Properties, Classification, and Management of Oxisols

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The Guy D. Smith Memorial Slide Set

Oxisols

Historical Background

003 - 1807 is frequently used as the benchmark year for studies on the soils of the tropics. In that year, Francis Buchanan, a British medical doctor and naturalist published his historical document of his travels in South India (Buchanan, 1807) wherein he described the material used for constructions. He coined the term “laterite” which is still used today but with a wide variety of meanings. The slide shows a monument built by the Geological Survey of India in December 1979, to commemorate Buchanan’s contribution (the lower part of the monument is draped in the kilt of the Buchanan clan). The monument is built at the Government Guest House at Angadipuram, Kerala State, where Buchanan described laterite and which is today considered as the type locality. In modern terminology, the material is called plinthite and when it is exposed, it hardens to a rock-like material very suitable for construction of small structures.

004 - Dr. Guy D. Smith (smoking a cigar) is considered the father of Soil Taxonomy. In 1950, Dr. Charles Kellogg, then the Administrator of the Soil Conservation Service, charged Dr. Smith to develop a new classification system as the existing system of Thorp and Smith (1949) was proving inadequate to meet the needs of the expanding national soil survey program. Dr. Smith made this his life’s challenge and guided the development of Soil Taxonomy not only to the time of its publication in 1975 but also almost until his death in 1983. The person in the red hat is Dr. Stanley Buol, who headed the International Committee on Oxisols (ICOMOX). The person in the blue pullover is Dr. Juan Comerma from Venezuela, who provided a South American perspective to the knowledge of Oxisols.

005 - Major contributions to the classification of Oxisols were provided by the Brazilians under the leadership of Dr. Marcelo CamargoD, with the blue cap, of EMBRAPA-SNLCS and Dr. Jacob BennemaD (then working for FAO). In fact, many of the basic concepts and definitions of Oxisols were modified from the Brazilian classification. In the slide are Dr. Camargo and the current Director of EMBRAPA-CNPS, Dr. Antonio Ramalho. They and their colleagues made their knowledge, experience, and database available to ICOMOX.

006 - In 1978, USDA-SCS established the International Committee on Classification of Low Activity Clay soils (ICOMLAC) with Dr. Frank Moormann (then at the International Institute of Tropical Agriculture, Nigeria) as the Chairman (Moormann, 1985). Later, ICOMLAC and ICOMOX, worked together. In the slide are Drs. Moormann (white hat), Hari Eswaran (yellow hat) and Rene TavernierD (red hat). Dr. Tavernier of the University of Ghent, Belgium, worked closely with Dr. Guy Smith and contributed to the terminology of Soil Taxonomy. His experience of the soils of Zaire was valuable to bring the Central African experience to the classification.

007 - Oxisols have a unique mineralogy and chemistry. Dr. Goro Uehara from the University of Hawaii and his students and colleagues, provided much of the basic information to understand the properties and behavior of the colloid composition. Dr. Uehara, with the blue shirt, also provided the basic concept and definition of low activity clays.

008 - European colleagues have a long history of soil survey and research in the tropics and many of the European classification systems have classes equivalent to Oxisols. Prof. Karel Sys of Belgium (whose face appears on the left of the slide), Prof. Tavernier, Dr. Klaus Flach of USDA-SCS, Prof. Dr. Ernst Schlichting of Germany, and Dr. Marcel Jamagne of France, are some of the contributors.

009 - Dr. Lek Moncharoen (Thailand, with spear) and Dr. Fred Beinroth (University of Puerto Rico) jointly organized the workshop held in Thailand and Malaysia. Dr. Beinroth organized a total of 10 workshops on soil classification during the period 1976 to 1990. These workshops provided the venue for soil scientists from all over the world to meet and discuss Soil Taxonomy. The Circular Letters of the International Committees provided the communication among all interested persons.

010 - Prof. George Aubert (ORSTOM, France) is the author of the French CPCSS classification (Aubert, 1958) and his more than 30 years of experience in the tropics provided the field information for all international classification systems. He and his school also injected the strong genetic bias in not only the French system but in all other classification systems.

011 - Dr. Francesco Palmieri of Brazil is one of the soil scientists with a strong field background in soil survey who provided practical inputs to the system.

012 - The slide shows the participants of the 8th. International Soil Classification Workshop held in Brazil in 1986. A major purpose of the workshop was the discussion of the issues that were highlighted in the Circular Letters of ICOMOX. State-of-the-art papers were also submitted at such workshops and were included in the proceedings. (The workshop proceedings are highlighted in the Bibliography).

Oxisols

Concept, Definition and Diagnostic Criteria

Some Synonyms for Oxisols

Red Earths

Ground-water laterites

Latosols

(some) Kraznozems

Kaolisols

Zheltozems

Sols Ferrallitiques

Ferralsols

Oxisols

Facts

Oxisols only occupy about 23% of the tropics and plinthite is less than 1% of all Oxisols.

If managed properly, oxisols are highly productive.

Oxisols

Myth:

"Over a very large part of the tropics, the soil has become laterite. That is, through leaching the main plant foods...are removed from the top horizons of the earth. What is left is a reddish mottled clay, consisting almost entirely of hydroxides of iron and alumina whose most distinguished trait is the tendency to solidify on exposure to air... The pure laterites and latosols cover the greater part of the tropics and are either agriculturally poor or virtually useless" (Kamark, 1972).

016 - During the historical development of the concept of Oxisols several myths were perpetuated. Part of the reason for this was due to the absence of reliable databases and an incomplete knowledge of the nature and properties of Oxisols. In the early years of the use of Soil Taxonomy, persons were not rigidly using the Keys to the classification and as a result, some soils were misclassified. This was corrected to some extent through the training courses and workshops conducted by the USDA-NRCS/World Soil Resources group.

Oxisols

Oxisols characteristically occur in tropical regions on landscapes that have been stable since at least the early Pleistocene and sometimes since the mid- or end-Tertiary period. Oxisols typically develop in humid tropical climates, but because of past climate change some are even found in areas bordering arid environments.

017 - Large contiguous areas of Oxisols are found on old geomorphic surfaces, such as the Congo Basin and the Amazon Shield. These surfaces are peneplained and are comprised of mid- to end-Tertiary deposits, some of them pre-weathered. Oxisols have developed on such deposits. In general these old peneplains are flat but some have been dissected. In SE Asia and in Oceania, where the landscapes are Quaternary, Oxisols are formed on basic or ultrabasic rocks which are highly weatherable.

Unique properties of Oxisols

- Extreme weathering of primary minerals, other than the resistant ones such as quartz and zircon, to kaolinite and oxyhydrates of Fe and Al;

- Very low physical and chemical activity of the clay fraction; and

- Loamy or clayey texture.

Oxic Horizon Definition

1. A thickness of 30 cm or more;
2. A particle size of sandy loam or finer,
3. <10% weatherable minerals in the 50 to 200 micron fraction;
4. Rock structure <5% of its volume or with sesquioxide coatings on lithorelicts with weatherable minerals;
5. A diffuse upper particle size boundary or does not meet the requirements of a kandic horizon;
6. A CEC of <16 or ECEC<12cmol+ per kg clay. The oxic horizon does not have andic properties.

019 - Key to the identification of Oxisols is the presence or absence of two diagnostic horizons -- the oxic and kandic horizon -- and the particle-size class of the surface 18 cm of the soil. The slide states the definition of the oxic horizon. A subsurface horizon must meet all the properties to qualify for an oxic horizon.

The Kandic Horizon

The Kandic horizon is a diagnostic horizon that combines properties of both the argillic and oxic horizons. The Kandic horizon is diagnostic for Oxisols only if it underlies a coarser textured surface horizon that has 40% or more clay, and the horizon has a weatherable mineral content similar to the oxic horizon.

Defining properties include:

- In most cases, a minimum thickness of 30cm,
- the chemical requirements of Oxisols in >50% of thickness,
- a loamy fine sand or finer particle size

020 - The kandic horizon shares some of the properties of the oxic and argillic horizons. Like the argillic, it has a clay increase with depth. On the other hand, it has the charge characteristics and weatherable mineral requirements of an oxic horizon.

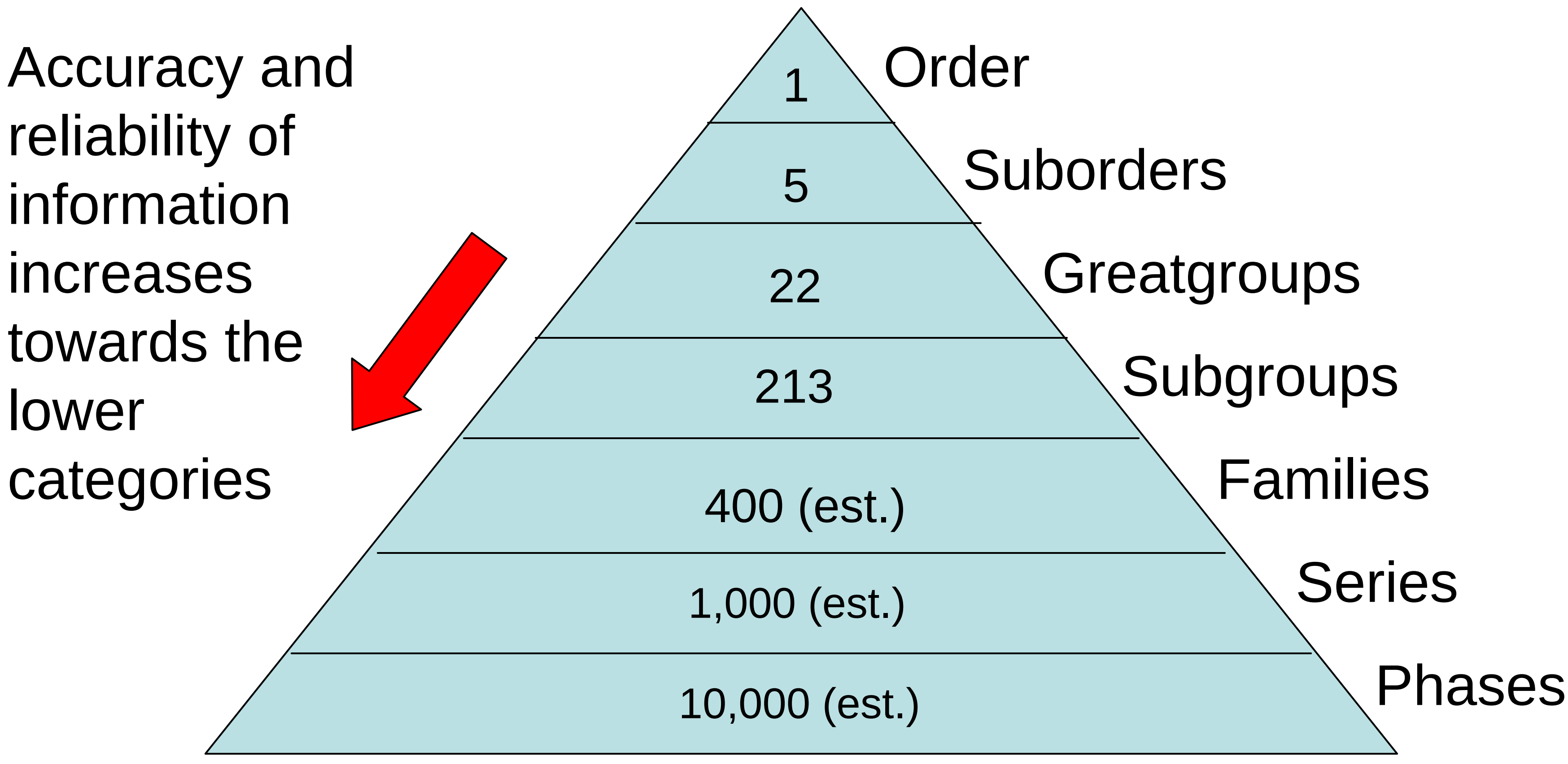
Oxic Horizon Definition

- An oxic horizon, that has its upper boundary within 150 cm of the mineral soil surface, and no kandic horizon that has its upper boundary within that depth; or

- 40% or more clay in the fine-earth fraction between the soil surface and a depth of 18 cm (after mixing), and a kandic horizon that has weatherable mineral content of an oxic horizon and has its upper boundary within 100 cm of the mineral soil surface.

021 - There are two parts to the definition of Oxisols.

Information content and reliability of predictions of soil performance as a function of categories in Oxisols



Number of classes in each category

022 - There are several categories in Soil Taxonomy, with the Order being the highest category. Each of the 12 Orders has a number of Suborders each of which is divided into lower categories as shown in the slide for Oxisols. At each categorical level, Soil Taxonomy provides a key for the identification of the class at the next level and it is imperative that the key be used for the identification of the class. An important feature of the structure into categories is that, as the soil is placed into lower categories, the information content in the taxa name increases in two ways; first, by the definition of the category and, second, due to the elimination of the other classes (so by default the soil will not have properties definitive for the classes it does not belong to).

023 - The sombric horizon is a dark colored subsurface horizon found in soils on old geomorphic surfaces of Central Africa and parts of South America. It is a distinctive horizon in the field and to some, it is indicative of a buried horizon. Its origin and genesis is still being debated but it is included as a diagnostic horizon in Soil Taxonomy due its distinctive feature in an otherwise nondescript soil. Mostly, it occurs as a continuous horizon within 1 m of the soil surface.

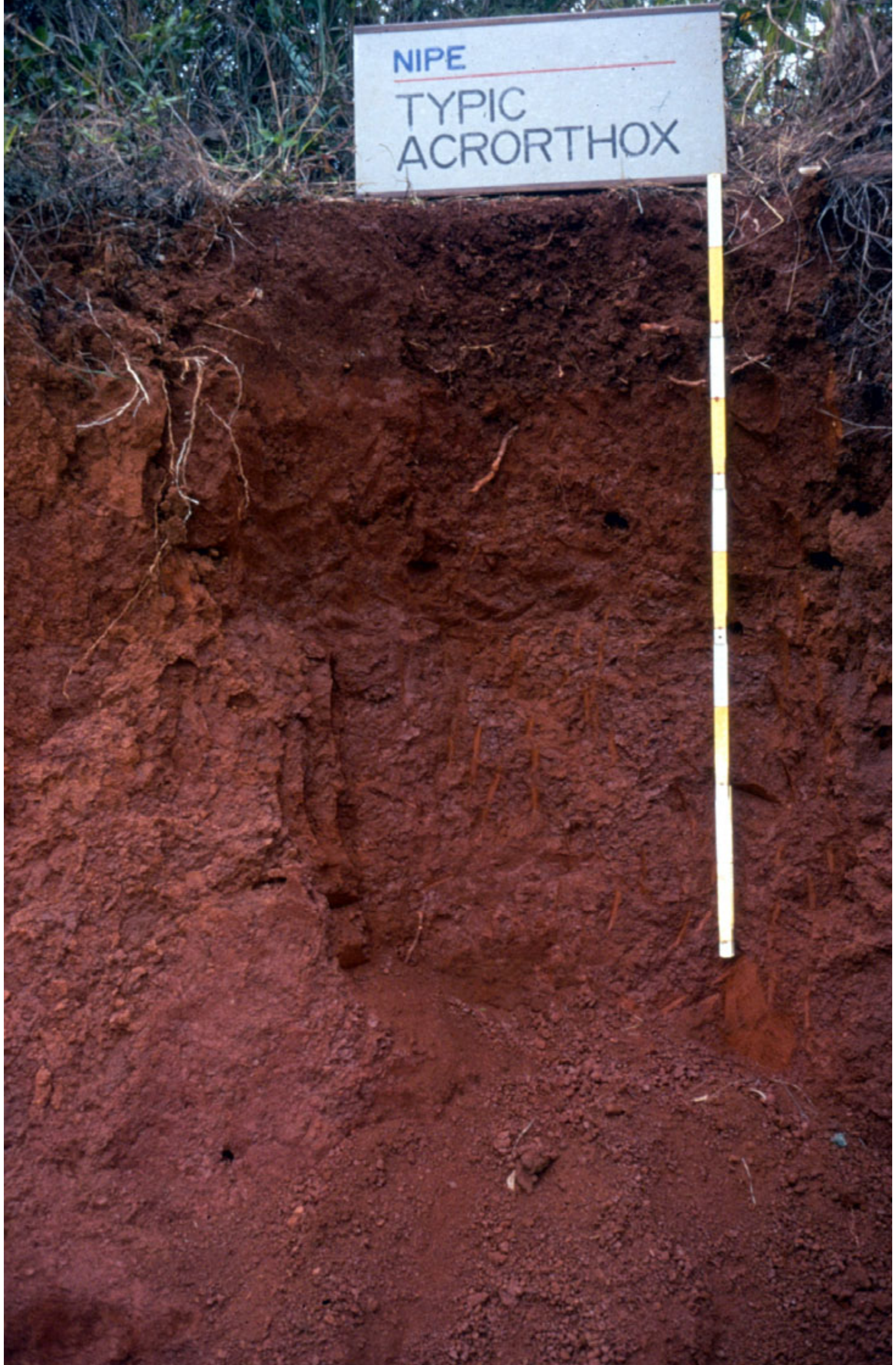
024 - The higher organic carbon content of the sombric horizon is its most important property. In this low CEC soil, the higher carbon results in a higher CEC and thus the ability to store nutrients and water. In this slide from Rwanda, the sombric horizon in this road-cut is covered with moss as compared to the overlying or underlying layers. This points to some of the plant favorable properties of this subsurface horizon.

025 - Some members of the Oxisols, as this soil from Brazil, have an aquic soil water condition whereby a major part of the soil is saturated with water during long periods of the year. When the soil is saturated, redox conditions prevail and Fe2+ is moved out of the system resulting in a whitish, iron impoverished soil. The iron precipitates in the lower part of the soil (not seen in the slide) and leads to the formation of plinthite.

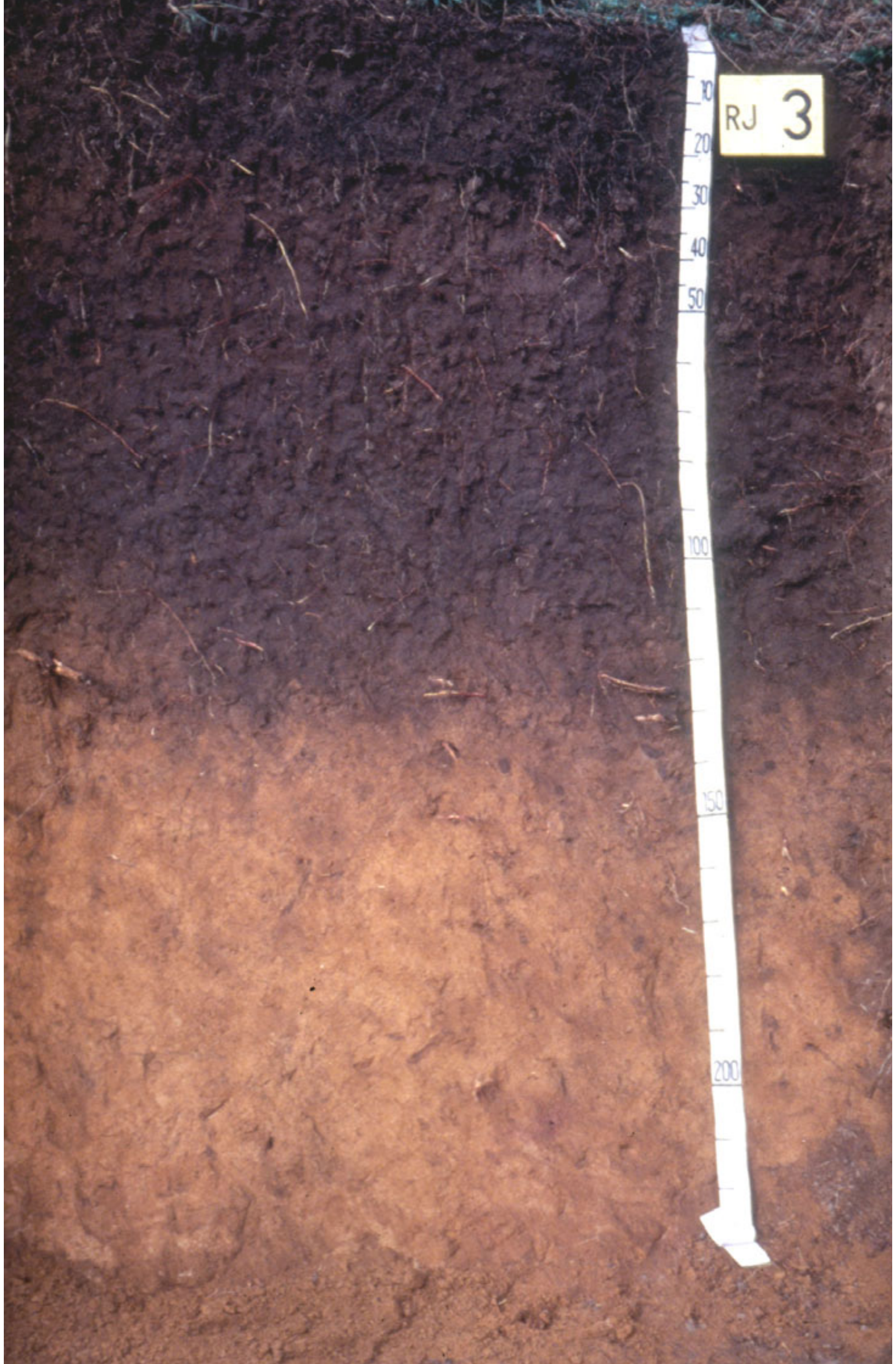
026 - Plinthite is a diagnostic feature of many soils which are hydromorphic or have gone through a hydromorphic phase during their evolution. The slide is a close-up of a continuous phase of plinthite in a soil from Malaysia. Plinthite is the reddish material which forms a dendritic pattern. The white material is largely kaolinite and quartz, and is devoid of iron. (Bar on left side has 10 cm intervals.)

027 - In a deep profile in Kerala State, India, the lower zone is largely plinthite which is soft and can be cut with a knife. The upper, more reddish zone, is plinthite which is in stages of hardening towards the stage called petroplinthite. Hardening of plinthite takes place slowly when the ground-water table is lowered and the soil surface ground cover is removed. If the surface non-plinthic soil horizons are eroded away, the underlying plinthite is exposed and hardens rapidly to petroplinthite.

028 - A petroferric contact is an abrupt contact between soil material and an underlying layer of hard and impermeable, cemented petroplinthite gravel. The contact is impermeable to both roots and water. The slide is of a soil (Wenchi series) in Bolgatanga, Ghana, close to the border with Burkina Faso. The petroferric contact begins at between 10 and 20 cm in this profile. During the rainy season, the soil material above the contact is saturated and there may even be ponding. Rice is grown in this condition. After the rains, a crop of millet is grown on the residual moisture stored in the top soil.



029 - The surface horizon or epipedon in most lowland Oxisols is light colored and is an ochric epipedon. The organic carbon may be high (easily qualifying for a mollic or umbric epipedon) but the value and chroma is more than 3.5. The horizon is also usually thin, about 10 cm thick, and this is frequently lost by erosion. Residue management is a critical practice on such soils as this one from Puerto Rico.



030 - In soils of higher elevations or those with an isothermic soil temperature regime, organic matter generally increases in the surface horizon. Many of the Oxisols in cool zones have a mollic or umbric epipedon as shown in the slide. Presence of this epipedon is a most favorable property in these nutrient deficient Oxisols and every care must be taken to preserve these surface horizons.

Oxisols

Taxonomic Classification

032 - The Key to the Orders enables the placement of the soil at the Order level. If the soil does not meet the requirements of Gelisols, Histosols, Spodosols, or Andisols, then the soil properties are tested against the requirements for Oxisols. If the requirements are met, the Key will direct the reader to the Key for the Suborders.

Oxisols - Suborders
Identification of Taxonomic Class

1. Oxisols that have aquic conditions:

AQUOX

2. Other Oxisols that have an aridic soil moisture regime:

TORROX

3. Other Oxisols that have an ustic or xeric soil moisture regime:

USTOX

4. Other Oxisols that have a perudic soil moisture regime:

PEROX

5. Other Oxisols:

UDOX

033 - The Key to the Suborders is used in the same manner as that for the Orders. This slide summarizes the requirements for Oxisol suborders. However, for correct placement, the complete definitions provided in the Key should be followed.

Taxonomy of Oxisols

Differentiating Criteria for Suborders

- Soil Moisture Regimes
- Aquic Conditions
- Histic Epipedon
- Soil Color

034 - There are two important sets of differentiating criteria used in the classification of Suborders. The first set is the soil moisture regimes (which are discussed later) such as torric (aridic), ustic, udic, and perudic. The second is a set of criteria which together define the aquic conditions. This includes the aquic soil water conditions *ss*, the presence of a histic epipedon, and some restrictive soil color requirements. Each of these criteria adds another set of properties to the soil that is being classified.

Taxonomy of Oxisols

Suborder and Greatgroup taxa

Suborder	Greatgroup	No. Subgroups
Aquox	Acraquox	3
	Eutraquox	5
	Haplaquox	5
	Plinthaquox	2
Perox	Acroperox	13
	Eutroperox	16
	Haploperox	14
	Kandiperox	14
	Sombriperox	4

035 - Each of the Suborders has a set of Great Groups. The number of Subgroups in each Great Group is also provided in the slide. Note that the kind of Great Groups differ in each of the Suborders. For example, there is no “Sombriaquox” in the Aquox because no such soils have been described.

Taxonomy of Oxisols

Suborder and Greatgroup taxa

Suborder	Greatgroup	No. Subgroups
Udox	Acrudox	15
	Eutrudox	16
	Hapludox	15
	Kandiudox	14
	Sombriudox	4
Ustox	Acrustox	15
	Eutrustox	16
	Haplustox	13
	Kandiustox	16
	Sombriustox	4

036 - The Ustox, Udox, and Perox have the most Great Groups due to the wide extent of these soils and the large supporting database.

Taxonomy of Oxisols

Suborder and Greatgroup taxa

Suborder	Greatgroup	No. Subgroups
Torrox	Acrotorrox	3
	Eutrotorrox	3
	Haplotorrox	3

037 - List of the Torrox Great Groups.

Oxisols – Great Groups
Taxonomic Classes

Structure of Great Group names:

Plinthaquox
Eutrotorrox
Kandiustox

	Aquox	Torrox	Ustox	Perox	Udox
With acric properties	Acr	Acro	Acr	Acro	Acr
With plinthite	Plinth				
With high base saturation	Eutro	Eutro	Eutr	Eutro	Eutr
With kandic horizon			Kandi	Kandi	Kandi
With sombric horizon			Sombri	Sombri	Sombri
Other	Hapl	Haplo	Hapl	Haplo	Hapl

038 - This is a summary slide showing the formative elements for the Great Groups and their use in each Suborder. For example, the Plinthaquox Great Group belongs to the Aquox suborder; the Eutrotorrox belongs to the Torrox suborder, and the Kandiustox great group belongs to the Ustox suborder.

Taxonomy of Oxisols
Differentiating criteria for Subgroups

- Al & Fe percentages
- Andic-like properties
- Organic carbon content
- Cation exchange capacity
- Petroferric contact
- Plinthite
- Sombric horizon
- Aquic conditions
- Delta pH
- Kandic horizon
- Histic epipedon
- Lithic contact
- Soil color
- Soil depth

039 - The large number of Subgroups requires many differentiating criteria; some significant ones are shown in the slide

Oxisols
Taxonomic Classes - Subgroups

Select Subgroup adjectives are listed with their meanings:

Histic -	with histic epipedon
Plinthic -	with plinthite
Aeric -	better drained
Humic -	greater than 16 Kg per square meter organic carbon
Petroferric -	with a cemented horizon
Aquic -	with aquic conditions
Lithic -	with lithic contact
Plinthaquic -	with both aquic conditions and plinthite
Rhodic -	with red color
Xanthic -	with yellow color
Typic -	other soils

Oxisols
Family Differentiae

- Particle-size class
- Mineralogy class
- Soil temperature class

041 - At the Family level, three differentiae are used together with the Subgroup name to name the Family class.

Oxisols
Family Differentiae

Particle-size classes

- Skeletal:
    - Sandy-skeletal,
    - Loamy-skeletal,
    - Clayey-skeletal
- Sandy
- Loamy:
    - Coarse-loamy,
    - Fine-loamy,
    - Coarse-silty,
    - Fine-silty
- Clayey:
    - Fine
    - Very fine

042 - The first differentiae is the particle-size class and several classes are provided. Soil Taxonomy provides the definition for each class.

Oxisols – Mineralogy Classes Key to Identification

1. >40% iron oxides in fine earth fraction
2. >40% gibbsite in fine earth fraction
3. 18-40% iron oxides in fine earth fraction
4. 18-40% gibsite in fine earth fraction
5. >50% kaolinite in <0.002 mm fraction
6. >50% halloysite in <0.002 mm fraction

Mixed - If none of the above
Ferritic - 1 with/without 2,3,5,6
Gibbsitic - 2 with/without 3,5,6
Ferruginous - 3 with/without 5,6
Allitic - 4 with/without 5,6
Sesquic 3 & 4 with/without 5,6
Kaolinitic - 5
Halloysitic - 6

043 - The second differentiae is the mineralogy class and the mineralogy classes in Oxisols are presented as a Key.

Family Differentiae for Oxisols

Soil Temperature Regimes

Temperate:	**Tropical:**
Mesic	Isomesic
Thermic	Isothermic
Hyperthermic	Isohyperthermic
Megathermic	Isomegathermic

044 - The third differentiae for the Family level is the soil temperature class and the possible soil temperature regimes are listed.

Family name - clayey, kaolinitic, isohyperthermic, Aquic Petroferric Kandiustox

Implications:

- More than 35% clay in the oxic horizon. The clay mineral is dominantly kaolinite, nutrient retention is low.
- Seasonal soil temperature variation is low. Summer soil temp. particularly surface temp. may be greater than 60 degrees Celsius affecting seed germination.
- Soil surface crusting may occur.

045 - It is now possible to present the complete Family classification of a soil as illustrated in the slide. The Family name carries the Family modifiers and the name of the Subgroup. The next level is the Soil Series. The typifying Series in a Family can be used to provide an alternative and local name of the Family. For example, if this Family has Kluang Series as the central family member, then the soil is said to belong to the Kluang Family of soils.

Order Name: Oxisols

Implication:

•Has an oxic horizon with its upper boundary within 150cm of soil surface, or

•Has 40 % or more clay between the soil surface and 18cm depth and a kandic horizon with no weaterable minerals.

Suborder Name: Ustox

Implications:

- Has an ustic soil moisture regime.
- Has a few months in a year when the soil experiences moisture stress.
- Is a well drained soil.

Greatgroup name: Kandiustox

Implication:

- Has more than 40% clay between the soil surface and 18 cm depth.
- Has a kandic horizon, or has a clay increase with depth.
- Surface soil has a good tilth.
- Subsoil can retain more nutrients and moisture.

Subgroup Name: Aquic Petroferric Kandiustox

Implication:

•Has seasonal moisture saturation and seasonal deficit.

•Has a petroferric contact within 125 cm of the soil surface.

•Petroferric contact perches water and is impermeable to roots.

•Soil is effectively shallow and may experience water-logged conditions during wet season and moisture stress conditions during dry season.

Family name - clayey, kaolinitic, isohyperthermic, Aquic Petroferric Kandiustox

Implications:

- More than 35% clay in the oxic horizon. The clay mineral is dominantly kaolinite, nutrient retention is low.

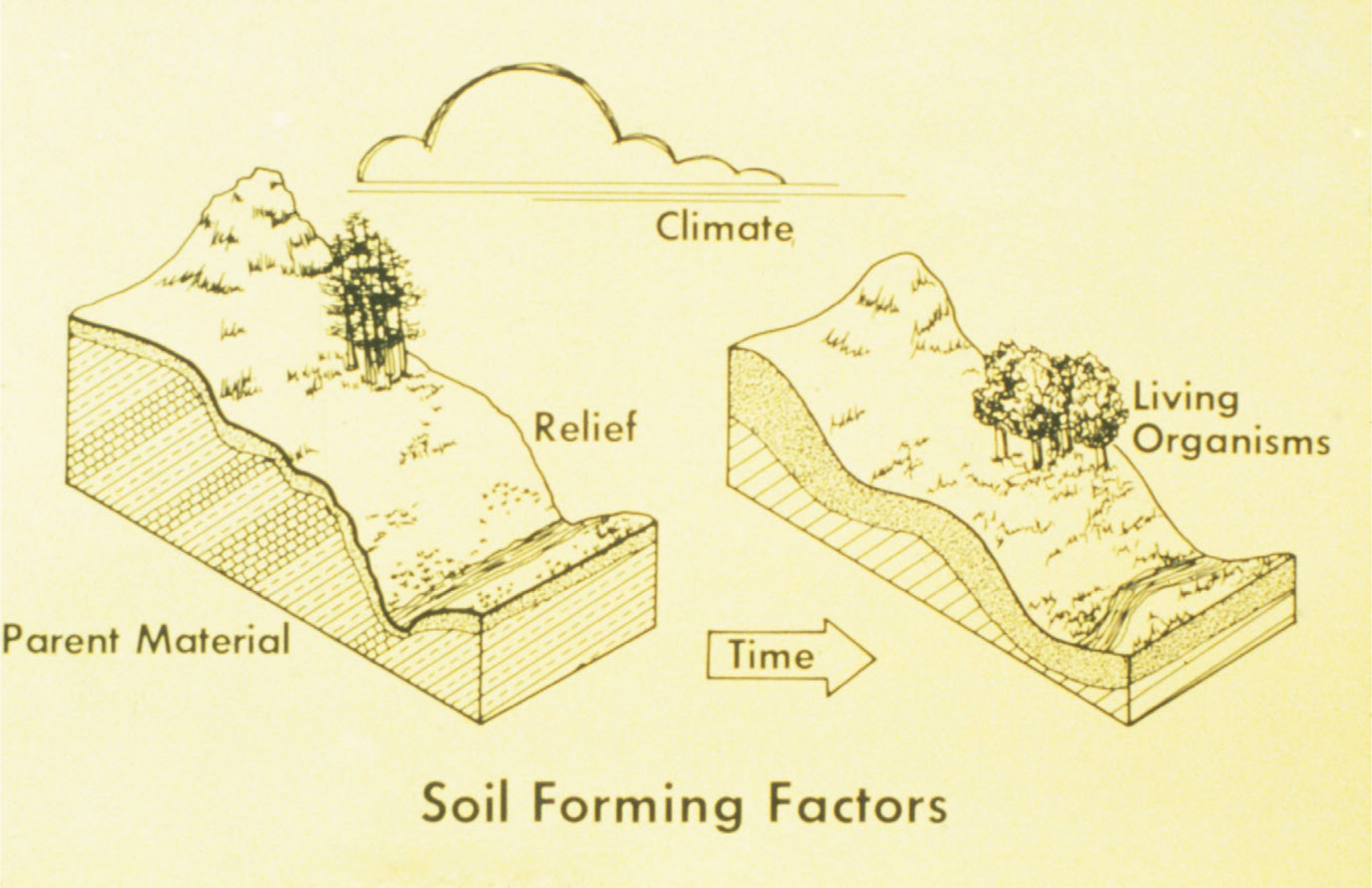
- Seasonal soil temperature variation is low. Summer soil temp. particularly surface temp. may be greater than 60 degrees Celsius affecting seed germination.

- Soil surface crusting may occur.

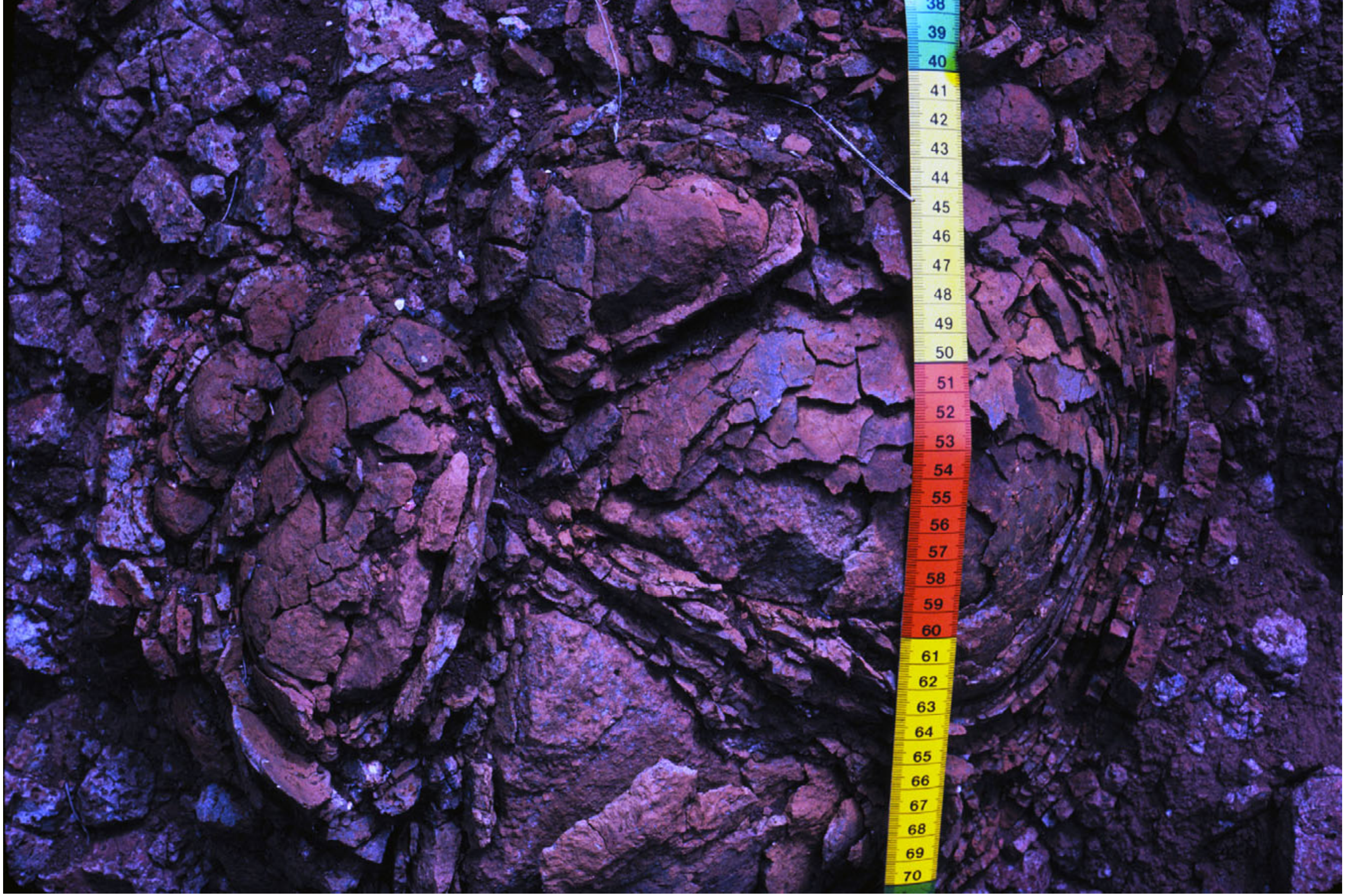
50 - Thus, by arriving at the Family level of classification, a whole range of properties can be inferred from the soil name. This is one of the advantages of the nomenclature of Soil Taxonomy which is absent in most other classification systems. It is now possible to give a name to a soil based on its properties and, equally important, dissect the name and derive the properties from the name.

Oxisols

Formation and Landscape Relationships

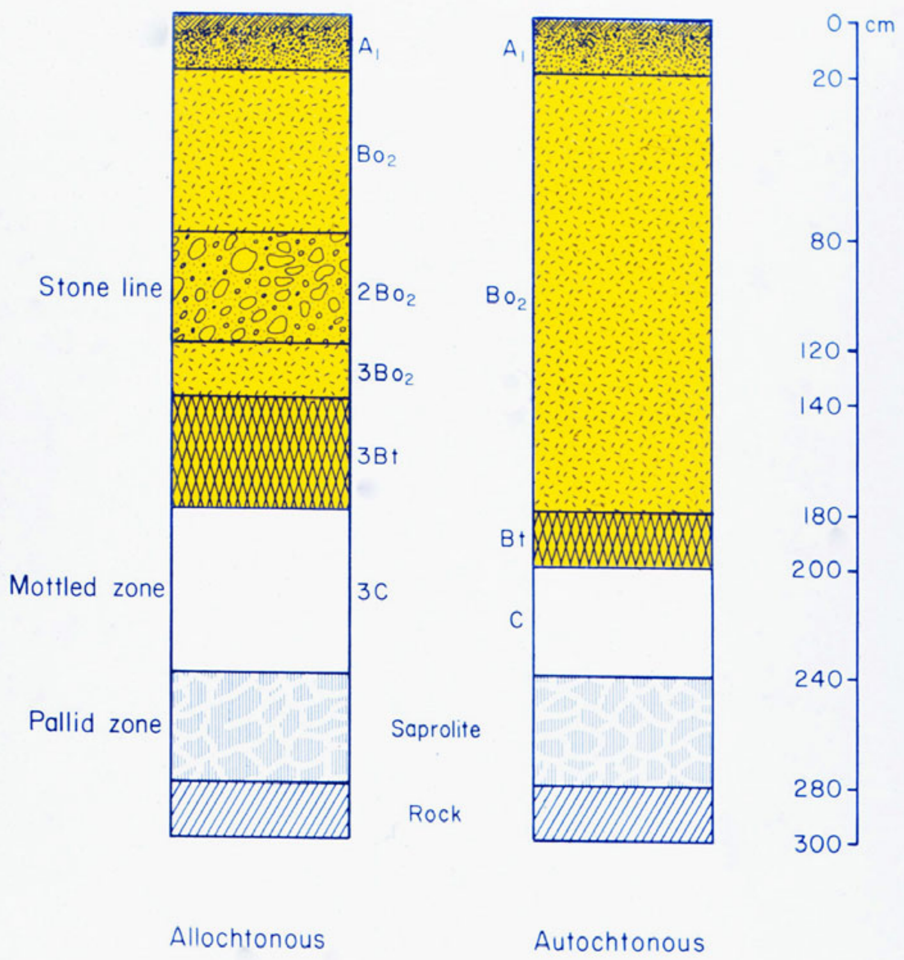


052 - The slide shows a diagram illustrating the classic factors of soil formation. A factor which is more important in the formation of Oxisols than in many other kinds of soils is the geomorphic evolution of the landscape. Landscape genesis determines many of the soil characteristics and may have a greater influence in determining the properties of the soil than the other factors of soil formation.



053 - Weathering of a rock is a first step leading to soil formation. In the slide, basalt shows exfoliation (onion structure) due to weathering. The foliation is caused by temperature and moisture changes during the year. Other rocks may show other morphological changes upon weathering.

054 - On old landscapes, landscape deformation is an important process. On sloping land, soil creep displaces the soil. The slide shows a quartz vein being dislodged and broken up leading to the formation of a stone-line. Stone-line formation, more frequently, results from geologic erosion and deposition. Stone-lines frequently suggest that the soils are formed on transported deposits and points to the allochtonous nature of the material.



055 - The diagram illustrates an allochtonous (transported) and autochtonous (in situ) profile. The former frequently has stone-lines while the latter shows the classical sequence of horizons -- soil-saprolite-rock -- with no interruptions or discontinuities.

056 - Climatic and geomorphic processes are not the only processes operating to form or modify the soil. In the tropics, biological activity is very high. Due to the high surface temperatures, many organisms live below ground. The termite nest, seen in the slide, is characteristic of semi-arid landscapes in the tropics. Termite activity homogenizes the soil and frequently erases the products of soil formation, such as cutans or clay skins. Termites also transport organic matter from the soil surface to deep layers in the soil where decomposition is much slower. Many soils of the tropics, particularly Oxisols, have much higher amounts of soil organic carbon than their counterparts in temperate regions.

057 - Oxisols occur in a wide variety of landforms and climates. This slide from the semi-arid southwest of Puerto Rico shows an undulating topography with an ustic soil moisture regime.

058 - Oxisols can also form in more dissected landscapes as in the tropical rainforest in northeastern Puerto Rico which has a perudic soil moisture regime.

059 - The slide shows an Oxisol (Nipe soil -- Anionic Acrudox) from Puerto Rico formed on ultrabasic rocks (exposed on the left of the picture). The rock on the right of the picture is an andesitic rock and weathers to form a brown soil. The Nipe soil, which is dark red, can be seen moving downslope onto the brown soil. This process is called soil creep, which is not very evident in other soils.

060 - Peneplanation results in slightly undulating or nearly level landforms as seen in the foreground of this landscape in Puerto Rico. This geomorphic surface is a remnant of the St. John Peneplain that has escaped erosion. Oxisols occupy the flat landforms. The faint skyline at the horizon represents concordant hills that mark the surface of the Tertiary peneplain that is now undergoing erosion and dissection.

061 - The tops of the concordant hills have a rolling landscape as shown in this picture. The soils on the upper part of the low hills are Oxisols. Ultisols occur on the side-slopes, and towards the valleys, Inceptisols and Entisols are present. This is a view of the St. John Peneplain in Puerto Rico.

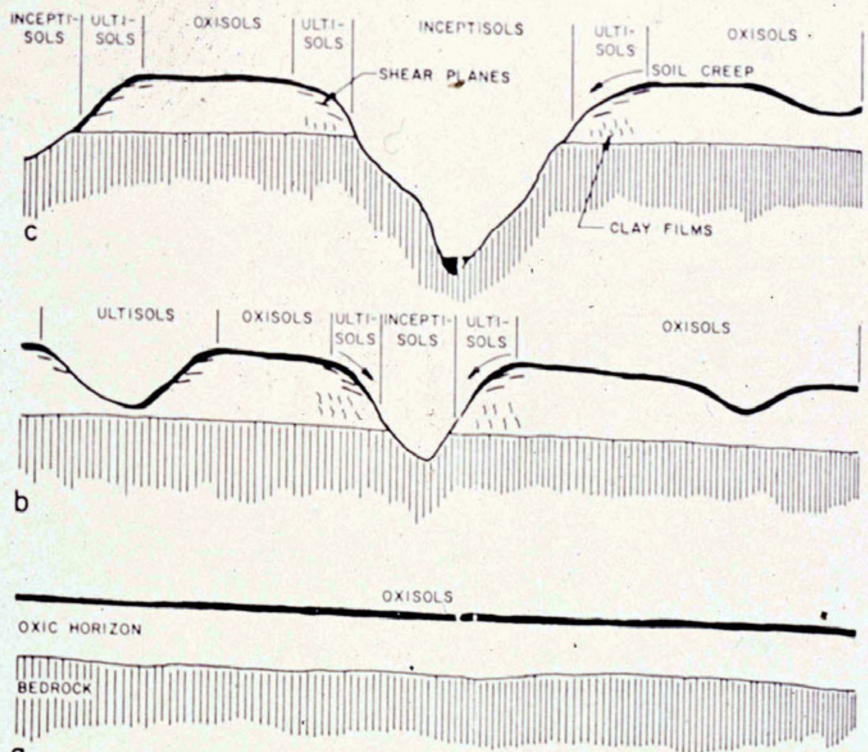


Fig. 7—Sketch illustrating different stages of dissection of an Oxisol-surface and the resulting Inceptisol-Ultisol-Oxisol pattern. a . . . undissected; b . . . moderately dissected; and c . . . strongly dissected.

062 - Landscape relations are shown in this diagram of Beinroth et al. (1974). The diagram illustrates an originally flat lava flow undergoing dissection. Erosion and dissection reduces the general level of the landscape. Accompanying this is the general cutting down of the drainage way, which effectively lowers the ground water-table. All of these processes affect the soil characteristics and properties.

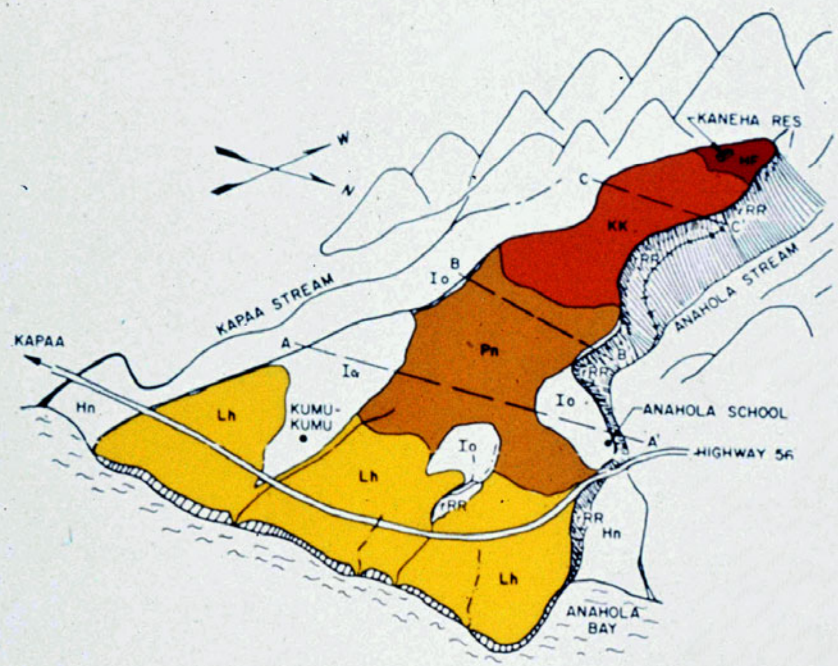


Fig. 5—Generalized soil-geomorphic pattern on Kumukumu surface, Kamalomaloo area, NE Kauai, Hawaii. Hf = Halii (Gibbsihumox); Hn = Hanalei (Fluvaquents); Io = Ioleau (Tropohumults); Kk = Kapaa (Gibbsiorthox); Lh = Lihue (Eutrorthox); Pn = Puhi (Eutrorthox); and rRR = rough broken land.

063 - This slide is another illustration of the landscape relationships of Oxisols (Beinroth et al., 1974). This sequence is in Hawaii where the kind of soil is a function of not only the slope but also the number, kind, and thickness of the pyroclastic layers (see slide 64) that is present. There are other landscape relation studies and the reader is referred to the papers of Lepsch and Buol (1974 and 1977) for a study in Brazil.

064 - These soils in Hawaii formed on two generations of pyroclastic materials. The upper material is weathered to form an Oxisol. The buried material has Ultisol features.

Oxisols

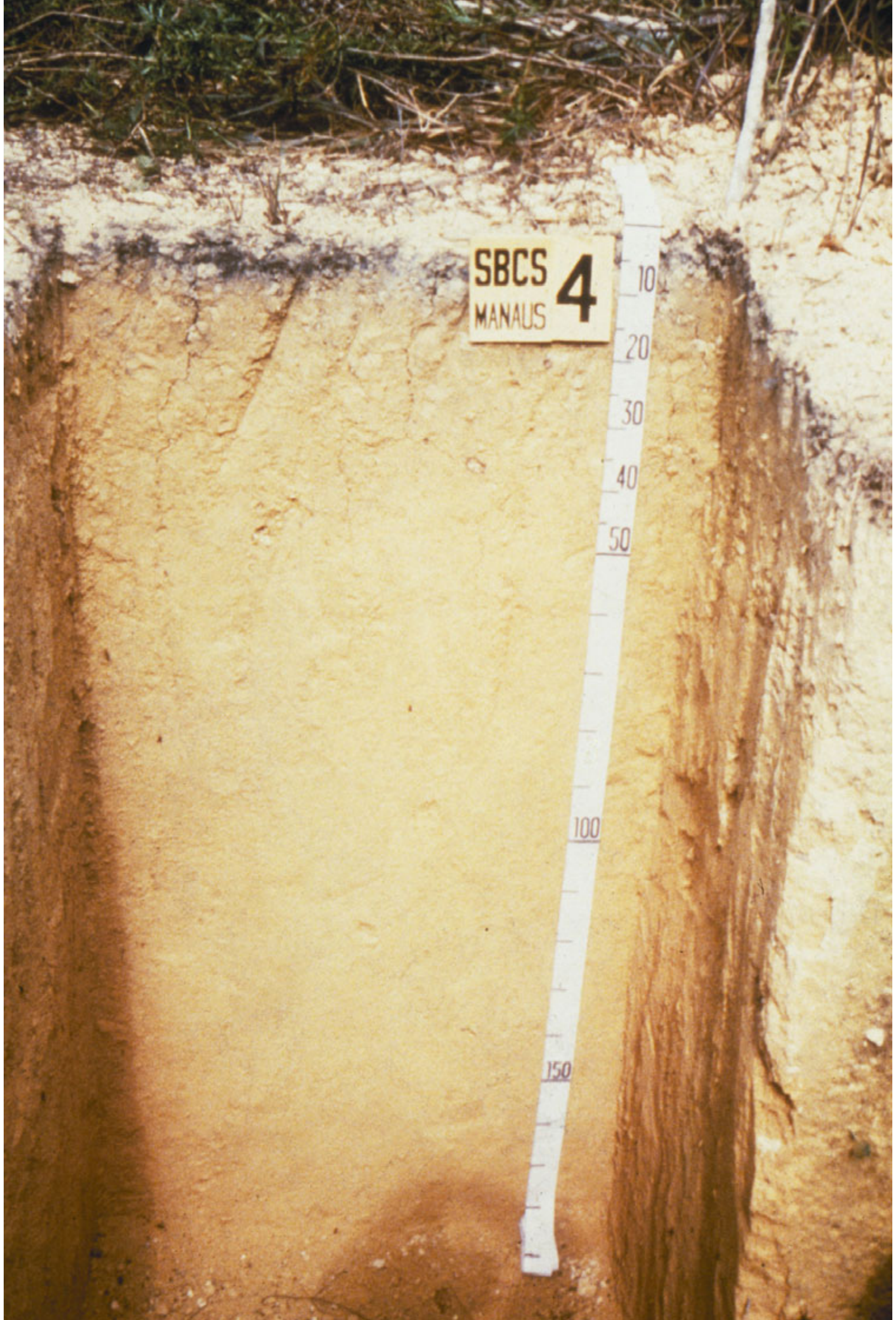
Morphology

066 - The slide shows a deep soil formed on Tertiary transported materials at Malacca, Malaysia. The top 2 m of the soil (clayey-skeletal, oxidic isohyperthermic, Typic Hapludox) is composed of transported petroplinthite which rests on weathered saprolite developed from shale. A large lateritic boulder is in the foreground.

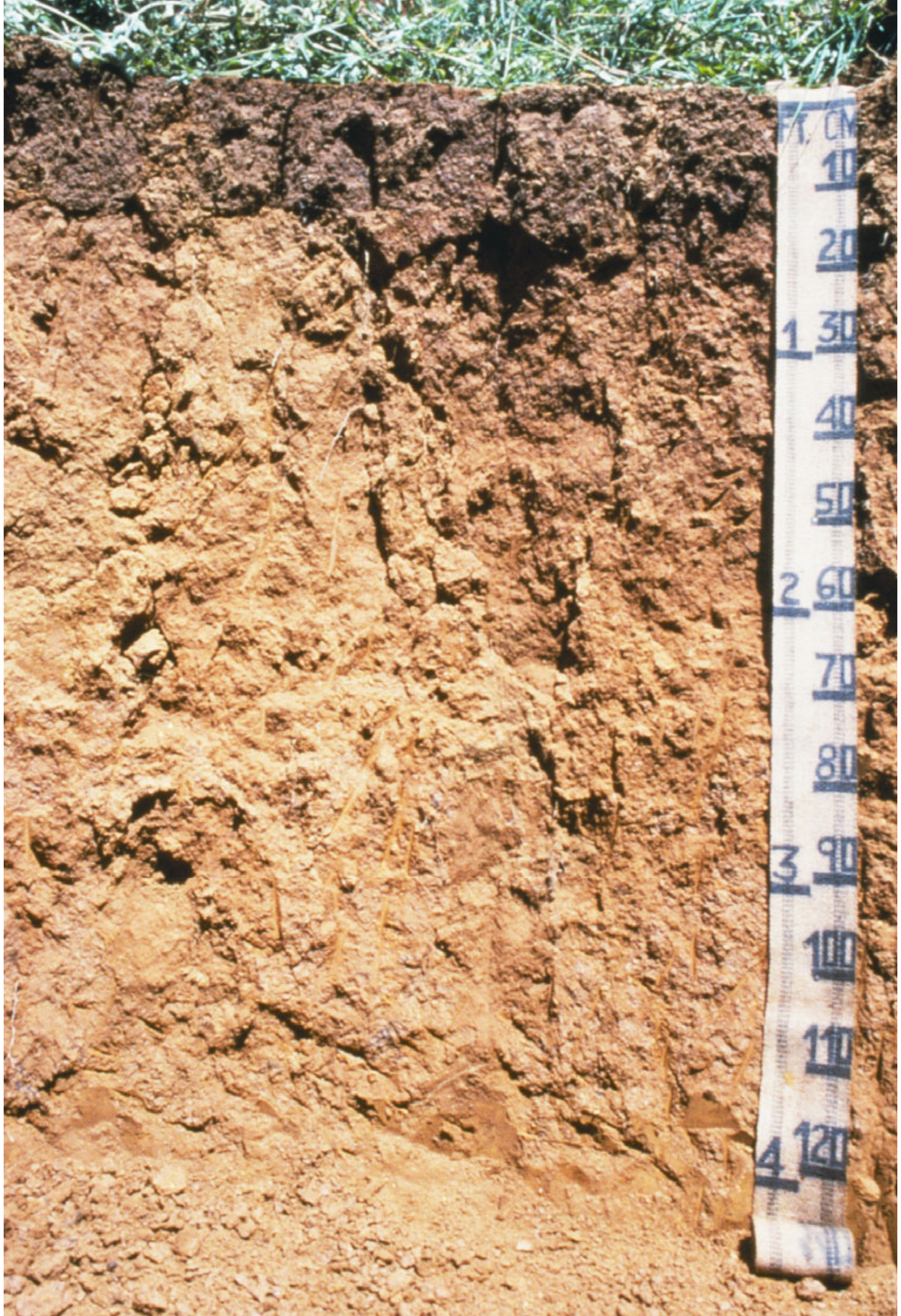
067 - This is a typical soil of Southern Kerala, India, showing a deep weathering profile with a thin cap of transported petroplinthite. The soil shows the classical sequence comprised of red and mottled clay, the pallid zone which is whitish and bleached, and the underlying saprolite rock. The land was uplifted during the Tertiary and subsequent to the uplift there was down-cutting of the drainage ways and a consequent lowering of the ground water-table. The plinthite and petroplinthite are relic features. After stabilization of the landscape, a new sequence of erosion and transport results in the present-day rounded hills with lateritic cappings.

068 - A close-up view of the profile in slide 67. The upper part of the profile is composed of poorly sorted petroplinthic gravel. There is an almost abrupt contact with the lower zone composed of plinthite. The soil is a Plinthic Haplustox from Trivandrum, Kerala, India.

069 - The slide shows an Anionic Acrudox from Kuantan, Malaysia. The soil is developed on basalt. The rock was K/Ar dated to 1.9 million years. The basalt is a tholeitic basalt with many quartz inclusions and so the soil material has a high quartz content. The yellow to brownish colors are due to the very high amounts of manganese in this soil (>1.5% MnO_2). A few drops of H_2O_2 on the soil causes it to effervesce. The oxic horizon extends from about 20 cm depth to more than 3 m.

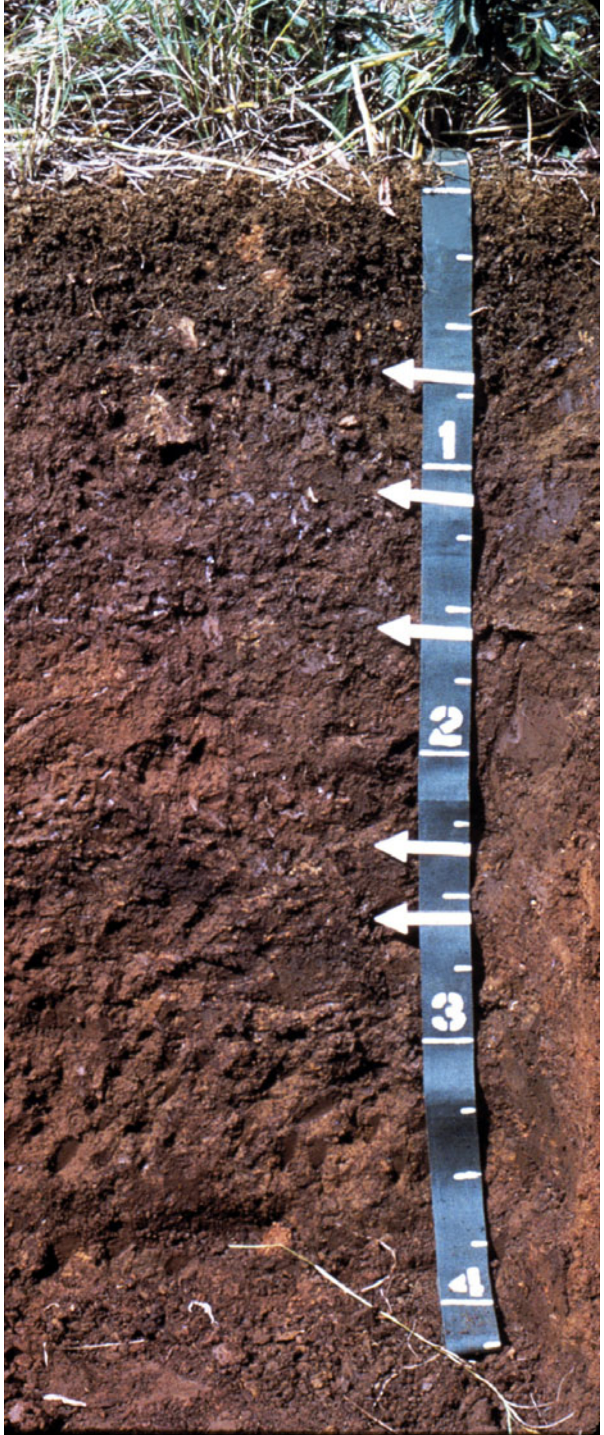


070 - This clayey, kaolinitic, isohyperthermic, Xanthic Hapludox from Manaus, Brazil (03º 08’ S; 60º 01’ W; 100 m) is an example of a yellow Oxisol. It is formed in Cretaceous/Tertiary sandy clay deposits.



071 - This clayey, kaolinitic, isohyperthermic Typic Eutrustox from northwestern Puerto Rico is developed in pre-weathered Quaternary sediments and limestone residue.

072 - This is the Sungei Mas series (Anionic Acrudox) from Malaysia. This is an example of an Oxisol developed from the weathering product of ultrabasic rock. The general slope in the area is about 12 to 18 %. The soil is under secondary forest and the area receives about 4,000 mm annual rainfall. Such soils have been referred to as ‘chocolate soils’ in earlier literature due to the characteristic colors. Free iron oxide content is about 35% Fe_2O_3 in the soil and organic carbon is about 2% (B horizon). Despite the high carbon content, CEC is low, the charge is net positive, permanent charge is low, and pH dependent charge is high. The green rock in the lower part of the slide is serpentinite.



073 - This is the Halii series (Anionic Acrudox) from Hawaii. Previously, this soil was classified as a Gibbsiorthox. It has about 45% gibbsite and about 12 % Fe_2O_3 in the fine earth fraction. The soil is formed on volcanic ash and cinder materials and has a relatively high organic carbon content. The high gibbsite content will place it in the gibbsitic mineralogy class.

074 - Oxisols at high elevations (> 1,000 m) in the tropics have a humus-rich surface horizon which may qualify for a mollic or umbric epipedon. The slide shows a Humic Rhodic Eutrustox from Rwanda. There is more than 16 kg of organic carbon to a depth of 1 m over an area of 1 m^2. These soils are better suited for low input agriculture than those of the lowland tropics which contain less organic matter. If rainfall is favorable, they have few constraints for production of grain and cash crops. At the high elevations in the tropics, pest and disease infestation is less than at lower elevations. For these and other reasons, the high elevation plateaus support some of the highest human population densities in the world. A typical farming system of central Africa is illustrated in the slide. Bananas are inter-cropped with maize; peanuts are in the foreground.

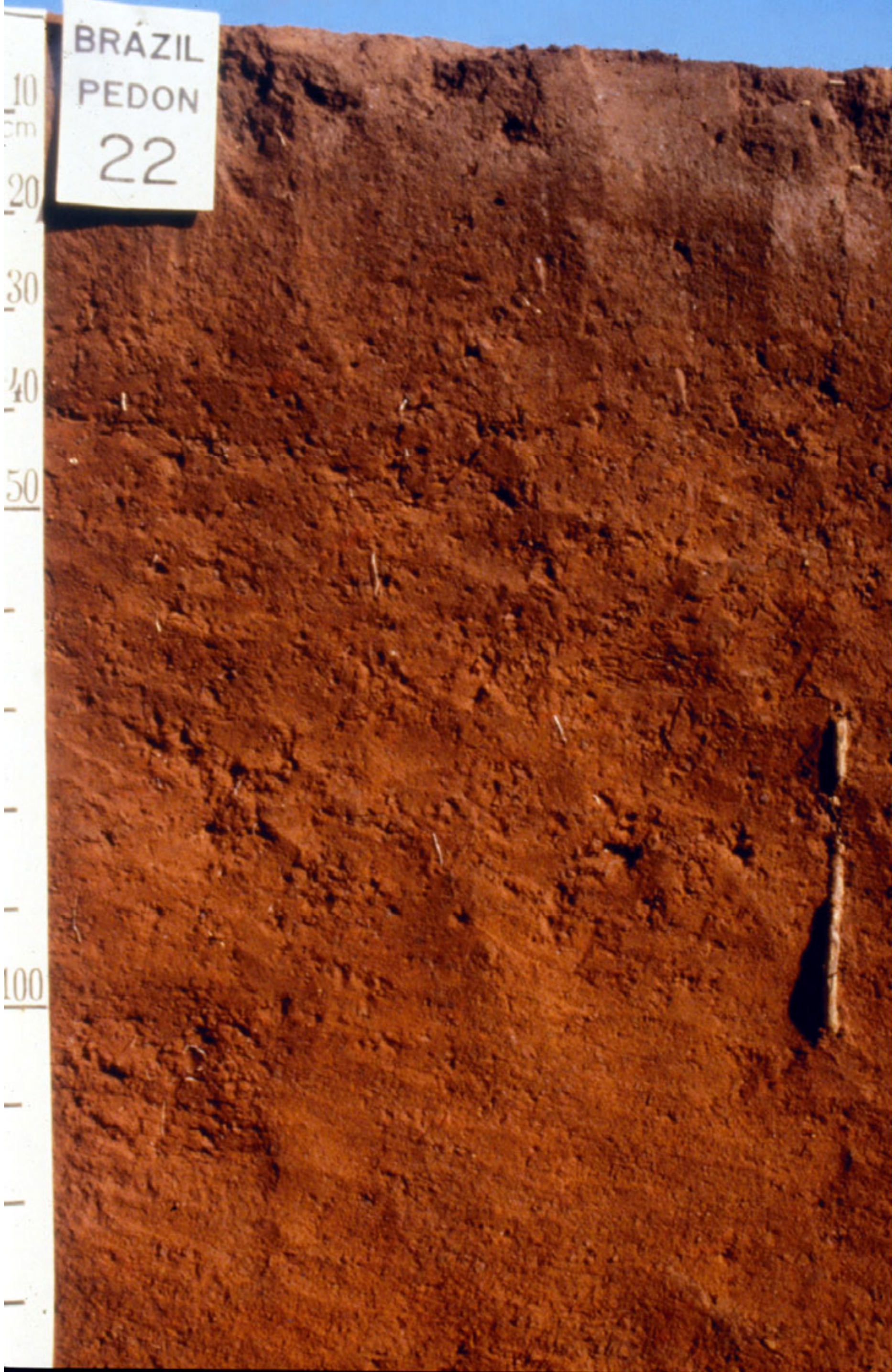
075 - Another typical feature in the highland soils of Central Africa is the presence of the sombric horizon as shown in the slide. It is a subsurface dark colored horizon. The presence of this horizon makes the soil distinctive. The soil is a Sombriudox from Rwanda.

076 - Although most Oxisols are deep, some are shallow. The next two slides illustrate this. This slide is of the Matanzas series (Typic Eutrudox) from Puerto Rico formed on weathering products of limestone. It is highly probable that the soil material is a mixture of direct weathering products and transported infilling of a microkarst landscape.

077 - The Nipe series (Anionic Acrudox) of Puerto Rico is normally a deep soil. On side slopes, the rock or saprolitic material may come close to the surface as shown in the slide. The Nipe Series is similar to the Sungei Mas Series of Malaysia described earlier (see slide 72).

078 - Oxisols do not form when there is insufficient rain for weathering. However, in some areas, such as in parts of Oahu, Hawaii, and north eastern Brazil, Oxisols are found with present-day aridic soil moisture regimes. These soils are developed in transported deposits that acquired oxic properties during previous weathering under more humid conditions. The slide is the Wahiawa series (Typic Haplotorrox) from Hawaii and land-use is irrigated pineapple. With high input management, the soils are very productive. However, as the soils are very friable and have high infiltration rates, leaching of nutrients (nitrates) and contamination of ground water should be expected in such soils and landscapes.

079 - The slide shows the Chok Chai series (clayey, kaolinitic, isohyperthermic Typic Haplustox) from Thailand. The soil is developed on weathering products of granodiorite.

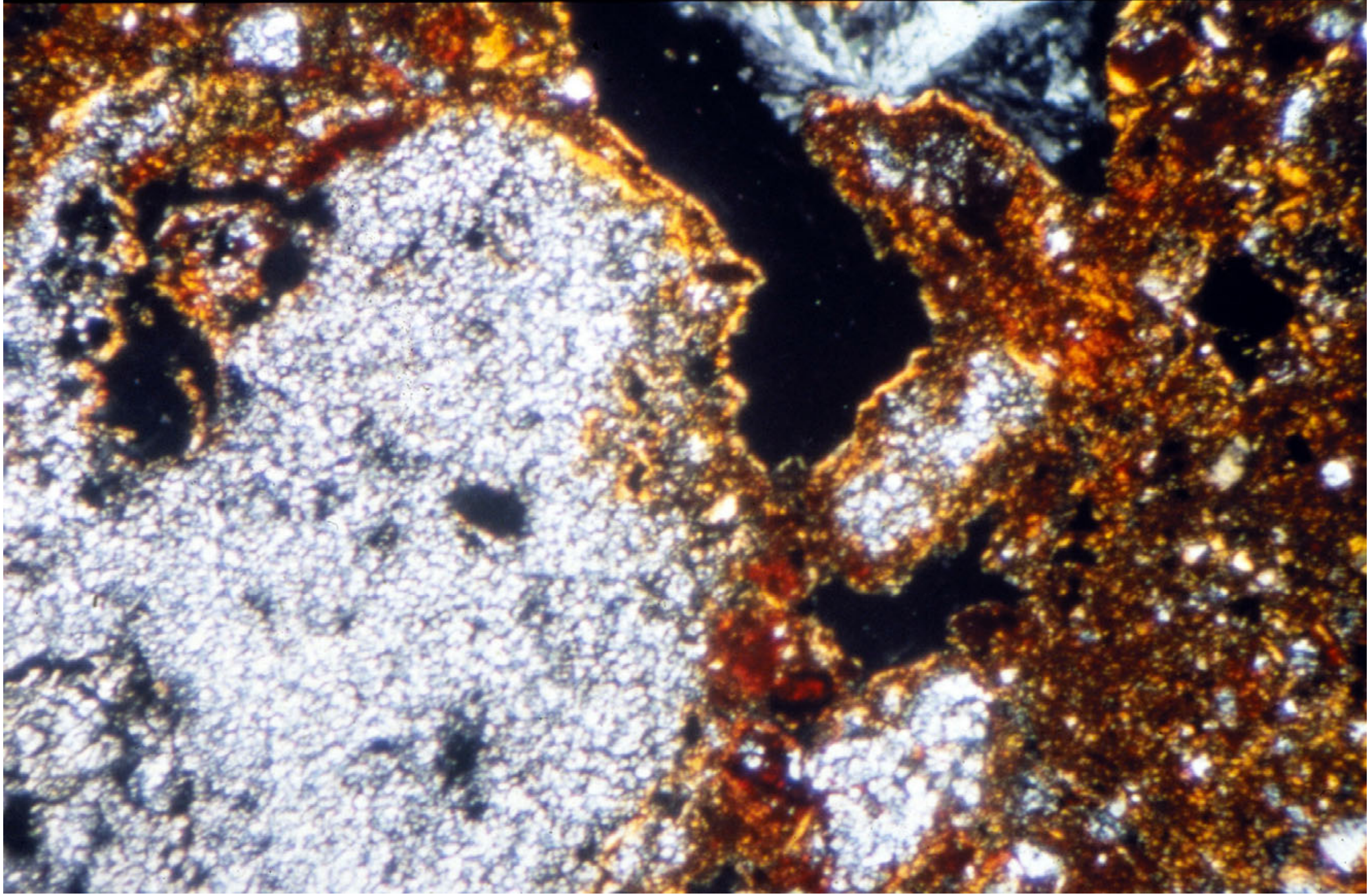


080 - This is a fine, mixed, isohyperthermic, Humic Rhodic Haplustox from Planaltina, Federal District, Brazil (15º 35’ S; 47º 43’ W; 960 m).

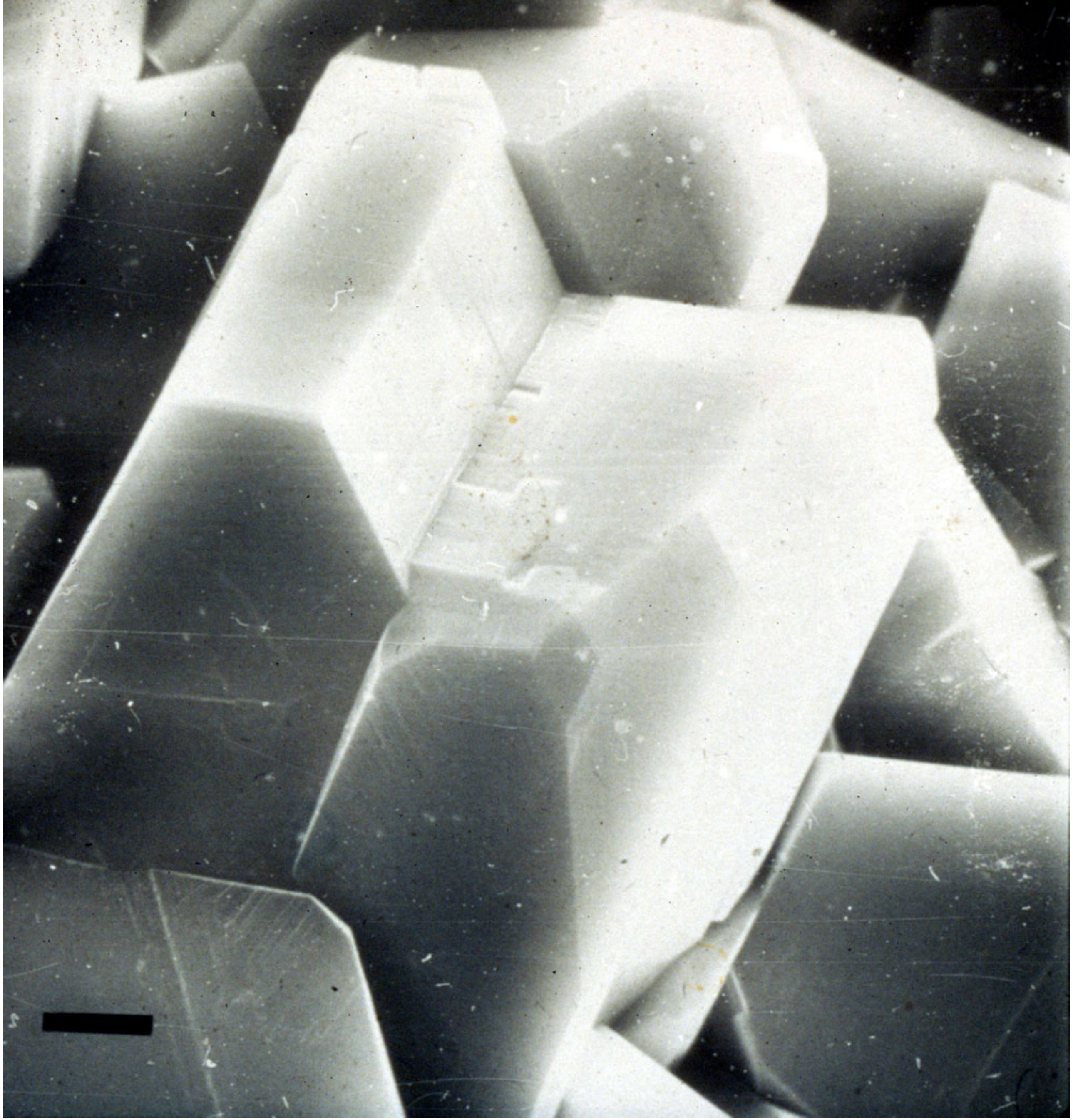
081 - This slide shows a clayey, kaolinitic, isohyperthermic, Humic Haplaquox from the Federal District, (15º 35' 30'' S; 47º 43' 10'' W; 950 m) Brazil. The Aquox frequently occur in narrow valleys adjoining better drained Oxisols of the uplands.

Oxisols

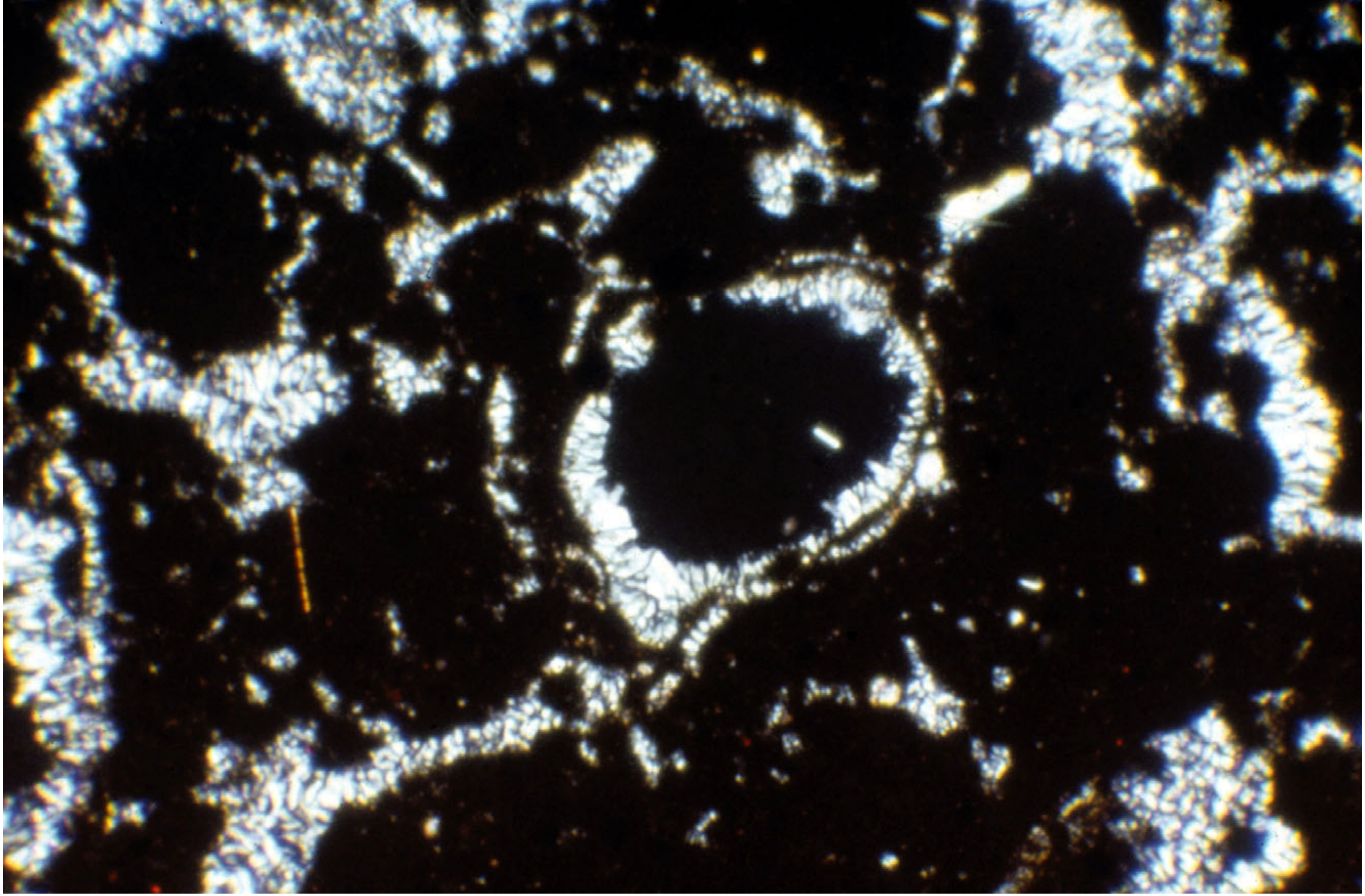
Properties



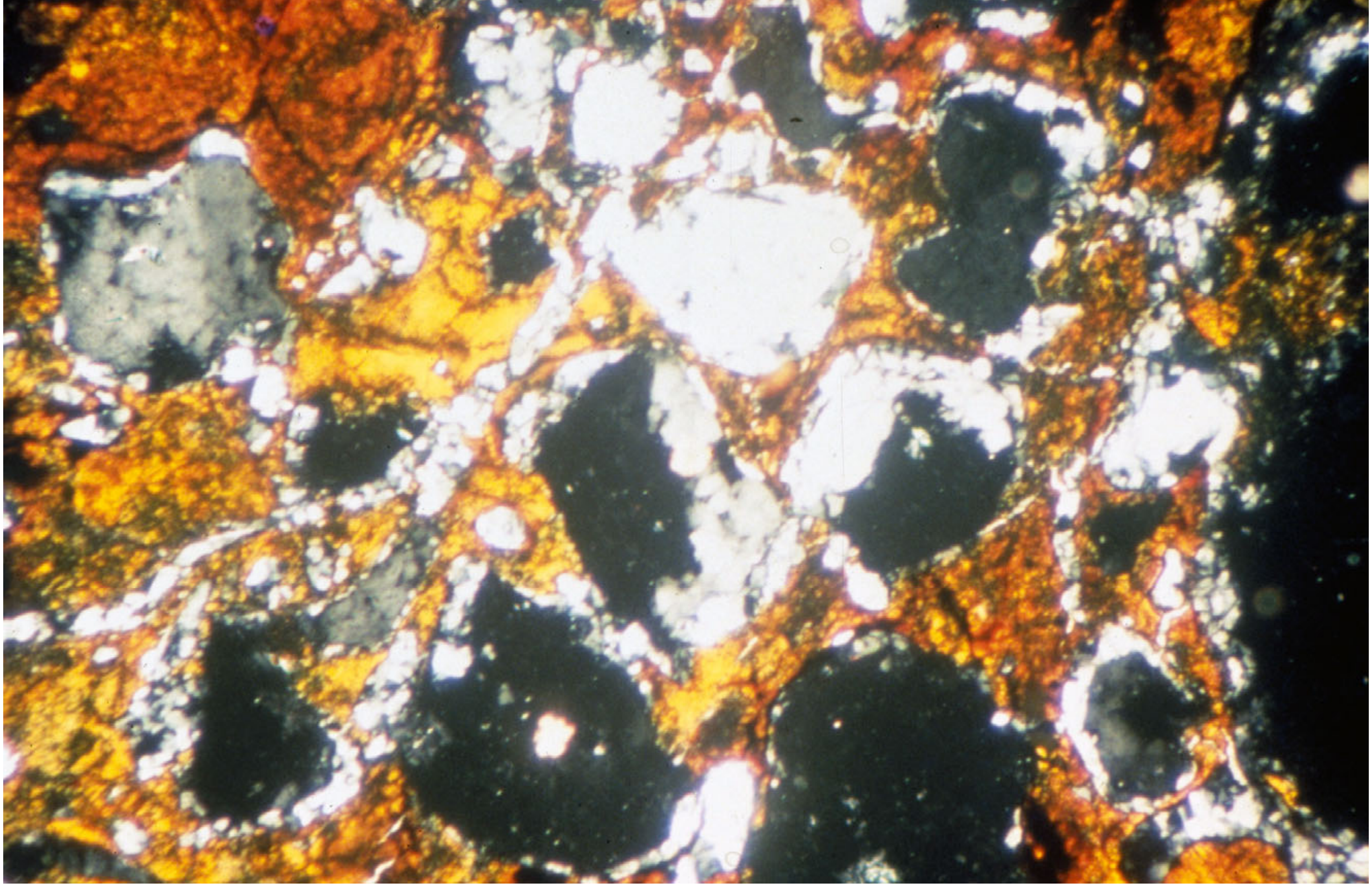
083 - Gibbsite is present as a secondary mineral in many Oxisols. Weathering of primary minerals releases Si and Al; Si is lost in the soil solution while the Al crystallizes as gibbsite and the most common product is gibbsite crystal nodules. The large whitish nodule on the slide (crossed polarized light, magnification X50) is composed of gibbsite. Voids are black in the micrograph and the void walls are coated with a thin lining of translocated clay (argillans). The cutans are probably relic features in this Oxisol.



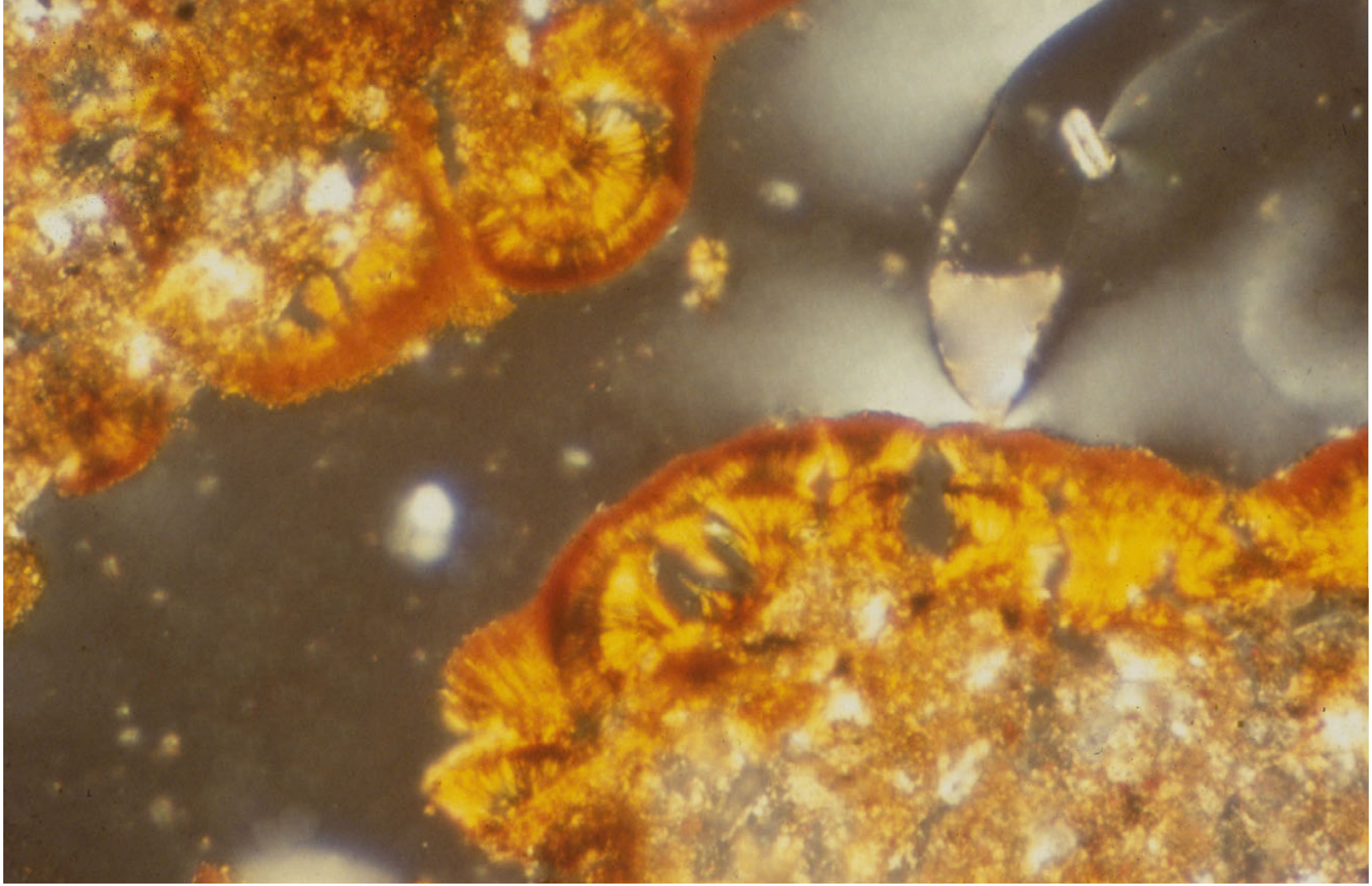
084 - The gibbsite crystals in the gibbsitic nodules of micrograph 83 are well crystallized as shown in this SEM micrograph taken at a magnification of X 2,500. The crystals are euhedral and twinning is common. Typically, gibbsite crystals are fine-silt-sized. In many Oxisols, there is usually more gibbsite in the silt than in the clay fraction. It is for this reason that in the definition of gibbsitic families, the amount of gibbsite is expressed on the fine-earth (< 2 mm) fraction.



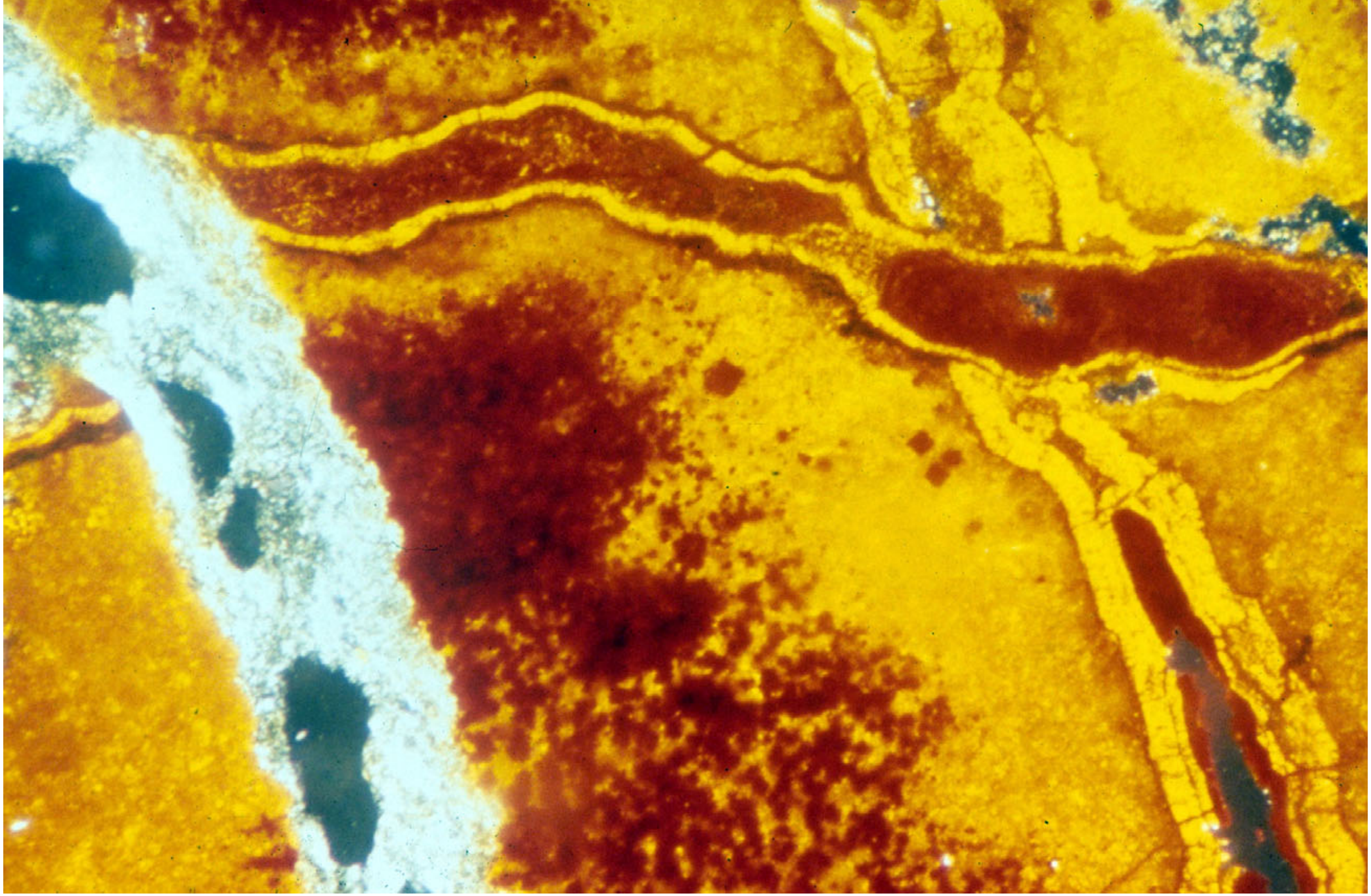
085 - Many different forms of gibbsitic features may be seen in thin-sections and their formation is not well understood. In this thin-section micrograph (X 80), the reddish brown and almost opaque material is the isotropic soil material. It is isotropic because of the presence of high amounts of iron (28% Fe_2O_3) in this Acrudox from Madagascar. The voids are black and the void wall is coated by a thin layer of gibbsitic crystals which are oriented perpendicular to the wall. This and the thin-section in slide 86 of another soil clearly establishes the fact that Al can move in the soil.



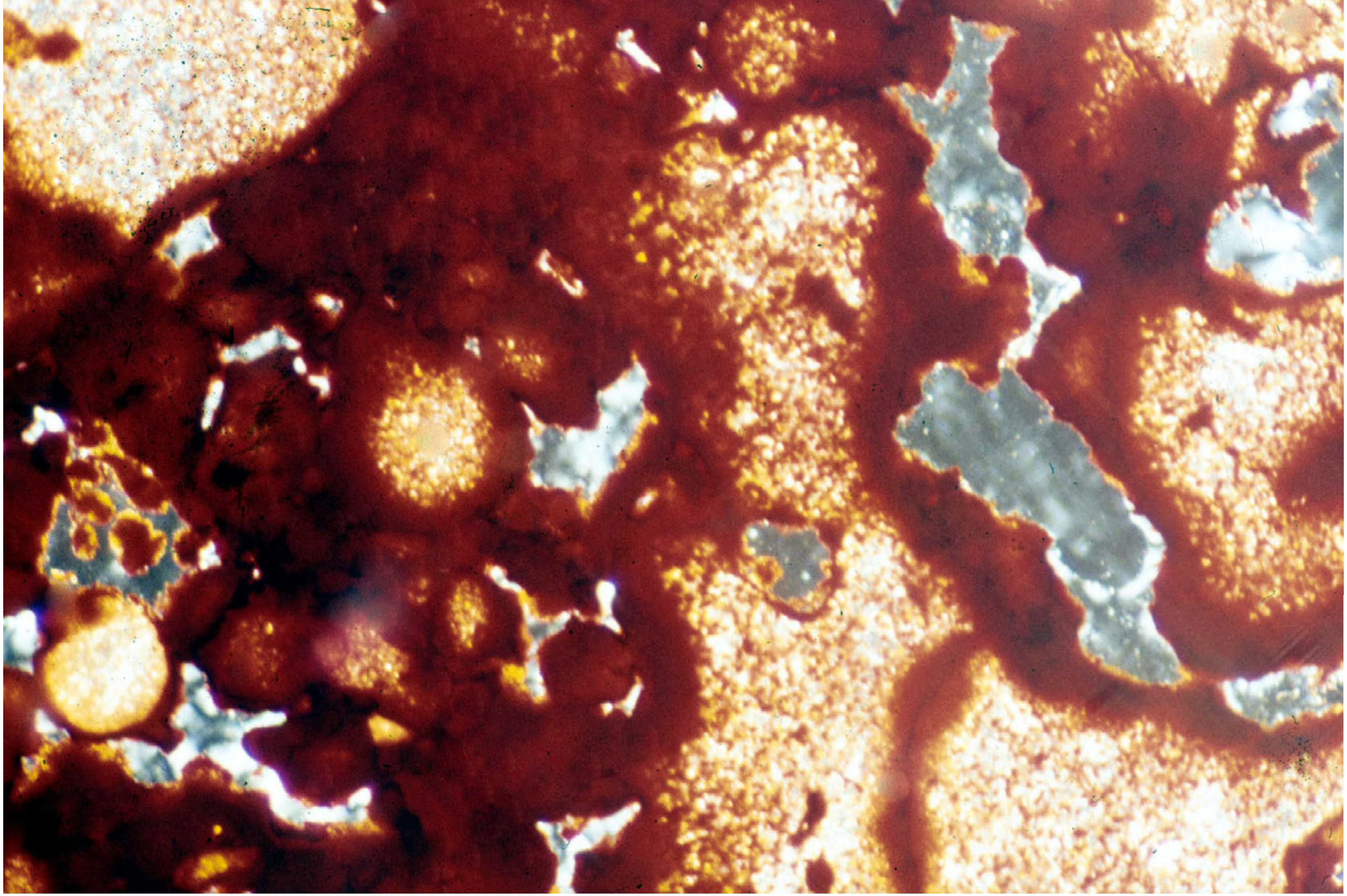
086 - This slide is of a thin-section of a Bt horizon at about 3.5 m depth in a Haplustox from Ituri, Dem. Rep. of Congo. The large white or gray grains are quartz. The fine crystals in the micrograph (X 80) are gibbsite crystals. The yellow mass, almost in the center of the micrograph, is a zone of illuvial argillans. The veins of gibbsite can be seen to cut across the illuvial argillans indicating that gibbsite formation is a process subsequent to clay illuviation. Here is also a feature that shows that the veins are not formed merely by capillary rise as was shown in the case of runiquartz.



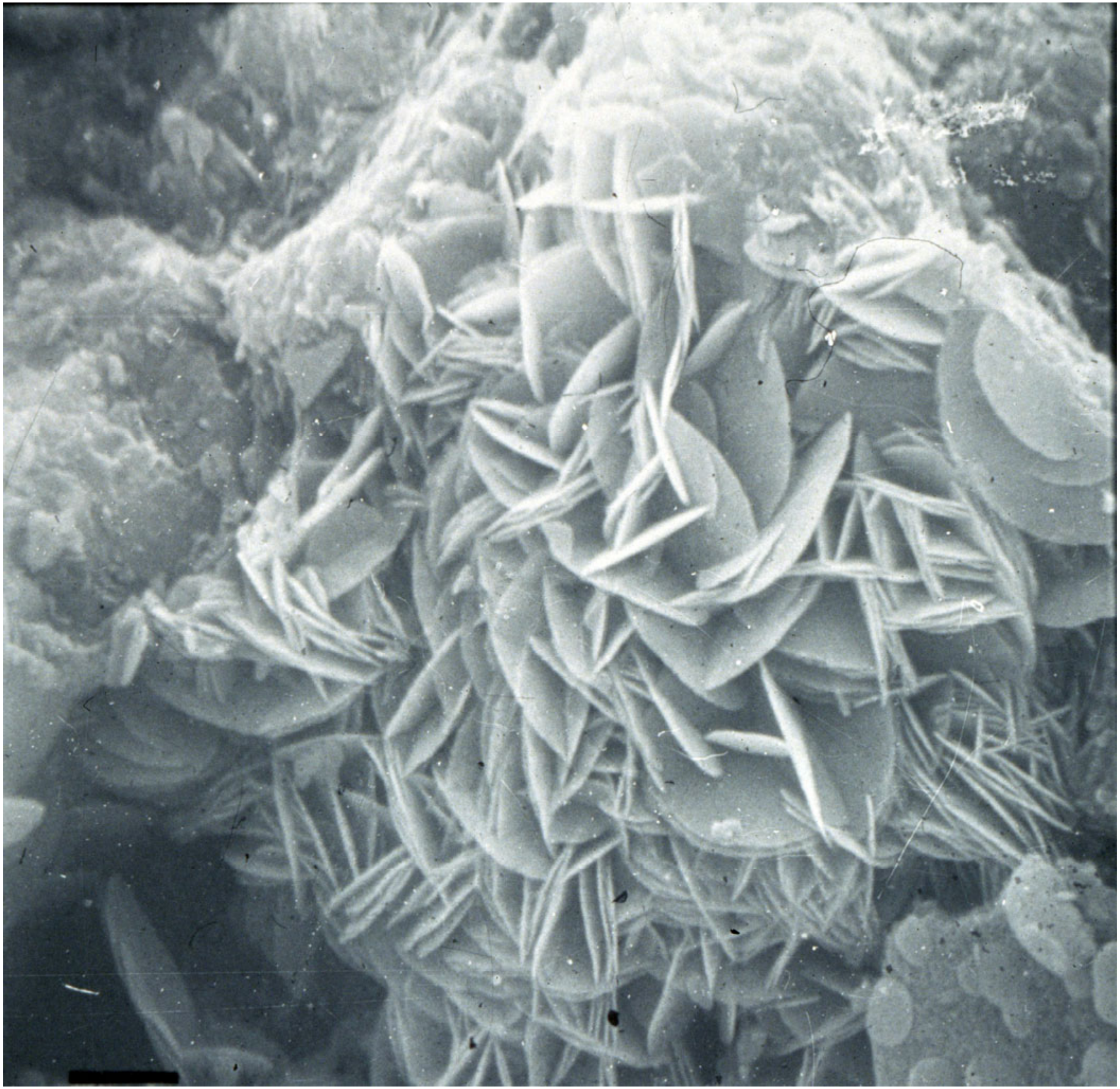
087 - The other frequent mineral in Oxisols is goethite. The micrograph (X 100) is from a Haplaquox in Malaysia. The void wall is coated by bands of goethite crystals arranged in a concentric form. Such forms are frequent in wet soils.



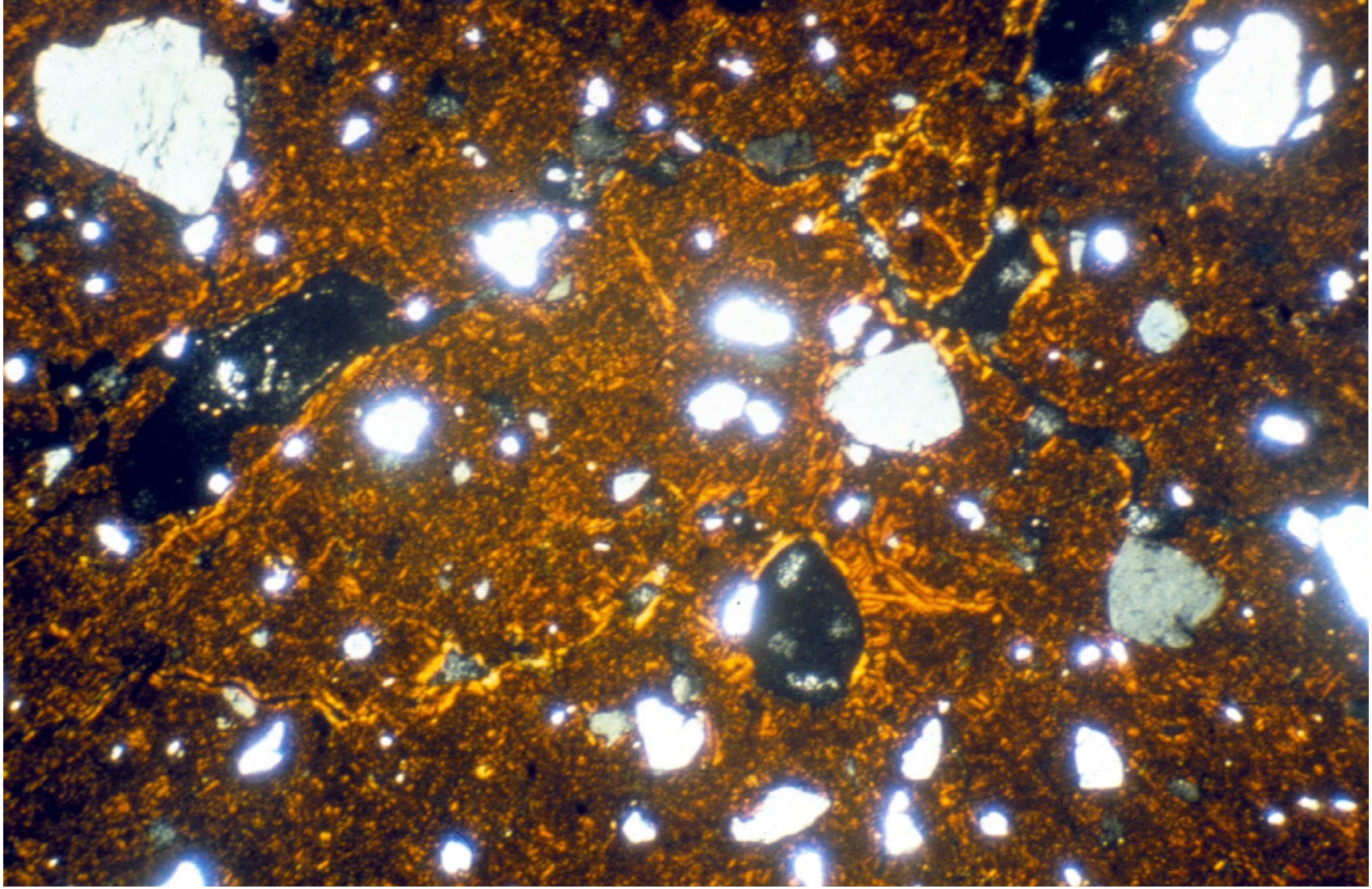
088 - In plinthite other forms of goethite and hematite are common. The yellow mass and veins in the micrograph (X 50) of plinthite from Venezuela is goethite. The hematite aggregates are present as reddish spherules embedded in the goethite mass. The white zones are the iron-free zones and are composed of kaolinite and quartz.



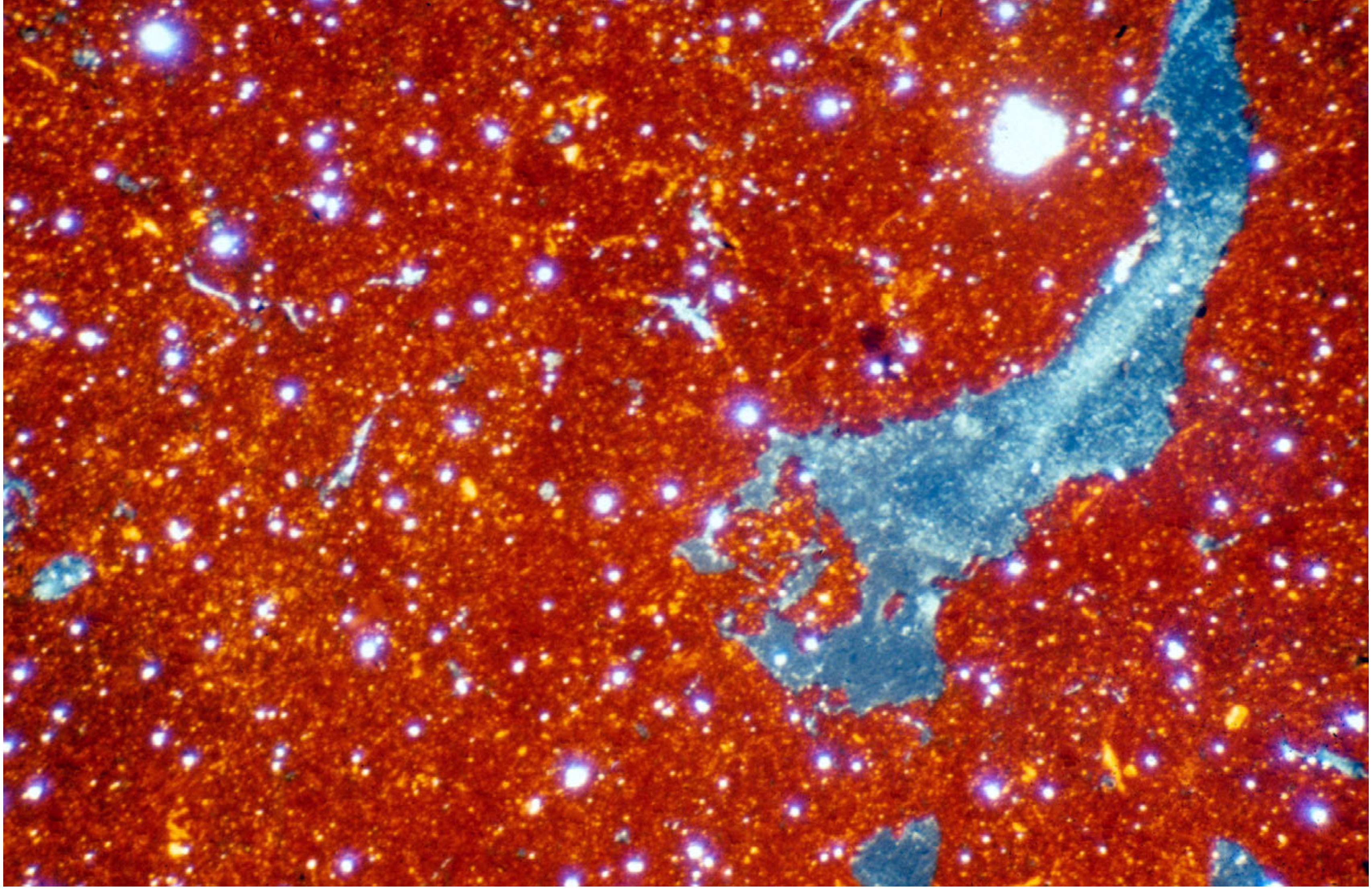
089 - Laterite or petroplinthite shows characteristic forms in thin-sections. This thin-section (X 80) is of a lateritic brick referred to in slide 27. The matrix is composed of red hematite crystals clustered as aggregates. The white and yellow materials are kaolinite.



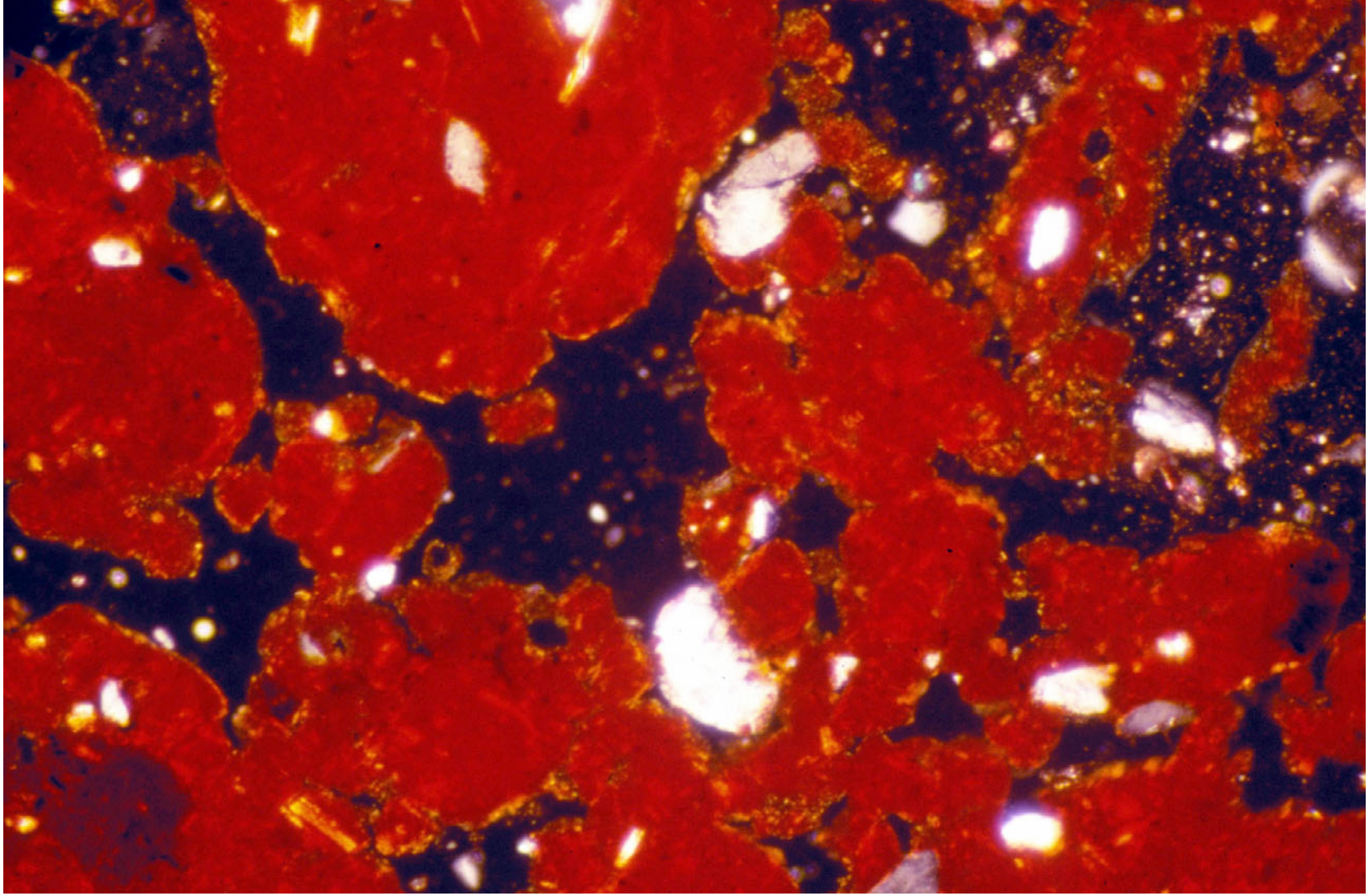
090 - This slide shows a SEM micrograph (X 10,000) of goethite crystal aggregates in a petroplinthite fragment. The goethite crystals have a typical lenticular shape and appears welded together. This gives the petroplinthic material its strength. Both goethite and hematite have different habits and they show different crystal forms.



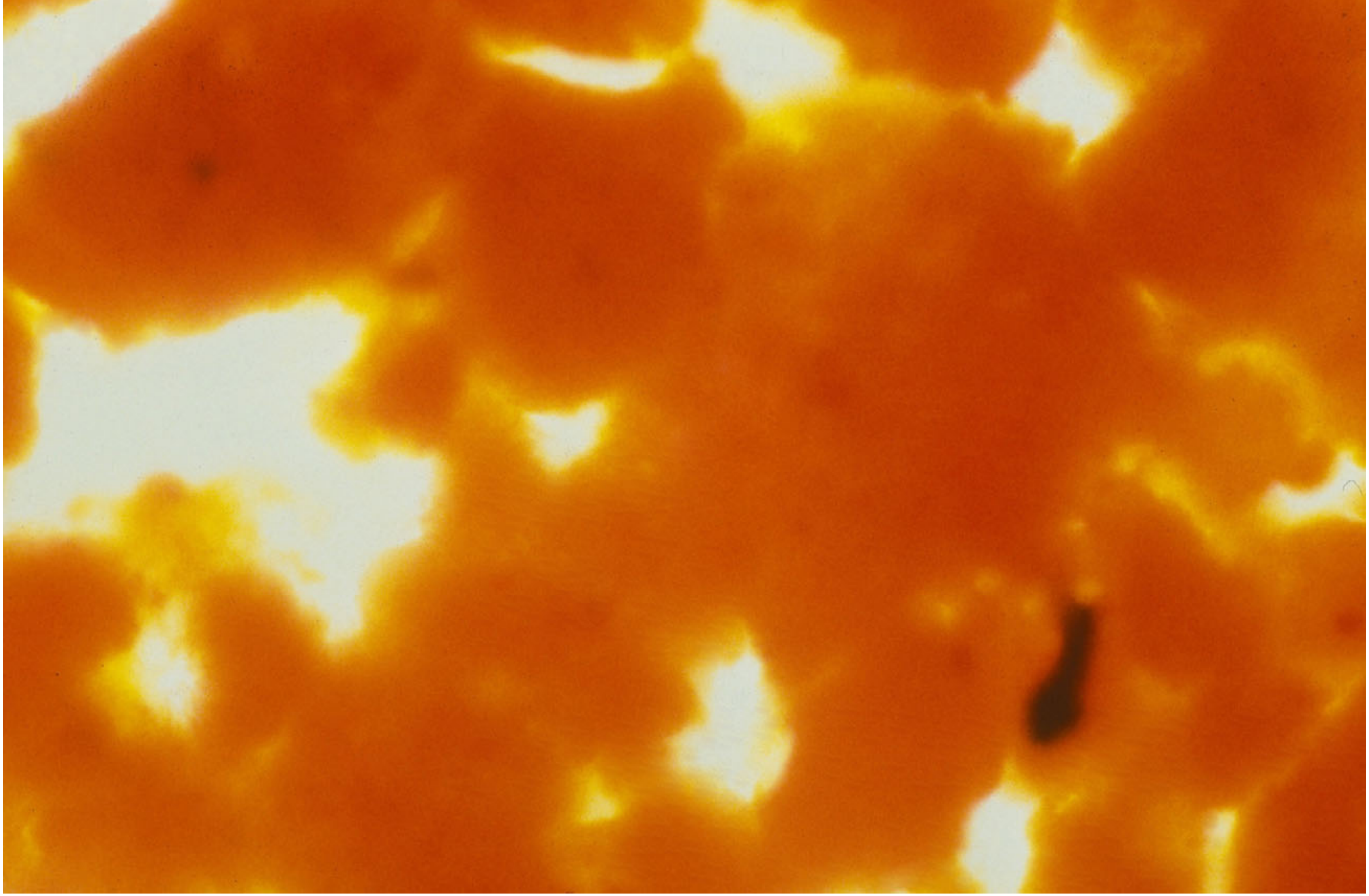
091 - In most Oxisols, the fabric is homogenous without too many specific entities like those illustrated previously. This micrograph (X 80) is of a Kandiudox from Rwanda. It shows a thin lining of ferriargillans (yellow coatings on the void walls). The presence of the clay skins is evidence of the transitional nature of the soil and that clay illuviation and accumulation was an important process. The transitional nature is indicated by the ‘kandi’ prefix in the soil name.



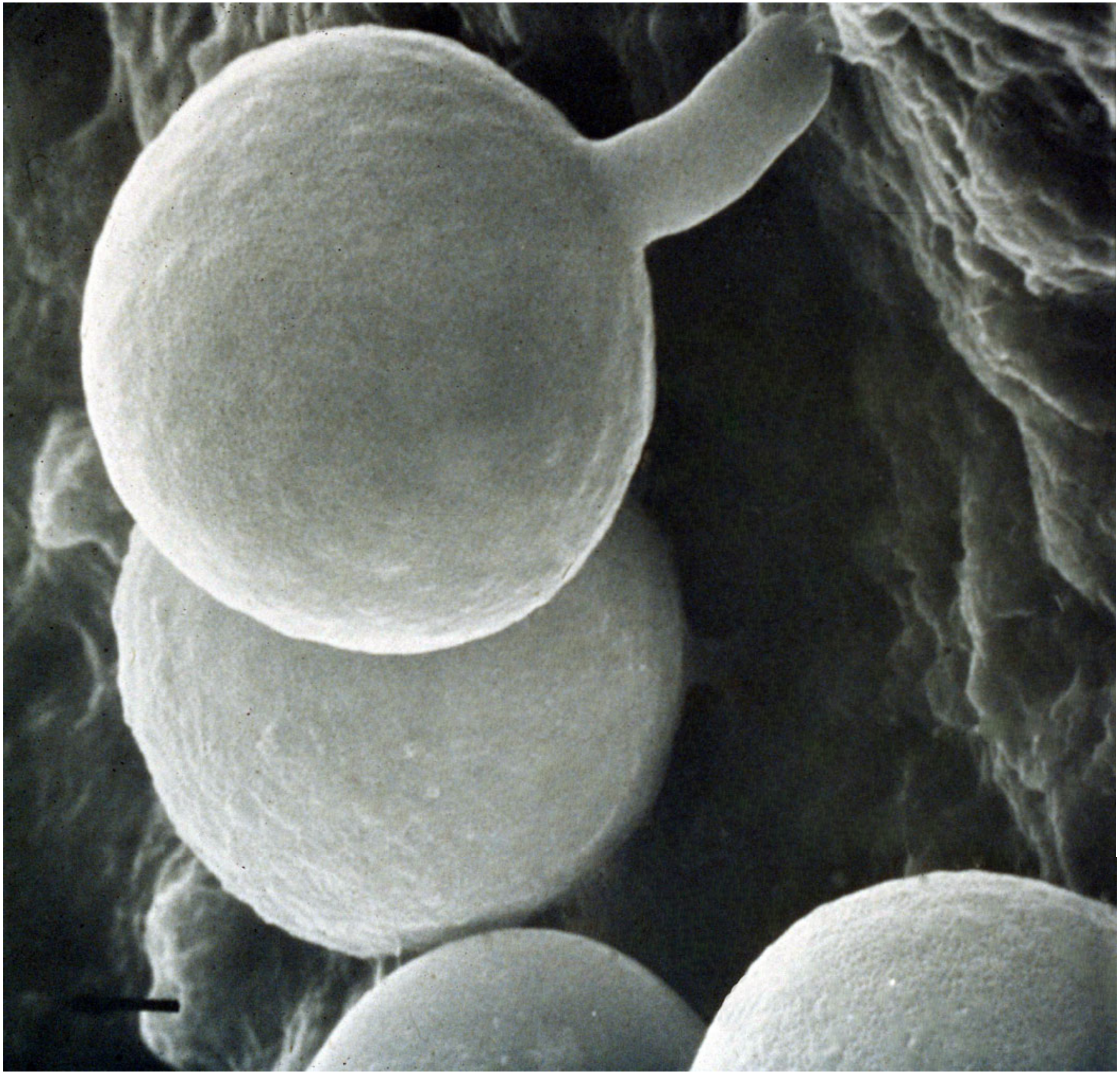
092 - This micrograph is of the Bo horizon of the Chok Chai series from Thailand (see slide 79). The matrix is uniformly red indicating little reorganization of the iron. The white mineral is silt-sized quartz. There is no differentiation of the fabric in this Haplustox.



093 - This micrograph is at a magnification of X 100. The plasma within the aggregates is very homogenous and is composed of an intricate mixture of kaolinite and iron oxyhydrates.



094 - When the same feature in slide 93 is observed at a higher magnification (X 150), the plasmic material appears spongy. It is also hydrophobic and repels water and so the aggregates are not wetted easily. Water retained at tensions of 1/3 and 15 bar show that the available water holding capacity of this soil is very low, < 25 mm per 100 cm of soil. The measured clay in this soil is 65% and the anomaly with respect to water holding capacity is due to the very low specific surface area.



095 - The surface horizon of Oxisols have a relatively high organic matter content, unless eroded. Biological activity is high. A SEM study (X 10,000) of such a surface horizon shows the presence of fungal hyphae and fruiting bodies. Fungi and mycorrhiza are generally indicators of good soil quality.

096 - The drier tropics are also typified by the presence of large termite nests which can reach 5 m in height. There are species of termites which are subsoil dwellers and termite galleries may go several meters into the soil. Bioturbation of the soil is an important soil forming process in tropical soils.

097 - Oxic B horizons have a friable consistency. When a large chunk of soil is gradually crushed in the hands, the soil material breaks down and fine rounded bodies are left behind. Belgian pedologists, working in Africa, used to call this “Variole,” meaning the soil has chicken-pox. They are only observed it in Oxisols. These are referred to as ‘pedovites or soil eggs’. Their origin is not established. The slide shows pedovites from the Kuantan series in Malaysia (see slide 69).

098 - The very good and stable structure of Oxisols and their rapid infiltration rates, makes them resistant to erosion. In fact, steep slopes and road banks are usually stable and these are generally indicators that the soils in the area are Oxisols. However, misuse of these soils can result in accelerated erosion and experiments, as shown in the picture, are being conducted to determine rates and processes.

Oxisols - Summary of morphological properties I

- Lack of distinct horizon differentiation (color and texture) with diffuse horizon boundaries.
- Generally deep sola.
- Isothermic Oxisols have thick humus-rich surface horizons.
- Saprolite zone or transition to rock is thin.

Oxisols - Summary of morphological properties II

- Soils on old surfaces are formed on stratified materials; substratum may have mineralogical discontinuity with solum.
- Stone-lines are common in soils on old geomorphic surfaces; petroplinthite gravel may form the stone-line.
- Iron-coated rock fragments with weatherable minerals may be present in Oxisols.

Oxisols - Summary of physical properties I

- Low available water-holding capacity.
- High hydraulic conductivity.
- High aggregate and structural stability.
- Low plasticity; low wettability.
- Friable consistency when dry; non-plastic and non-sticky when wet.
- Low specific surface area.

Oxisols - Summary of physical properties II

- Weak grade of structure; structural elements fail abruptly.
- High prorosity; water is stored and released at tensions <1 bar.
- Water release characteristics not related to texture; a sandy Oxisol behaves similarly to a clayey one.
- Low amounts of water-dispersible clay.

Oxisols - Summary of mineralogical properties I

- Only traces of weatherable minerals in silt and fine-sand fraction; dominant minerals are quartz, rutile, anatase, and zircon.

- Clay fraction is dominantly kaolinite of low crystallinity; associated minerals are goethite, hematite, and illite (muscovite).

Oxisols - Summary of mineralogical properties II

- Hydroxy-interlayered vermiculites may be present in surface horizons.

- Gibbsite, when present, is dominantly in the fine-silt fraction.

Oxisols - Summary of chemical properties I

- Low clay activity - low pH dependent and permanent charge.
- Soil pH generally near Zero Point of Net Charge (ZPNC).
- Delta pH generally narrow (<0.5); in Anionic subgroups, delta pH is zero or positive.
- Phosphorus fixation generally high and related to amount of free iron.

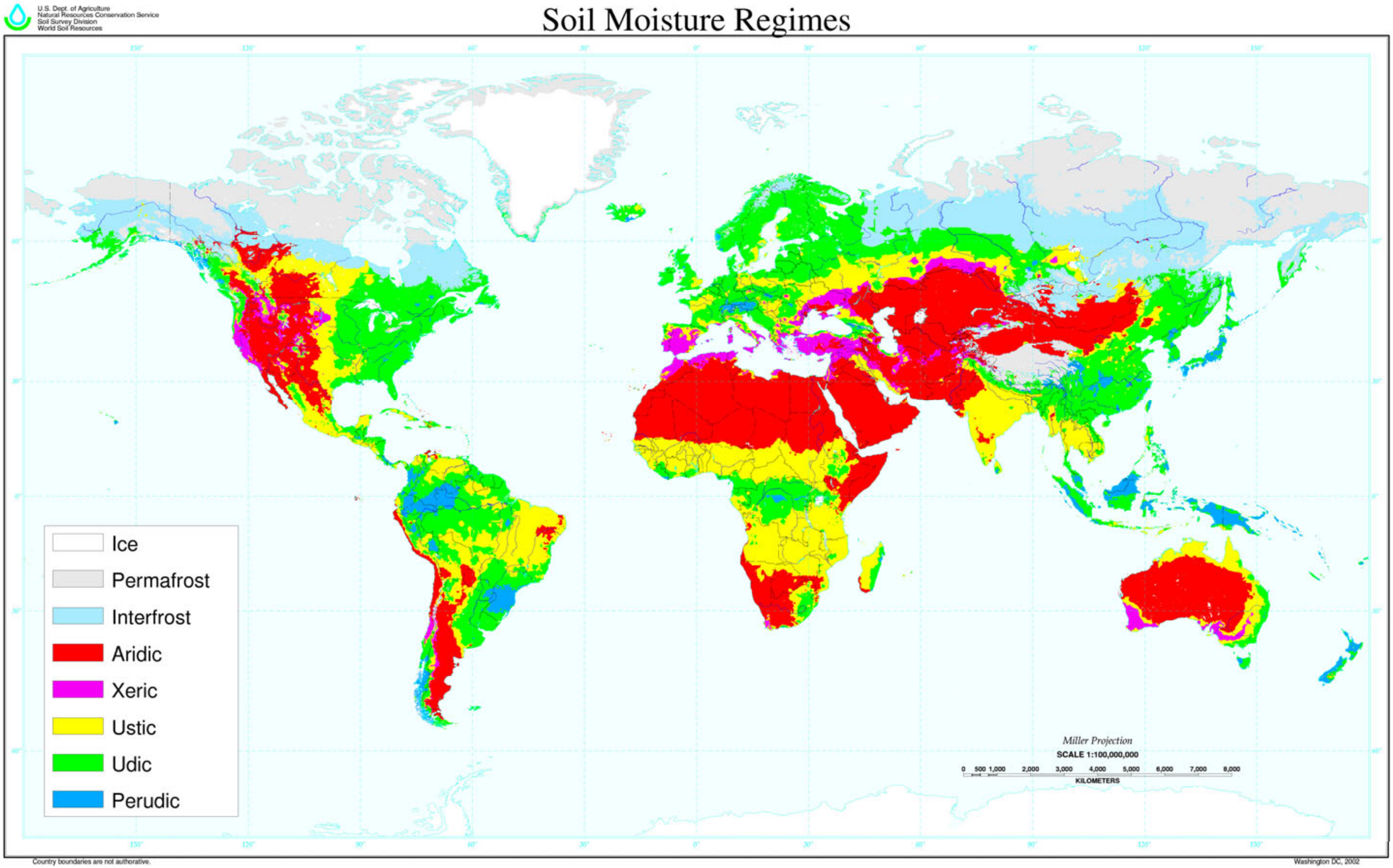
Oxisols - Summary of chemical properties II

- Iron rich soils tend to repel anions such as sulfates and nitrates.

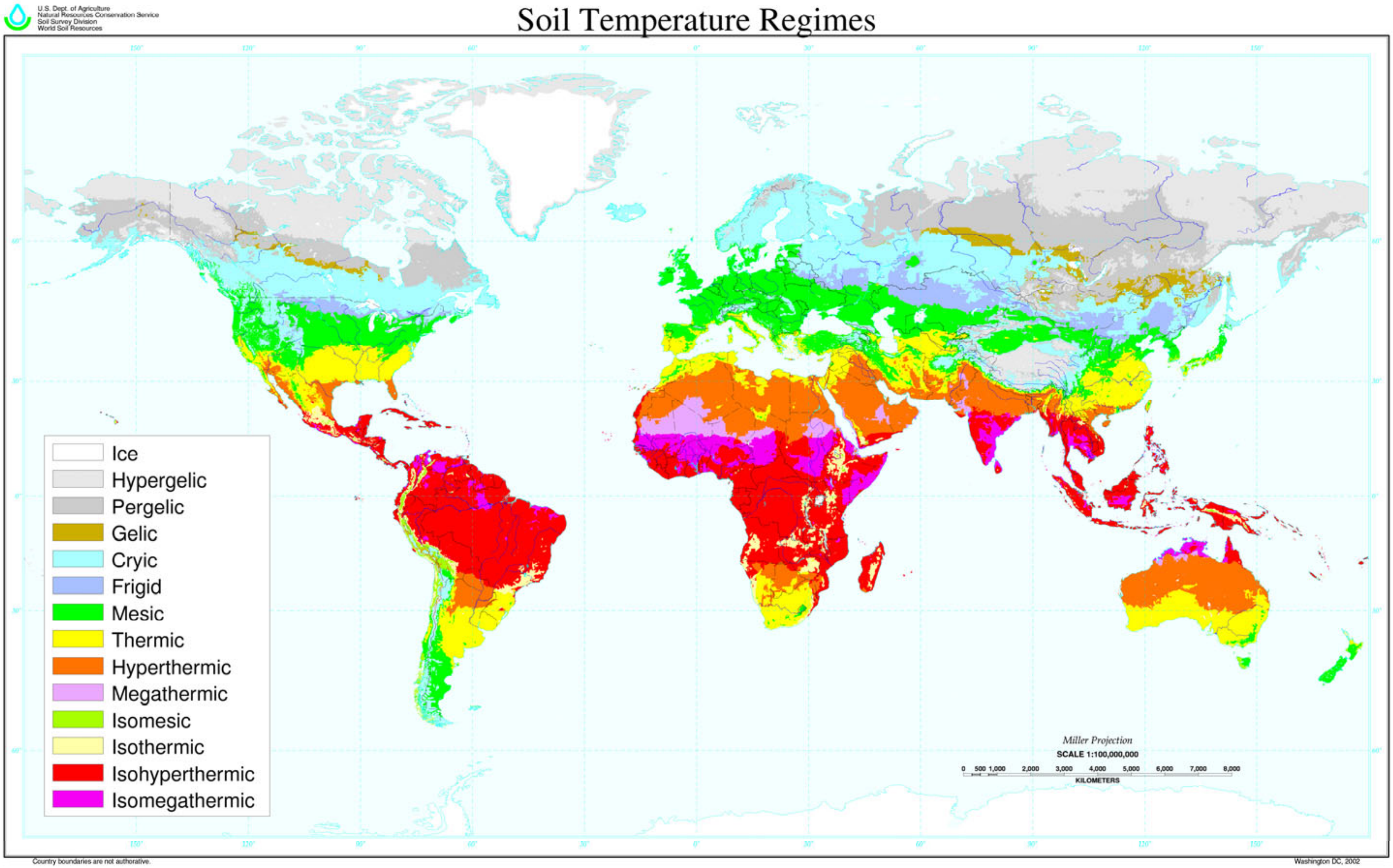
- In soils with a low or positive delta pH, CEC increasing upon liming.

- More than 80% of CEC may be contributed by organic matter.

Global Extent and Geographic Distribution

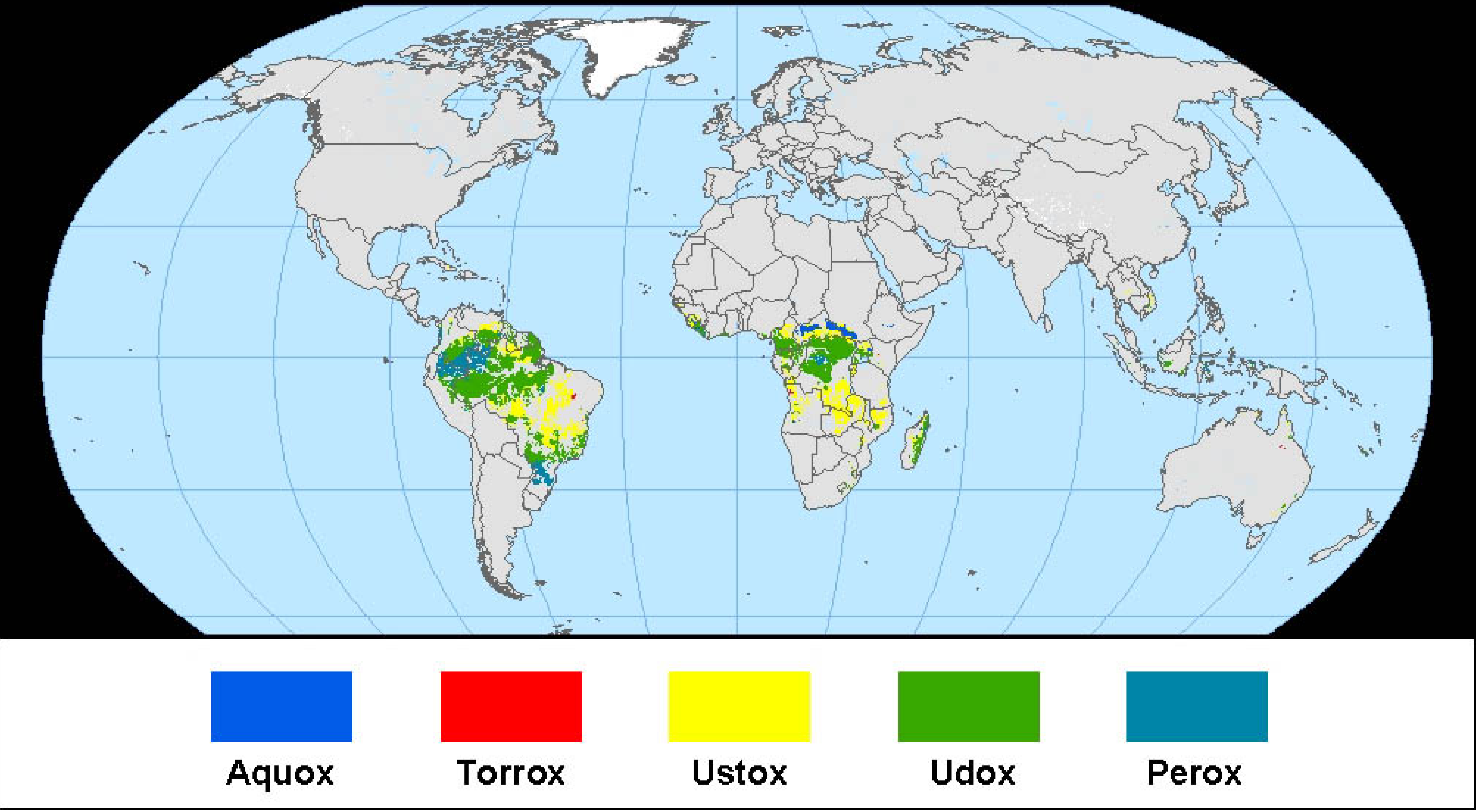


108 - To place the distribution of Oxisols in its proper perspective, the first global map presented here is that of the soil moisture regimes (SMR). The tropics, for convenience, is the zone between the Tropics of Cancer and Capricorn. By definition, there is no xeric SMR in this zone which contains all the other SMRs.

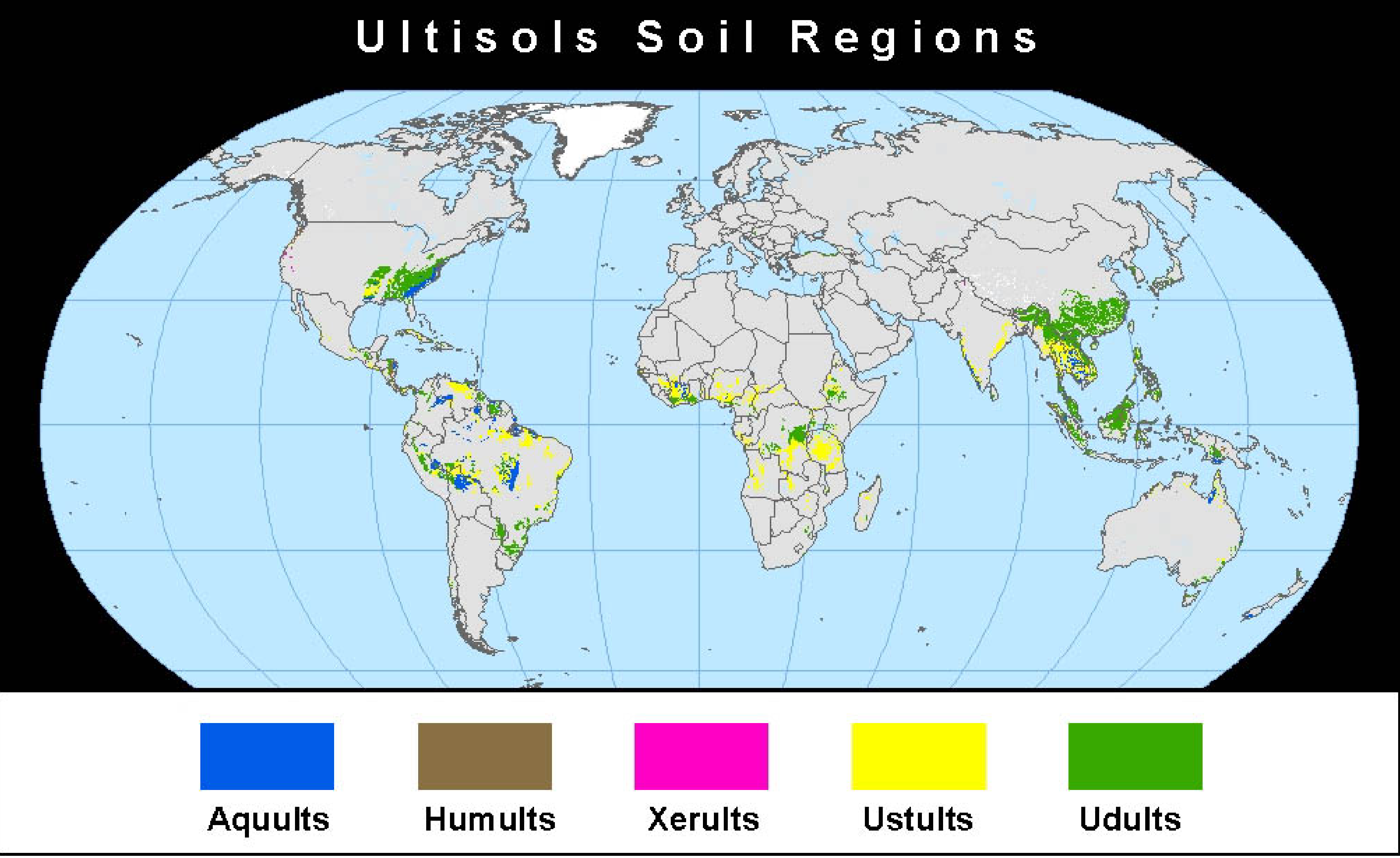


109 - The slide shows the global distribution of the soil temperature regimes (STR). The tropics are characterized by ‘iso-’ STRs. As will be shown later, the Oxisols, though dominant in the iso-STRs, also extend into the non-iso thermic STR as in Southern Brazil.

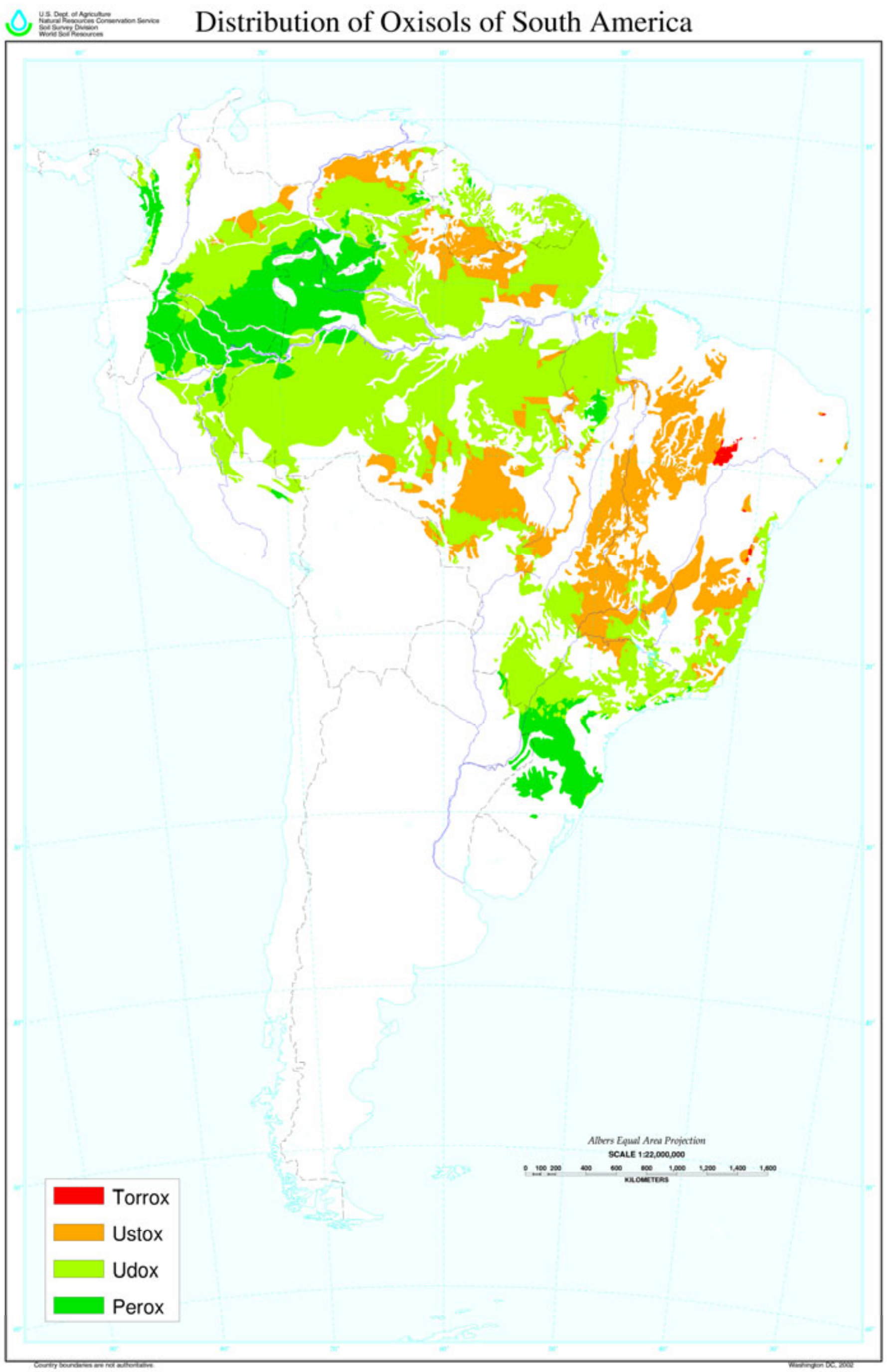
Oxisols Soil Regions



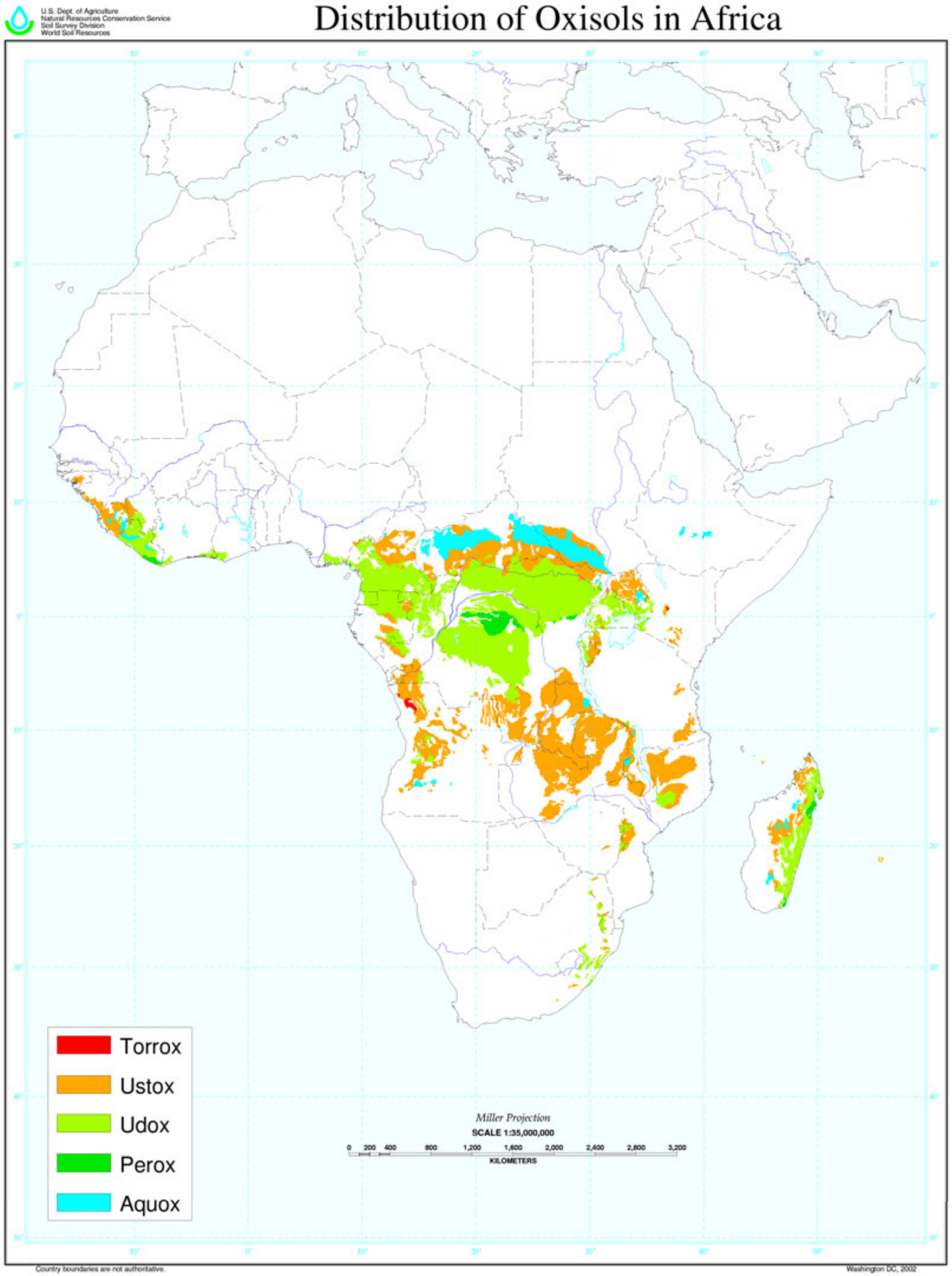
110 - Over 90% of the Oxisols occur in the tropics. South America and Central Africa have large contiguous areas of Oxisols. In South East Asia, the distribution is localized and generally confined to those areas with basic rocks. In S. America and C. Africa, the Oxisols are found on old geomorphic surfaces and developed on pre-weathered and transported sediments. These are referred to as allochtonous Oxisols. In S.E. Asia and the Pacific Islands, many of the Oxisols are formed from the weathering products of the underlying rock and are referred to as autochtonous Oxisols.



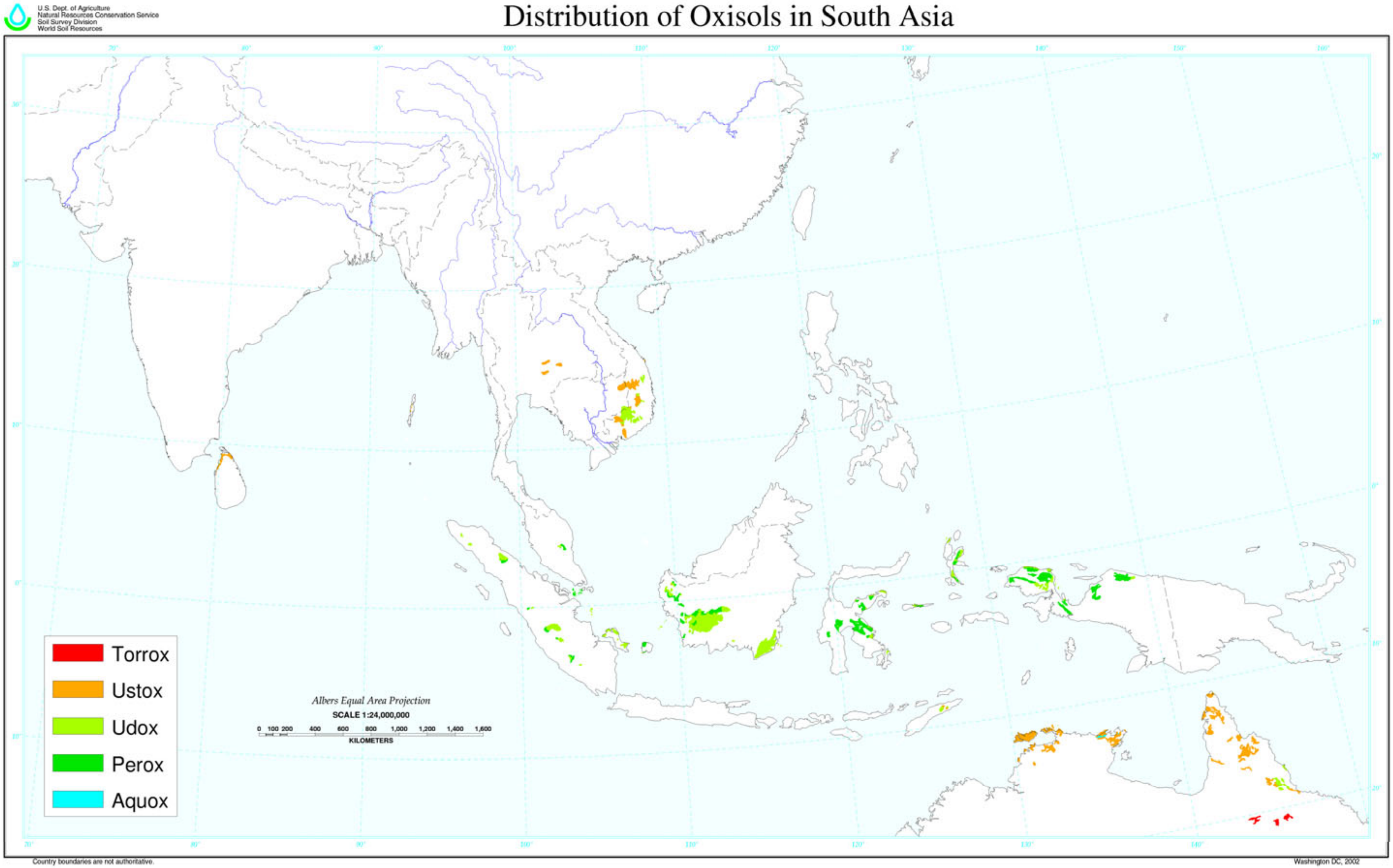
111 - Oxisols are geographically associated with Ultisols in the tropics. This map shows the distribution of Ultisols.



112 - S. America has the largest contiguous extent of Oxisols, with Brazil having the largest area. The western extent of the Oxisols shown on the map is in error. Recent soil survey activities in this part of Brazil and Peru shows that the soils are Ultisols and not Oxisols. Corrections will be made in future global maps.



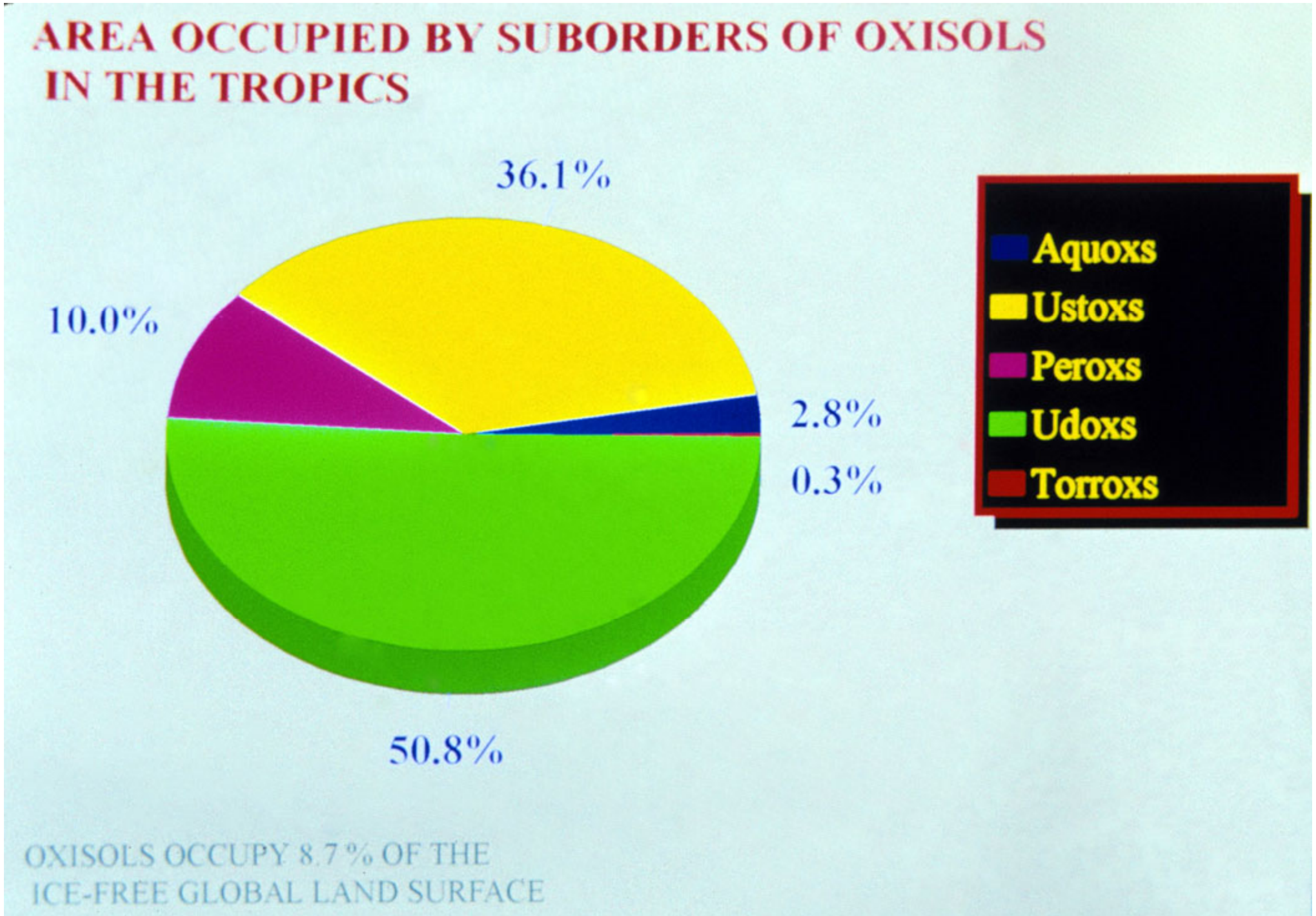
113 - Zaire has probably the largest extent of Oxisols in Africa. New surveys in Zambia suggest that the extent indicated in the FAO-UNESCO Soil Map of the World is probably in error.



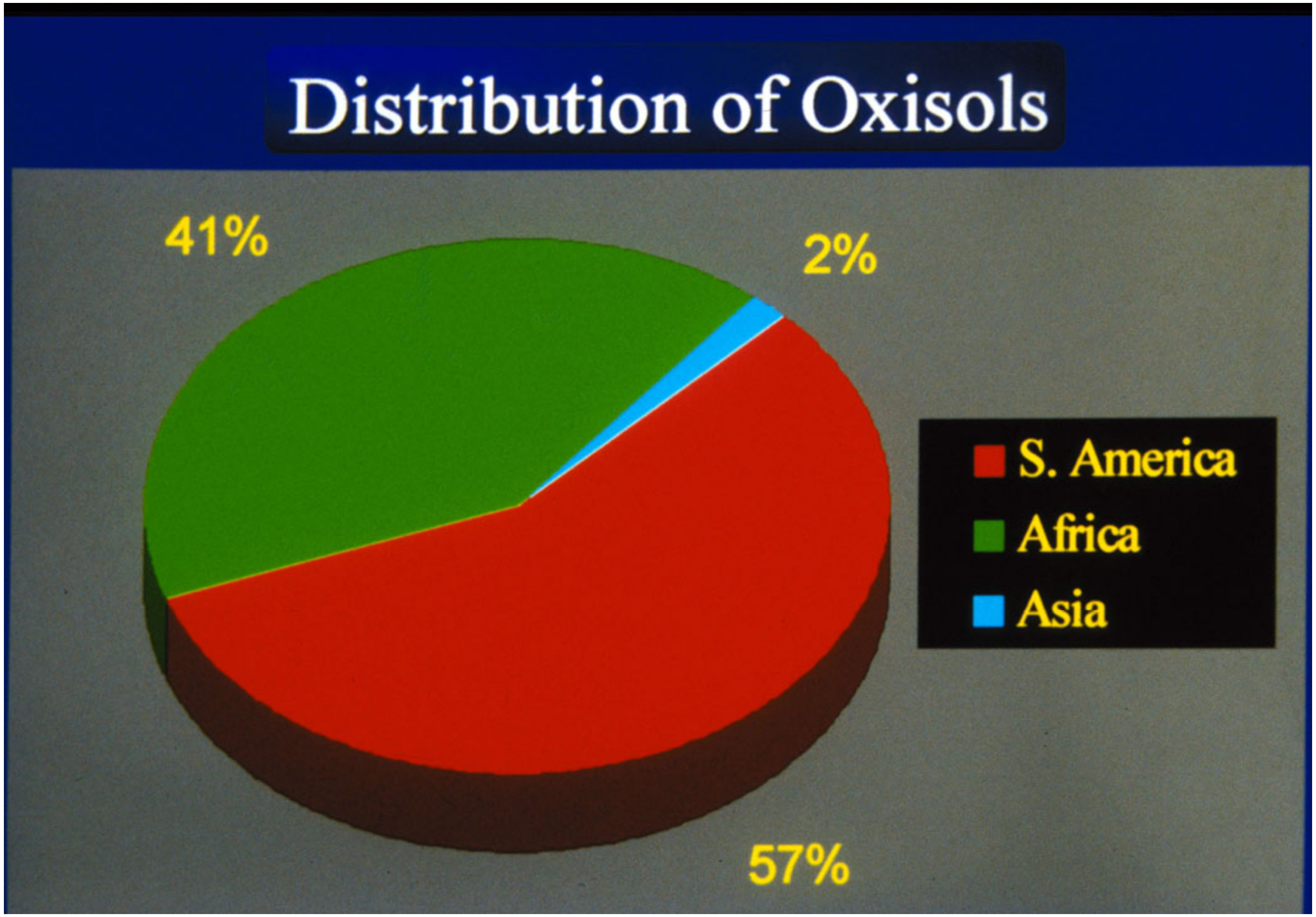
114 - In S.E. Asia, Oxisols are present in small isolated areas. Probably the largest area is in Borneo (Kalimantan) but even this is yet to be verified.

Global Distribution of Soil Orders

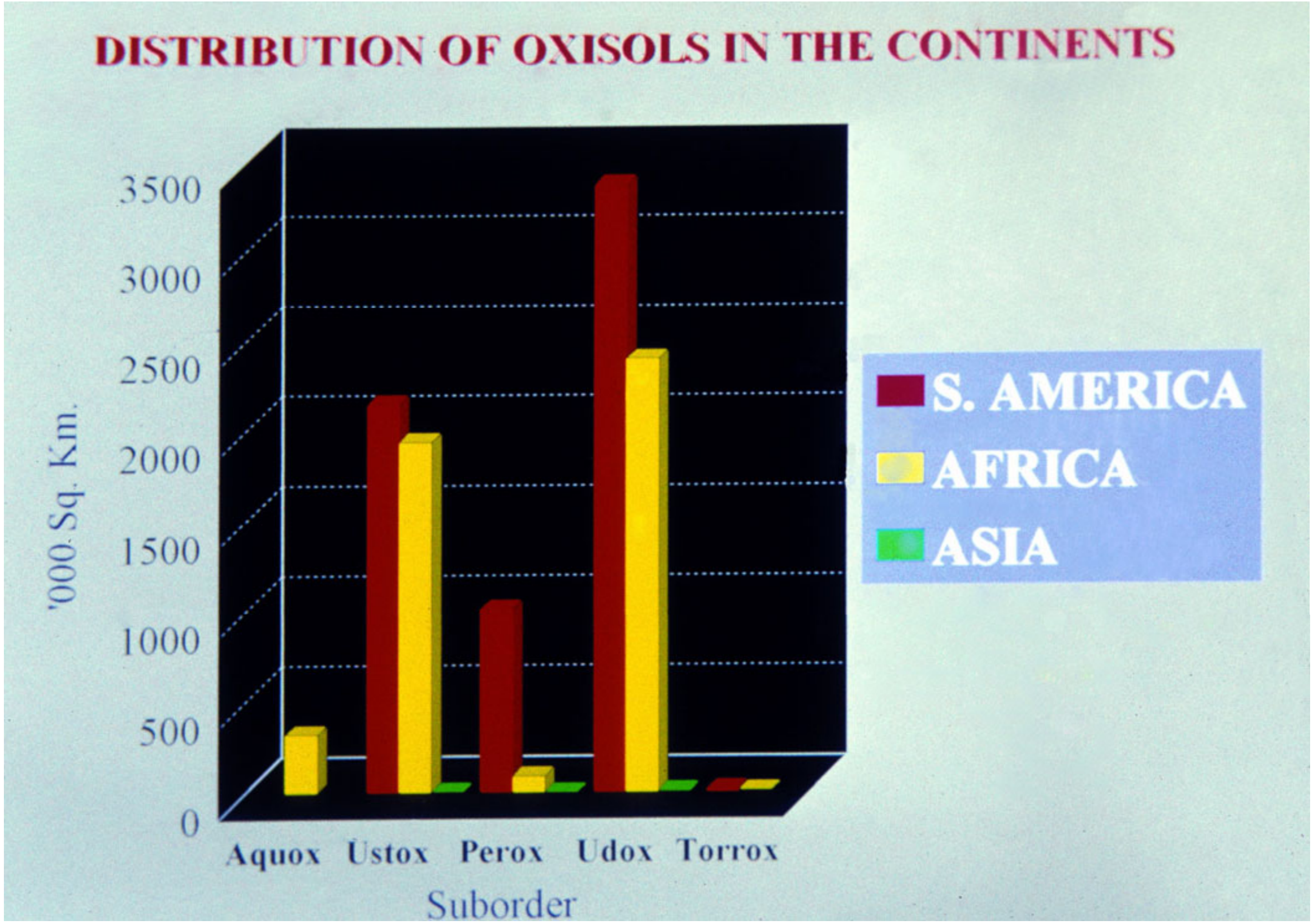
Order	Area '000 km^2	Percent
Gelisols	11,869	9.07
Histosols	1,526	1.17
Spodosols	4,596	3.51
Andisols	975	0.75
Oxisols	**9,811**	**7.50**
Vertisols	3,160	2.42
Aridisols	15,464	11.82
Ultisols	10,550	8.07
Mollisols	9,161	7.00
Alfisols	13,159	10.06
Inceptisols	19,854	15.18
Entisols	23,432	17.91
Non-soil	7,269	5.56



116 - The pie chart shows the relative areas of the Suborders of Oxisols. Udox are the most extensive and occupy over 50% of the Oxisol area. The Aquox occupy just under 3% while the extent of Torrox is about 0.3%. Most of the Torrox are in Brazil with a very small area in Hawaii.



117 - Over 98% of the Oxisols are found in S. America and Africa. S. America has more than 57% of the Oxisols of the world.



118 - The slide shows the relative distribution of the Oxisols in the three continents.

Use and Management

120 - Plinthite and plinthic materials are sources of engineering materials in many countries. In a country which has practically no stones for construction, such as Bangladesh, plinthic materials are oven-baked and used as stones for road building. The slide shows plinthite being cut out in Kerala, Southern India, for making bricks.

121 - The plinthite bricks are sun-dried and become very hard. Occasionally they are oven-baked. On drying, the iron minerals, such as goethite and hematite, form a strong cement and hold the material together.

122 - Traditionally, plinthite bricks have had many uses and many historic buildings made of this material still stand today. The slide shows a Portuguese fort built in 1511 in the town of Malacca, Malaysia. The fort not only withstood the climate but also the wars between the various colonial powers who needed it to control the Straits of Malacca. In the State of Karnataka, India, tombstones dating back to 600 years and made of laterite have been found. In fact, plinthite was such an essential building material that there are few areas in the western part (the piedmont of the Western Ghats) of India which have not been excavated and reworked.

123 - Large scale land clearing, as in Brazil, Indonesia and Malaysia is frequently done with heavy machinery. The timber-tracks as shown in the slide become the main arteries for land-settlers to invade the land. Land clearing is the first cause of land destruction in these tropical forest areas. Further soil degradation ensues after the forest undergrowth is burnt and the land is cleared for agriculture. The slide is from Acre State, Brazil, where a pasture of Brachiaria is being established. A few Brazil Nut trees are the only remnants of the former forest.

124 - Sheet erosion is not readily apparent on the field but gullies, as shown in this slide from the savanna region near Brasilia, Brazil, are ample evidence that erosion is active in this landscape. Soil erosion caused by land clearing has removed the top soil in the area and with this all the sustaining nutrients are also gone. If these nutrients are not replenished, the soil becomes non-productive very quickly.

125 - The slide demonstrates the consequence of large scale land clearing. The slide shows the Iguassu Falls at the border of Argentina and Brazil. The water is red due to the very high sediment load resulting from land clearing activities in Brazil.

126 - A scene similar to slide 125, is seen in this photograph of the Blue Water Falls in Kenya. The picture was taken in 1992 and the water was loaded with sediment. The second author had visited the falls in 1982, when the water was really ‘blue.’

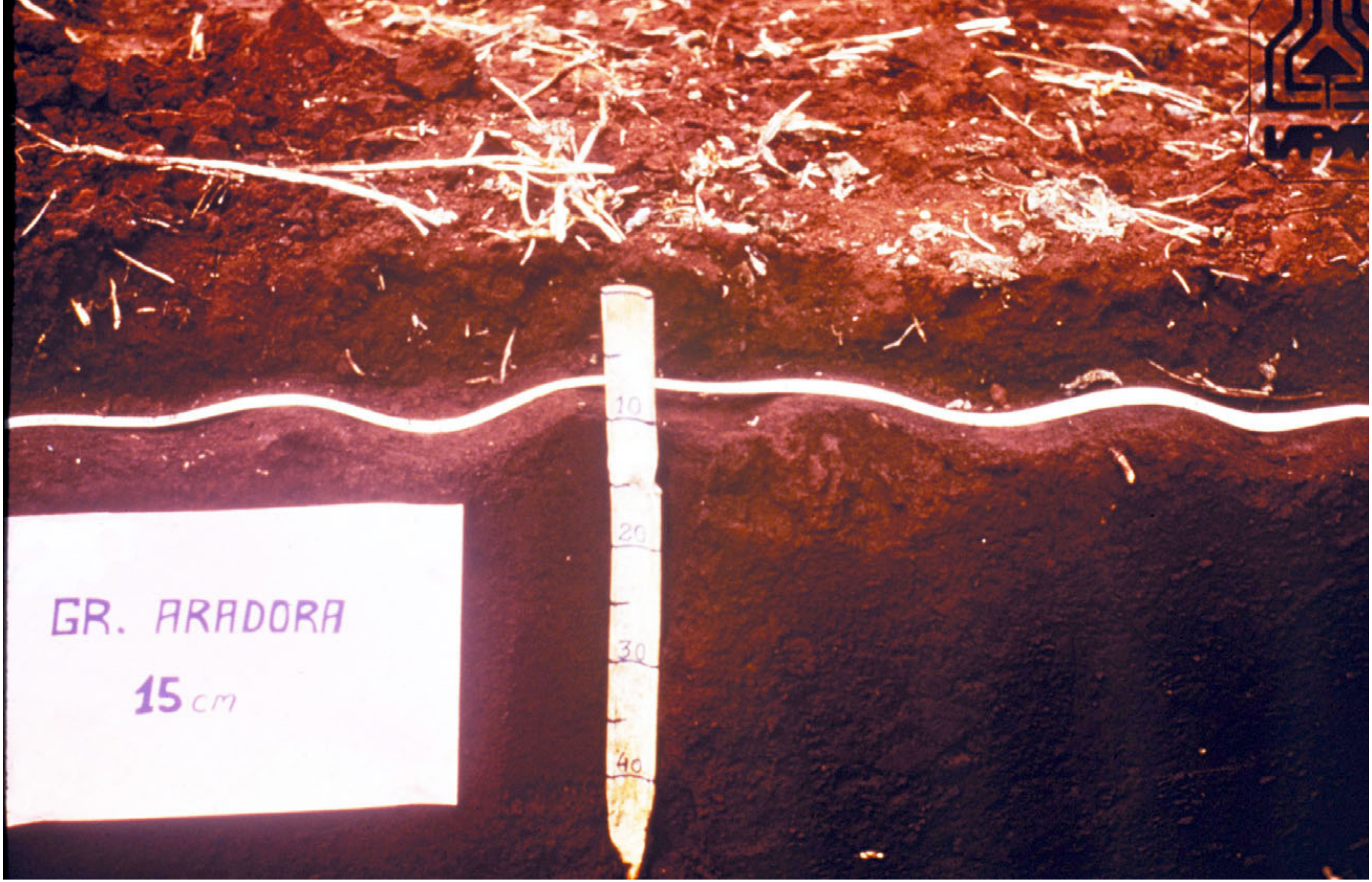
127 - Pressures of modern society are frequently the root cause for resource exploitation. The picture shows intensive tomato cultivation on sloping Oxisols, near Rio de Janeiro. The land form is not suitable for this type of cultivation. The farmers are aware of this but would rather make a ‘quick-buck’ when the price is right than invest in other technology.

128 - A gully formed by rill erosion (at the same area in slide 127) is developing at the point where the irrigation and rain water is seeking a channel to move downslope. Sheet erosion is also rampant and this piece of land had to be abandoned after two or three crops.

129 - Even if the land is abandoned, the consequence of misuse is not over. Land-slips and landslides continue for a long time. Because top soil is gone, vegetation cannot reestablish and so erosion continues until bare rock is exposed. The slide was taken in the same area as slides 127 and 128 near Paty do Alferes near Rio de Janeiro, Brazil.

130 - Under plantation or cash-crop forms of agriculture, farmers make investments in some form of soil conservation practices. This picture is from Londrina, Parana State, Brazil, where corn was planted as an inter-row crop with coffee. The corn is harvested but the straw has been plowed in leaving the soil surface susceptible to erosion.

131 - In an adjoining area in Londrina, the farmer practices no-till soybean after a preceding crop of wheat. This system of crop production, which is increasingly being practiced in Brazil, keeps the soil well protected against heavy rainfall, thus diminishing problems of soil erosion.



132 - Due to the nature of the colloid aggregation, soil compaction is not easily achieved and was also not a major problem in many Oxisols. However, due to introduction of heavier machinery, compaction results, as shown in the slide. Clayey soils with low sesquioxide content are more prone to compaction.

133 - Hand-clearing procedures for land clearing, though not as efficient as mechanized clearing, are generally less taxing on the soil. This method is sometimes referred to as 'slash and burn,' as shown in the picture from Cameroon. The vegetation is allowed to dry out and then it is burned. The ash that accumulates on the soil is a concentrated source of nutrients. The emission of carbon dioxide to the atmosphere contributes to global warming and this is one of the negative consequences of burning.

134 - After a complete burn there are still stumps and large logs on the ground. These will take a few years to rot. In the meantime, the farmer has his first crop of upland rice as shown in the picture taken along the Trans-Amazon highway between Itaituba and Altamira Counties, Para State, Brazil.

135 - Depending on the country and region, the second and successive crops vary. In the Amazon region, pasture establishment is a general practice. In southern Brazil, wheat is planted as shown in this picture from Cascavel, Parana State, Brazil. After harvest, the straw is burned. Farmers believe that burning provides the nutrients and reduces insect pests and also weeds. Burning also facilitates subsequent soil tillage.

136 - Establishment of a good crop on Oxisols requires good nutrient management. Nutrients must be applied in small amounts and periodically to counteract leaching losses and fixation. This is particularly true for phosphorous as shown in the picture. In the absence of P, as in the foreground, the maize does not grow.

137 - In addition to nutrients, water is the other essential input. Hawaiian sugarcane plantations receive drip irrigation to provide the moisture needed for growth. Oxisols are sometimes referred to as ‘droughty’ soils as they suffer from moisture stress earlier than other adjoining soils.

138 - On a Eutrustox in Puerto Rico, up to 10,000 kg/ha of maize have been produced under optimum water and nutrient management conditions.

139 - Plantations of rubber (Hevea brasiliensis) are the most profitable land use on Oxisols in Malaysia and some other S.E. Asian countries. The rubber tree with an economic life of 35 or more years is adapted to the low nutrient content soils. It does best on soils with udic soil moisture regimes; from a plant physiology point of view, a perudic SMR is also desirable. However, as tapping of the tree is done in the morning, the rainfall pattern should be such that the rain is during the late afternoon or at night. If rain occurs after tapping, the latex is washed out of the tapping cut and does not accumulate in the collection cups. The tree is very susceptible to moisture stress. Yield decline commences after more than a few days of moisture stress. The ustic SMR is not suitable for rubber though it is grown under such SMRs in southern India and West Africa.

140 - Young rubber is planted on contour terraces and a cover crop (Centrosema pubescens or Pueraria spp.) is planted for soil conservation purposes. The slide shows a typical rubber plantation in Malaysia. The houses of the workers are strategically placed around the plantation for ease of transit.

141 - Oil-palm (Elaeis guinensis) is also grown on Oxisols. It does very well on moderately to poorly drained soils and Oxisols are not the best soils for oil-palm. Oil-palm also requires better nutrient supply and, like rubber, is susceptible to moisture stress. When there is moisture stress, the fronds droop as shown in the slide.

142 - This slide shows mature oil-palms in a plantation of about 12 years. Cover crops are maintained as in rubber plantations. The cover crops die out when the canopy of the palm closes and cuts out the light. Decay of the cover provides nitrogen and other nutrients to the feeder roots of the rubber tree or oil-palm.

143 - A crop that adapts to low nutrient and soil moisture stress conditions is pineapple (Ananas sativus). This is a pineapple plantation at the north coast of Puerto Rico. Though the crop requires moisture stress at maturity of the fruit, during the vegetative growth stage, supplementary irrigation ensures a good crop.

144 - It is significantly more risky to grow annual crops on Oxisols. Many of the resource poor farmers of the tropics, who have to live on Oxisols, have to be supported and so research is conducted by national and international institutions around the world. The slide shows experiments at Isabela, Puerto Rico, evaluating the nutrient and moisture requirements of many food crops.

145 - Understanding the moisture variability in this unique soil has been a challenge for many soil scientists and agronomists. Piezometers in the soil are monitored daily to provide data which are then used in a model to evaluate moisture supply and retention patterns. This slide illustrates the work of a USAID funded project in Jaiba, Minas Gerais, Brazil.

146 - The shifting cultivator opens small (less than 0.25 ha) tracts of land to establish his farm. The slide shows a cleared tract of land in Itaituba, Para State, Brazil. The clearing is done with machete and burning.

147 - A range of crops is planted in the first season after clearing. The photograph taken along the Trans-Amazon Highway between Itaituba and Altamira in Para State shows an inter-cropping of cassava with maize. All kinds of combinations of crops may be seen along the highway.

148 - Within a year or two, beside the plot of land with food crops, the farmer sets up a pasture. The picture, taken in Assis, Acre County in Brazil, shows degraded pasture. Cattle is an important component of the farming system in this part of the country.

149 - Once the farmer is established on the land, he starts to plant perennials. The picture shows a stand of babacu palm (Orbygnia martiana) which is a native palm of the northeastern part of Brazil. The nuts are used as food, or oil is extracted for use as a lubricant in precision machinery. The fronds and trunk can be used for fuel.

150 - In Yurimaguas, Peru, farmers plant the peech palm (Guilierma especiasa) which produces a very nourishing drink and food. Cattle graze under the palms and the cover crop is maintained for the cattle.

151 - Papaya (Carica papaya) and other crops are grown for cash on the Oxisols of Peru. If a market is readily available, papaya is an excellent cash crop for Oxisols. With some supplementary nitrogen and phosphorous fertilizers, it is a lucrative crop.

152 - Apart from food crops, a whole range of economic crops can be grown in the tropics. The slide shows an annatto plantation in Belem County, Para State, Brazil. The red fruit of Annatto (Bixa orellana) produces a dye used in the cosmetic industry.

153 - In the Amazon jungle, an important second story crop is gurana (Paullinia cupania) which produces bright red fruits, the size of cherries. Each fruit contains a large number of seeds which is ground to a paste and used for medicinal purposes. The pulp is also squeezed for a drink which has a very high ascorbic acid content. (Locally, gurana juice is spiked with vodka or other alcoholic beverages which results in a refreshing drink that is said to make life easier in the hot, humid, insect-ridden tropical forest.)

154 - Mango (Mangifera indica) is a good cash crop. The quality of the fruit improves in areas with prolonged moisture stress (ustic SMR).

155 - Another secondary story crop in the tropical jungle is cacao (Theobrama cacao) which is now successfully cultivated in plantations. The ripe pod is split open and the large chestnut-sized seeds covered with mucilage is scraped out and stored in a box for fermentation. After fermentation, the seeds are cleaned, dried, and powdered for chocolate making.

156 - Cropping systems vary with the climatic endowments of the land. Soybean is an important crop in the thermic soil temperature regime areas. The picture shows a farm with cassava (Manihot utilissima) in the foreground and soybean (Glycinia max) in the background in Londrina, Parana State, Brazil.

157 - Complex inter-cropping systems can be seen as farmers attempt to reduce their risks. The picture shows such a system. Maize is planted 20 days after common beans, which is an inter-crop. After the harvest of beans, oats are the subsequent crop. Later, the maize is manually harvested and the stalk is used as support for a later pea plant. This is an example of multiple cropping at its best.

158 - This is an example of inter-cropping of coffee (Coffea arabica) with rice (Oriza sativa). The 2.5 year old coffee is intercropped with three rows of rice. Inter-cropping is done until the coffee is about 5 years old. In the last year of the inter-crop, the rice may be replaced with a bean crop.

159 - Mulching is a common land management practice in coffee plantations. The 6-year old coffee was planted with mucuna preta (Stizolobium aterrimum) which is used as green manure. The mulch also helps to conserve the soil moisture. The mucana plant further has nematocoidal properties.

160 - This is a close-up of the mucuna mulch plant (Stizolobium aterrimum). This legume is capable of fixing 150 kg of N per hectare per year and also offers good protection against raindrop splash erosion.

Oxisols - Summary of fertility and management related properties I

•Liming not only provides calcium but also increases CEC.
•Phosphorus availability is low and phosphorus fixation is high; good management requires periodic applications of phosphorus fertilizers.
•Due to high leaching rates, repeated applications of nutrients is essential.
•Maintaining soil surface cover is an integral part of management.

Oxisols - Summary of fertility and management related properties II

•Deep incorporation of nutrient elements promotes root proliferation and enhances nutrient use efficiency.
•Soil is droughty; short dry spells induce moisture stress in plants; supplemental irrigation required in semi-arid areas.
•To avoid moisture stress, annual crops are planted at lower population density.
•To reduce erosion, perennials are planted with inter-row crops.

Sustainable Development Considerations

164 - As shown earlier, large areas of Oxisols of the world are still under forest. The hostile environment of the tropical forests helped preserve and protect them from human onslaught. However, due to pressures on land resulting from the ever-increasing population, they have become a new frontier to conquer. Forest fires now light the skies of the humid tropics, destroying biodiversity, and increasing the atmospheric carbon dioxide.

165 - The slide shows a two year old pasture in the foreground and new forest being cleared in the background.

166 - Tropical forests yield a number of forest products. The picture shows cane rattan being harvested for furniture making. Rattan furniture is popular in the tropics because it is not eaten by termites.

167 - Other forest products include fuel wood. Difficulties in obtaining fuel for cooking and other household uses is one of the factors that lead to slow deforestation. This picture from Pucalpa, Peru, shows boys harvesting wood for sale. Agroforestry can be developed to provide the necessary wood and this could reduce the pressures on the forest ecosystem.

168 - In the great plains of Africa, wildlife is under threat as populations compete for land. Some countries, like Kenya, have established national parks to protect this biodiversity. In others, poaching is a way of life. Rhinos are endangered because their horns have medicinal value. The elephant is hunted for its ivory tusks.

169 - Zebras and other wild animals are being stressed as wildlife refuges become reduced in size. These animals have adapted to the ecosystem. The wild-life areas have a range of soils, each with its own animal population supporting capacity. Competition for the good land for agriculture relegates the poorer land to wild animals and this is also an indirect impact on biodiversity.

Oxisols - Sustainability and environmental considerations I.

- High loss of applied nutrients may pollute ground water.

- Luxuriant forest vegetation is not an indicator of high agricultural productivity.

- Most agricultural systems are non-sustainable under low-input conditions.

- With good management, stability of production is ensured.

Oxisols - Sustainability and environmental considerations II.

•Tropical forest ecosystems are in a steady state condition with soil and climate.

•Disturbance of forest ecosystems results in irreversible loss of biodiversity.

•Plantations do not replace forest ecosystems in terms of biodiversity.

•Degraded Oxisols have low resilience and require high inputs to sustain production.

Oxisols Conclusions - I.

Oxisols occupy about one fourth of the land surface of the tropics and are the single most extensive kind of soil in that region. Oxisols thus constitute a major land resource and one fo the few remaining frontiers for agricultural development, particularly in Africa and Latin America. Although most Oxisols are inherently infertile, they can be managed to be highly productive.

Oxisols Conclusions - II.

Their distinctive chemical, physical, mineralogical, and morphological properties combine to make Oxisols unique soils that require high-input management practices to ensure sustainable crop production. Under low-input agriculture, productivity is low and the potential for degradation is high. Once degraded, Oxisols are difficult to rehabilitate because of their low resilience.

Oxisols - Conclusions III.

Oxisols support the largest extent of tropical forests. Conversion to agricultural land will be at the expense of forests with the concomitant loss of biodiversity and negative impact on global climate. Landuse policies and practices guided by an understanding of the nature, properties, and ecological functions of Oxisols are critical to sustain the integrity and productivity of these soil resources.