3$ (Pct.)	Ext iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract Acidity	CEC: Sum Cations	CEC: NH_4OAc pH7
0-14	0.64	0 03	20 06		0 40	0.22		5 8	5 6	-0 2	1 15	0.43	0 19	0 03	1 80	2 26	4,06	1 80
14-34	0.42	0.02	19 09		0 38	0.31		4.1	4.0	-0 1	0 27	0 32	0.03	0,03	0.65	3,76	4,41	1.26
34-62	0 29	0 03	9 09		0 34	0 33		4,3	3 9	-0.4	0 27	0.32	0.03	0 03	0.65	3,01	3 66	1 18
62-85	0.29	0 03	9 12		0 38	0 70		4 1	3.9	-0 2	0.21	0.53	0 03	0 03	0 80	4 15	4 95	2.12
85-115	0 20	0 05	4.39		0 34	0 76		4.1	3 8	-0.3	0 21	0.43	0 02	0 01	0 67	3 78	4 45	2.05
115-150	0 18	0.02	10 65		0 38	0 59		4 1	4.0	-0.1	0 56	0 40	0 02	0 01	0.99	3 40	4 39	1.57
150-175	0 18	0 06	3 02		0 42	0 61		4 1	4 0	-0 1	0 32	0.43	0.03	0 03	0.81	2 26	3 07	1 34
175-200	0.15	0.01	18 07		0 44	0 59		4 1	4 0	-0 1	0.34	0 35	0 03	0.03	0.75	3 77	4 52	1 57

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Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay: CEC NH_4OAc	Ratio to clay: CEC NH_4Cl	Ratio to clay: Ext. iron	Ratio to clay: 15 bar water	Base Saturation: Sum Cations	Base Saturation: NH_4OAc	Available: P (Bray No2)	Available: K NH_4OAc pH7.1N
	←meq / 100 g→		meq/100g clay					←Pct→		←ppm→	
0–14	1.57	tr	—	0.72	0.63	0.09	1.04	44.33	100.00	7	59
14–34	0.86	0.28	12.74	0.17	0.12	0.04	0.39	14.74	51.59	3	12
34–62	0.78	0.22	11.38	0.18	0.12	0.05	0.44	17.76	55.08	2	8
62–85	1.38	0.61	4.45	0.14	0.09	0.05	0.42	16.16	37.74	2	8
85–115	1.57	0.78	7.67	0.11	0.08	0.04	0.59	15.06	32.68	2	8
115–150	1.37	0.67	12.48	0.12	0.10	0.04	0.39	22.55	63.06	1	8
150–175	0.98	0.52	10.15	0.10	0.07	0.05	0.37	26.38	60.45	2	[illegible]
175–200	1.77	0.52	9.55	0.12	0.13	0.04	0.39	16.59	47.77	1	4

Depth (cm)	Mineralogy (X-ray Diffraction): Clay fraction	Silt fraction
0–14	Kaolinite, x-ray amorphous	
14–34		
34–62	Kaolinite x-ray amorphous	
62–85		
85–115	Kaolinite x-ray amorphous	
115–150		
150–175		
175–200		

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SOIL CLASSIFICATION-
SERIES - - - - - - - -YASOTHON (YT)
SOIL NO - - - - - - - S78FN-000-005 COUNTY - - - THAILAND
GENERAL METHODS- - -1A,1B1B,2A1,2B SAMPLE NOS. 78P1742-78P1749

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, MTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

APRIL 1979

DEPTH CM	HORIZON	SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	SAND 2-.10	INTR II .2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	RATIO 8D1 15-BAR TO CLAY
		(- - - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - - - PCT LT 2MM - - -)				(- - SAND - -)					(- -SILT- - -)							
0-14	A1	80.6	14.9	4.5		1.0	8.3	15.9	38.4	17.0	12.1	2.8		63.6				.42
14-34	A3	78.5	15.4	6.1		1.2	8.1	15.1	36.3	17.8	12.2	3.2		60.7				.38
34-62	B1	78.5	13.8	7.7		1.1	8.2	15.6	36.8	16.8	11.0	2.8		61.7				
62-85	B21T	71.9	12.3	15.8		1.9	9.1	14.5	33.1	13.3	11.1	1.2		58.6				.32
85-115	B21T	69.7	11.7	18.6		2.0	8.6	14.4	30.3	14.4	10.1	1.6		55.3				.30
115-150	B21T	70.8	14.3	14.9		1.9	7.9	13.9	33.2	13.9	12.7	1.6		56.9				.32
150-175	B22T	72.7	13.2	14.1		2.5	8.7	14.7	31.8	15.0	10.8	2.4		57.7				.31
175-200	B22T	71.7	13.8	14.5		1.6	9.0	14.6	32.9	13.6	11.8	2.0		58.1				.32

DEPTH CM	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2) VOL. GT 2 PCT	WEIGHT GT 75 PCT	75-20	20-5	5-2	LT .074	20-2 PCT LT20	(BULK DENSITY) 4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	(WATER CONTENT) 4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	CARBONATE 6E1B LT 2 PCT	3A1A LT .002 PCT	(PH) 8C1A 1/1 H2O	8C1E 1/2 CACL
			(- - - PCT LT 75 - - -)															
0-14													1.9				6.2	5.6
14-34													2.3				4.8	4.1
34-62																	4.9	4.3
62-85													5.0				4.7	4.0
85-115													5.5				4.7	4.0
115-150													4.8				4.8	4.1
150-175													4.4				4.9	4.2
175-200													4.7				4.9	4.2

DEPTH CM	(ORGANIC MATTER) 6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	(EXTRACTABLE BASES 5B4A) 6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	ACTY 6H1A BACL TEA	AL 6G1E KCL EXT	(CAT EXCH) 5A3A EXTB ACTY	5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA SAT NHAC PCT	(BASE SAT) 5C3 EXTB ACTY PCT	5C1 NHAC PCT
						(- - - MEQ / 100 G - - -)													
0-14	.55			.3		1.4	.6	TR	.2	2.2	1.2		3.4	2.3	.51	2.3	61	65	96
14-34	.29			.4		.2	.3	TR	.0	.5	1.9	.3	2.4	1.8	.30	.7	11	21	28
34-62	.18			.4		.2	.3	TR	.0	.5	1.4	.2	1.9	1.4	.18	.7	14	26	36
62-85	.17			.8		.2	.6	TR	.0	.8	2.7	1.0	3.5	2.7	.17	.3	7	23	30
85-115	.13			1.0		.1	.5	.0	.0	.6	3.0	1.2	3.6	2.8	.15	.2	4	17	21
115-150	.09			.8		.1	.4	.0	.0	.5	2.4	.9	2.9	2.2	.15	.3	5	17	23
150-175	.08			.7		.2	.4	TR	.0	.6	1.9	.5	2.5	2.2	.16	.5	9	24	27
175-200	.07			.7		.2	.4	TR	.0	.6	2.0	.5	2.6	2.1	.14	.5	10	23	29

DEPTH CM	PH 8C1C KCL	CEC 5A7A NHCL MEQ / 100 G
0-14	5.5	1.8
14-34	4.0	
34-62	4.1	
62-85	3.8	
85-115	3.9	2.0
115-150	3.9	
150-175	4.0	1.4
175-200	4.0	

SAND MINERALOGY (7B1) PLACEMENT: SILICEOUS.
052-085 FNES - RE99 QZ98 OP2 VFNS - RE99 QZ98 ZR TM FK.
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS OP = OPAQUE QZ = QUARTZ TM = TOURMALINE FK = POTASSIUM FELDSPAR.

Micromorphological description of Yasothon series

50 cm. depth

The NRDP is granic. Plasma forms about 10% of the s-matrix. The grains are fine to medium sand-sized quartz and angular to sub-rounded (Fig.16a). Fig.17a taken with plain light shows the distribution of the plasma with respect to the grains. The brownish yellow plasma is aggregated and clusters of these aggregates are present sticking to the quartz grains as in spodic horizons.

Traces of illuviation argillans are present, mainly adhering to the cracks and notches of the larger quartz grains. These are remnants of cutans and indicate that the layer is a former argillic undergoing degradation.

100 cm. depth

The NRDP of the horizon is plasmi-granic. Plasma occupies about 20-25% of the area and 50-60% of this plasma is composed of illuviation argillans. Fig.17a and 17b, show the nature of the s-matrix under plain and polarized light, respectively. Under both kinds of illumination, the nature of the cutans and identification of the cutanic material are very clear. The plain light micrograph shows the smooth homogenous nature of the argillan as compared to the aggregated habit of the plasma of the s-matrix. Fig.17c, d are higher magnifications showing the composition of the argillan. The dark extinction lines traversing the cutanic materials show that it is very well oriented.

The plasmic fabric is essentially argillasepic. One of the reasons for this is the aggregation of the plasma. Except for a few, fine, lateritic nodules, there are no other pedological features.

150 cm.depth

The NRDP of this horizon is granic with a distinct decrease in plasma as compared to the overlying horizon. The grains are more angular and fragmented (Fig.16b). Comparison of the size and shape of the grains suggests a discontinuity at this level.

Illuviation argillans occupy about 2% of the area. They are mostly associated with quartz grains--free grain argillans--and are especially located on the notches (Fig.16b). The micromorphology indicates that this is a B_3 horizon.

Interpretation

This is perhaps the model profile of a soil with an argillic horizon. About 50-60% of the clay in the B_{2t} horizon has accumulated there by vertical translocation from the overlying horizons. This is one of the few profiles that I have seen where the clay increase is due largely to accumulation by translocation. The loamy parent material and the ustic soil moisture regimes are contributory factors.

The sample at 150 cm. shows both a decrease in plasma and argillans. In the field, the pedon was classified as an Arenic Paleustult. The micromorphological study indicates that the pedon may be more appropriately classified as Arenic Haplustult.

Classification : Typic Rhodustults.

Comments :

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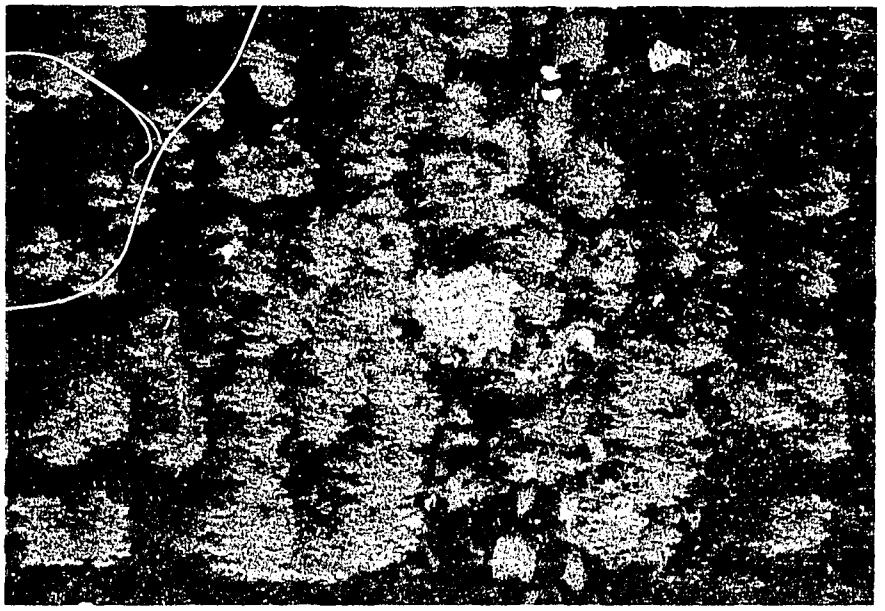

x 40

Plain Light

50 cm depth

(a)

x 40

150 cm depth

(b)

Fig. 16. Yasothon series.

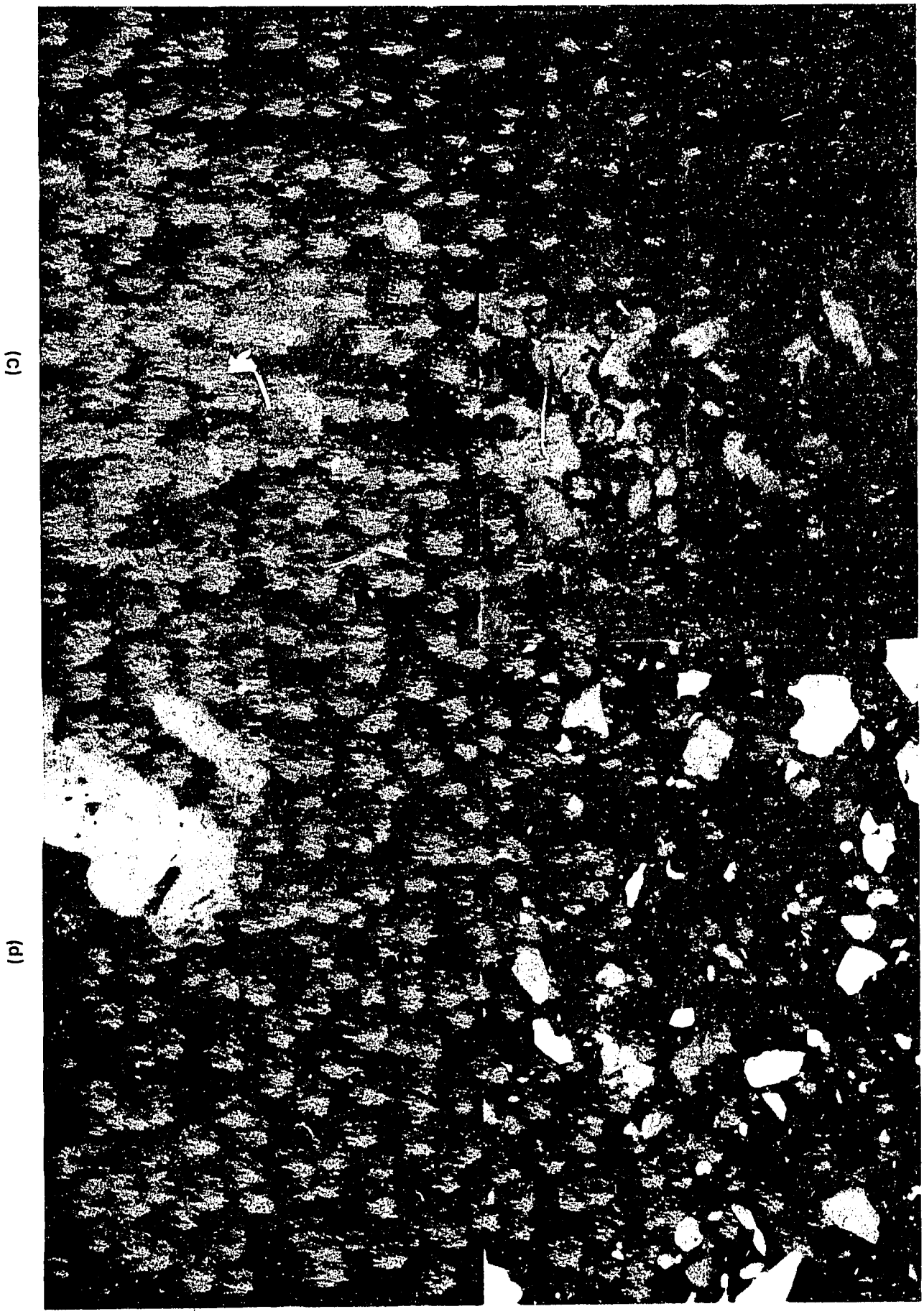

Fig. 17. Yasothon series at 100 cm. depth.

Pedon No. 6
Chok Chai series

Location : About 30 m. South of Chok Chai-Dejudom Rd. (at km.18.5) Amphoe Chok Chai, Nakhon Ratchasima Province.

Parent material : Tertiary basalt.

Physiography : Lava plain. Slope : Southeast-facing slope of 2-3 percent.

Relief : Undulating.

Elevation : Approx. 260 m. Drainage : Well drained.

Climate : "Tropical Savanna", annual rainfall 1181.2 mm. , mean temperature 26.2 °C.

Vegetation : Bamboo, kapok and low secondary shrubs; many areas are used for upland crop such as cassava (approx. yield 20.37 m. ton/ha) and corn (1.8 m. ton/ha).

Limitations effecting plant growth : Low nutrient status.

Horizon	Depth (cm.)	Horizon Description
A_1	0-10/14	Dark reddish brown (2.5YR3/4) clay; moderate coarse subangular blocky, and moderate fine and medium granular structure; slightly hard, firm, sticky, plastic; many very fine and fine roots; medium acid (pH 6.0); clear, wavy boundary.
B_{21t}	14/10-36	Dark red (10YR3/6) clay; moderate coarse subangular blocky structure; slightly hard, friable, sticky, plastic; moderately thick cutans on ped faces; common very fine and few fine roots; strongly acid

		(pH 5.5); gradual, smooth boundary.
B_{22t}	36-86	Dark red (10YR3/6) clay; weak coarse subangular blocky breaking to moderate medium and fine subangular blocky structure; slightly hard, friable, slightly sticky, slightly plastic; shining surface on ped faces; many fine and few coarse roots; very strongly acid (pH 5.5); gradual, smooth boundary.
B_{23t}	86-156	Dark red (10R3/6) clay; weak coarse subangular blocky breaking to moderate fine and medium subangular blocky structure; slightly hard, friable, slightly sticky, slightly plastic; patchy thin cutans on ped faces; few fine rounded ironstone concretions; few fine and coarse roots; very strongly acid (pH 5.0); gradual, smooth boundary.
B_{24t}	156-220	Dark red (10R3/6) clay; weak fine and medium subangular blocky structure; very friable, slightly sticky, slightly plastic; patchy thin cutans on ped faces; few fine and medium roots; very strongly acid (pH 5.0).

SOIL Pedon No. 6 : Chok Chai series **LOCATION** Amphoe Chok Chai, Nakhon Ratchasima Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development **LAB. Nos.** 6972 – 6979

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm of whole Soil Pct.	Bulk Density g/cc.		Water Content (Pct.): Water at Saturation	1/3 bar	15 bar	Saturation Percentage	Electrical Cond. mmhos/cm.	
0-10/14	A_1	22.9	25.8	51.3						0.31	1.01		59.4	21.68	17.63	43.5	0.14	
10/14-36	B_{21t}	17.0	20.4	61.7						0.24	1.07		60.23	24.58	19.29	49.2	0.00	
36-60	B_{22t}	15.8	24.4	59.8						0.47	1.17		74.34	23.30	19.13	53.2	0.03	
60-86		18.2	19.2	62.6									65.43	23.28	18.89	56.3	0.0	
86-120	B_{23t}	15.4	23.0	61.6						1.02	1.20		67.41	24.76	18.00	50.4	0.03	
120-156		16.1	20.6	63.3									67.13	23.63	18.45	56.1	0.07	
156-185	B_{24t}	17.4	23.8	58.8						0.84	1.17		60.24	23.42	18.23	51.0	0.03	
185-220		16.9	23.2	59.9									61.09	21.04	18.18	53.6	0.03	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N		Carbonate as $CaCo_3$ (Pct.)	Ext. Iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	CEC: NH_4OAc pH7
0-10/14	1.45	0.10	14.50		0.67	3.01		4.4	4.3	-0.1	2.31	1.60	0.18	0.04	4.13	9.48	13.61	8.20
10/14-36	0.62	0.11	5.75		0.57	2.98		4.2	3.9	-0.3	0.97	0.73	0.10	0.04	1.84	9.30	11.14	5.83
36-60	0.42	0.11	3.78		0.47	2.93		3.9	3.8	-0.1	0.47	0.41	0.08	0.04	0.98	9.62	10.60	5.73
60-86	0.28	0.03	7.65		0.47	2.68		3.8	3.7	-0.1	0.44	0.53	0.08	0.04	1.07	9.70	10.77	4.94
86-120	0.16	tr	—		0.55	3.04		3.8	3.7	-0.1	0.30	0.36	0.06	0.04	0.76	8.05	8.81	4.67
120-156	0.14	0.04	4.00		0.44	2.73		3.9	3.8	-0.1	0.30	0.29	0.06	0.03	0.68	8.29	8.97	4.71
156-185	0.26	0.02	10.83		0.46	2.75		3.9	3.9	-0.0	0.23	0.16	0.06	0.06	0.51	9.06	9.57	5.03
185-220	0.14	0.02	5.83		0.46	3.56		4.1	3.9	-0.2	0.23	0.16	0.08	0.03	0.48	8.15	8.63	4.73

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Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay				Base Saturation		Available				
				CEC NH_4OAc	CEC NH_4Cl	Ext. iron	15 bar water	Sum Cations	NH_4OAc	P (Bray No.2)	K NH_4OAc pH7.1N			
	←meg/100 g→		meg/100g clay					←Pct→		←ppm→				
0 –10/14	5.16	0.12	8.28	0.16	0.10	0.06	0.34	30.35	53.37	5	5			
10/14–36	3.94	0.15	3.22	0.10	0.06	0.05	0.31	16.52	31.55	2	23			
36 – 60	3.59	1.70	4.48	0.10	0.06	0.05	0.31	9.25	17.10	2	12			
60 – 86	3.55	1.67	4.38	0.08	0.06	0.04	0.31	9.93	21.66	2	12			
86 – 120	3.29	1.71	4.01	0.08	0.05	0.05	0.31	8.63	16.27	1	16			
120 – 156	3.23	1.88	4.04	0.08	0.05	0.04	0.29	7.58	14.44	1	12			
156 – 185	3.30	1.95	4.18	0.08	0.06	0.05	0.31	5.33	10.14	1	12			
185 – 220	3.33	1.68	3.61	0.08	0.06	0.06	0.30	5.56	10.15	1	16			

Depth (cm.)	Mineralogy (X – ray Diffraction)	
	Clay fraction	Silt fraction
0 – 10/14	Kaolinite, x–ray amorphous	
10/14 – 36		
36 – 60	Kaolinite, x–ray amorphous	
60 – 86		
86 – 120	Kaolinite, x–ray amorphous	
120 – 156		
156 – 185		
185 – 220		

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SOIL CLASSIFICATION-
SERIES - - - - - - - -CHOK CHAI (CI)
SOIL NO - - - - - - - S78FN-000-007 COUNTY - - - THAILAND
GENERAL METHODS- - -1A,1B1B,2A1,2B SAMPLE NOS. 78P1756-78P1763

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, MTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

APRIL 1979

DEPTH CM	HORIZON	SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	VCOS 2-1	COS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	SAND 2-.10	INTR II 2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	RATIO 8D1 15-BAR TO CLAY
		(- - - - - - - - - - - - - - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - - - - - - - - - - - - - PCT LT 2MM)																
0-14	A1	26.9	16.3	56.8		1.2	1.3	2.6	9.9	11.9	10.0	6.3		15.0				.26
14-36	B21T	19.6	10.7	69.7		1.0	1.0	1.9	7.3	8.4	9.4	1.3		11.2				.25
36-60	B22T	21.2	11.9	66.9		3.6	1.2	1.6	6.7	8.1	8.6	3.3		13.1				.26
60-86	B22T	19.0	12.1	68.9		.8	.7	1.5	7.3	8.7	7.9	4.2		10.3				.26
86-120	B23T	19.1	12.2	68.7		1.2	1.2	1.6	6.4	8.7	8.1	4.1		10.4				.25
120-156	B23T	19.3	10.9	69.8		1.6	1.1	1.6	6.8	8.2	8.8	2.1		11.1				.25
156-185	B3	20.2	12.3	67.5		1.8	1.3	1.7	6.6	8.8	7.7	4.6		11.4				.25
185-220	B3	18.9	13.2	67.9		1.2	.8	1.4	6.6	8.9	7.0	6.2		10.0				.25

DEPTH CM	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2) VOL. GT 2 PCT	WEIGHT GT 75 PCT	75-20	20-5	5-2	LT .074	20-2 PCT LT20	(BULK DENSITY) 4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	(WATER CONTENT) 4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	CARBONATE 6E1B LT 2 PCT	3A1A LT .002 PCT	(PH) 8C1A 1/1 H2O	8C1B 1/2 CACL
			(- - - PCT LT 75 - - -)															
0-14													15.0				5.4	4.7
14-36													17.2				4.8	4.1
36-60													17.1				4.8	4.1
60-86													17.6				4.8	4.1
86-120													17.2				4.9	4.1
120-156													17.3				4.9	4.1
156-185													17.0				4.9	4.1
185-220													17.3				4.8	4.1

DEPTH CM	(ORGANIC MATTER) 6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	(EXTRACTABLE BASES 5B4A) 6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	ACTY 6H1A BACL TEA	AL 6G1E KCL EXT	(CAT EXCH) 5A3A EXTB ACTY	5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA 5P1 SAT NHAC PCT	(BASE SAT) 5C3 EXTB ACTY PCT	5C1 NHAC PCT
						(- - - - - - - - - - - MEQ / 100 G - - - - - - - - - - -)													
0-14	1.18			6.0		3.2	1.7	TR	.1	5.0	8.7	.2	13.7	9.9	.17	1.9	32	36	51
14-36	.58			6.5		1.1	.8	.0	TR	1.9	9.2	1.8	11.1	7.5	.11	1.4	15	17	25
36-60	.37			6.7		.4	.4	TR	TR	.8	9.0	2.9	9.8	7.2	.11	1.0	6	8	11
60-86	.27			6.4		.2	.5	TR	TR	.7	8.3	2.5	9.0	6.7	.10	.4	3	8	12
86-120	.20			6.5		.0	.4	.0	.0	.4	8.2	2.3	8.6	6.2	.09			5	6
120-156	.17			6.4		.1	.2	TR	TR	.3	8.0	2.5	8.3	6.4	.09	.5	2	4	5
156-185	.17			6.6		.2	.1	TR	TR	.3	8.0	2.5	8.3	6.1	.09	2.0	3	4	5
185-220	.17			6.2		.3	.2	TR	TR	.5	7.8	2.4	8.3	6.0	.09	1.5	5	6	8

DEPTH CM	PH 8C1C KCL	CEC 5A7A NHCL MEQ / 100 G
0-14	4.3	6.0
14-36	3.9	
36-60	3.8	3.8
60-86	3.8	
86-120	3.8	
120-156	3.8	3.6
156-185	3.8	
185-220	3.8	

SAND MINERALOGY (7B1) PLACEMENT: SILICEOUS.
036-060 FNES - RE100 QZ99 PO TM OP VFNS - RE100 QZ99 OP TM.
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS OP = OPAQUE QZ = QUARTZ TM = TOURMALINE.

Micromorphological description of Chok Chai series

50 cm.depth

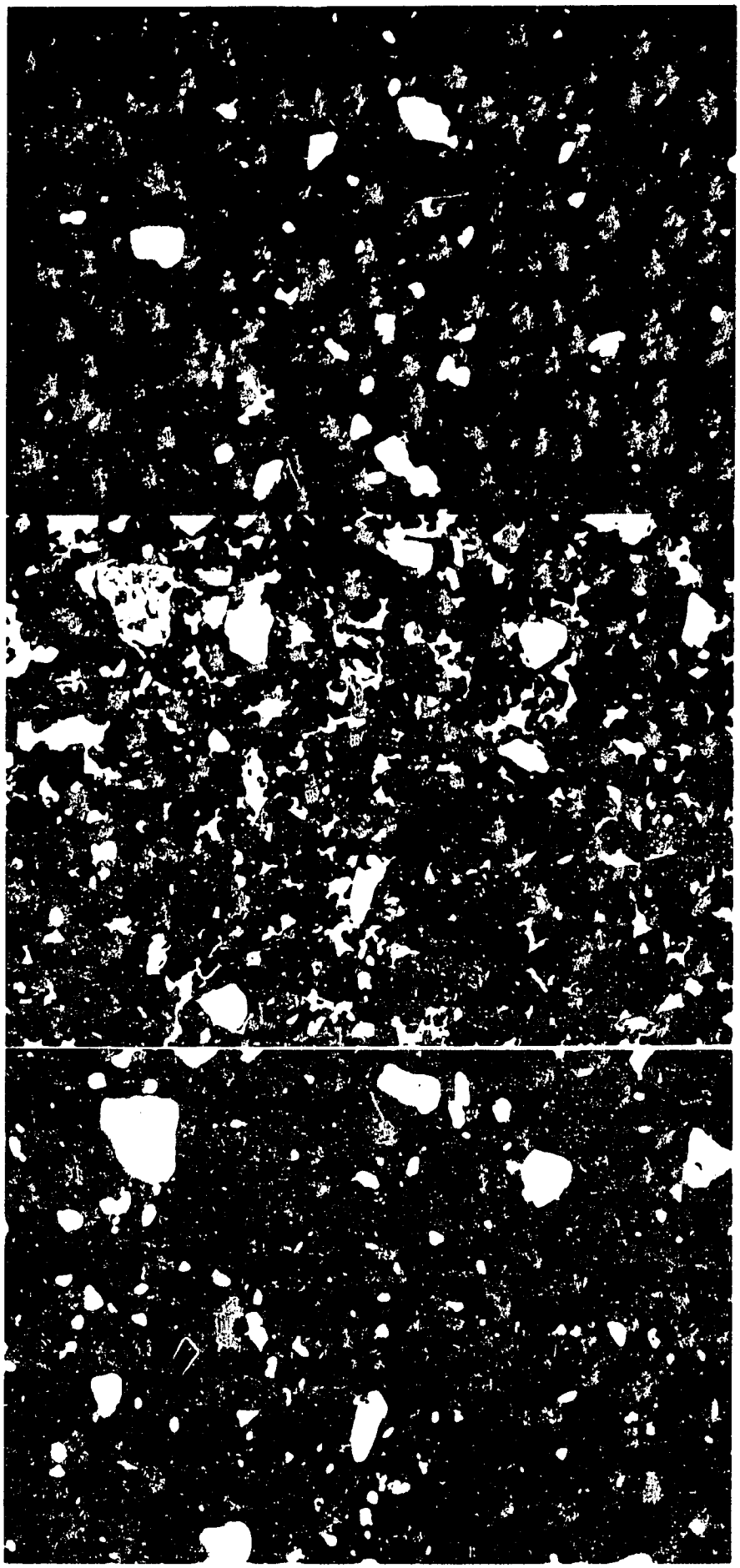
The specific related distribution pattern (SRDP) is agglutinic (Fig.18a,b) and locally the normal related distribution pattern (NRDP) is grani-plasmic. The aggregation of the plasma into microaggregates is a characteristic feature of 'Acri' great groups of the Oxisols and especially well expressed in ustic moisture regimes, as in this pedon. Plasma dominates the s-matrix. Few, fine sand-sized quartz grains are present. Few, fine, sesquioxidic nodules are also present.

Locally, there are a few spots where illuviation argillans are present. These are well oriented and indicate recent translocation. They however occupy less than 1% of the total area.

100 cm.depth

The agglutinic SRDP is still evident here, although they are more closely packed (Fig.18c). Perhaps as a result of the packing, the aggregates develop a subcutanic orientation of the plasma resulting in an ooidsepic plasmic fabric. The ooidsepic fabric (Fig.18a) accentuates the agglutinic nature of the RDP in this compack matrix.

Apart from a few papules, there is no other evidence of translocated clay. It is interesting to note the presence of runiquartz indicating the autochthonous nature of the profile.



x 40

50 cm depth

(a)

x 40

50 cm depth

Plain Light

(b)

x 40

100 cm depth

(c)

Fig. 18. Chok Chai series.

Interpretation

The pedon has all micromorphological properties of an Oxisol. Micromorphologically, the pedon could be classified as an Acrustox (the final classification will be made after the physio-chemical data are available).

In this acric material, there are indications that some clay movement is taking place. This is at a very initial stage and so will not be considered in the classification.

Classification : Typic Haplustox

Comments :

Pedon No. 7
Kula Ronghai series

Location : 150 m. North of Nakhon Ratchasima-Khonkaen Highway, Amphoe Muang, Nakhon Ratchasima Province.

Parent material : Old alluvium

Physiography : Low alluvial terrace.

Relief : Flat Slope : Less than 1 percent

Elevation : Approx. 160-170 m. Drainage : Poorly drained

Climate : "Tropical Savanna"; annual rainfall 1181.2 mm; mean temperature 26.2 °C.

Vegetation : Transplanted rice (approx. yield 1-1.5 ton/ha)

Limitations effecting plant growth : Impeded drainage, high salinity.

Horizon	Depth (cm)	Horizon Description
Ap	0-17	Dark grayish brown (10YR4/2) fine sandy loam; common medium distinct brown (7.5YR4/4-4/6) mottles; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; many fine roots; neutral (pH 7.0); clear, smooth boundary.
B_{21tg}	17-45	Gray (10YR5/1) loam; many medium distinct yellowish brown (10YR5/6) mottles; moderate medium and coarse prismatic breaking to medium and coarse subangular blocky structure; friable, sticky, plas-

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		tic; broken thin cutans on ped faces and in pores; common very fine roots; few hard iron manganese oxide concretions; moderately alkaline (pH 8.0); clear, smooth boundary.
B_{22tg}	45-60	Brown (7.5YR5/2) loam; many medium distinct yellowish brown (10YR5/6) mottles; moderate medium and coarse subangular blocky structure; friable, sticky, plastic; broken thin cutans on ped faces and in pores; few very fine roots; common hard iron-manganese oxide and secondary lime concretions; moderately alkaline (pH 8.0); gradual, smooth boundary.
B_{23tg}	60-83	Pinkish gray (7.5YR6/2) loam; many medium distinct yellowish brown (10YR5/6) mottles; moderate medium and coarse subangular blocky structure; friable, sticky, plastic; patchy thin cutans on ped faces; few very fine roots; few hard iron-manganese oxide concretions; common hard secondary lime concretions; moderately alkaline (pH 8.0); gradual, smooth boundary.

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B_{3g}	83-112	Gray (7.5YR6/1) loam; many coarse prominent brownish yellow (10YR6/8) mottles; weak medium and coarse subangular blocky structure; sticky, very plastic; broken moderately thick cutans on ped faces, few very fine roots; few hard Fe/Mn concretion and common secondary lime concretion; moderately alkaline (pH 8.0); gradual, smooth boundary.
C_{1g}	112-166	Greenish gray (5G6/1) loam; many coarse prominent yellowish brown (10YR5/8) mottles; massive; very sticky, very plastic; pressure faces with thin sand layer and some sand pockets along cracks, few hard Fe/Mn concretion and secondary lime concretion diameter up to 3-5 cm; moderately alkaline (pH 8.0); gradual, smooth boundary.
C_{2g}	166-200	Light gray (5Y7/1) loam; many coarse prominent yellowish brown (10YR5/8) mottles; massive; very sticky, very plastic; pressure faces with thin sand layer and some sand pockets along cracks; few hard Fe/Mn concretion and common secondary lime concretion diameter up to 3-5 cm; moderately alkaline (pH 8.0).

SOIL Pedon No.7 : Kula Ronghai series . **LOCATION** Amphoe Muang, Nakhon Ratchasima Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development. **LAB. Nos.** 7081—7087

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm. of whole Soil Pct.	Bulk Density g/cc.		Water Content: Water at Saturation	1/3 bar	15 bar	Saturation Percentage	Electrical Cond. mmhos/cm.	
		Pct.											Pct.					
0-17	A_p	57.5	28.4	14.1	0.2	1.4	7.3	24.0	24.6		1.40				4.27	31.3	4.35	
17-45	B_{21t}	43.7	34.7	21.6	1.1	1.3	4.5	23.5	13.3		1.69		57.04		10.43	47.7	2.42	
45-60	B_{22t}	44.5	34.5	21.0	1.7	2.3	5.4	21.4	13.7		1.82		54.23		10.27	40.5	2.22	
60-83	B_{23t}	44.1	34.9	21.0	3.0	2.8	5.1	21.9	11.3		1.85		57.36		11.80	58.9	1.88	
83-112	B_{3g}	45.2	34.3	20.5	2.1	2.4	5.1	21.4	14.2		1.74		56.97		13.61	81.8	0.93	
112-166	C_{1g}	40.6	36.4	23.0	0.7	1.0	3.1	21.0	14.8		1.70				15.54	98.4	0.64	
166-200	C_{2g}	42.8	36.2	21.0	0.5	0.9	2.6	19.7	19.1		1.72				14.46	101.8	0.58	

Depth (cm.)	Organic Carbon	Nitrogen	C/N		Carbonate as $CaCo_3$	Ext. Iron as Fe		pH 1:1 Water	pH 1:1 KCl	pH	Extractable bases: Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	NH_4OAc pH7
	Pct.				Pct.						meq/100 g							
0-17	0.58	0.05	11.27		0.53	0.2[illegible]		6.9	6.0	-0.3	3.04	0.61	0.12	1.03	5.[illegible]0	1.51	7.21	11.43
17-45	0.19	0.03	5.61		1.21	0.46		7.7	6.6	-1.1	5.56	1.22	0.12	2.45	9.35	1.55	19.80	11.31
45-60	0.11	0.02	4.91		5.50	0.20		8.4	7.0	-1.4	19.51	1.55	0.10	2.94	24.10	0	24.10	10.77
60-83	0.12	0.04	2.93		4.92	0.23		8.6	7.1	-1.5	14.69	1.78	0.12	4.08	20.67	0	20.67	9.75
83-112	0.12	0.01	10.25		5.15	0.31		8.8	7.0	-1.8	10.70	2.3[illegible]	0.13	4.90	18.03	0	18.03	10.48
112-166	0.09	0.02	5.17		1.72	0.35		8.8	7.0	-1.8	4.28	2.54	0.14	5.86	12.82	0	12.82	12.38
166-200	0.09	0.02	5.47		1.48	0.52		8.8	6.8	-1.7	3.66	2.46	0.14	6.42	12.68	0	12.68	11.69

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Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay				Base Saturation		Available		SAR	ESP		Saturation extract			
				CEC NH_4OAc	CEC NH_4Cl	Ext. iron	15 bar water	Sum Cations	NH_4OAc	P (Bray No.2)	K NH_4OAc pH7.1N				Ca	Mg	Na	K
	meq/100 g		meq/100g clay					Pct.		ppm					meq/liter			
0-17	4.93	tr	–	0.81	0.35	0.02	0.30	79.08	49.87	2	31	10.89	0.44		12.65	3.64	31.25	0.23
17-45	10.22	tr	–	0.52	0.47	0.02	0.48	47.22	82.67	1	39	20.37	10.08		3.14	0.49	27.50	0.04
45-60	9.60	tr	–	0.51	0.46	0.01	0.49	100	100	2	39	33.95	14.6[illegible]		1.11	0.21	27.50	0.02
60-83	10.58	tr	–	0.46	0.50	0.01	0.58	100	100	1	47	51.39	25.64		0.45	0.13	27.75	0.02
83-112	11.20	tr	–	0.51	0.55	0.02	0.66	100	100	1	39	32.14	37.98		0.18	0.06	11.25	0.02
112-166	12.06	tr	–	0.54	0.56	0.02	0.68	100	100	1	47	25.86	41.52		0.09	0.08	7.50	0.02
166-200	12.41	tr	–	0.66	0.59	0.02	0.69	100	100	1	59	18.75	48.59		0.19	0.13	7.50	0.02

Depth (cm.)	Mineralogy (X-ray Diffraction)	
	Clay fraction	Silt fraction
0-17	Kaolinite 50-60%; not well crystalline montmorillonite 40-50%, some quartz.	Mainly quartz.
17-45	Kaolinite, montmorillonite, trace amount of quartz.	Quartz, some calcite.
45-60	Montmorillonite 50-60%; kaolinite 40-50%, small amount of quartz.	Quartz, some calcite; small amount of feldspar.
60-83	Montmorillonite 50-60%; kaolinite 40-50%, small amount of quartz.	Quartz, some calcite; small amount of feldspar.
83-112	Montmorillonite 5[illegible]-65%; kaolinite 35-45%, trace amount of quartz.	Quartz, trace amount of calcite and feldspar.
112-166	Montmorillonite 50-60%; kaolinite 40-50%, trace amount of quartz and possible trace amount of illite.	Quartz, some feldspar.
166-200	Montmorillonite 50-60%; kaolinite 40-50%, trace amount of quartz. (?)	Quartz, some (rather small) feldspar, probably trace amount of calcite.

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Micromorphological description of Kula Ronghai series

14-45 cm. depth

Plasma is yellowish-brown, silasepic to argillasepic plasmic fabric in some places; commonly thin illuviated cutans along skeleton grains and voids with locally thick clay coating along voids about 1-2% by volume, presence of argillic horizon; some sharp and smooth boundary of sesquioxidic concretion with quartz grains are inside and show both inundulic to porphyroskelic fabric; skeleton grains are dominant and mainly are sub-angular to sub-rounded of various size of quartz with some runi-quartz and some small grains of tourmaline and epidote.

45-60 cm. depth

Plasma is somewhat increase, silasepic to argillasepic porphyroskelic in some places with vesicles and channels; slightly increase of illuviated cutans, usually along the wall of voids, argillic horizons are present; seems some decrease of sesquioxidic concretions; presence of secondary limestone, also some cryptocrystalline limestone formed in some parts of channels; skeleton grains are as above and with some flake of feldspar, some lithorelicts quartzite and rare chalcedony nodules (chert?).

60-83 cm. depth

Plasma still increase and more compact with strong argillasepic porphyroskelic fabric in many places; increase of clay coating and clay skin to about 4-5% by volume, many places are thick illuviated cutans show strong orientation; decrease of sesquioxidic concretions; some increase of recrystalline and crysptocrystalline limestone in larger size than the upper

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horizon and commonly in the soil matrix with quartz grains are inside (neo-culcitan); decrease of skeleton grains; some root fragments.

83-112 cm.depth

Plasma is yellowish-brown with some decrease, silasepic to argillasepic porphyroskelic in some places; illuviated cutans are decrease but argillic horizon still present by showing locally weak to merate illuviated cutans along voids and some neo-cutan usually associated with voids and are strong orientation; sesquioxidic concretions are rare; seems decrease of recrystalline limestone and neo-calcitan; skeleton grains are as above but with some more dense, runi-quartz are present.

112-200 cm.depth

Plasma is decrease, silasepic to weak argillasepic plasmic fabric; illuviated cutan is less than 1% by volume, absence of argillic horizons; *decrease of secondary limestone; skeleton grains are finer and mainly are sub-angular to sub-rounded quartz with chalcedony nodules (chert?).

* some neo-sesquan and quasi-sesquan :

Classification : Typic Natraqualfs

Comments

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Pedon No. 8
Ban Chong series

Location : 50 m. East of Kabin-Khorat Rd. (at km. 73), Amphoe Kabin Buri, Prachin Buri Province.

Parent material : Shale

Physiography : Low hill with strongly convex slopes.

Relief : Rolling Slope : East-facing slope of 16 percent.

Elevation : Approx. 460 m.

Climate : "Tropical Savanna"; annual rainfall 2,200 mm. (approx.) mean temperature 26°C - 27°C.

Drainage : Well drained.

Vegetation : Bamboo, low secondary shrubs.

Limitations effecting plant growth : Low nutrient status, moderately damage from past erosion.

Horizon	Depth (cm.)	Horizon Description
B_1	0-13	Yellowish red (5YR5/8) clay; weak medium and coarse subangular blocky structure; very hard, firm, sticky, plastic; many very fine and medium roots; very strongly acid (pH 5.0); clear, smooth boundary.
B_{21t}	13-33	Red (2.5YR5/8) clay; moderate coarse prismatic breaking to weak medium and coarse subangular blocky structure; slightly hard, firm, sticky, plastic; patchy thin cutans on ped faces; common very fine, fine and few medium roots;

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very strongly acid (pH 4.3); gradual, smooth boundary.

B_{22t}	33-106	Yellowish red (5YR5/8) or red (2.5YR5/8) clay; few fine distinct reddish yellow (7.5YR6/8) mottles; strong medium and coarse subangular blocky structure; firm, sticky, plastic; broken moderately cutans on ped faces; common fine and few very fine roots; few weathered shale fragments; few termite holes; very strongly acid (pH 4.5); gradual, smooth boundary.
B_{23t}	106-143	Yellowish red (5YR5/8) and red (2.5YR 5/8) clay; few fine distinct reddish yellow (7.5YR6/8) mottles; moderate medium and coarse subangular blocky structure; very hard, firm, sticky, plastic; broker moderately thick cutans on ped faces; few fine and medium roots; common medium quartz and weathered shale fragments; very strongly acid (pH 4.5); gradual, smooth boundary.
B_{3t}	143-173	Red (2.5YR5/8) clay; common medium distinct reddish yellow (7.5YR6/8) mottles; moderate medium and coarse subangular blocky structure; firm, sticky, plastic; patchy thin cutans on ped faces; few very

		fine, fine and medium roots; common angular quartz and weathered shale fragments; very strongly acid (pH 4.5); gradual, smooth boundary.
C	173-230	Mixed red (2.5YR5/8) and reddish yellow (7.5YR6/8) in situ weathered shale, common very fine, few fine and coarse roots; few angular quartz fragments; very strongly acid (pH 4.5).

SOIL Pedon No8 : Ban Chong series **LOCATION** Amphoe Kabin Buri, Prachin Buri Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development. **LAB. Nos.** 7053 – 7061

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm of whole Soil Pct.	Bulk Density g/cc.		Water Content (Pct.): Water at Saturation	1/3 bar	15 bar	Saturation Percentage	Electrical Cond. mmhos /cm.	
0–13	B_1	18.7	34.1	47.2						1.32	1.32		62.12		24.82	79.4	0.10	
13–33	B_{21t}	13.5	29.7	56.8							1.30		92.19		8.92	88.8	0.04	
33–53		14.2	26.4	59.4									78.45		30.45	75.7	0.04	
53–80	B_{22t}	13.8	27.2	59.0						0.65	1.26		92.02		30.74	81.5	0.03	
80–106		12.9	30.6	56.5									98.04		31.78	83.6	0.04	
106–127	B_{23t}	11.2	31.7	57.1						4.32	1.24		99.65		33.07	80.0	0.03	
127–143		10.7	29.4	59.9									92.50		32.48	78.8	0.04	
143–173	B_{3t}	12.3	35.0	52.7						9.62	1.28		85.60		31.59	93.0	0.04	
173–230	C	19.1	43.8	37.1						15.63	1.26		81.77		28.39	72.3	0.03	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N		Carbonate as $CaCo_3$ (Pct.)	Ext. iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	CEC: NH_4OAc pH7
0–13	1.07	0.08	12.44		1.03	3.22		4.0	3.7	-0.3	0.81	0.82	0.37	0.03	1.83	9.26	11.09	8.56
13–32	0.85	0.08	7.83		1.29	3.63		3.9	3.7	-0.1	0.24	0.23	0.10	0.03	0.60	9.04	9.64	7.02
32–53	0.41	0.06	6.81		1.14	3.96		3.9	3.8	-0.1	0.24	0.21	0.08	0.03	0.56	9.86	9.42	5.03
53–80	0.30	0.04	7.14		1.13	2.70		3.9	3.8	-0.1	0.18	0.25	0.07	0.03	0.53	9.31	9.84	7.08
80–106	0.41	0.04	11.08		1.46	2.87		4.0	3.8	-0.2	0.27	0.30	0.04	0.03	0.64	10.04	10.68	6.79
106–127	0.34	0.04	8.10		1.24	1.87		4.0	3.8	-0.2	0.53	0.22	0.05	0.02	0.82	8.54	9.36	6.92
127–143	0.39	0.05	7.5		1.37	3.06		4.3	3.8	-0.5	0.54	0.25	0.03	0.01	0.83	9.95	6.78	6.74
143–173	0.30	0.03	10.71		1.17	3.85		4.4	3.8	-0.6	0.80	0.36	0.04	0.03	1.23	8.53	9.76	6.50
173–230	0.21	0.02	9.13		1.44	3.92		4.4	3.8	-0.6	0.45	0.20	0.04	0.03	0.72	8.51	9.23	6.65

Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay: CEC NH_4OAc	Ratio to clay: CEC NH_4Cl	Ratio to clay: Ext. iron	Ratio to clay: 15 bar water	Base Saturation: Sum Cations	Base Saturation: NH_4OAc	Available: P (Bray No.2)	Available: K NH_4OAc pH7.1N			
	←meg/100 g→		meg/100g clay					←Pct→		←PPm→				
0—13	7.47	1.41	6.86	0.20	0.18	0.07	0.55	16.50	18.14	1	144			
13—32	4.39	2.16	3.85	0.21	0.08	0.06	0.51	6.22	8.55	1	35			
32—53	4.39	1.58	3.60	0.08	0.07	0.07	0.51	5.94	11.13	1	16			
53—80	6.77	1.14	3.85	0.12	0.11	0.05	0.52	5.39	7.51	1	12			
80—106	5.65	1.69	4.12	0.12	0.10	0.05	0.56	5.99	9.43	1	12			
106—127	6.57	1.55	4.15	0.12	0.12	0.03	0.58	8.76	11.85	tr	12			
127—143	5.55	1.63	4.11	0.11	0.09	0.05	0.54	8.49	12.31	1	12			
143—173	5.48	1.74	5.65	0.12	0.10	0.07	0.60	12.60	18.92	1	12			
173—230	4.93	2.38	8.30	0.18	0.13	0.11	0.77	7.80	10.8[illegible]	tr	8			

Depth (cm.)	Mineralogy (X— ray Diffraction): Clay fraction	Silt fraction
0—13	Mostly kaolinite, ± 5% vermiculite.	Quartz, appreciable amount of kaolinite, small amount of goethite.
13—32		
32—53	Mainly kaolinite; ± 5% vermiculite; trace amount of montmorillonite (?), trace amount of illite (?)	Quartz, moderate content of kaolinite, probably trace amount of goethite.
53—80		
80—106	Mainly kaolinite; ± 5% vermiculite.	Quartz, appreciable amount of kaolinite, small amount of goethite.
106—127		
127—143	Mainly kaolinite; ± 5% vermiculite possibly trace amount of chlorite and illite.	Quartz, appreciable amount of kaolinite, small amount of goethite
143—173	Mainly kaolinite; ± 5% vermiculite.	Quartz, moderate content of kaolinite.
173—230	Mainly kaolinite; ± 5% vermiculite.	Kaolinite, rather high content of quartz, trace amount of goethite.

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Micromorphological description of Ban Chong series.

50 cm. depth.

The NRDP is plasmi-porphyric (Fig.19a). The plama is brownish yellow in colour and in some parts there is some staining with organic matter. Plasmic fabric is insepic, argillasepic; locally some skel and vosepic fabrics are present. Some quartz grains are present and these range in size from fine to coarse sand-sized.

Thick illuviation ferri-argillans (Fig.19a and 19b) occupy about 5% of the area. Some of these are fragmented and this could arise through the drying process. Infilling of fine voids to form papules is also frequent.

Few grains of runiquartz are also present. In addition, there are also few, large aggregates of reddish soil material. Both these are admixtures during transport of the sediment.

100 cm. depth.

The s-matrix of the soil material is similar to the over-lying material. There is a small decrease in the amount of illuviation argillans which occupy about 2-3% of the surface. Plasmic fabric is slightly better expressed. The reddish soil aggregates noted in the overlying horizon are finer and more frequent here (Fig.19c).

Interpretation

The pedon was classified as a Typic Paleustult in the field. This classification is confirmed by the micromorphological study.

x 40

50 cm depth

(a)

x 80

50 cm depth

(b)

x 40

100 cm depth

(c)

Fig. 19. Ban Chong series.

The plasmic fabric indicates that weathering is not advanced. A CEC of more than 16 meq. per 100 g clay is expected and will be confirmed when chemical analyses are done. The soil material is of transported origin. There is an admixture of highly weathered and less weathered materials.

Classification : Oxic Paleustults.

Comments :

Pedon No. 9
Kabin Buri series

Location : About 100 m. North of Kabin - Nakhon Nayok Rd. (at km. 184.2), Amphoe Kabin Buri, Prachin Buri Province.

Parent material : Shale.

Physiography : Slightly dissected erosional surface.

Relief : Undulating.

Elevation : Approx. 30-35 m.

Slope : East facing slope of 3 percent.

Drainage : Well drained.

Climate : "Tropical Savanna", annual rainfall 2,200 mm. (approx.); mean temperature 27 °C.

Vegetation : Low secondary shrubs, mainly Siam weed (Eupatorium odoratum).

Limitations effecting plant growth : Shallowness, low nutrient status.

Horizon	Depth (cm.)	Horizon description
A_1	0-7	Dark reddish brown (5YR3/3) gravelly clay loam, dark brown (7.5YR4/2) dry, soft, slightly sticky, slightly plastic; common medium roots; strongly acid (pH 5.5); gradual, smooth boundary.
B_1	7-26	Dark red (2.5YR3/6) very gravelly clay; reddish brown (5YR5/4-4/4) dry; soft, slightly sticky, slightly plastic; common medium roots; 60 % by volume of loose ironstone concretions; strongly acid

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		(pH 5.5); gradual, smooth boundary.
B_{21t}	26-62	Red (2.5YR4/6) very gravelly clay; reddish brown (2.5YR5/4) dry; soft, sticky, plastic; moderately thick cutans around gravel faces; 70% by volume of loose ironstone concretions; very strongly acid (pH 5.0); gradual, smooth boundary.
B_{22t}	62-130	Red (2.5YR5/6) very gravelly clay; soft, sticky, plastic; moderately thick cutans around gravel faces; 70-75 % by volume of loose ironstone concretions; very strongly acid (pH 5.5); gradual, smooth boundary.
B_3	130-180	Mixed brownish yellow (10YR6/6) yellow (10YR7/6), strong brown (7.5YR5/6) and red (2.5YR4/6) very gravelly sandy clay loam; soft, sticky, plastic; 75-90 % by volume of loose ironstone concretions; very strongly acid (pH 5.0).

Classification : Oxic Haplustults.

Comments :

SOIL Pedon No.9 : Kabin Buri series **LOCATION** Amphoe Kabin Buri, Prachin Buri Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development. **LAB. Nos.** 7066 – 7071

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm. of whole Soil Pct.	Bulk Density g/cc.		Water Content (Pct.): Water at Saturation	1/3 bar	15 bar	Saturation Percentage	Electrical Cond. mmhos /cm.	
0 - 7	A_1	35.2	31.0	33.8						29.18	1.30		79.35		17.00	53.6	0.35	
7 - 28	B_1	23.8	28.3	48.1						56.91	1.56		82.99		18.49	56.4	0.08	
28–62	B_{21t}	17.3	27.0	55.7						70.11	1.78		83.40		20.34	55.0	0.05	
62 – 95	B_{22t}	17.8	19.2	63.0						68.82	1.83		79.24		19.95	57.1	0.03	
95 – 130		21.8	20.6	57.6									77.50		20.75	55.6	0.04	
130 – 180	B_3	48.6	19.1	32.3	15.8	14.7	8.7	7.9	1.5				65.10		18.63	54.4	0.05	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N		Carbonate as $CaCO_3$ (Pct.)	Ext. iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	CEC: NH_4OAc pH7
0 - 7	2.88	0.19	25.10		0.72	1.25		5.1	4.4	-0.7	1.86	1.52	0.28	0.05	3.70	10.38	14.08	10.28
7 - 28	1.19	0.11	12.56		0.55	1.37		4.8	4.0	-0.8	0.64	0.33	0.07	0.03	1.07	10.43	11.50	7.06
28-62	0.63	0.06	10.10		0.58	1.29		4.7	3.9	-0.8	0.49	0.15	0.06	0.03	0.73	9.23	9.96	5.87
62-95	0.45	0.09	5.23		0.72	1.57		4.8	3.8	-1.0	0.28	0.12	0.06	0.02	0.48	8.44	8.92	5.90
95-130	0.32	0.09	8.65		1.00	1.56		4.7	3.8	0.9	0.21	0.13	0.06	0.03	0.43	8.09	8.52	4.90
130-180	0.21	tr	–		0.87	1.50		4.9	4.0	-0.9	0.17	0.17	0.05	0.02	0.41	8.62	7.03	4.73

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Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay: µCEC NH_4OAc	CEC NH_4Cl	Ext. iron	15 bar water	Base Saturation: Sum Cations	NH_4OAc	Available: P (Bray No.2)	K NH_4OAc pH7.1N			
	←meg/100 g→		meg/100g clay					←Pct→		←PPm→				
0-7	5.81	0.15	11.39	0.30	0.17	0.04	0.50	28.32	36.06	8	94			
7-26	4.28	0.88	4.05	0.15	0.09	0.03	0.38	9.30	15.16	3	23			
26-62	3.02	1.06	3.21	0.10	0.05	0.02	0.37	7.33	12.44	2	12			
62-95	3.39	1.40	2.98	0.09	0.08	0.02	0.32	5.38	8.14	3	16			
95-130	3.82	1.83	3.92	0.09	0.06	0.02	0.36	5.05	8.78	2	12			
130-180	4.77	1.39	5.57	0.15	0.15	0.05	0.58	5.83	8.67	1	2			

Depth (cm.)	Mineralogy (X-ray Diffraction): Clay fraction	Silt fraction
0-7	Mostly kaolinite; 5-10% hydroxy alumina interlayer vermiculite; possibly trace amount of quartz.	quartz, some kaolinite.
7-26	Mainly kaolinite; 5-10% hydroxy alumina interlayer vermiculite.	quartz, some kaolinite.
26-62	Mainly kaolinite; 5-10% hydroxy alumina interlayer vermiculite.	quartz, some kaolinite; trace amount of feldspar (?)
62-95		
95-130	Mainly kaolinite; 5-10% hydroxy alumina interlayer vermiculite.	quartz, small amount of kaolinite.
130-180	Mainly kaolinite; 5-10% hydroxy alumina interlayer vermiculite.	quartz, some kaolinite; small amount goethite and small amount of anatase.

Pedon No.10
Phak Khat series

Location : About 50 m. East of Sa Kaeo-Pong Nam Ron Rd. (45.7 km. South of Sa Kaeo), Amphoe Wang Nam Yen, Prachin Buri Province.

Parent material : Old alluvium over micaceous mudstone.

Physiography : Alluvial plain.

Relief : Nearly flat Slope : 1 to 2 percent.

Elevation : Approx. 150 m. Drainage : Somewhat poorly drained.

Climate : "Tropical Savanna", annual rainfall 2037 mm. mean temperature 27.5 °C.

Vegetation : Corn

Limitations effecting plant growth : Impeded drainage.

Horizon	Depth (cm.)	Horizon Description
Ap	0-13	Mixed dark grayish brown (10YR4/2) and yellowish brown (10YR5/4, 10YR5/6) silt loam; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; common medium roots; slightly acid (pH 6.5); clear, wavy boundary.
B_1	13-32	Mixed yellowish brown (10YR5/4, 10YR5/6) and strong brown (7.5YR5/6) clay loam; common fine distinct yellowish red (5YR4/6) mottles; moderate medium subangular blocky

structure: firm, sticky, plastic; common medium roots: strongly acid (pH 5.5); clear, smooth boundary.

B_{21tg}	32-78	Pinkish gray (7.5YR6/2) clay: many medium faint strong brown (7.5YR5/6, 7.5YR5/8) and common medium distinct yellowish red (5YR4/6) mottles: moderate medium subangular blocky structure: firm, sticky, plastic; broken moderately thick cutans on ped faces: few medium roots; common hard rounded iron manganese oxide concretions of 0.5 to 1.0 cm. in diameter: very strongly acid (pH 5.0); gradual, smooth boundary.
B_{22tg}	78-120	Light brownish gray (10YR6/2) clay: many medium distinct strong brown (7.5YR5/8) mottles: weak coarse subangular blocky structure: firm, sticky, plastic: broken thin cutans on ped faces: very strongly acid (pH 5.0); gradual, smooth boundary.
B_{23tg}	120-145	Mixed light brownish gray (10YR6/2) and light gray (10YR7/1) cobbly clay many medium faint yellowish brown (10YR5/8); weak coarse subangular blocky structure; firm, sticky, plastic: patchy moderately

		thick on ped faces; many coarse, soft micaceous mudstone cobbles; strongly acid (pH 5.5); clear, smooth boundary.
B_{3tg}	145-175	Cobbly clay: massive: firm, sticky, plastic; many coarse, soft micaceous mudstone cobbles; very strongly acid (pH 5.5); clear, wavy boundary.

Remarks : Weathered micaceous mudstone occurs below 175 cm. from the soil surface.

SOIL Pedon No.10 : Phak Khat series **LOCATION** Amphoe Wang Nam Yen, Prachin Buri Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development. **LAB. Nos.** 7040 – 7046

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm of whole Soil Pct.	Bulk Density g/cc.		Water Content: Water at Saturation (Pct.)	1/3 bar (Pct.)	15 bar (Pct.)	Saturation Percentage	Electrical Cond. mmhos/cm.	
0 – 13	A_p	25.8	49.9	24.3						1.78	1.35		58.39	25.42	14.95	50.0	0.68	
13 – 32	B_1	22.2	44.8	33.0						3.23	1.40		60.50	24.87	16.95	56.3	0.15	
32 – 55	B_{21tg}	21.2	36.5	42.3						2.69	1.51		53.97	24.43	18.38	50.6	0.08	
55 – 78		18.6	31.9	49.5									57.74	28.08	22.46	61.0	0.09	
78 – 120	B_{22tg}	20.1	31.0	48.9						5.37	1.62		59.52	20.89	22.37	69.3	0.06	
120 – 145	B_{23tg}	16.3	37.5	46.2						1.83	1.55		58.36	19.97	21.72	78.6	0.08	
145 – 175	B_{3tg}	14.0	32.4	53.6						14.09	1.72		67.57			67.1	0.12	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N		Carbonate as $CaCo_3$ (Pct.)	Ext. iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC Sum Cations	CEC NH_4OAc pH7
0–13	1.88	0.13	14.35		0.77	1.97		5.8	5.3	−0.5	10.89	2.36	0.68	0.28	14.21	5.47	19.68	12.52
13–32	0.86	0.07	11.62		0.73	2.65		4.3	3.7	−0.6	4.64	2.19	0.18	0.08	7.29	10.22	17.51	12.72
32–55	0.44	0.04	12.22		1.23	2.99		4.3	3.6	−0.7	6.30	2.41	0.17	0.17	9.04	10.65	19.69	15.77
55–78	0.33	0.03	12.22		1.15	2.33		4.5	3.6	−0.9	11.41	3.60	0.21	0.24	15.46	7.66	23.12	21.13
78–120	0.30	0.03	11.11		1.21	2.14		4.7	3.5	−1.2	15.46	4.28	0.24	0.31	20.29	1.61	21.90	22.50
120–145	0.20	0.03	7.41		1.84	1.52		4.5	3.5	−1.0	23.08	5.78	0.19	0.46	29.51	7.68	37.19	27.98
145–175	0.04	0.02	1.48		2.36	1.02		5.1	3.7	−1.4	32.24	7.19	0.23	0.59	40.32	5.62	45.94	35.53

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Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay: CEC NH_4OAc	Ratio to clay: CEC NH_4Cl	Ratio to clay: Ext. iron	Ratio to clay: 15 bar water	Base Saturation: Sum Cations	Base Saturation: NH_4OAc	Available: P (Bray No.2)	Available: K NH_4OAc pH7.1N			
	←meg/100 g→		meg/100g clay					←Pct→		←PPm→				
0–13	11.83	tr	—	0.52	0.49	0.08	0.62	72.21	100	4	238			
13–32	10.29	3.23	31.88	0.39	0.31	0.08	0.51	41.63	57.31	1	82			
32–55	13.11	5.03	33.26	0.37	0.31	0.07	0.43	45.91	57.32	1	59			
55–78	19.98	5.26	41.86	0.43	0.40	0.05	0.45	66.87	72.48	1	78			
78–120	21.10	2.60	46.81	0.46	0.43	0.04	0.46	92.65	90.18	1	94			
120–145	27.56	1.08	66.21	0.61	0.60	0.03	0.47	79.35	100	2	59			
145–175	33.06	0.20	75.60	0.66	0.62	0.02	—	87.77	100	30	70			

Depth (cm.)	Mineralogy (X-ray Diffraction): Clay fraction	Silt fraction
0–13	Kaolinite > montmorillonite > Vermiculite, small amount of quartz.	Quartz, some feldspar.
13–32	Kaolinite > Vermiculite (> montmorillonite) trace amount of quartz and probably trace amount of illite	Mainly quartz.
32–55		
55–78	Kaolinite ≈ montmorillonite	Quartz, trace amount of feldspar
78–120	Kaolinite ≈ montmorillonite (intensity rather low)	Quartz, trace amount of feldspar
120–145	Montmorillonite 65–75%, Kaolinite 30–35% trace amount of quartz	Quart, trace amount of feldspar, small amount of 14 Å group of clay minerals
145–175	Montmorillonite (with small amount of vermiculite) 80–90% Kaolinite 10–15%, trace amount of illite (?)	Quartz, small amount of feldspar and 14 Å group of clay minerals.

Micromorphological description of Phak Khat series.

13-32 cm. depth.

Plasma is yellowish brown, insepic to argillasepic plasmic fabric in few places; very locally illuviated cutan along vesicles but less than 1% by volume; many small to large iron oxide nodules and concretions; skeleton grains are subrounded various size of quartz but mainly in silt size with some runiquartz and few rock fragments quartzite.

32-78 cm. depth.

Some increase of plasma: illuviated cutan is about 2-3% by volume, presence of argillic horizon; many of iron oxide nodules and concretions and in various size; skeleton grains are as above but seems some decrease and with increase of runi-quartz and rock fragments quartzite.

78-120 cm. depth.

Decrease of plasma: illuviated cutan decrease to about 1-2% by volume and still presence of argillic horizon; decrease of sesquioxidic nodules and concretions: skeleton grains decrease and mainly are subrounded to rounded silt size quartz with some muscovite, chlorite and sericite flake in groundmass, runiquartz, quartzite and few nodules of mudstone.

120-145 cm. depth.

Decrease of plasma, silasepic to masepic plasmic fabric, flake orientation due to frequently small flake of muscovite, chlorite and sericite in groundmass: illuviated cutan less than 1% by volume; decrease of sesquioxidic nodules: skeleton grains are as about but with increase of muscovite and sericite flake in groundmass and also mudstone nodules.

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145-175 cm. depth.

Dominant of weathered micaceous mudstone which consists of rounded silt size quartz about 35 % by volume, small muscovite and sericite flake in groundmass and also banded of clay minerals, many places show bedded structure (sedimentary relict); may be classify as C horizon.

Classification : Aeric Tropaqualfs.

Comments :

1076

Pedon No.11
Phangnga series

Location : About 1.5 km. South of Ban Makham (Makham Village), Amohoe Makham, Chanthaburi Province.

Parent material : Granite.

Physiography : Erosion surface.

Relief : Undulating.

Slope : North-facing slope of 3 to 4 %

Elevation : Approx. 30 m.

Drainage : Well drained.

Climate : "Tropical Monsoon", annual rainfall 3014.0 mm., mean temperature 27 °C.

Vegetation : Old native rubber.

Limitations effecting plant growth : Low nutrient status.

Horizon	Depth (cm.)	Horizon Description
A_1	0-16	Brown (10YR4/3) medium sandy clay loam; moderate fine subangular blocky structure; friable, slightly sticky, slightly plastic; many fine and few coarse roots, strongly acid (pH 5.5); clear, smooth boundary.
B_{1t}	16-33	Mixed dark yellowish brown (10YR4/4) and yellowish brown (10YR5/6) medium sandy clay loam; moderate medium subangular blocky structure; firm, sticky, slightly plastic; patchy thin organic matter coated

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		in place and in root channels; common medium and few coarse roots; strongly acid (pH 5.5); clear, smooth boundary.
B_{21t}	33-62	Yellowish brown (10YR5/6) clay with discernible sand fractions; moderate medium and coarse subangular blocky structure; firm, sticky, plastic; patchy moderately thick cutans on ped faces; few coarse roots; strongly acid (pH 5.5); gradual, smooth boundary.
B_{22t}	62-112	Brownish yellow (10YR6/6) clay with discernible sand fractions; weak medium subangular blocky structure; firm, sticky, plastic; broken moderately thick cutans on ped faces; strongly acid (pH 5.5); clear, wavy boundary.
B_{23t}	112-135	Mixed brownish yellow (10YR6/6) and dark yellowish brown (10YR4/4) slightly gravelly clay; weak medium subangular blocky structure; firm, sticky, plastic, broken moderately thick cutans on ped faces; gravels composed of 15 to 20% by volume of ironstone concretions; strongly acid (pH 5.5); gradual, smooth boundary.
B_{3t}	135-180	Mixed brownish yellow (10YR6/6), white

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(10YR8/1) and yellowish red (5YR4/6) clay with discernible sand fractions; weak coarse subangular blocky structure; firm, sticky, plastic; few scattered hard ironstone concretions, quartz and feldspars fragments; medium acid (pH 6.0).

SOIL Pedon No.11 : Phangnga series

LOCATION Amphoe Makham, Chanthaburi Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development

LAB. Nos. 7032 - 7039

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm. of whole Soil Pct.	Bulk Density g/cc.		Water Content (Pct.): Water at Saturation	1/3 bar	15 bar	Saturation Percentage	Electrical Cond. mmhos/cm.	
0-16	A_1	62.7	16.5	18.8	3.6	14.3	18.0	20.8	6.0	2.00	1.44		58.96	14.85	12.91	42.0	0.30	
16-33	B_{1t}	53.4	13.9	32.7	9.1	16.2	12.1	7.4	8.6	3.88	1.57		57.28	18.34	15.72	44.8	0.13	
33-62	B_{21t}	44.9	13.1	42.0						6.70	1.56		59.24	24.24	18.82	57.3	0.04	
62-85	B_{22t}	42.2	14.2	43.6							1.61		58.72	25.52	19.17	76.7	0.06	
85-112		38.7	16.4	44.9									59.79	24.44	19.87	65.4	0.08	
112-135	B_{23t}	39.0	15.5	45.5						45.62	1.51		56.29	25.72	19.25	63.1	0.06	
135-155	B_{3t}	38.4	15.4	46.2						14.68	1.54		52.67	23.62	19.50	80.0	0.03	
155-180		35.5	13.3	51.2									51.61	22.67	19.19	84.1	0.04	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N		Carbonate as $CaCO_3$ (Pct.)	Ext. iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	CEC: NH_4OAc pH7
0-16	1.61	0.11	14.12		0.20	0.63		4.2	4.0	-0.2	0.20	0.25	0.29	0.08	0.82	6.08	6.90	3.63
16-33	0.72	0.07	10.00		0.34	0.87		4.2	4.0	-0.2	0.05	0.02	0.12	0.08	0.27	6.09	6.36	2.37
33-62	0.45	0.05	6.82		0.59	1.43		3.9	3.9	0	0.03	0.04	0.04	0.01	0.12	6.10	6.22	3.17
62-85	0.32	0.07	4.37		0.55	1.35		4.0	4.0	0	0.05	0.04	0.05	0.03	0.17	4.97	5.14	2.17
85-112	0.36	0.05	7.66		0.49	1.56		4.3	4.0	-0.3	0.06	0.04	0.08	0.08	0.26	5.72	5.98	3.48
112-135	0.25	0.06	4.37		0.57	2.43		4.1	4.0	-0.1	0.09	0.06	0.04	0.01	0.20	6.51	6.71	2.94
135-155	0.22	0.04	5.21		0.51	2.03		4.0	3.9	-0.1	0.15	0.09	0.0[illegible]	[illegible]	0.31	6.86	7.17	2.93
155-180	0.11	0.05	2.36		0.49	1.80		4.4	3.9	-0.5	0.12	0.09	0.08	0.08	0.37	5.35	5.72	2.95

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Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay				Base Saturation		Available				
				CEC NH_4OAc	CEC NH_4Cl	Ext. iron	15 bar water	Sum Cations	NH_4OAc	P (Bray No.2)	K NH_4OAc pH7.1N			
	←meg/100 g→		mg/100g clay					←Pct→		←ppm→				
0-16	2.37	0.70	8.08	0.19	0.12	0.03	0.69	11.88	22.59	6	86			
16-33	2.17	1.29	4.77	0.07	0.06	0.03	0.48	4.25	11.39	2	39			
33-62	1.79	1.46	3.78	0.08	0.04	0.03	0.45	1.93	3.79	1	12			
62-85	1.83	1.71	4.31	0.05	0.04	0.03	0.44	3.31	7.83	1	8			
85-112	1.98	1.60	4.14	0.08	0.04	0.04	0.44	4.35	7.47	1	23			
112-135	1.99	1.60	3.98	0.06	0.04	0.05	0.42	2.98	6.60	1	8			
135-155	2.17	1.81	4.63	0.06	0.05	0.04	0.42	4.32	10.56	1	12			
155-180	2.59	1.95	4.30	0.06	0.05	0.04	0.38	6.47	12.54	1	12			

Depth (cm.)	Mineralogy (X-ray Diffraction)	
	Clay fraction	Silt fraction.
0-16	Kaolinite	Quartz, some kaolinite.
16-33	Kaolinite.	Quartz; abundant kaolinite
33-62	Kaolinite.	Quartz; appreciable amount of kaolinite.
62-85		
85-112	Kaolinite.	Quartz; abundant kaolinite.
112-135		
135-155	Kaolinite.	Quartz; abundant kaolinite, some goethite.
155-180	Kaolinite; trace amount of 14 A group of clay minerals (?).	Quartz; abundant kaolinite, some goethite.

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Micromorphological description of Phangnga series.

33-62 cm. depth.

Plasma is brownish yellow, masepic to argillasepic plasmic fabric with channels and vesicles; few small iron oxide nodules; illuviated cutan usually associated with voids about 1-2 % by volume, presence of argillic horizons; skeleton grains are various size of angular quartz from coarse sand to fine sand with few feldspar, rare zircon, and trace garnet.

62-112 cm. depth.

As above, but with slightly increase of illuviated cutan associated with voids, presence of argillic horizon, and also some small flake of feldspar that weathering to kaolinite are observed; skeleton grains are as above but presence of granite rock fragments (only quartz remain).

135-180 cm. depth.

Variable materials :

a. Paler material : soil matrix that are as above but with decrease of illuviated cutan less than 1 % by volume, absence of argillic horizon and skeleton grains seems somewhat larger size.

b. Redder material : neo-sesquan and quasi-sesquan that usually associated with voids about 5-10 % by volume show as mottled or hard ironstone in field.

Classification a) Typic Paleudults.

Comments b) Ferric Aeresol.

c) Sol Ferralitique Fortement desaturé lessive a remanic.

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Pedon No.12
Phuket series

Location : Pliu Agricultural Station, Amphoe Laem Sing, Chanthaburi Province

Parent Material : Granite

Physiography : Foothill slope.

Relief : Rolling Slope : East-facing slope of 10 percent

Elevation : 80 m. Drainage : Well drained

Climate : "Tropical Monsoon"; annual rainfall 3014.0 mm.; mean temperature 26.4 ^{o}C

Vegetation : Native rubber

Limitations effecting plant growth: Low nutrient status, prone to erosion.

Horizon	Depth	Horizon Description
A_1	0-16	Reddish brown (5YR4/4) medium sandy loam; moderate fine subangular blocky structure; soft, friable, slightly sticky, slightly plastic; many fine and coarse roots; very strongly acid (pH 5.0); clear, smooth boundary.
B_{21}	16-35	Yellowish red (5YR5/8) medium sandy clay; weak fine and medium subangular blocky structure; friable, sticky, slightly plastic; common fine and medium roots; few scattered ironstone concretions and quartz grains; very strongly acid (pH 5.0); gradual, smooth boundary.

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B_{22t}	35-68	Red (2.5YR5/8) medium sandy clay; weak fine and medium subangular blocky structure; friable, sticky, slightly plastic; patchy thin cutans on ped faces; few fine roots; few scattered ironstone concretions and quartz grains; very strongly acid (pH 5.0); gradual, smooth boundary.
B_{23t}	68-117	Red (2.5YR4/6) sandy clay to clay; moderate medium subangular blocky structure; friable, sticky, plastic; broken thin cutans on ped faces; few fine roots; few fine mica flakes; very strongly acid (pH 5.0); gradual, smooth boundary.
B_{24t}	117-144	Red (2.5YR4/6) slightly gravelly sandy clay; moderate medium subangular blocky structure; friable, sticky, plastic; broken thin cutans on ped faces; few fine roots; gravels composed of quartz grains, ironstone concretions and few feldspars; very strongly acid (pH 4.5); gradual; smooth boundary.
B_{25t}	144-180	Red (2.5YR4/6) slightly gravelly clay; moderate medium and coarse subangular blocky structure; friable, sticky, plastic; broken thin cutans on ped faces; gravels composed of quartz grains, ironstone concretions and very few feldspars; very strongly acid (pH 4.5

SOIL Pedon No.12 : Phuket series

LOCATION Amphoe Laem Sing, Chanthaburi Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development.

LAB. Nos. 6936-6942

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm. of whole Soil Pct.	Bulk Density g/cc.		Water Content (Pct.): Water at Saturation	1/3 bar	15 bar	Saturation Percentage	Electrical Cond. mmhos/cm.	
0-16	A_1	63.8	14.3	21.9	9.5	17.5	20.6	8.7	7.5	8.14	1.12		63.20	12.54	11.36	33.3	0.29	
16-35	B_{21}	49.6	11.4	39.0	15.3	14.5	11.1	7.2	1.5	16.69	1.53		75.07	17.76	16.70	57.1	0.09	
35-68	B_{22t}	48.1	6.8	45.1	15.1	13.6	11.4	7.5	0.5	15.59	1.39		71.29	20.54	16.74	46.5	0.08	
68-90	B_{23t}	44.4	6.4	49.2	12.6	12.2	10.5	7.3	1.8	14.04	1.32		71.91	22.18	16.74	50.0	0.10	
90-117		45.0	5.0	50.0	12.8	13.5	10.7	7.5	0.5				73.77	22.33	16.70	46.6	0.08	
117-144	B_{24t}	43.0	12.4	44.6	10.0	13.4	10.9	6.8	1.9	16.87	1.35		78.52	20.82	17.13	52.4	0.09	
144-180	B_{25t}	41.9	14.4	43.7	12.6	11.1	9.6	7.3	1.3	15.17	1.53		71.55	20.76	16.74	49.5	0.09	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N		Carbonate as $CaCo_3$ (Pct.)	Ext. iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	CEC: NH_4OAc pH7
0-16	1.68	0.11	15.00		0.52	0.84		4.7	4.2	-0.5	0.53	0.40	0.26	0.05	1.24	6.85	8.09	4.70
16-35	0.65	0.05	12.58		0.45	1.02		4.8	4.1	-0.7	0.11	0.05	0.18	0.03	0.37	7.28	7.65	3.52
35-68	0.36	0.04	10.29		0.61	0.80		4.8	4.0	-0.8	0.14	0.03	0.14	0.05	0.36	5.80	6.16	3.19
68-90	0.27	0.03	8.12		0.50	0.64		4.7	4.1	-0.6	0.11	0.05	0.10	0.08	0.34	7.72	8.06	3.01
90-117	0.27	0.04	6.41		0.67	1.16		4.7	4.0	-0.7	0.21	0.09	0.14	0.03	0.47	6.20	6.67	3.23
117-144	0.27	0.06	4.35		0.53	1.44		4.7	4.0	-0.7	0.14	0.06	0.15	0.05	0.40	9.98	7.38	3.28
144-180	0.23	0.03	6.97		0.49	1.39		4.8	4.0	-0.6	0.14	0.09	0.11	0.03	0.37	6.23	6.60	3.03

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Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay				Base Saturation		Available				
				CEC NH_4OAc / CEC NH_4Cl		Ext. iron	15 bar water	Sum Cations	NH_4OAc	P (Bray No2)	K NH_4OAc pH7.1N			
	← meg / 100 g →		mag/100g clay					← Pct →		← PPm →				
0-16	2.46	0.36	7.31	0.21	0.11	0.03	0.52	15.33	26.38	6	82			
16-35	1.60	1.30	4.18	0.09	0.04	0.03	0.43	4.84	10.51	2	55			
35-68	2.21	1.22	3.50	0.07	0.05	0.02	0.37	5.84	11.29	2	43			
68-90	1.79	1.20	3.13	0.06	0.04	0.01	0.34	4.22	11.30	1	31			
90-117	2.18	1.31	3.56	0.06	0.04	0.02	0.33	7.05	14.55	2	47			
117-144	1.72	1.09	3.34	0.07	0.04	0.03	0.38	5.42	12.20	1	43			
114-180	1.97	1.44	4.14	0.07	0.05	0.03	0.38	5.61	12.21	2	35			

Depth (cm.)	Mineralogy (X-ray Diffraction)	
	Clay fraction	Silt fraction

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SOIL CLASSIFICATION-

SERIES - - - - - - - PHUKET (PK)

SOIL NO - - - - - - S78FN-000-G02 COUNTY - - - THAILAND

GENERAL METHODS- - - 1A,1B1B,2A1,2B SAMPLE NOS. 78P1720-78P1726

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, MTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

APRIL 1979

DEPTH CM	HORIZON	SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	SAND: VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	SILT: COSI .05-.02	FNSI .02-.002	VFSI .005-.002	SAND 2-.10	INTR II .2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	RATIO 8D1 15-BAR TO CLAY
		(PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B — PCT LT 2MM)																
0-16	A1	71.2	7.8	21.0		25.1	19.8	11.4	11.1	3.8	3.2	4.6		67.4				.54
16-35	B21	51.3	4.9	43.8		17.2	12.6	7.3	7.8	6.4	2.0	2.9		44.9				.39
35-68	B22T	48.7	9.3	42.0		20.6	14.1	6.0	6.2	1.8	5.2	4.1		46.9				.31
68-90	B23T	50.4	6.1	43.5		20.7	13.8	6.9	6.4	2.6	1.6	4.5		47.8				.38
90-117	B23T	44.5	12.4	43.1		17.2	13.2	5.7	7.0	1.4	5.4	7.0		43.1				.36
117-144	B24T	45.7	10.1	44.2		15.7	13.5	6.8	6.6	3.1	2.3	7.8		42.6				.38
144-180	B3T	42.5	12.3	45.2		13.0	12.4	6.9	7.1	3.1	3.7	8.6		39.4				.34

DEPTH CM	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2) VOL. GT 2 PCT	WEIGHT: GT 75 PCT	75-20	20-5	5-2	LT .074	20-2 PCT LT20	(BULK DENSITY) 4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	(WATER CONTENT) 4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	CARBONATE 6E1B LT 2 PCT	3A1A LT .002 PCT	(PH) 8C1A 1/1 H2O	8C1B 1/2 CACL
			(PCT LT 75)															
0-16													11.3				4.9	4.4
16-35													17.3				4.9	4.2
35-68													13.0				4.9	4.3
68-90													16.4				5.0	4.3
90-117													15.5				5.0	4.3
117-144													17.0				5.0	4.3
144-180													15.5				5.0	4.3

DEPTH CM	(ORGANIC MATTER) 6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	(EXTRACTABLE BASES 5B4A) 6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	ACTY 6H1A BACL TEA	AL 6G1E KCL EXT	(CAT EXCH) 5A3A EXTB ACTY	5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA 5F1 SAT NHAC PCT	(BASE SAT) 5C3 EXTB ACTY PCT	5C1 NHAC PCT
						(MEQ / 100 G)													
0-16	1.38			1.3		.6	.4	.1	.2	1.3	7.0	.6	8.3	5.8	.28	1.5	10	16	22
16-35	.60			2.0		.1	.1	.1	.2	.5	7.1	1.4	7.6	5.0	.11	1.0	2	7	10
35-68	.29			2.1		TR	TR	TR	.1	.1	6.7	1.4	6.8	4.8	.11			1	2
68-90	.20			2.2		.1	TR	.1	.1	.3	6.6	1.5	6.9	4.6	.11		2	4	7
90-117	.20			2.1		.1	.2	TR	.1	.9	6.9	1.4	7.8	4.7	.11	.1	2	12	19
117-144	.19			2.[illegible]		.1	TR	TR	.1	.2	6.2	1.6	6.4	4.8	.11		2	3	4
144-180	.19			2.[illegible]		.1	.1	.1	.1	.4	7.3	1.8	7.7	5.3	.12	1.0	2	5	8

DEPTH CM	PH 8C1C KCL	CEC 5A7A NHCL MEQ / 100 G
0-16	4.1	3.0
16-35	4.0	
35-68	4.1	
68-90	4.1	
90-117	4.1	2.3
117-144	4.1	2.4
144-180	4.0	

SAND MINERALOGY (7B1) PLACEMENT: MIXED.
035-068 FNES - RE69 QZ67 FK27 BT3 MS1 OP1 PO1 COS1-RE76 QZ36 FK19 HN1 PO40 BT3 MS1;
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS BT = BIOTITE HN = HORNBLENDE MS = MUSCOVITE OP = OPAQUE
PO = PLANT OPAL QZ = QUARTZ FK = POTASSIUM FELDSPAR.

Micromorphological description of Phuket series

50 cm. depth

The NRDP is porphyric. Grains are medium sand-sized quartz and are angular and fragmented. Plasma is bright yellow under plain light and plasmic fabric is weakly expressed vo-skelomnisepic. A few, fine, muscovite flakes are present.

There is little or no evidence of clay translocation; a few, fine, papules are present. Large gibbsite nodules (Fig.20) are frequent.

Interpretation

The horizon is a weakly expressed oxic horizon. The presence of discernable structure observed in the field is related to the weakly developed plasmic fabric. Absence of translocated clay excludes an argillic horizon.

The micromorphology reaffirms the field classification as a Tropeptic Haplorthox. The profile has similar properties to some Rengam series in Peninsular Malaysia.

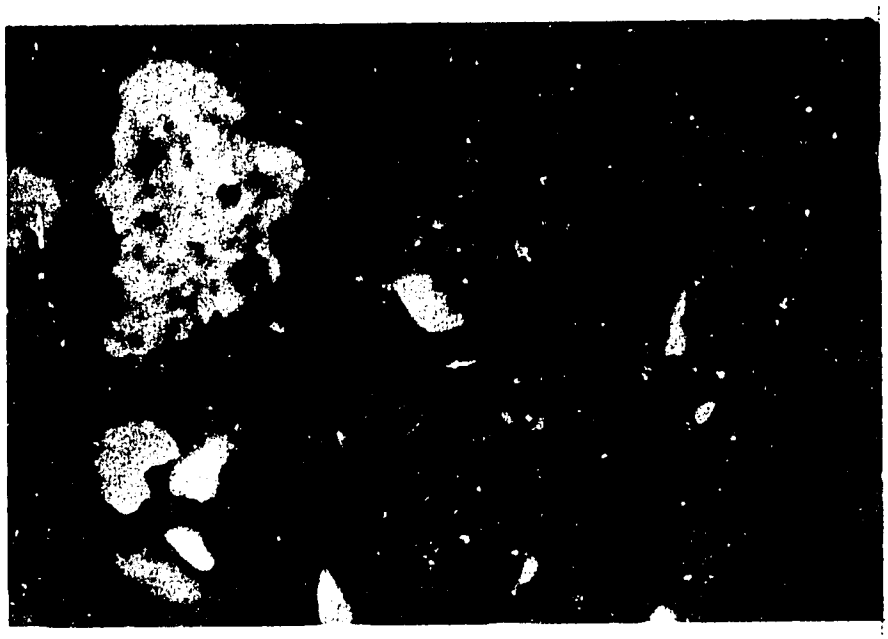
Classification : Tropeptic Haplorthox.

Comments : This pedon has a thin oxic horizon overlying a well-developed argillic horizon.

a) Orthoxic Hapludults.

b) Ferric Aerisol.

c) Sol Ferralitique lessive



x 40

50 cm depth

Fig. 20. Phuket series.

Pedon No.13
Songkhla series

Location : Pliu Agricultural Station, Amphoe Laem Sing, Chanthaburi Province

Parent material : Transported materials from granite.

Physisography : Small alluvial fan.

Relief : Gently undulating Slope : 2 to 3 percent

Elevation : Approx. 73 m. Drainage : Somewhat pooly drained

Climate : "Tropical Monsoon"; annual rainfall 3014.0 mm.; mean temperature 26.4°C

Vegetation : Durian (Durio zibethinus, Linn.) rambutan (Nephelium lappaecum, linn.)

Limitations effecting plant growth : Low nutrient status.

Horizon	Depth (cm.)	Horizon Description
A_{11}	0-15	Dark grayish brown (10YR4/2) medium loamy sand; weak fine subangular blocky structure; very friable, slightly sticky, non plastic; many fine and medium roots; strongly acid (pH 5.5); gradual, smooth boundary.
A_{12}	15-34	Very dark grayish brown (10YR3/1-2) or dark grayish brown (10YR4/2) medium loamy sand; weak fine subangular blocky

structure; very friable, slightly sticky, non plastic; common fine roots, very strongly acid (pH 5.0); clear, wavy boundary.

B_{21t}	34-60	Light yellowish brown (10YR6/4) medium sandy clay loam; moderate medium and coarse subangular blocky structure; friable, sticky, slightly plastic; broken thin cutans on ped faces; very strongly acid (pH 5.0); clear. smooth boundary.
B_{22t}	60-85	Mixed light gray (10YR6/2) and brown (10YR5/3) medium sandy clay loam; many coarse prominent red (2.5YR5/8) and strong brown (7.5YR6/6) mottles; moderate medium and coarse subangular blocky structure; friable, sticky, slightly plastic; broken thin cutans on ped faces; very strongly acid (pH 5.0); gradual smooth boundary.
B_{23tg}	85-125	Light gray (10YR6/1) medium sandy clay to clay; many coarse prominent red (10R 4/6, 2.5YR5/8) and strong brown (7.5YR6/6) mottles; moderate coarse subangular blocky structure; firm, sticky, slightly plastic; broken moderately thick cutans on ped faces; very strongly acid (pH5.0);

gradual, smooth boundary.

B_{24tg}	125-180	Light gray (10YR6/1) clay with discernible medium sand fractions; many coarse prominent red (10YR4/8) and strong brown (7.5YR5/8) mottles; weak coarse subangular blocky structure; firm, sticky, slightly plastic, broken moderately thick cutans on ped faces; very strongly acid (pH 5.0).

SOIL Pedon No.13 : Songkhla series **LOCATION** Amphoe Laem Sing, Chanthaburi Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development. **LAB. Nos.** 7015—7021

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm. of whole Soil Pct.	Bulk Density g/cc.		Water Content (Pct.): Water at Saturation	1/3 bar	15 bar	Saturation Percentage	Electrical Cond. mmhos/cm.	
0-15	A_{11}	74.3	15.8	9.9	7.9	33.4	22.2	8.2	2.6	1.04	1.52		52.21	9.87	6.75	26.7	0.23	
15-34	A_{12}	75.1	13.0	11.9	6.5	26.6	27.5	8.4	6.1	1.78	1.53		46.07	8.47	7.08	28.2	0.16	
34-60	B_{211}	63.0	8.8	28.2	4.9	19.8	24.3	11.5	2.5	1.41	1.76		51.78	14.23	11.25	50.0	0.10	
60-85	B_{221}	62.1	8.0	29.9	9.3	19.7	21.6	10.1	1.4	1.86	1.65		57.11	15.20	12.06	53.3	0.06	
85-125	B_{23tg}	55.0	6.2	38.8	5.9	16.8	19.8	10.1	2.4	1.30	1.69		61.94	17.80	15.17	50.6	0.05	
125-150	B_{24tg}	53.7	7.6	38.7	5.5	17.1	20.0	10.4	0.7	3.98	1.56		65.28	20.12	16.00	48.4	0.06	
150-180		55.9	6.6	37.5	8.0	19.4	18.3	8.5	1.7				61.59	18.81	15.13	68.0	0.06	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen	C/N		Carbonate as $CaCO_3$ (Pct.)	Ext. iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	CEC: NH_4OAc pH 7
0-15	1.05	0.08	13.29		0.16	0.10		4.5	4.0	-0.5	0.18	0.07	0.16	0.03	0.44	5.31	5.75	2.61
15-34	0.78	0.06	13.68		0.18	0.10		4.4	3.9	-0.5	0.06	0.01	0.09	0.01	0.17	4.54	4.71	2.37
34-60	0.32	0.04	7.80		0.29	0.09		4.4	3.8	-0.6	0.05	0.03	0.13	0.03	0.24	4.60	4.84	2.[illegible]8
60-85	0.16	0.02	6.96		0.35	0.12		4.5	3.7	-0.8	0.05	0.03	0.09	0.03	0.20	5.40	5.60	2.46
85-125	0.14	0.02	6.09		0.21	0.18		4.5	3.8	-0.7	0.05	0.01	0.09	0.03	0.18	5.43	5.61	2.66
125-150	0.09	0.06	15.50		0.44	0.32		4.6	3.7	-0.9	0.06	0.01	0.09	0.03	0.19	5.45	5.64	2.85
150-180	0.16	0.02	8.89		0.21	0.17		4.5	3.8	-0.7	0.05	0.03	0.08	0.03	0.19	4.26	4.45	3.07

193

Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay				Base Saturation		Available				
				CEC NH_4OAc	CEC NH_4Cl	Ext. Iron	15 bar water	Sum Cations	NH_4OAc	P (Bray No.2)	K NH_4OAc pH7.1N			
	←meg/100 g→		meg/100g clay					←Pct→		←PPm→				
0 - 15	1.97	0.87	13.23	0.28	0.20	0.01	0.68	7.65	10.88	15	59			
15 - 34	1.58	0.94	9.33	0.20	0.13	0.01	0.60	3.61	7.17	6	27			
34 - 60	1.84	1.74	7.02	0.10	0.08	0.00	0.40	4.96	8.63	2	35			
60 - 85	2.15	1.83	6.79	0.08	0.07	0.00	0.40	3.57	8.13	2	27			
85 - 125	1.41	1.79	5.08	0.07	0.04	0.01	0.39	3.21	6.77	2	23			
125 - 150	2.51	1.76	5.04	0.07	0.06	0.01	0.41	3.37	6.67	2	27			
150 - 180		2.27	6.56	0.08		0.01	0.40	4.27	6.19	2	23			

Depth (cm.)	Mineralogy (X- ray Diffraction)	
	Clay fraction	Silt fraction
0 - 15	Kaolinite, trace amount of illite and HA' group of clay minerals.	Quartz, small amount of feldspar, trace amount of kaolinite.
15 - 34	Kaolinite; trace amount of illite (?)	Quartz, some feldspar, trace amount of kaolinite.
34 - 60	Kaolinite.	Quartz, some feldspar, small amount of kaolinite.
60 - 85	Kaolinite.	Quartz, small amount of kaolinite, small amount of feldspar
85 - 125	Kaolinite; trace amount of illite (?)	Quartz, trace amount of kaolinite.
125 - 150		
150 - 180	Kaolinite; trace amount of illite.	Quartz, some kaolinite.

694

Micromorphological description of Songkhla series

100 cm. depth

The NRDP is plasmi-phyric. Grains are dominantly medium to coarse sand-sized quartz. The plasma is pale white under plain light and the argillans have a waxy appearance. The plasmic fabric is skel-omnisepic.

Illuviation argillans composed almost purely of kaolinite (Fig.21a) occupy about 15% of the area. Some large voids are completely infilled with kaolinite to form clay plugs (Fig.21b). The very thick kaolinans are the most striking features.

A secondary feature of importance are the diffuse ferrans. Iron diffuses into the kaolinan or the matrix of the soil material resulting in reddish features. These are weak expressions of aquic features.

Interpretation

Translocation of clay and its accumulation in the subsoil is the most important pedogenic process in this profile.

Classification : Aeric Paleaquults.

Comments : This pedon is intergraded to Typic Paleudults. There is still questionable that the matrix color of B_{22t} horizon is 10YR6/2 or 10YR5/3.

a) Plintic Paleaquult.

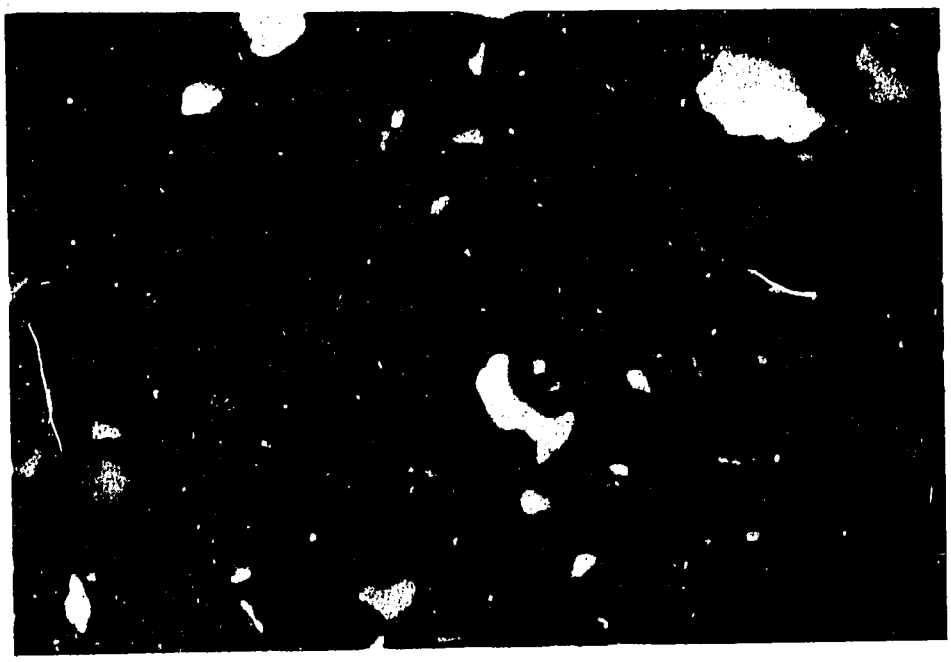
b) Plintic Aerisol.

c) Sol hydromorphic, peuhumifere a gley, lessive.

695

x 40

(a)



x 40

(b)

Fig. 21. Songkhla series.

SOIL CLASSIFICATION-
SERIES - - - - - - - -THAMAI (TI)
SOIL NO - - - - - - - S78FN-000-004 COUNTY - - - THAILAND
GENERAL METHODS- - -1A,1B1B,2A1,2B SAMPLE NOS. 78P1736-78P1741

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, MTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

APRIL 1979

DEPTH CM	HORIZON	SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	SAND 2-.10	INTR II .2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	RATIO 8D1 15-BAR TO CLAY
		(- - - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - - -)				(- - - SAND - - -)					(- - SILT - -)							
		(- - - PCT LT 2MM - - -)																
0-20	A1	3.6	20.2	76.2		1.1	.5	.5	.8	.7	6.9	13.3		2.9				.39
20-50	B210X	3.6	21.8	74.6		1.0	.5	.4	.8	.9	8.7	13.1		2.7				.38
50-95	B220X	3.9	22.6	73.5		.7	.5	.5	1.2	1.0	8.3	14.3		2.9				.38
95-125	B230X	3.0	18.2	78.8		.5	.6	.4	.8	.7	5.4	12.8		2.3				.38
125-155	B230X	2.5	19.9	77.6		.5	.4	.3	.7	.6	6.3	13.6		1.9				.39
155-180	B230X	2.5	18.3	79.2		.6	.4	.3	.6	.6	5.5	12.8		1.9				.39

DEPTH CM	VOL. GT 2 PCT	GT 75 PCT	75-20	20-5	5-2	LT .074	20-2 PCT LT20	4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	CARBONATE 6E1B LT 2 PCT	3A1A LT .002 PCT	PH 8C1A 1/1 H2O	PH 8C1E 1/2 CACL
	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2)	(- - WEIGHT - -)	(- - - PCT LT 75 - - -)					(BULK DENSITY)			(- - - WATER CONTENT - - -)							
0-20													29.4				5.4	4.5
20-50													28.5				5.4	4.5
50-95													28.2				5.2	4.3
95-125													30.2				5.2	4.5
125-155													30.5				5.1	4.4
155-180													30.5				5.1	4.4

DEPTH CM	(ORGANIC MATTER) 6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	ACTY 6H1A BACL TEA	AL 6G1E KCL EXT	(CAT EXCH) 5A3A EXTB ACTY	5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA 5F1 SAT NHAC PCT	(BASE SAT) 5C3 EXTB ACTY PCT	5C1 NHAC PCT
						(- -EXTRACTABLE BASES 5B4A- -)													
						(- - - MEQ / 100 G - - -)													
0-20	.62			9.0		2.0	.8	.4	.2	3.4	19.2	.7	22.6	12.6	.17	2.5	16	[illegible]	27
20-50	1.46			9.1		2.0	1.3	.4	.3	4.0	22.5	.7	26.5	14.9	.20	1.5	13	[illegible]	22
50-95	1.01			9.3		1.1	.6	.3	.1	2.1	23.7	1.7	25.8	13.7	.19	1.8	8	8	15
95-125	.60			9.4		2.1	.5	.1	TR	2.7	20.8	.7	23.5	13.1	.17	4.2	16	11	21
125-155	.35			9.4		1.6	.3	.1	.0	2.0	20.6	1.3	22.6	11.6	.15	5.3	14	9	17
155-180	.30			9.4		1.8	.4	.1	.0	2.3	20.2	1.1	22.5	11.6	.15	4.5	16	10	20

DEPTH CM	PH 8C1C KCL	CEC 5A7A NHCL MEQ / 100 G
0-20	4.5	6.4
20-50	4.4	
50-95	4.2	5.8
95-125	4.5	
125-155	4.3	6.7
155-180	4.4	

SAND MINERALOGY (7B1) PLACEMENT: SILICEOUS.
050-095 VFNS - RE97 QZ15 FE81 PO1 MS2 FK1 COS1 - RE99 QZ10 FE89 PO FK1.
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS MS = MUSCOVITE PO = PLANT OPAL QZ = QUARTZ FK = POTASSIUM FELDSPAR.

		ture; very friable, slightly sticky, slightly plastic; common fine and medium roots; strongly acid (pH 5.5); diffuse, smooth boundary.
B_{23}	95-180	Dark reddish brown (5YR3-4/4) clay; weak medium subangular blocky structure; very friable, slightly sticky, slightly plastic; few fine roots; strongly acid (pH 5.5).

SOIL Pedon No.14: Tha Mai series **LOCATION** Amphoe Tha Mai, Chanthaburi Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development. **LAB. Nos.** 6952– 6957

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm. of whole Soil Pct.	Bulk Density g/cc.		Water Content: Water at Saturation (Pct.)	1/3 bar (Pct.)	15 bar (Pct.)	Saturation Percentage	Electrical Cond. mmhos/cm.	
0 20	A_1	5.0	33.4	61.6						11.57	0.89		86.85	55.64	31.17	69.3	0.13	
20 50	B_{21}	8.0	38.8	53.2						0.96	0.89		100.60	37.01	31.49	74.3	0.11	
50 95	B_{22}	10.4	32.4	57.2						1.10	0.94		98.88	37.12	31.25	65.2	0.10	
95 125		4.9	29.1	66.0						1.17	1.07		93.19	39.19	33.06	69.7	0.10	
125 155	B_{23}	3.8	26.6	69.6						0.48	1.02		96.17	39.80	33.25	69.3	0.05	
155 180		[illegible]	34.9	61.2						—	—		88.47	38.17	33.72	70.7	0.05	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N		Carbonate as $CaCO_3$ (Pct.)	Ext. iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	CEC: NH_4OAc pH7
0 20	1.65	0.12	10.78		1.08	11.00		5.3	4.2	1.1	2.53	0.08	0.29	0.47	4.09	18.97	23.06	17.56
20 50	0.83	0.08	13.41		1.00	9.18		5.3	4.3	1.0	1.96	1.24	0.20	0.31	3.44	16.72	20.16	11.17
50 95	0.79	0.09	8.98		0.86	9.22		5.2	4.1	1.1	1.00	0.54	0.14	0.28	1.96	19.72	21.68	10.50
95 125	0.63	0.15	4.09		1.08	10.15		5.3	4.2	1.1	1.84	0.48	0.06	0.12	2.50	17.74	20.24	9.52
125 155	0.42	0.08	6.27		1.07	10.18		5.2	4.2	1.0	1.44	0.32	0.06	0.11	1.93	18.52	20.45	8.92
155 180	0.41	0.04	9.32		0.87	10.76		5.1	4.4	0.7	1.61	0.38	0.06	0.11	2.16	16.95	19.11	10.22

Depth (cm.)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay				Base Saturation		Available				
				CEC NH_4OAc	CEC NH_4Cl	Ext. iron	15 bar water	Sum Cations	NH_4OAc	P (Bray No.2)	K NH_4OAc pH7.1N			
	←meq/100 g→		meq/100g clay					←Pct→		←ppm→				
0 20	9.92	0.22	7.00	0.29	0.16	0.18	0.51	17.74	23.29	55	88			
20 50	6.57	0.31	7.05	0.21	0.12	0.17	0.59	17.06	30.80	55	74			
50 95	5.03	0.67	4.80	0.18	0.09	0.16	0.55	9.04	18.67	65	43			
95 125	4.98	0.27	4.20	0.14	0.08	0.15	0.50	12.35	26.26	90	16			
125 155	3.95	0.48	3.46	0.13	0.06	0.15	0.48	9.44	21.64	95	12			
155 180	5.00	0.37	4.13	0.17	0.08	0.18	0.55	11.30	21.14	90	8			

Depth (cm.)	Mineralogy (X- ray Diffraction)	
	Clay fraction	Silt fraction

100

SOIL CLASSIFICATION-

SERIES - - - - - - - -THAMAI (TI)

SOIL NO - - - - - - - S78FN-000-004 COUNTY - - - THAILAND

GENERAL METHODS- - -1A,1B1B,2A1,2B SAMPLE NOS. 78P1736-78P1741

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, NTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

APRIL 1979

DEPTH CM	HORIZON	PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - PCT LT 2MM: SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	VCOS 2-1	COBS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	SAND 2-.10	INTR II .2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	RATIO 8D1 15-BAR TO CLAY
0-20	A1	3.6	20.2	76.2		1.1	.5	.5	.8	.7	6.9	13.3		2.9				.39
20-50	B210X	3.6	21.8	74.6		1.0	.5	.4	.8	.9	8.7	13.1		2.7				.38
50-95	B220X	3.9	22.6	73.5		.7	.5	.5	1.2	1.0	8.3	14.3		2.9				.38
95-125	B230X	3.0	18.2	78.8		.5	.6	.4	.8	.7	5.4	12.[illegible]		2.3				.38
125-155	B230X	2.5	19.8	77.6		.5	.4	.3	.7	.6	6.3	13.6		1.9				.39
155-180	B230X	2.5	18.3	79.2		.6	.4	.3	.6	.6	5.5	12.8		1.9				.39

DEPTH CM	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2) VOL. GT 2 PCT	WEIGHT GT 75 PCT	75-20	20-5	5-2	LT .074	20-2 PCT LT20	BULK DENSITY 4A2D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	WATER CONTENT 4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	CARBONATE 6E1B LT 2 PCT	3A1A LT .002 PCT	PH 8C1A 1/1 H2O	8C1E 1/2 CACL
0-20													29.4				5.4	4.5
20-50													28.5				5.4	4.5
50-95													28.2				5.2	4.3
95-125													30.2				5.2	4.5
125-155													30.5				5.1	4.4
155-180													30.5				5.1	4.4

DEPTH CM	(ORGANIC MATTER) 6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	(EXTRACTABLE BASES 5B4A) 6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	ACTY 6H1A BACL TRA G	AL 6G1E KCL EXT	(CAT EXCH) 5A3A EXTB ACTY	5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA 5F1 SAT NHAC PCT	(BASE SAT) 5C3 EXTB ACTY PCT	5C1 NHAC PCT
						MEQ / 100 G													
0-20	.68			9.0		2.0	.8	.4	.2	3.4	19.2	.7	22.6	12.6	.17	2.5	16	15	27
20-50	1.46			9.1		2.0	1.3	.4	.3	4.0	22.5	.7	26.5	14.9	.20	1.5	13	15	27
50-95	1.01			9.3		1.1	.6	.3	.1	2.1	23.7	1.7	25.8	13.7	.19	1.8	8	8	15
95-125	.60			9.4		2.1	.5	.1	TR	2.7	20.8	.7	23.5	13.1	.17	4.2	16	11	21
125-155	.35			9.4		1.6	.3	.1	.0	2.0	20.6	1.3	22.6	11.6	.15	5.3	14	9	17
155-180	.30			9.4		1.3	.4	.1	.0	2.3	20.2	1.1	22.5	11.6	.15	4.5	16	10	20

DEPTH CM	PH 8C1C KCL	CEC 5A7A NHCL MEQ / 100 G
0-20	4.5	6.4
20-50	4.4	
50-95	4.2	5.8
95-125	4.5	
125-155	4.3	6.7
155-180	4.4	

SAND MINERALOGY (7B1) PLACEMENT: SILICEOUS.
050-095 VFNS - RE97 QZ15 FE81 PO1 MS2 FK1 COS1 - RE99 QZ10 FE89 PO FK1.
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS MS = MUSCOVITE PO = PLANT OPAL QZ = QUARTZ FK = POTASSIUM FELDSPAR.

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Micromorphological description of Tha Mai series.

20-50 cm. depth.

Plasma is dark brown, inundulic plasmic fabric grade to agglomero plasmic fabric, plasma is low birefringent; peds separate to micro-peds, presence of oxic horizon; some small iron oxide nodules: skeleton grains are rare and are silt size quartz with small pseudomorphic altered pyroxene (hightly weathered of augite); few root fragments.

50-90 cm. depth.

As above but plasma is more light and with slightly increase of small flake of augite as groundmass and small augite grains, with depth.

Classification : a) Typic Haplorthox.

: b)

c) Sol Ferralitique moyenment desature typique.

Pedon No.15
Khlong Chak series

Location : About 100 m. South of Sukhumvit Rd. (at km. 326.2), Amphoe Muang, Chanthaburi Province.

Parent material : Shale.

Physiography : Residual hill.

Relief : Undulating Slope : 4 percent.

Elevation : 30 m. Drainage : Well drained.

Climate : "Tropical Monsoon", annual rainfall 3014.0 mm., mean temperature 26.4°C.

Vegetation : Old native rubber.

Limitations effecting plant growth : Shallowness, low nutrient status, prone to erosion.

Horizon	Depth (cm.)	Horizon Description
A_1	0-15	Brown or dark brown (10YR4/3) slightly gravelly loam; moderate fine subangular blocky structure; slightly hard, friable, slightly sticky, slightly plastic, many fine and medium roots; slightly acid (pH 6.5); clear, smooth boundary.
B_{21t}	15-45	Yellowish red (5YR/6) very gravelly clay; moderate fine subangular blocky structure, friable, sticky, plastic; broken moderately thick cutans around gravel faces; few medium roots; 70-80% by volume of loose ironstone concretions of about 1 cm. in

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		diameter, very strongly acid (pH 5.0); gradual, smooth boundary.
B_{22t}	45-110	Yellowish red (5YR5/8) very gravelly clay; moderate fine subangular blocky structure; friable, sticky, plastic, moderately thick cutans around gravel faces; 70-80% by volume of loose ironstone concretions of 0.5 to 1.0 cm. in diameter; medium acid (pH 6.0); gradual, smooth boundary.
B_{23t}	110-140	Yellowish red (5YR5/6) very gravelly clay; most features are identical to the above horizon except ironstone concretions are bigger.
B_{24t}	140-180	Mixed yellowish red (5YR5/6), strong brown (7.5YR5/6) and brownish yellow (10YR6/6) very gravelly clay; most features are identical to the above horizon.
B_3	180-210	Mixed brownish yellow (10YR6/6,10YR6/8), very pale brown (10YR7/4) and light gray (10YR7/2) slightly gravelly clay: weak medium subangular blocky structure; firm, sticky, plastic; 10 to 20 % by volume plastic of loose ironstone concretion; very strongly acid (pH 5.0).

Classification : Typic Paleudults.

Comments :

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SOIL Pedon No.15 : Khlong Chak series **LOCATION** Amphoe Muang, Chanthaburi Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development. **LAB. Nos.** 6985 – 6990

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm of whole Soil Pct.	Bulk Density g/cc.		Water Content (Pct.): Water at Saturation	1/3 bar	15 bar	Saturation Percentage	Electrical Cond. mmhos /cm.	
0-15	A_1	42.0	34.3	23.7						40.26	1.26		65.85	21.04	16.22	50.0	0.38	
15-45	B_{21t}	24.2	22.1	53.7						52.27	1.38		85.12	27.10	22.79	73.2	0.06	
45-75	B_{22t}	22.2	26.8	51.0						53.20	1.26		82.81	26.75	23.11	79.7	0.05	
75-110	B_{22t}	22.7	29.0	48.3									77.27	27.00	22.95	89.7	0.03	
110-140	B_{23t}	21.1	27.1	51.8						54.36	1.62		60.32	26.75	22.86	62.9	0.07	
140-180	B_{24t}	17.6	28.4	54.0									77.77	28.10	22.96	76.5	0.06	
180-210	B_3	15.1	36.1	48.8						42.06	1.55		64.22	28.85	23.51	68.7	0.08	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N		Carbonate as $CaCo_3$ (Pct.)	Ext. iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	CEC: NH_4OAc pH7
0-15	2.30	0.13	16.41		0.26	0.59		5.2	4.4	-0.8	1.92	0.81	0.28	0.06	3.07	8.66	11.73	6.52
15-45	0.94	0.07	14.03		0.37	0.05		5.4	4.1	-1.3	1.22	0.14	0.05	0.05	1.40	6.98	8.44	4.49
45-75	0.47	0.07	7.01		0.33	0.05		5.5	3.9	-1.6	1.03	0.20	0.04	0.03	1.30	6.17	7.47	3.76
75-110	0.43	0.06	6.03		0.43	0.95		5.3	3.9	-1.4	1.04	0.25	0.03	0.03	1.35	6.17	7.52	4.15
110-140	0.16	0.06	2.56		0.35	1.24		5.3	3.8	-1.5	0.63	0.55	0.03	0.03	1.24	5.80	7.04	3.78
140-180	0.27	0.03	9.45		0.35	1.01		5.4	3.7	-1.7	0.31	0.58	0.03	0.03	0.95	5.80	6.75	3.90
180-210	0.25	0.03	9.28		0.34	1.10		5.2	3.7	-1.5	0.27	0.41	0.03	0.04	0.75	6.38	7.13	3.76

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Depth (cm.)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay: CEC NH_4OAc	Ratio to clay: CEC NH_4Cl	Ratio to clay: Ext. iron	Ratio to clay: 15 bar water	Base Saturation: Sum Cations	Base Saturation: NH_4OAc	Available: P (Bray No.2)	Available: K NH_4OAc pH7.1N			
	←meq / 100 g→		meq/100g clay					←Pct→		←PPm→				
0-15	5.22	0.14	13.54	0,28	0.12	0,02	0.68	28.17	47.08	4	90			
15-45	2.91	0.73	4.08	0.08	0.05	0.02	0.42	17.30	32.52	2	12			
45-75	3.88	0.39	3.21	0.07	0.07	0.03	0.45	17.40	34.57	2	12			
75-110	3.05	0.50	3.83	0.09	0.06	0.02	0.48	17.95	32.53	1	4			
110-140	3.70	0.82	3.98	0.07	0.07	0.02	0.44	17.61	32.80	1	8			
140-180	4.06	1.07	3.74	0.07	0.08	0.02	0.43	14.07	24.34	1	8			
180-210	3.78	1.38	4.36	0.08	0.07	0.02	0.42	10.52	19.95	1	4			

Depth (cm.)	Mineralogy (X-ray Difiraction): Clay fraction	Silt fraction
0 - 15	Mainly kaolinite; trace amount of 14A'group of clay minerals presumably vermiculite.	Quartz, some kaolinite.
15 - 45	Mainly kaolinite; trace amount of 14A'group of clay minerals(?)	Quartz, some kaolinite.
45 - 75		
75 - 110	Mainly kaolinite; trace amount of 14A' group of clay minerals presumably vermiculite.	Quartz, some kaolinite.
110 - 140	Mainly kaolinite; trace amount of vermiculite.	Quartz, some kaolinite.
140 - 180	Mainly kaolinite; trace amount of 14A' group of clay minerals.	Quartz, some kaolinite.
180 - 210	Mainly kaolinite; trace amount of 14A'group of clay minerals.	Quartz, moderate content of kaolinite, small amount of goethite(?).

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Pedon No.16
Kho Hong series

Location : Ban Ton Lam Duan, Amphoe Muang, Rayong Province

Parent material : Old Alluvium

Physiography : Coalescing fans.

Relief : Gently undulating Slope : 2 to 4 percent.

Elevation : Approx. 40 m. Drainage : Well drained

Climate : "Tropical Savanna"; Annual Rainfall 1350.2 mm; mean temperature 27.9°C

Vegetation : Cassava

Limitations effecting plant growth : Low nutrient status.

Horizon	Depth (cm.)	Horizon Description
Ap	0-26	Dark yellowish brown (10YR4/4) sandy loam; weak fine subangular blocky structure; very friable, slightly sticky, slightly plastic; common very fine roots; strongly acid (pH 5.5); clear, smooth boundary.
B_{1t}	26-41	Yellowish brown (10YR5/4) sandy loam; weak fine subangular blocky structure; firm, slightly sticky, slightly plastic; few fine roots; very strongly acid (pH 4.5); gradual, smooth boundary.
B_{21t}	41-76	Brownish yellow (10YR6/6) sandy loam; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic;

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		patchy thin clay coatings on ped faces; few fine roots; few pieces of charcoals; few termite holes; very strongly acid (pH 5.0); gradual, smooth boundary.
B_{22t}	76-135	Yellow (10YR7/6) light sandy clay loam; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; patchy thin clay coatings on ped faces, very strongly acid (pH 5.0); abrupt, wavy boundary.
B_{3tcn}	135-150	Very pale brown (10YR7/4) very gravelly sandy loam to sandy clay loam; massive; friable, slightly sticky, slightly plastic; gravels composed of unconsolidated, hard iron-manganese oxide concretions and quartz cobbles of about 2-6 cm. in diameter; very strongly acid (pH 5.0).

SOIL Pedon No.16 : Kho Hong series **LOCATION** Amphoe Muang, Rayong Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development. **LAB. Nos.** 6966 – 6971

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm. of whole Soil Pct.	Bulk Density g/cc.		Water Content: Water at Saturation (Pct.)	1/3 bar (Pct.)	15 bar (Pct.)	Saturation Porcentage	Electrical Cond. mmhos /cm.	
0–26	Ap	65.6	23.4	11.0	0.9	1.4	7.9	38.8	18.6	0.28	1.47		45.42	7.42	5.16	26.2	0.34	
26–41	B_1t	59.5	25.0	15.5	1.3	1.6	8.3	31.4	16.9	0.25	1.62		55.32	11.32	6.84	32.6	0.10	
41–76	$B_{21}t$	56.2	24.2	17.6	1.7	1.7	7.7	33.9	13.2	0.58	1.63		51.03	11.91	7.54	37.4	0.08	
76–100	$B_{22}t$	57.6	23.1	19.1	2.9	2.2	8.3	30.8	13.6	1.10	1.59		47.48	12.28	7.77	38.5	0.06	
100–135		56.4	24.9	18.7	2.9	2.0	8.3	28.5	16.7				49.44	12.97	7.90	32.1	0.07	
135–150	B_3tcn	61.4	20.6	18.0	5.2	5.3	8.8	28.3	13.8	58.5a	1.65		50.61	11.95	8.73	32.4	0.06	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N		Carbonate as $CaCo_3$ (Pct.)	Ext. Iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	CEC: NH_4OAc pH7
0–26	0.44	0.03	16.37		0.34	0.19		4.5	4.2	-0.3	1.03	0.17	0.8	0.03	1.31	3.02	4.33	1.81
26–41	0.33	0.03	10.44		0.42	0.25		4.0	3.9	-0.1	0.54	0.04	0.3	0.03	0.64	4.17	4.81	1.92
41–76	0.23	0.01	19.33		0.47	0.25		4.0	3.8	-0.2	0.15	0.05	0.4	0.03	0.27	3.78	4.05	2.28
76–100	0.22	0.02	13.00		0.44	0.26		3.9	3.7	-0.2	0.12	0.07	0.4	0.03	0.26	4.53	4.79	1.97
100–135	0.18	0.04	4.43		0.36	0.25		3.6	3.5	-0.1	0.12	0.04	0.3	0.03	0.22	4.55	4.77	2.00
135–150	0.15	0.07	2.14		0.42	0.76		3.9	3.8	-0.1	0.12	0.07	0.5	0.03	0.27	6.07	6.34	2.54

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Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay				Base Saturation		Available				
				CEC NH_4OAc	CEC NH_4Cl	Ext. iron	15 bar water	Sum Cations	NH_4OAc	P (Bray No.2)	K NH_4OAc pH7.1N			
	←meq/100 g→		meq/100g clay					←Pct→		←PPm→				
0 – 26	1.18	0.27	14.36	0.16	0.11	0.02	0.47	30.25	72.38	7	23			
26 – 41	1.52	1.12	11.35	0.12	0.10	0.02	0.44	13.31	31.33	2	12			
41 – 76	1.73	1.22	8.47	0.13	0.10	0.01	0.43	8.67	11.84	2	12			
76 – 100	1.65	1.25	7.91	0.10	0.09	0.01	0.41	5.43	13.20	2	8			
100 – 135	1.76	1.42	8.77	0.11	0.09	0.01	0.42	4.61	11.00	2	8			
135 – 150	1.74	1.01	7.11	0.14	0.10	0.04	0.49	4.26	10.63	1	6			

Depth (cm.)	Mineralogy (X– ray Diffraction)	
	Clay fraction	Silt fraction

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SOIL CLASSIFICATION-

SERIES - - - - - - - -KHCHONG (KH)

SOIL NO - - - - - - - S78FN-000-006 COUNTY - - - THAILAND

GENERAL METHODS- - -1A,1B1B,2A1,2B SAMPLE NOS. 78P1750-78P1755

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, NTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

APRIL 1979

DEPTH CM	HORIZON	PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B: SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	SAND: VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	SILT: COSI .05-.02	FNSI .02-.002	VFSI .005-.002	SAND 2-.10	INTR II .2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	RATIO 8D1 15-BAR TO CLAY
		PCT LT 2MM																
0-26	AP	71.5	16.3	12.2		.9	1.9	6.3	34.3	28.1	16.3	TR			43.4			.34
26-41	B1	66.7	15.8	17.5		1.4	1.9	5.4	32.7	25.3	15.4	.4			41.4			.33
41-76	B21T	64.4	14.9	20.7		1.9	2.4	5.4	29.1	25.6	14.9	TR			38.8			.33
76-100	B22T	63.3	15.5	20.2		2.8	2.0	5.1	29.4	24.0	14.5	2.0			39.3			.34
100-135	B22T	61.1	17.4	21.5		2.1	1.9	4.5	26.7	25.9	16.2	1.2			35.2			.32
135-150	B3CN	65.9	14.2	19.9		12.2	6.5	5.5	23.1	18.6	13.0	1.2			47.3			.38

DEPTH CM	PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2: VOL. GT 2 PCT	GT 75 PCT	WEIGHT 75-20	20-5	5-2	LT .074	20-2 PCT LT20	BULK DENSITY: 4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	WATER CONTENT: 4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	CARBONATE 6E1B LT 2 PCT	3A1B LT .002 PCT	PH: 8C1A 1/1 H2O	8C1B 1/2 CACL
			PCT LT 75															
0-26													4.2				4.9	4.5
26-41													5.8				4.5	4.1
41-76													6.9				4.6	4.0
76-100													6.8				4.5	4.0
100-135													6.8				4.4	4.0
135-150													7.6				4.7	4.1

DEPTH CM	ORGANIC MATTER: 6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	EXTRACTABLE BASES 5B4A-MEQ/100 G: 6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	ACTY 6H1A BACL TEA	AL 6G1E KCL EXT	(CAT EXCH) 5E3A EXTB ACTY	5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA 5F1 SAT NHAC PCT	(BASE SAT) 5C3 EXTB ACTY PCT	5C1 NHAC PCT
0-26	.45			.3	1.0	.2	.0	TR	1.3	2.5	.2	3.8	2.4	.20	5.0	42	34	54
26-41	.23			.3	.1	TR	.0	.0	.1	3.4	1.4	3.5	2.7	.15		4	3	4
41-76	.19			.4	.2	TR	.0	.0	.2	3.7	1.6	3.9	2.9	.14		7	5	7
76-100	.14			.5	.1	TR	.0	.0	.1	3.3	1.7	3.4	3.0	.15		3	3	3
100-135	.13			.5	.0	TR	TR	.0		3.5	1.8		2.9	.13				
135-150	.12			3.2	.1	TR	TR	TR	.1	4.9	1.4	5.0	4.0	.20			2	3

DEPTH CM	PH 8C1C KCL	CEC 5A7A NHCL MEQ / 100 G
0-26	4.2	1.4
26-41	3.9	
41-76	3.9	2.0
76-100	3.8	
100-135	3.8	
135-150	4.0	2.1

SAND MINERALOGY (7B1) PLACEMENT: SILICEOUS.
076-100 FNES - RE100 QZ99 ZR TM VFNS - RE100 QZ99 ZR TM.
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS QZ = QUARTZ TM = TOURMALINE ZR = ZIRCON.

Micromorphological description of Kho Hong series

50 cm. depth.

The NRDP is plasmi-granic. Grains are fine to medium sand-sized quartz. The small amount of plasma, brownish yellow in colour, is present as aggregates in the intergranular voids. Plasmic fabric is insopic-argillasepic. Few runiquartz grains are present.

Illuviation argillans (2-3%) are present (Fig.22a) as thin coatings on grains. Locally, where the s-matrix has a graniplasmic NRDP, the cutans are thicker. The argillans are well oriented.

100 cm. depth.

The horizon differs from the overlying, in having a higher amount of plasma. There is a better sorting of the grains (Fig.22b); most of the quartz belongs to the fine sand size. There are much fewer argillans (1-2%) and these occur as coatings around grains. The plasmic fabric is argillasepic.

130 cm. depth.

There is a slight decrease in plasma. There is also a slight decrease in the size of the grains though a few coarse sand-sized grains are also present. The illuviation argillans are fewer ($\angle$ 1%) and thinner (Fig. 22c).

Interpretation

The plasma in the soil had all characteristics of being oxic. Absence of weatherable minerals and other properties would qualify the soil as an Oxisol. However, clay translocation has taken place and the horizon of the

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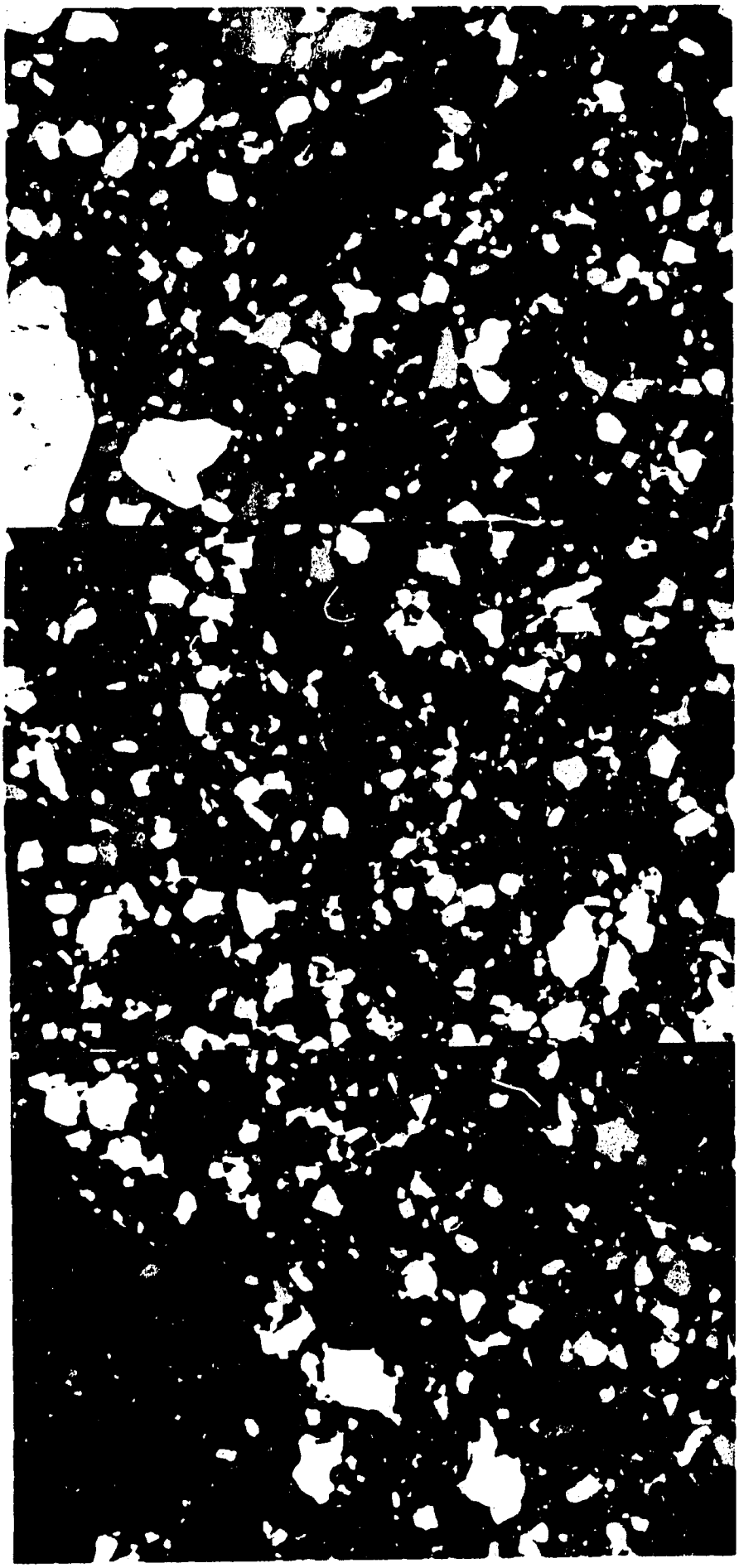

x 40

50 cm depth

(a)

x 40

100 cm depth

(b)

x 40

130 cm depth

(c)

Fig. 22. Khô Hong series.

maximum accumulation of translocated clay is at 50 cm.

This implies that clay translocation is recent and taking place in oxic material; The pedon, however, will be classified as Paleudult.

<u>Classification</u> : a) Typic Paleudults.

<u>Comments</u> : b) Dystic Nitosol. (petric phan)

c) Sol Ferralitique moyenment desature lessive a Remanic.

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Pedon No.17
Chalong series

Location : 2 km. West of Ban Mab Ta Put (100 m. South of Sukumvit Rd.), Amphoe Muang; Rayong Province.

Parent material : Transported materials from granite and other contact metamorphic rocks.

Physiography : Buried erosion surface.

Relief : Undulating Slope : 3 percent.

Elevation : Approx. 34 m. Drainage : Well drained.

Climate : "Tropical Savanna", annual rainfall 1492.8 mm. mean temperature 27 °C.

Vegetation : Cassava.

Limitations effecting plant growth : Low nutrient status.

Horizon	Depth (cm.)	Horizon Description
A_1	0-10	Brown (10YR4/3) medium loamy sand; moderate medium subangular blocky structure; very friable, slightly sticky, slightly plastic; common fine roots; slightly acid (pH 6.0); clear, smooth boundary.
B_1	10-40	Brownish yellow (10YR6/6) medium sandy clay loam; moderate medium and coarse subangular blocky structure; friable, sticky, slightly plastic; patchy thin clay and organic matter coatings on ped faces and along root channels; few fine

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roots; strongly acid (pH 5.5); gradual, smooth boundary.

B_{21t}	40-63	Reddish yellow (7.5YR6/6) medium sandy clay loam; common medium prominent yellowish red (5YR5/8) mottles; moderate subangular blocky structure; friable, sticky, plastic; broken thin clay coatings on ped faces; moderately thick organic matter coatings along root channels; few fine roots; very strongly acid (pH 5.0); clear, wavy boundary.
B_{22tcn}	63-96	Reddish yellow (7.5YR6/8) gravelly medium sandy clay; common medium prominent red 10R4/8) mottles; weak medium subangular blocky structure; friable, sticky, plastic; broken moderately thick clay coatings on ped faces; 30% by volume of ironstone concretions of 0.5 to 1.0 cm. in diameter, few quartz, very strongly acid (pH 5.0); clear, irregular boundary.
B_{23tcn}	96-130	Mixed brownish yellow (10YR6/8) and yellowish brown (10YR5/8) gravelly clay; many medium prominent red (10R4/8) and strongly brown (7.5YR5/8) mottles; weak medium subangular blocky structure, friable,

		sticky, plastic; broken moderately thick clay coatings on ped faces, 20% by volume of ironstone concretions of 0.5 to 1.0 cm. in diameter; very strongly acid (pH 4.5); gradual, smooth boundary.
B_{24t}	130-180	Mixed brownish yellow (10YR6/6), yellowish brown (10YR5/6) and light gray (10YR 7/1) clay; many coarse prominent yellowish red (5YR4/6), dark red and red (10R3-4/6) mottles; firm, sticky, plastic; broken moderately thick clay coatings on ped faces; few ironstone concretions, few fine and medium roots; very strongly acid (pH 5.0).

SOIL Pedon No.17 : Chalong series — **LOCATION** Amphoe Muang Rayong Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development. — **LAB. Nos.** 7008 7014

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm of whole Soil Pct.	Bulk Density g/cc.		Water Content: Water at Saturation (Pct.)	1/3 bar	15 bar	Saturation Percentage	Electrical Cond. mmhos /cm.	
0-10	A_1	71.8	18.0	10.2	13.0	23.1	24.9	8.3	2.5	2.40	1.48		47.29	7.36	6.80	29.2	0.37	
10-40	B_1	74.8	7.0	18.2	41.2	15.5	10.1	4.3	3.7	4.35	1.90		41.05	7.36	6.00	26.8	0.13	
40-63	B_{21t}	62.5	6.8	30.7	35.0	14.8	6.8	5.0	0.9	13.74	1.67		42.30	13.1	10.55	49.1	0.11	
63-96	B_{22ten}	48.5	11.3	40.2	24.0	10.9	7.2	3.3	3.1	35.96	1.75		40.18	18.20	15.36	57.8	0.05	
96-130	B_{23tsn}	39.4	17.2	43.4						40.89	1.77		58.49	30.46	25.39	68.3	0.05	
130-150	B_{24t}	35.5	20.5	44.0						34.11	1.69		62.26	30.46	25.39	69.1	0.09	
150-180		31.0	17.7	51.3									57.71	3.59	1.43	76.0	0.10	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N		Carbonate as $CaCO_3$ (Pct.)	Ext. iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	CEC: NH_4OAc pH7
0-10	1.07	0.06	17.83		0.68	0.30		5.1	4.6		1.86	0.74	0.14	0.03	2.57	4.54	7.11	3.64
10-40	0.31	0.03	12.40		0.57	0.45		4.5	3.9		0.85	0.32	0.06	0.03	1.06	3.02	4.08	1.42
40-63	0.40	0.04	9.52		0.64	0.78		4.0	3.6		0.41	0.22	0.10	0.03	0.76	4.55	5.31	2.15
63-96	0.31	0.02	18.24		0.52	1.17		4.2	3.7		0.61	0.16	0.09	0.11	0.97	5.33	6.30	2.23
96-130	0.25	0.03	9.42		0.64	1.99		4.2	3.7		0.26	0.25	0.06	0.02	0.59	6.14	6.73	3.42
130-150	0.25	0.03	9.62		0.38	2.71		4.0	4.0		0.29	0.31	0.08	0.02	0.70	3.28	3.98	5.32
150-180	0.27	0.03	7.71		0.60	2.41		4.2	3.9		0.26	0.33	0.08	0.05	0.72	6.23	6.95	3.35

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Depth (cm.)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay: CEC NH_4OAc	Ratio to clay: CEC NH_4Cl	Ratio to clay: Ext. iron	Ratio to clay: 15 bar water	Base Saturation: Sum Cations	Base Saturation: NH_4OAc	Available: P (Bray No.2)	Available: K NH_4OAc pH7.1N			
	←meg/100 g→		meg/100g clay					←Pct.→		←PPm→				
0-10	3.37	tr		0.36	0.33	0.03	0.85	38.15	70.60	3	43			
10-40	1.58	0.20	6.92	0.08	0.09	0.02	0.44	25.98	74.65	2	23			
40-63	1.39	0.97	5.64	0.07	0.05	0.03	0.43	14.31	35.35	2	35			
63-98	1.39	0.91	4.68	0.08	0.03	0.03	0.39	15.40	43.50	1	23			
98-130	1.83	1.09	3.87	0.08	0.04	0.05	0.37	8.77	17.25	1	20			
130-150	2.28	1.07	4.02	0.12	0.05	0.06	0.40	17.59	13.18	1	23			
150-180	2.31	1.34	4.11	0.07	0.05	0.05	0.38	10.36	21.49	1	27			

Depth (cm.)	Mineralogy (X-ray Diffraction): Clay fraction	Silt fraction
0-10	Kaolinite with trace amount of illite.	Quartz ; small amout of kaolinite.
10-40	Kaolinite ; trace amount of illite.	Quartz ; small amount of kaolinite
40-63	Kaolinite ; trace amount of illite.	Quartz ; small amount of kaolinite.
63-98		
98-130	Kaolinite ; trace amount of illite.	Quartz ; some kaolinite and goethite.
130-150		
150-180	Kaolinite ; probably trace amount of illite.	Quartz ; some kaolinite and goethite.

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Micromorphological description of Chalong series

20 cm. depth.

Weakly developed pale yellowish illuviation argillans with moderate continuous arientation as thin layers in voids.

Papules of strongly oriented clay with rather sharp boundaries about 0.2 mm. long.

Rounded iron nodules with diffuse boundaries, about 0.6 mm. some reddish brown iron nodules with sharp boundaries about 0.1 mm. There are some laterite. Fragments containing small subangular quartz grains of about 0.8 mm. long.

50 cm. depth.

Very thick yellowish channel argillans with strong continuous orientation, embedded grain argillans.

Prolate papules of strong orientation clay with sharp boundaries.

Brownish iron nodules with sharp boundaries 0.2-0.7 mm. diameter including subangular grains of quartz.

100 cm. depth.

Yellowish illuviation argillans with strong and continuous orientation on ped surface, yellowish gray channel illuviation argillans and yellowish brown ferri-argillans.

Palules of strongly oriented yellowish clay with diffuse boundary 0.2 mm. in diameter.

Sharp regular brownish nodules or iron oxide about 0.8-1.8 mm. including small subangular grains of quartz, and brownish nodules of iron oxide with sharp boundary, about 2.6 mm, long.

150 cm. depth.

Yellowish illuviation argillans and yellowish brown illuviation ferri-argillans with strong and continuous orientation, well developed on channel.

Papules of strongly oriented yellowish clay with sharp boundary about 0.4 mm. long.

Reddish brown iron nodules with sharp boundary about 1.7-5.0 mm. in diameter, including subangular grains of quartz diffuse irregular yellowish brown nodules of 0.4 mm. in diameter, also including few small subangular grains of quartz.

Classification : Oxic ? Plinthustults.

Comments : a) Typic Plintustult.

b) Plintic Acresol.

c) Sol Ferralitique fortement descature lessive.

Pedon No.18
Ban Bung series

Location : Ban Huai Pong, Amphoe Muang, Rayong Province.

Parent material : Transported materials from granite.

Physiography : Narrow flood plain.

Relief : Nearly flat Slope : Less than 1 percent.

Elevation : 24 m. Drainage : Somewhat poorly drained

Climate : "Tropical Savanna"; annual rainfall 1492.8 mm., mean temperature 26.75 °C.

Vegetation : Cassava, coconut, and truck crops.

Limitations effecting plant growth : Unfavorable texture in surface soil, low nutrient status.

Horizon	Depth (cm.)	Horizon Description
A_1	0-22	Brown (10YR5/3) loamy sand; single grain; very friable, non sticky, non plastic; few fine roots; moderately acid (pH 6.0); clear, smooth boundary.
A_2	22-40	Light brownish gray (10YR6/2) loamy sand; weak fine subangular blocky structure easily breaking to single grains; very friable, slightly sticky, slightly plastic; slightly acid (pH 6.5); gradual, smooth boundary.
B_1	40-74	Light yellowish brown (10YR6/4) loamy medium sand; common medium distinct

		strong brown (7.5YR5/6) mottles; weak coarse subangular blocky structure; very friable, non sticky, non plastic; very strongly acid (pH 5.0); gradual, smooth boundary.
B_{21t}	74-160	Light yellowish brown (10YR6/4) medium sandy loam; many coarse distinct mottles of strong brown (7.5YR5/6); weak coarse subangular blocky structure; very friable, slightly sticky, non plastic; very strongly acid (pH 5.0), abrupt, smooth boundary.
II B_{22tg}	160-190	Pinkish gray (7.5YR7/2) coarse sandy clay; many coarse prominent red (10R4/6) and many coarse distinct strong brown (7.5YR5/8) mottles; weak medium subangular blocky structure; friable, sticky, slightly plastic; broken moderately thick cutans on ped faces; medium acid (pH 6.0).

SOIL Pedon No.18: Ban Bung series **LOCATION** Amphoe Muang. Rayong Province

SOIL LABORATORY Soil Analysis Division. Department of Land Development. **LAB. Nos.**

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm of whole Soil Pct.	Bulk Density g/cc.		Water Content (Pct.): Water at Saturation	1/3 bar	15 bar	Saturation Percentage	Electrical Cond. mmhos /cm.	
0 22	A_1	87.9	9.6	2.5	15.3	26.2	30.9	13.8	1.7		1.47			3.58	1.77		94.08	
22 40	A_2	84.4	12.6	3.0	7.9	22.3	34.3	15.3	4.1		1.64			9.56	5.46		15.78	
40 74	B_1	83.3	10.2	6.5	10.3	23.3	32.3	14.0	3.4		1.56			8.67	5.49		87.22	
74 160	$B_{21}t$	77.5	7.2	15.5	13.2	23.6	26.7	11.0	3.0		1.50			7.98	5.11		18.72	
160 190	$IIB_{22}t$	61.8	15.2	23.0	5.6	17.8	26.2	9.8	2.4		1.70			9.12	5.86		19.55	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N		Carbonate as $CaCo_3$ (Pct.)	Ext. iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	CEC: NH_4OAc pH7
0 22	0.27	0.02	13.5					5.30	4.15	1.15	0.6	0.1	0.10	0.2	1.0	2.0	3.0	1.3
22 40	0.02	0.01	2.0					6.10	4.25	1.85	0.4	0.1	0.03	0.2	0.7	1.0	1.7	0.9
40 74	0.02	0.01	2.0					5.85	4.15	1.70	0.4	0.1	0.05	0.4	1.0	1.2	2.2	0.8
74 160	0.04	0.[illegible]	2.0					5.20	3.80	1.40	0.4	0.2	0.10	0.2	0.9	3.6	4.5	3.5
160 190	0.02	0.01	2.0					5.10	3.90	1.20	0.3	0.2	0.10	0.5	1.1	4.0	5.1	7.4

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Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay: CEC NH_4OAc	CEC NH_4Cl	Ext. iron	15 bar water	Base Saturation: Sum Cations	NH_4OAc	Available: P (Bray No2)	K NH_4OAc pH7.1N			
	←meg/100 g→		meg/100g clay					←Pct→		←ppm→				
0 22				0 52			0 71	33 33	76 92	5 8	24			
22 40				0 30			1 82	41 18	77 78	2 5	10			
40 74				0 12			0 84	45 45	100	2 2	12			
74 160				0 23			0.33	20 00	25 71	2 5	36			
160 190				0 10			0 25	21 57	45 83	1 8	44			

Depth (cm.)	Mineralogy (X– ray Diffraction)	
	Clay fraction	Silt fraction
0–22	Mainly kaolinite, some quartz, trace of illite and small amounts of feldspars.	
22–40	Mainly kaolinite, trace of illite, some of quartz; small amounts of feldspars.	
40–74	Mainly kaolinite, 5% illite, some quartz, small amounts of feldspars.	
74–160	Mainly kaolinite, 5% illite, trace of quartz.	
160–190	Mainly kaolinite, 5–10% illite, small amounts of quartz.	

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Micromorphological description of Ban Bung series.

22-40 cm. depth.

Only some small rounded phytolites are seen locally.

40-74 cm. depth.

Grayish illuviation argillans with strong continuous orientation, very thick and well developed in voids, reddish brown channel illuviation ferri-argillans, locally compound cutans in channels.

74-160 cm. depth.

Grayish-yellow illuviation argillans with strong and continuous orientation, thick and well developed in channels and also on ped surfaces, yellowish brown and thin reddish brown illuviation ferri-argillans developed along the channels and on ped surface. Papules of strong oriented clay with sharp boundaries about 0.2 mm. long and some about 0.2 mm. in diameter, amorphous iron oxide is present as red dots, and some iron nodules.

160-190 cm. depth.

Grayish yellow illuviation argillans, with strong and continuous orientation; thick and well developed in voids.

Papules of strongly oriented, yellowish-gray hyaline clay with sharp boundaries, about 0.2-0.4 mm. in diameter small rounded phytolites.

Classification : Arenic (Aquic) Paleustults.

Comments : This pedon may be classified as Paleudults due to possibility of moisture storage by fluctuation of ground water.

b) Ferric Acresol

c) Sol Ferrigranaux tropical lessive.

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Pedon No.19
Mab Bon series

Location : About 100 m. North of Rayong Self Help Land Settlement Office, Amphoe Ban Kai, Rayong Province.

Parent material : Carboniferous granite.

Physiography : Dissected peneplain

Relief : Undulating. Slope : West-facing slope of 6 percent.

Elevation : 80 m. Drainage : Well drained.

Climate : "Tropical Savanna", annual rainfall 1492.8 mm., mean temperature 27 °C.

Vegetation : Cassava (approx. yield 16.5 ton/ha).

Limitations effecting plant growth : Low nutrient status, prone to erosion.

Horizon	Depth (cm.)	Horizon Description
A_1	0-20	Brown (10YR4/3) to dark grayish brown (10YR4/2) sandy loam; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; many fine and medium roots; neutral (pH 7.0); clear, smooth boundary.
B_{21t}	20-42	Brown (7.5YR5/4) to strong brown (7.5YR5/6) sandy clay loam; moderate medium subangular blocky structure; friable, sticky, slightly plastic; patchy thin cutans on ped faces; common fine roots; slightly acid (pH 6.5); clear, smooth boundary.

B_{22t}	42-90	Yellowish red (5YR5/8) gravelly clay; common medium spots of yellowish brown (10YR5/6); weak medium subangular blocky structure; friable, sticky, plastic; broken moderately thick cutans on ped faces; few fine roots; gravels composed of quartz grains of 2 to 5 mm. in diameter; medium acid (pH 6.0); gradual, smooth boundary.
B_{23t}	90-152	Mixed yellowish red (5YR5/6) and strong brown (7.5YR5/6) very gravelly clay; weak medium subangular blocky structure; friable, sticky, plastic; broken moderately thick cutans on ped faces; gravels composed of quartz grains of 2 to 10 mm. in diameter; strongly acid (pH 5.5); gradual, smooth boundary.
B_3	152-200	Mixed yellowish red (5YR5/6), yellowish brown (10YR5/6) and strong brown (7.5YR 5/6) very gravelly clay with common red (2.5YR3/6) spots; weak medium subangular blocky structure; broken moderately thick cutans on ped faces; gravels composed of quartz grains of 1 to 10 mm. in diameter; strongly acid (pH 5.5)

SOIL Pedon No.19 : Mab Bon series **LOCATION** Amphoe Ban-Kai, Rayong Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development. **LAB. Nos.** 6991 – 6998

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm of whole Soil Pct.	Bulk Density g/cc.		Water Content (Pct.): Water at Saturation	1/3 bar	15 bar	Saturation Percentage	Electrical Cond. mmhos/cm.	
0–20	A_1	57.7	26.0	16.3	7.1	12.3	15.8	12.7	9.8	4.94	1.43		65.36	8.04	6.77	35.9	0.48	
20–42	B_{21t}	51.3	22.3	26.4	8.6	12.2	13.1	13.1	4.3	17.77	1.57		67.25	8.69	6.35	38.4	0.20	
42–60	B_{22t}	38.3	19.0	42.7						59.85	1.68		78.00	7.84	4.96	50.0	0.15	
60–90		35.6	15.9	48.5									73.43			57.8	0.09	
90–120	B_{23t}	32.2	19.3	48.5						60.60	1.57		75.28	8.96	1.97	52.5	0.10	
120–152		33.5	18.7	47.8									70.25			56.1	0.11	
152–175	B_3	30.6	16.5	52.9						50.12	1.60		72.88	8.42	6.10	73.8	0.11	
175–200		28.9	22.6	48.5									74.10			57.9	0.13	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C/N		Carbonate as $CaCO_3$ (Pct.)	Ext. iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract Acidity	CEC: Sum Cations	CEC: NH_4OAc pH7
0–20	0.92	0.71	1.29		0.30	0.37		5.9	5.2	−0.7	0.89	0.49	0.71	0.03	2.12	3.03	5.15	3.47
20–42	0.67	0.06	10.98		0.42	0.52		5.8	4.8	−1.0	1.81	0.74	0.05	0.03	2.63	4.56	7.19	3.32
42–60	0.45	0.03	14.06		0.60	0.75		5.6	4.8	−0.8	1.80	0.98	0.28	0.03	3.09	4.18	7.27	3.54
60–90	0.36	0.04	9.72		0.52	0.94		4.8	4.2	−0.6	1.44	1.39	0.24	0.01	3.08	5.35	8.43	3.82
90–120	0.27	0.01	22.50		0.53	0.87		4.6	4.1	−0.5	0.82	0.90	0.32	0.03	2.07	5.04	7.11	3.65
120–152	0.30	0.04	6.82		0.52	1.15		4.5	3.8	−0.7	0.50	1.00	0.40	0.03	1.93	6.54	8.47	4.01
152–175	0.31	0.04	7.38		0.53	1.29		4.5	3.7	−0.8	0.32	0.73	0.43	0.03	1.51	5.79	7.30	3.72
175–200	0.38	0.04	10.05		0.64	1.53		4.5	4.0	−0.5	0.42	0.89	0.60	0.03	1.94	7.06	9.00	1.19

Depth (cm.)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay				Base Saturation		Available				
				CEC NH_4OAc	CEC NH_4Cl	Ext. iron	15 bar water	Sum Cations	NH_4OAc	P (Bray No.2)	K NH_4OAc pH7.1N			
	←meq/100 g→		meq/100g clay					←Pct→		←ppm→				
0-20	3.35	tr	—	0.21	0.21	0.02	0.55	41.17	61.10	8	257			
20-42	3.36	tr	—	0.13	0.13	0.02	0.42	36.58	79.22	5	66			
42-60	3.54	tr	—	0.08	0.08	0.02	0.38	42.50	87.29	3	94			
60-90	2.61	0.16	5.68	0.05	0.05	0.02	0.32	36.57	60.63	3	105			
90-120	2.84	0.28	4.84	0.06	0.06	0.02	0.34	29.11	56.71	2	109			
120-152	3.41	0.59	5.27	0.07	0.07	0.02	0.38	22.79	48.13	2	137			
152-175	3.10	0.78	4.33	0.06	0.06	0.02	0.34	20.68	40.59	2	148			
175-200	3.14	0.47	4.97	0.06	0.06	0.03	0.40	21.56	46.30	1	195			

Depth (cm.)	Mineralogy (X-ray Diffraction)	
	Clay fraction	Silt fraction
0-20	Mostly kaolinite; ≥ 10 % illite.	Quartz, appreciable content of feldspar, trace amount of kaolinite.
20-42	Mostly kaolinite; 5-10 % illite; trace amount of 14A' group of clay minerals(?), trace amount of quartz.	Quartz, appreciable content of feldspar, trace amount of kaolinite.
42-60		
60-90	Mainly kaolinite; 5-10 % illite.	Quartz, moderate content of feldspar.
90-120		
120-152	Mainly kaolinite, 5-10 % illite.	Quartz, moderate content of feldspar, small amount of kaolinite.
152-175		
175-200	Mainly kaolinite, 5-10 % illite.	Quartz, moderate content of felspar, small amount of kaolinite and goethite.

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Micromorphological description of Mab Bon series

20 cm. depth

Weakly developed thin illuviation ferriargillans with weak orientation on the ped surfaces and in the voids. Yellowish brown thin illuviation cutans in channel, composed of coarse clay including very small opaque dots and some silt grains. Reddish brown and dark brownish iron nodules with sharp boundary about 0.2 mm. in diameter. There are some yellowish brown concretions. Dark brownish-red subrounded iron nodules about 0.8 mm. long with sharp boundaries, containing small subangular grains of quartz with a regular jointed. They are considered as pedorelicts.

50 cm. depth

Yellowish hyaline moderately to strongly developed illuviation argillans with strong and continuous orientation, rather thick on ped surface, and thick on channels. Papules of strongly oriented yellowish hyaline clay with sharp boundary, about 0.1-0.3 mm. in diameter, diffuse irregular brownish red iron nodules about 1.4 mm. long, including small subangular gra of quartz, brownish nodules of amorphous iron oxide.

100 cm. depth

Yellowish hyaline illuviation argillans with strong continuous orientation, rather thick on ped surface and locally very thick on channels. Some reddish brown illuviation ferri-argillans, locally developed on walls of void, and containing very small opaque humus fragments oriented yellowish hyaline clay with rather sharp boundaries, about 0.2 mm. long and about 0.1mm.

in diameter. Pedorelicts occur as in the horizon above. Rounded brownish nodules of amorphous iron oxide, about 0.2 mm. in diameter with sharp boundaries.

150 cm. depth

Thick yellowish illuviation argillans with strong and continuous orientation are well developed in voids and channels, but thin on ped surface. Papules of strong continuous oriented yellowish hyaline clay with sharp boundaries about 0.8 mm. long and about 0.15 mm. in diameter.

Classification : Oxic Paleustults.

Pedon No.20
Surin series

Location : Ban Khlongsalaphet, Tambon Saraphi, Amphoe Chokchai, Nakhon Ratchasima Province.

Parent material : Basalt

Physiography : Lava plain.

Relief : Undulating Slope : 4-5 percent.

Elevation : 230 m. Drainage : Well drained.

Climate : "Tropical Savanna", annual rainfall 1181.2 mm., mean temperature 26.2 °C.

Vegetation : Cassava.

Limitations effecting plant growth : Shallowness.

Horizon	Depth (cm.)	Horizon Description
Ap	0-15	Dark reddish brown (5YR3/2) very gravelly sandy loam: weak fine and medium subangular blocky structure; very friable, slightly sticky, slightly plastic; many very fine and fine roots; gravels composed of 80-90% ironstone concretions; slightly acid (pH 6.5); gradual, smooth boundary.
A_3	15-35	Dark reddish brown (5YR3/3) very gravelly sandy clay loam; weak fine and medium subangular blocky structure; very friable, slightly sticky, slightly plastic; many very fine and fine roots; gravels composed

		of ironstone concretions; neutral (pH 7.0); abrupt, smooth boundary.
B_{21t}	35-62	Red (2.5YR4/6) very gravelly clay; moderate medium and coarse subangular blocky structure; friable, sticky, plastic; patchy thin cutans on ped faces; few very fine and fine roots, few decayed medium roots; gravels composed of ironstone concretions; strongly acid (pH 5.5); clear, smooth boundary.
B_{22t}	62-72/82	Red (2.5YR4/6) gravelly clay loam, moderate fine and medium subangular blocky structure; friable, sticky, plastic; patchy thin cutans on ped faces; few very fine and fine roots; gravels composed of basalt fragments and ironstone concretions; strongly acid (pH 5.5); clear, wavy boundary.
C	72/82- 95/98	Yellowish red (5YR4/6) clay with 80-90% weathered basalt fragments; few very fine roots; slightly acid (pH 6.5); gradual, wavy boundary.
R	95/98 +	Weathered basalt

SOIL Bonus Pedon No. 2 : Surin series **LOCATION** Amphoe Chok Chai. Nakhon Ratchasima Province

SOIL LABORATORY Soil Analysis Division, Department of Land Development **LAB. Nos.** 7088 – 7092

Depth (cm.)	Horizon	Size class and particle diameter (mm.) Total: Sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	Sand: Very Coarse (2-1)	Coarse (1-0.5)	Medium (0.5-0.25)	Fine (0.25-0.1)	Very fine (0.1-0.05)	Coarse fragments >2 mm. of whole Soil Pct.	Bulk Density g/cc.		Water Content (Pct.): Water at Saturation	1/3 bar	15 bar	Saturation Percentage	Electrical Cond. mmhos /cm.	
0 – 15	A_p	54.3	33.2	12.5	10.9	5.6	6.8	16.7	14.3	–	1.55		63.11		13.54	38.1	0.26	
15 – 35	A_3	55.2	25.6	19.2	10.2	4.6	6.3	18.9	15.2	–	1.41		59.47		13.53	37.3	0.20	
35 – 62	B_{21t}	32.1	21.3	46.6						–	1.47		83.40		22.28	59.0	0.05	
62 – 72/82	B_{22t}	34.7	30.3	35.0						–	1.33		87.16		22.69	61.4	0.04	
72/82 – 95/98	C	40.4	40.7	18.9						–	1.13		89.40		21.29	51.8	0.08	

Depth (cm.)	Organic Carbon (Pct.)	Nitrogen (Pct.)	C / N		Carbonate as $CaCo_3$ (Pct.)	Ext. iron as Fe (Pct.)		pH 1:1 Water	pH 1:1 KCl	Δ pH	Extractable bases (meq/100 g): Ca	Mg	K	Na	Sum of bases	Extract. Acidity	CEC: Sum Cations	CEC: NH_4OAc pH7
0 – 15	1.90	0.08	23.17		1.22	1.78		6.7	5.8	–0.9	6.50	2.04	0.38	0.03	8.95	5.48	14.43	12.29
15 – 35	0.42	0.11	3.85		1.33	1.47		7.0	6.0	–1.0	6.56	1.81	0.20	0.03	8.60	3.94	12.54	11.86
35 – 62	0.79	0.04	19.75		0.99	2.74		5.2	4.2	–1.0	3.16	5.46	0.24	0.04	8.90	8.86	17.76	13.29
62 – 72/82	0.15	0.03	4.90		0.79	2.10		4.9	3.9	–1.0	7.56	7.93	0.22	0.09	15.80	8.89	24.69	21.98
72/82 – 95/98	0.27	0.04	9.72		1.57	1.54		5.5	4.3	–1.2	14.94	9.67	0.32	0.11	25.04	7.98	33.02	24.93

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Depth (cm)	CEC NH_4Cl	KCl Ext. Al	Bases Plus Al	Ratio to clay: CEC NH_4OAc	Ratio to clay: CEC NH_4Cl	Ratio to clay: Ext. iron	Ratio to clay: 15 bar water	Base Saturation: Sum Cations	Base Saturation: NH_4OAc	Available: P (Bray No.2)	Available: K NH_4OAc pH7.1			
	←meg/100 g→		meg/100g clay					←Pct→		←ppm→				
0 - 15	10.44	tr	—	0.98	0.84	0.14	1.08	62.02	72.82	5	125			
15 - 35	9.51	tr	—	0.61	0.50	0.08	0.70	68.58	73.76	6	82			
35 - 62	9.65	0.28	19.70	0.29	0.21	0.06	0.48	50.11	66.97	1	66			
62 - 72/82	18.22	0.78	47.37	0.63	0.52	0.06	0.65	63.99	71.88	1	59			
72/82 - 95/98	18.99	tr	—	1.32	1.00	0.08	1.13	76.88	100	2	144			

Depth (cm)	Mineralogy (X-ray Diffraction): Clay fraction	Silt fraction
0 - 15	Kaolinite 80-90%, illite ≤ 5%, rather poor crystalline montmorillonite ≥ 10%	Quartz; trace amount of feldspar and goethite, trace amount of kaolinite (?)
15 - 35	Kaolinite, ≥10% rather poor crystaline montmorillonite trace amount of quartz.	Quartz; trace amount of kaolinite, small amount of hematite and magnetite.
35 - 62	Mostly kaolinite; 5-10% rather poor crystalline montmorillonite.	Quartz; trace amount of feldspar, probably trace amount of magnetite.
62 - 72/82	Mostly kaolinite, ≥10% montmorillonite trace amount of illite.	Quartz, some feldspar.
72/82 - 95/98	Mostly kaolinite, ≥10% montmorillonite.	Quartz, moderate content of albite, probably trace amount of goethite.

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Micromorphological of Surin series

35-62 cm. depth

Plasma is dark reddish brown of iron and magnesium rich plasma, dense and compact of argillasepic porphyroskelic with connected meta-vughs and channels; many large (coarse sand size) iron and magnesium nodule and concretions due to highly weathered of basaltic-rock fragments in situ; illuviated cutan (Ferri-argillan) about 1-2% by volumes; skeleton grains are some fine sand size of subangular quartz with pseudomorphous Fe-Mg-oxide after olivine.

62-72 cm. depth.

As above but with much increase of pseudomorphous after olivine and increase of illuviated cutan, ferri-argillan about 3-4% by volume; supported profile description that parent material is "residuum & locally colluvium from olivine basalt".

72/82-95/98 cm. depth.

Plasma is reddish brown to dark brown, porphyroskelic to locally argillasepic plasmic fabic; locally illuviated cutan along channels (ferri-argillan) but less than 1% by volume; phenocryst of olivine in basaltic rock fragments, increase of basaltic rock fragments and degree of weathering is less than the upper horizons, this due to weathered of parent material "olivine basalt" in situ (degree of weathering decrease with depth).

Classification : Ultic Haplustalfs.

Comments

APPENDIX A

WORKSHOP PROGRAM IN THAILAND

SUNDAY, 3 SEPTEMBER 1978 - ASIA HOTEL, BANGKOK

OPENING CEREMONY
Chairman: S. Panichapong

0900 Welcome Address - Director-General of Agriculture
Introductory Remarks - F. H. Beinroth
Keynote Address - G. D. Smith

1000 Coffee recess

WORK SESSION VII:
Alfisols and Ultisols with Low Activity Clays (LAC)
Chairman: G. Uehara

1020 Paper 17. Taxonomic problems of LAC Alfisols and Ultisols.
F. R. Moormann

1045 Paper 18. Concept of the argillic horizon and problems of its identification.
R. W. Arnold

1110 Paper 19. Concerning the mineralogy classes in the classification of LAC soils.
A. Herbillon and L. Rodrique

1135 Paper 20. Micromorphology of LAC Alfisols and Ultisols.
H. Eswaran

1200 Paper 21. The measurement of surface characteristics of LAC soils.
G. P. Gillman and P. Bakker

1220 Lunch

WORK SESSION VIII:
Occurrence of LAC Alfisols and Ultisols
Chairman: M. L. Leamy

1400 Paper 22. LAC Alfisols and Ultisols in Thailand.
L. Moncharoen and P. Vicharnsorn

1420 Paper 23. LAC Alfisols and Ultisols of Malaysia.
L. Jit Sai and M. Singh Kalsi and H. Eswaran

1440 Paper 24. LAC Alfisols and Ultisols of Sri Lanka.
K. de Alwis

1500 Paper 25. LAC Alfisols and Ultisols in Eastern Africa.
W. G. Sombroek and F. N. Muchena

1520 Paper 26. LAC Alfisols and Ultisols of Venezuela.
J. A. Comerma

1540 Paper 27. Occurrence of LAC soils in the United States and Puerto Rico
S. W. Buol

1600 Tea recess

WORK SESSION IX:
ICOMLAC
Chairman: H. Eswaran

1630 Paper 28. Report on status of ICOMLAC.
F. R. Moormann

1700 Briefing on field trips in Thailand.
Lek Moncharoen

1720 Adjourn

MONDAY, 4 SEPTEMBER 1978

FIELD TRIP, Bangkok to Nakhon Ratchasima
Pedon T1: Pak Chong series, Rhodic Paleustult
Lunch at Corn Research Center, Pak Chong
Pedon T2: Si Khiu series, Typic Paleustalf
Pedon T3: Warin series, Typic Paleustalf
Overnight in Kakhon Ratchasima, Chom Surang Hotel

TUESDAY, 5 SEPTEMBER 1978

FIELD TRIP, vicinity of Nakhon Ratchasima
Pedon T4: Korat series, Typic Paleustult
Pedon T5: Yasothon series, Arenic Paleustult
Lunch at Nakhon Ratchasima
Pedon T6: Chok Chai series, Tropeptic Haplustox
Pedon T7: Kula Ronghai series, Aeric Natraqualf
Overnight in Nakhon Ratchasima, Chom Surang Hotel

WEDNESDAY, 6 SEPTEMBER 1978

FIELD TRIP, Nakhon Ratchasima to Chantaburi
Pedon T8: Ban Cheong series, Typic Paleustult
Pedon T9: Kabin Burri series, Petroplinthic Paleustult
Lunch at Kabin Burri
Pedon T10: Phak Khat series, Aeric Paleaquult
Pedon T11: Pung Nga series, Typic Paleudult
Overnight in Chantaburi, Eastern Hotel

THURSDAY, 7 SEPTEMBER 1978

FIELD TRIP, vicinity of Chantaburi
Pedon T12: Phuket series, Tropeptic Haplorthox
Pedon T13: Huai Pong series, Typic Paleudult
Pedon T14: Tha Mai series, Haplic Acrorthox
Pedon T15: Klong Chak series, Typic Paleudult
Lunch at Chantaburi

WORK SESSION X, Eastern Hotel, Chantaburi:
Soil Survey and Classification in LDC's
Chairman: H. Ikawa

1430 Paper 29. Soil Taxonomy in tropical America.
R. Guerrero M.

1500 Paper 30. Report on the Soil Resource Inventories Project of Cornell University.
A. Van Wambeke and T. Forbes

1530 Tea recess

WORK SESSION XI:
ICOMLAC
Chairman: F. R. Moormann

1600 Summary of proposed changes in taxa of LAC Alfisols and Ultisols

1700 Adjourn

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FRIDAY, 8 SEPTEMBER 1978

FIELD TRIP, Chantaburi to Bangkok
Pedon T16: Kho Hong series, Typic Paleudult
Pedon T17: Chalong series, Oxic Plinthustult
Lunch at Travel Lodge
Pedon T18: Ban Bunt series, Arenic Paleustult
Pedon T19: MabBon series, Typic Paleustult
Overnight in Bangkok, Asia Hotel

SATURDAY, 9 SEPTEMBER 1978 - ASIA HOTEL, BANGKOK

WORK SESSION XII:
ICOMLAC
Chairman: J. E. McClelland

0900 Discussion and finalization of proposed changes for taxa of LAC Alfisols and Ultisols
Discussion leader: F. R. Moormann

1200 Lunch

SUMMARY SESSION
Chairman: F. H. Beinroth

1400 ICOMOX - H. Eswaran
ICOMLAC - F. R. Moormann
Recommendations

1530 Tea recess

CLOSING SESSION
Chairman: S. Panichapong

1600 The workshop in retrospect - R. Dudal
The task ahead - F. H. Beinroth
Vote of thanks - A. Van Wambeke
Closing remarks - S. Panichapong

1700 Adjourn

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APPENDIX B

LIST OF PARTICIPANTS

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APPENDIX C
TAXONOMIC EQUIVALENT OF THE PEDONS IN DIFFERENT SYSTEMS

PEDON	SOIL SERIES	SOIL TAXONOMY	FAO/UNESCO LEGEND	FRENCH SOIL CLASSIFICATION
T 1	PAK CHONG	Oxic Paleustult; clayey, kaolinitic, isohypertermic	Dystric Nitosol	Sols ferralitiques moyennement desaturesen (B) typiques, modal (X/211)
T 2	SI KHIU	Rhodic Paleusta fine-loamy, siliceous, isohyperthermic	Eutric Nitosol	Sols fersialitiques sans reserve calcique et lessives, modal (IX/221)
T 3	WARIN	Typic Paleustult; fine-loamy, siliceous, isohyperthermic	Dystric Nitosol	Sols fersialitiques sans reserve calcique et lessives, modal (IX/221)
T 4	KHORAT	Oxic Paleustult; coarse-loamy, siliceous, isohyperthermic	Ferric Acrisol	Sols ferragineux tropicaux lessives, modal (IX/121)
T 5	YASOTHON	Oxic Haplustult; coarse-loamy, siliceous, isohyperthermic	Ferric Acrisol	Sols fersialitiques sans reserve calcique et lessives, modal (IX/221)
T 6	CHOK CHAI	Typic Haplustox; clayey, kaolinitic, isohyperthermic	Rhodic Ferralsol	Sols ferralitiques fortement desaturesen (B) typiques, modal (X/311)
T 7	KULA RONGHAI	Typic Natraqualf; fine-loamy,mixed, isohyperthermic	Gleyic Solonetz	Sols sodiques a horizon B (XII/22)
T 8	BAN CHONG	Oxic Paleustult; clayey, kaolinitic, isohyperthermic	Dystric Nitosol	Sols ferralitiques, fortement desaturesen (B) lessives, modal (X/361)
T 9	KABIN BURI	Oxic Haplustult; clayey-skeletal, kaolinitic, isohyperthermic	Ferric Acrisol	Sols ferralitiques fortement desaturesen (B) lessives, modal (X/361)
T 10	PHAK KHAT	Aeric Tropaqualf; fine, mixed isohyperthermic	Gleyic Luvisol	Sols hydromorphes peu humiferes a gley, profond (XI/312)

PEDON	SOIL SERIES	SOIL TAXONOMY	FAO/UNESCO LEGEND	FRENCH SOIL CLASSIFICATION
T 11	PHANG NGA	Typic Paleudult; clayey, kaolinitic, isohyperthermic	Ferric Acrisol	Sols ferralitiques fortement desaturesen (B) lessives, modal (X/361)
T 12	PHUKET	Orthoxic Tropudult; clayey, kaolinitic, isohyperthermic	Ferric Acrisol	Sols ferralitiques fortement desaturesen (B) typiques, penevolue (X/315)
T 13	SONGKLA	Plinthic Paleaquult; fine-loamy, mixed, isohyperthermic	Dystric Nitosol	Sols hydromorphes peu humiferes a gley, lessives (XI/314)
T 14	THA MAI	Typic Haplorthox; clayey, kaolinitic, isohyperthermic	Orthic Ferralsol	Sols ferralitiques moyennement desaturesen (B) typiques, modal (XI/314)
T 15	KLONG CHAK	Typic Paleudult; clayey-skeletal, kaolinitic, isohyperthermic	Dystric Nitosol	Sols ferralitiques moyennement desaturesen (B) appauvris, faiblement remanie (X/235)
T 16	KHO HONG	Typic Paleudult; fine-loamy, siliceous, isohyperthermic	Dystric Nitosol	Sol ferralitiques fortement desaturesen (B) lessives, modal (X/361)
T 17	CHALONG	Oxic Plinthustult; clayey, kaolinitic, isohyperthermic	Plinthic Acrisol	Sols ferralitiques fortement desaturesen (B) lessives, modal (X/361)
T 18	BAN BUNG	Arenic Paleustult, sandy, siliceous, isohyperthermic	Ferric Acrisol	Sols ferrugineux tropicaux lessives, hydromorphe (IX/124)
T 19	SURIN	Oxic Paleustult; clayey-skeletal, kaolinitic, isohyperthermic	Eutric Nitosol	Sols ferralitiques faiblement desaturesen (B) remaniea, modal (X/131)