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VERTISOLS:

THEIR PROPERTIES, CLASSIFICATION, DISTRIBUTION, AND MANAGEMENT

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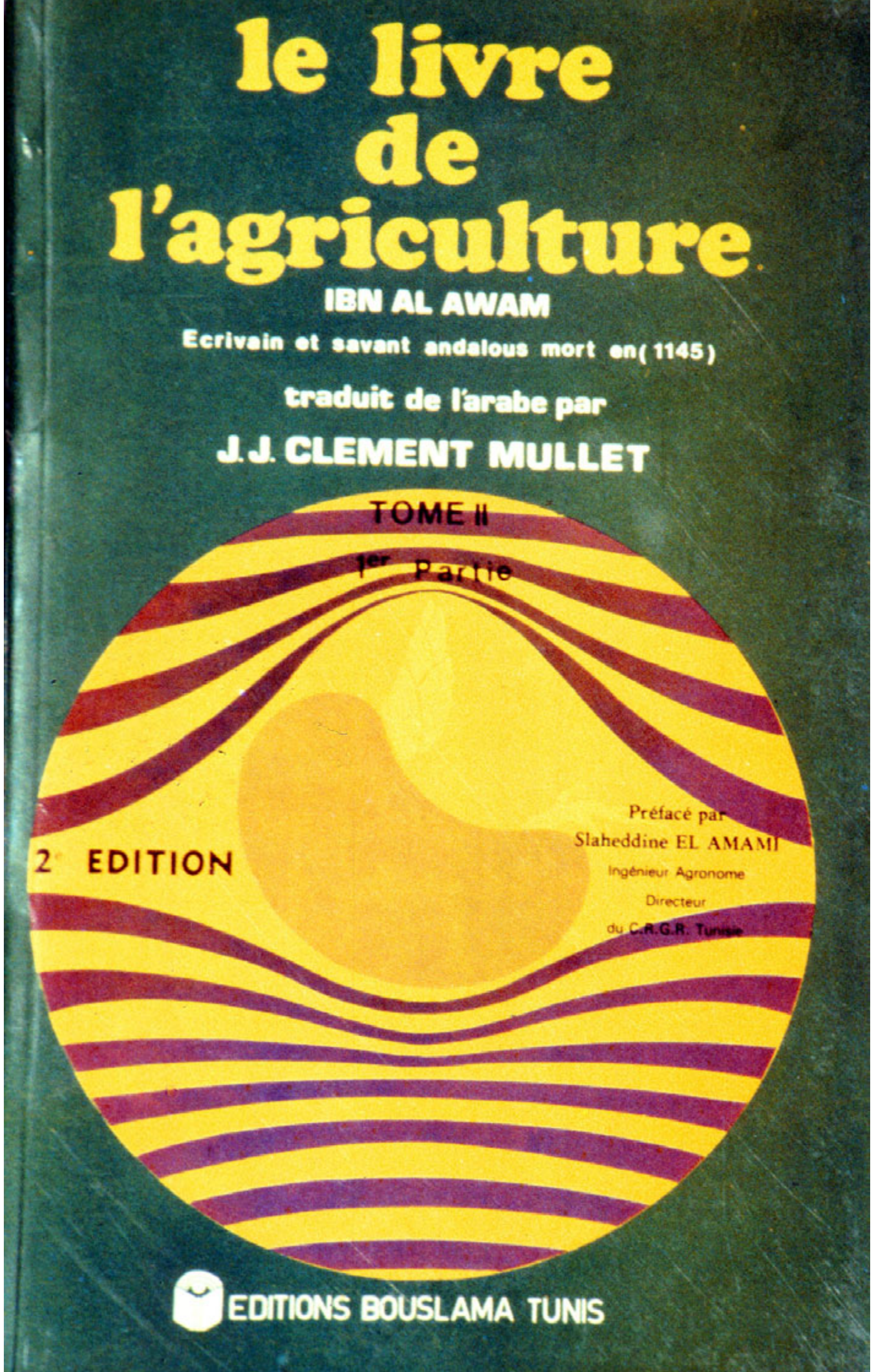


2 - Cover of the book, "Le Livre de l'Agriculture," written in the 12th Century in Arabic and translated to French (Ibn Al Awam, 1145). This book reveals not only the interest in differentiation of soils during that period but also the quality of observation, which is evident in their similarity with modern concepts of Vertisols and Mollisols.

12^{th} Century notion of Vertisols (I)

"DEMOCRITES states that the best natured soil is the one that takes in rain-water easily, that does not become sticky at the surface, and that does not crack when the rains have ceased (Mollisols?). As a result, says IBN HEDJADJ, to be a good soil it should be neither sticky nor hard (Vertisols?). Some have told me, he adds, "How can the wise DEMOCRITES criticize soils that crack since we see that the soils of the territory of Carmona (a city in Andalusia, Spain), which shows these features, produce higher yields of wheat than those on soils anywhere else?"

………………………………………………..Cont'd

3 - Excerpt from the writings of Ibn Al Awan, Part I.

12th Century notion of Vertisols (II)

*"So, I say that this soil can only be depreciated only in comparison with other soils which are of prime quality according to principles established above. On the other hand, one should not rank the soils that crack (**Vertisols**) among those of first quality just because they produce good wheat. Since a major part of the seeds and plants entrusted to these soils do not do well, how could we not give preference to other soils. The black soils with a not too dense texture, which resembles old and well-decomposed manure and in which all kinds of seeds and plants succeed (**Mollisols**), should be rated first class on account of its superior qualities."*

……………………………………Ibn-Al-Awam

4 - Excerpt from the writings of Ibn Al Awan, Part II.

Names That Include The Word "Black"

NAME	COUNTRY
Barros Pretos	Portugal
Black Cotton Soils	India
Black Earths	Africa, Australia
Terra Negra	Italy
Terres Noires Tropicaux	Africa
Terras Negras Tropcais	Mozambique
Tierras Negras de Andalucia	Spain
Tropical Black Earths	Ghana, Angola,
Tropical Black Soils	Africa, India

5 - Names that include the word "black." These connotative names proliferated in texts after the Second World War, as color was the most distinguishing feature. Such soils were recognized mainly in the tropics.

Names That Reflect The Black Color

NAME	COUNTRY
Karail	India
Melanites	Ghana
Teen Suda	Sudan
Tropical Chernozems	Africa, India
Impact Chernozems	USSR

6 - Some names reflect the black color specifically. A distinct misnomer is the 'tropical chernozems' as these are not chernozems as defined by the Russian pedologists.

Vernacular Names

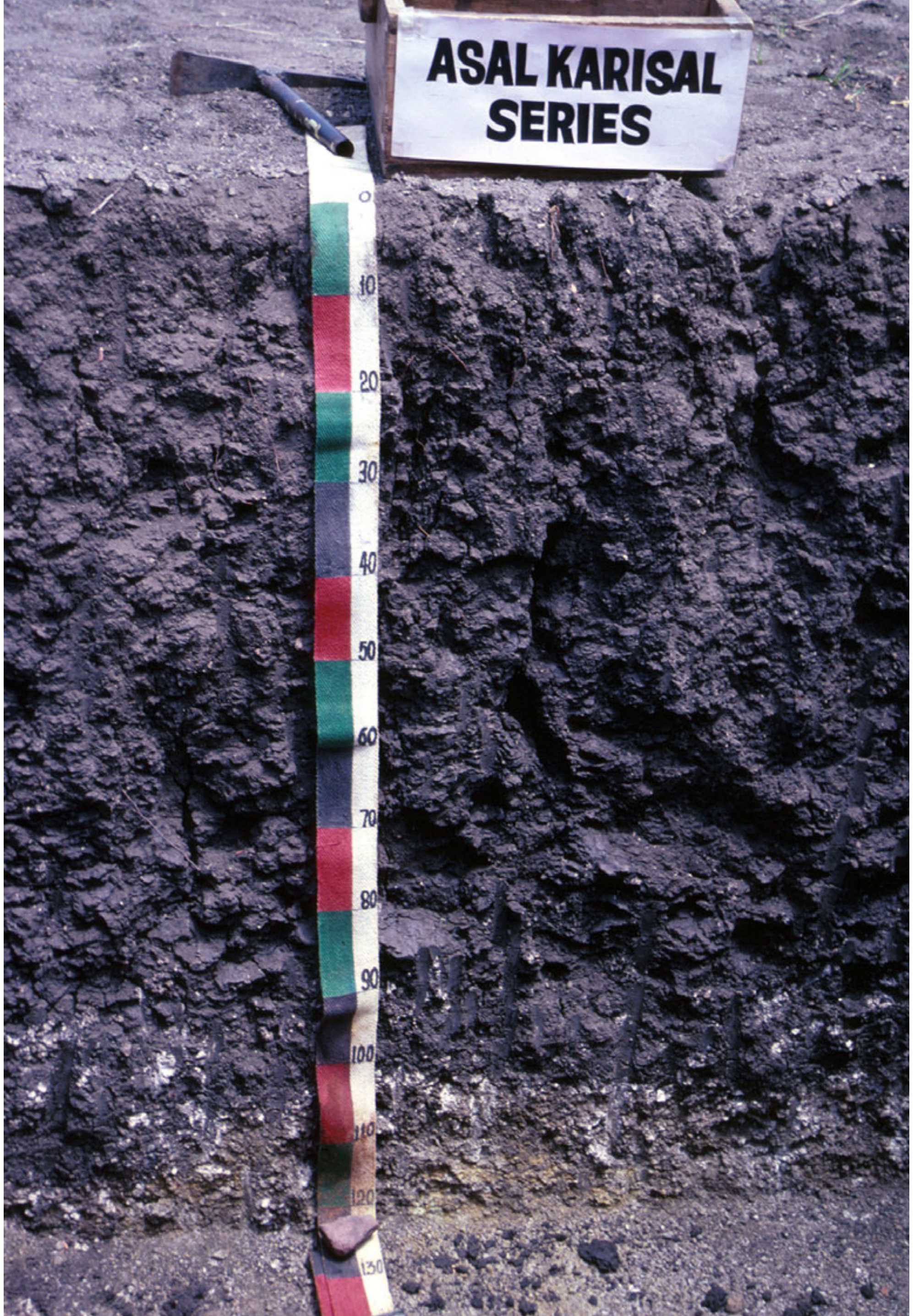
NAME	COUNTRY
Gilgai Soils	Australia
Firki	Nigeria
Mbuga	Tanzania
Morogan	Romania
Regur	India
Shachiang	China
Smolnitza	Bulgaria, Romania
Sols de Paluds	France
Tirs	Morocco

7 - This list of vernacular names is short but there are many others, particularly those of local importance. In recent times, some of these names have been used as equivalents to Vertisols. In India, local names change with the district.

Coined Names

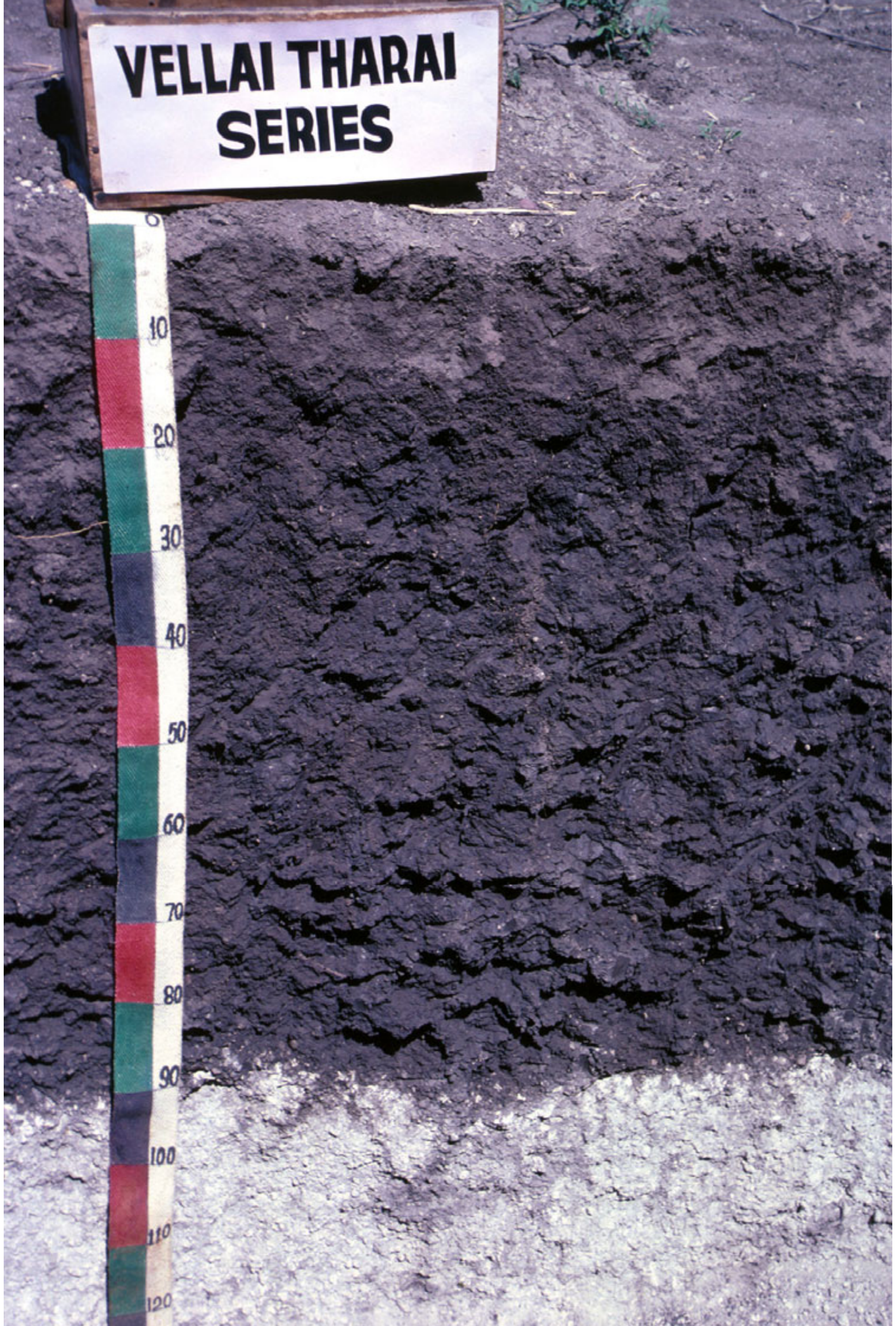
NAME	COUNTRY
Densinegra	Angola
Gravinegra	Angola
Grumusols	United States
Margalite	Indonesia
Vertisols	United States

8 - In the Western world, many coined names were introduced. The term "VERTISOLS" was introduced by Soil Taxonomy.

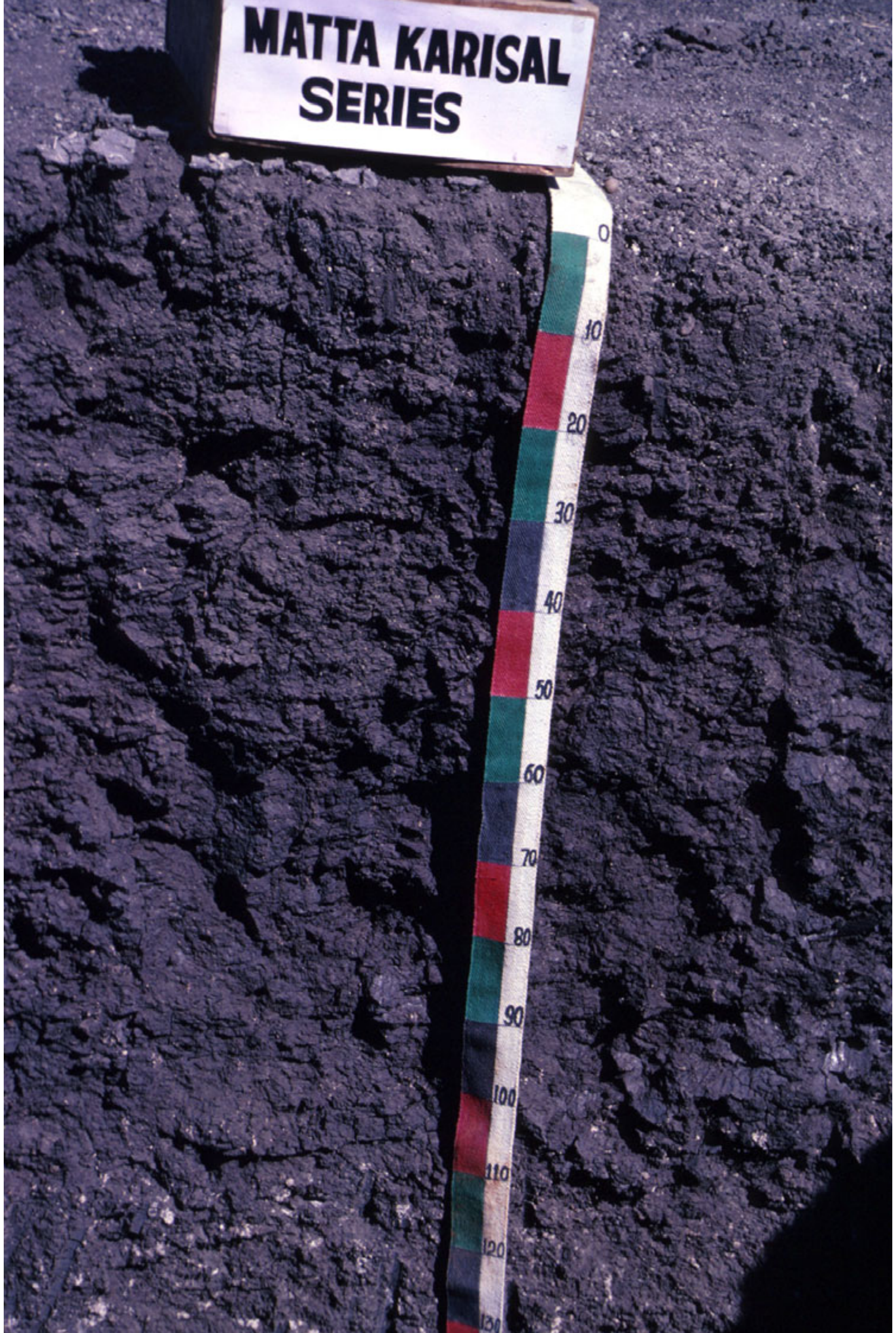


9 - This and the following four slides illustrate the ability of farmers to differentiate soils within a homogenous group. The local names have been adopted as the soil series name during the soil survey of the area in Tamil Nadu, India (Mosi et al., 1991). The first name is "Asal Karisal." The farmers use the generic term Karisal to denote black soils - "kari" means black in the Tamil language. The term "Asal" means typical or ordinary.

10 - "Potta Karisal" ("Potta" implies that the soil is subject to ponding). There are small nodules of carbonate (powdery lime) and manganese distributed throughout the profile. The soils belong to aquic suborders or subgroups.



11 - The local name of this soil is "Vellai Tharai" or white floor. The presence of the calcic horizon is distinct in this Calciustert. Sometimes "vellai," which means white also suggests white salt encrustations on the soil surface.



12 - This soil has an appropriate name, "Matta Karisal." Matta means useless or of poor quality. The soil is a Natrustert and has a high salt content. Farmers try to avoid such soils for obvious reasons. The term generally is used to indicate salinity problems.

13 - The local name is "Palupu Veppal." A 'Veppal' is also a black soil but does not crack. The soil is a Haplustept and is shown here as a comparison, to illustrate the ability of farmers to distinguish soils.

14 - One of the persons who documented the black soils of the tropics and subtropics is Dr. Rudy Dudal. Dr. Dudal was at that time with the FAO and his monograph (Dudal, 1965) was a benchmark publication.

15 - This photograph was taken during a workshop to study wet soils. On the left is Dr. Roger Langhor of the University of Ghent. His detailed observations and descriptions enabled the understanding of genesis of soils. In the center of the photo is the late Dr. Rene Tavernier who proposed the name "Tarrasols." Dr. Tavernier of the University of Ghent can be considered as the co-father of Soil Taxonomy as Dr. Guy Smith relied on him for many of the concepts and terms. On the right is Dr. Hari Eswaran, the senior author of this publication, who spent the decade of the eighties, teaching Soil Taxonomy around the world and who helped clarify many of the morphological properties of Vertisols.

16 - The person with the white hat is Mr. Terry Cook, formerly of NRCS, and who provided some of the best descriptions of Vertisols from around the world. In the center of the photo is Dr. John Witty also of NRCS (retired), who was responsible for coordinating the effort to refine Soil Taxonomy. The person with the blue shirt is Dr. Goro Uehara of the University of Hawaii, who contributed to the understanding of the colloid composition of soils.

17 - Mr. DeWayne Williams of NRCS has made some of the most detailed studies of Vertisols using 20 to 25 m long trenches (Williams et al., 1996)

18 - The person on the left is Dr. Richard Arnold of Cornell University and later NRCS. He provided some of the genetic theories in Soil Taxonomy. The person with the brown shirt is Dr. J.S. Kanwar, Deputy Director General of the International Crops Research Institute for the Semi-Arid Tropics. He made major contributions to the management of Vertisols in India.

19 - Dr. Johan Bouma, Agricultural University of Wageningen, Netherlands, has made several contributions including water movement in Vertisols. He elaborated on the notion of "by-pass" flows, which differentiates water movement in Vertisols from other soils.

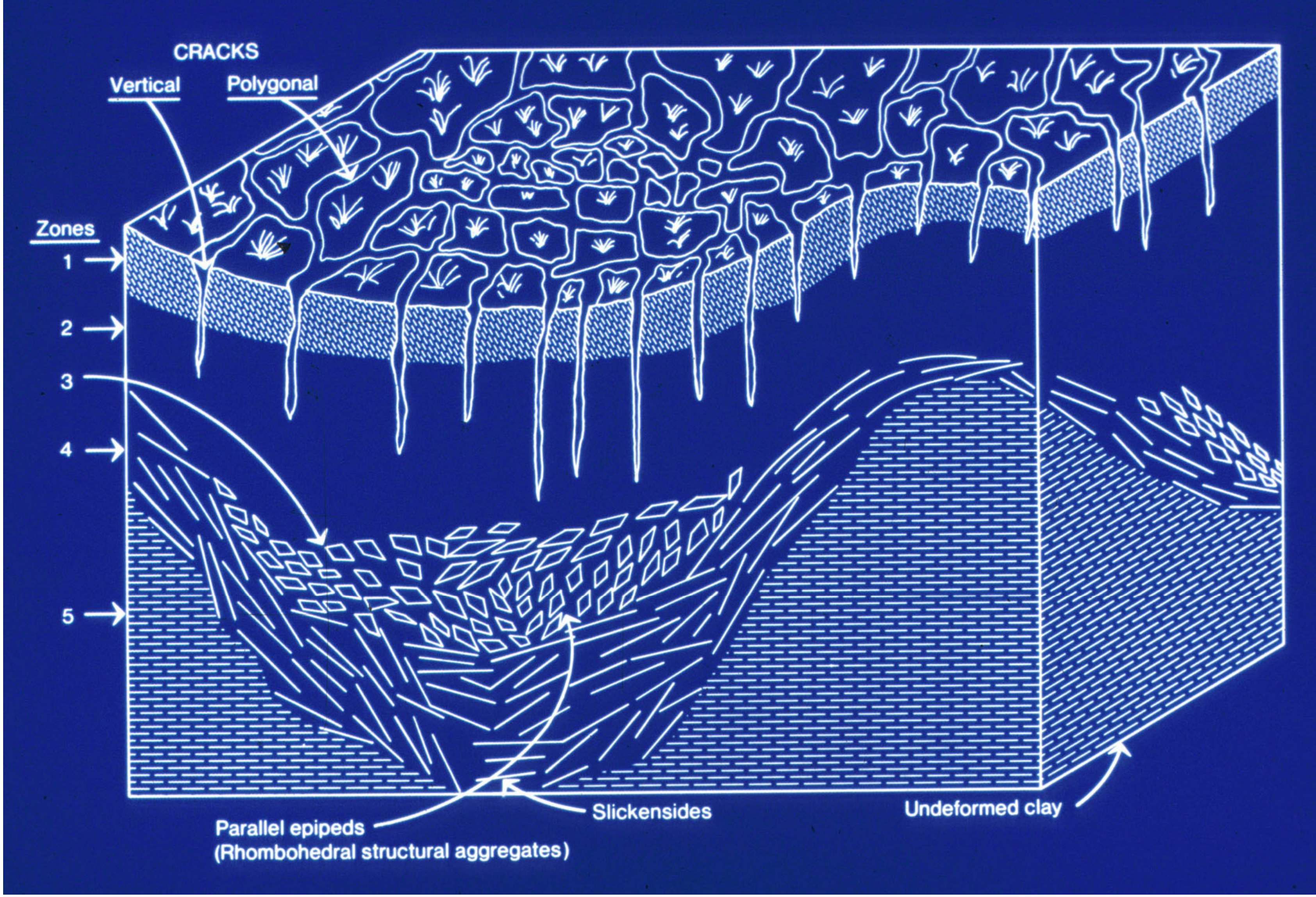
20 - The person with the blue jacket is the late Dr. Ahmed Osman, Director of Soils Division of the Arab Center for the Studies of Arid Zones and Dry Lands and Chairman of the International Committee on Aridisols. He and his colleagues provided considerable data on Vertisols from arid and semi-arid parts of the world. On the right with the brown sweater is Dr. Nazeer Ahmad, Director of Research in Guyana and formerly professor of Soils at the University of West Indies, Trinidad. His knowledge of the management of Vertisols in humid regions was valuable to the understanding of these soils.

GILGAI

The surface microrelief of soils produced by shrinking and swelling of the soil material; dry conditions cause the soil to shrink and moist conditions result in swelling; a basin shaped depression (diameter generally about 2-3 m) which is the gilgai, results; the depression is referred to as micro-low and the raised edges, as micro-highs. The gilgai may be linear instead of basin-shaped and these are parallel to the direction of the slope.

21 - Concept of gilgai

22 - Australian scientists (Hallsworth and Beckman, 1969) have recognized several kinds of Gilgai. Other terms, such as linear and wavy gilgai have also been used in the literature.

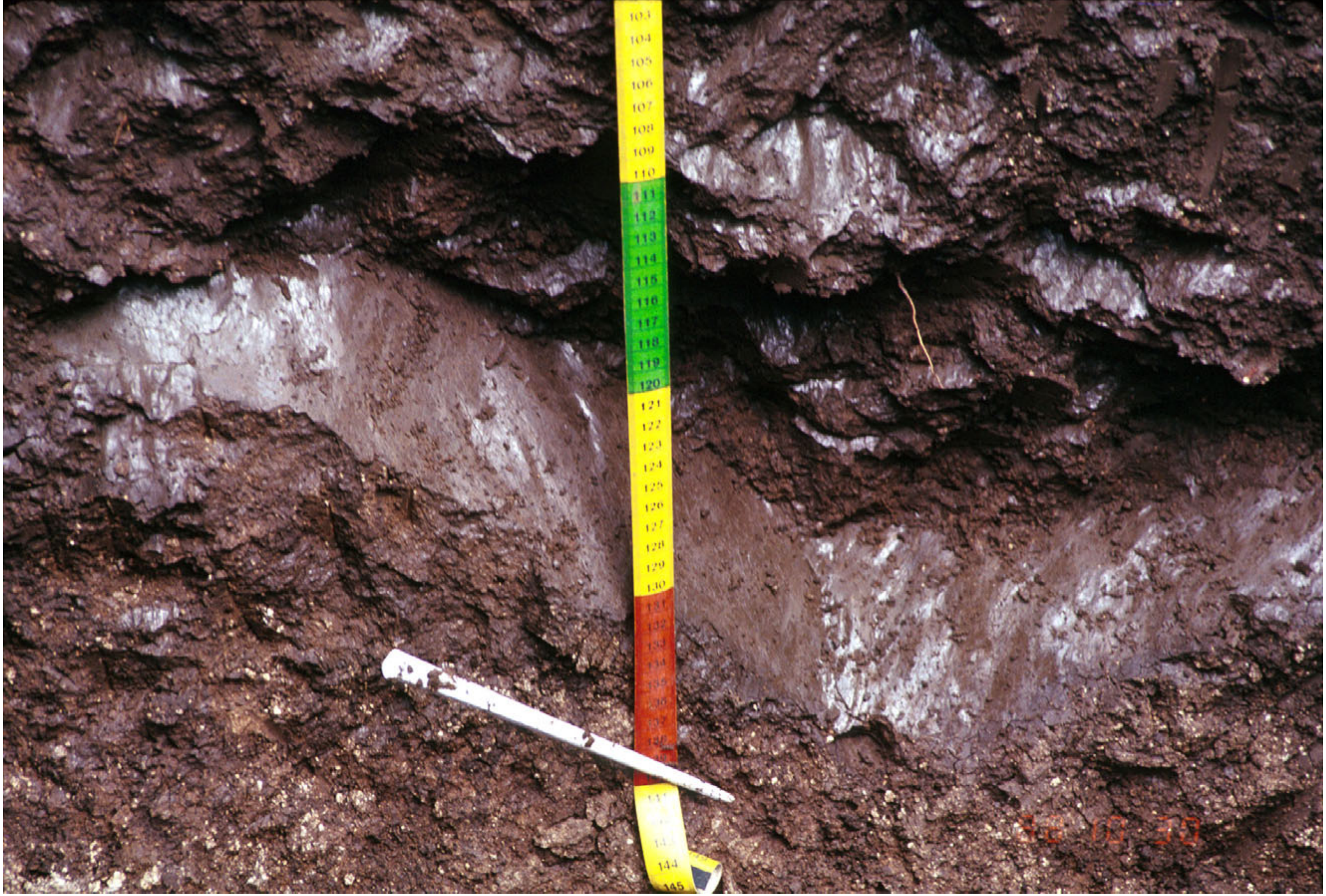


23 - A three dimensional model of a soil with gilgai micro-relief. The micro-lows or depressions seen on the landscape correspond to the 'bowl-shaped' arrangement of the slickensides and the sphenoids. The micro-high on the landscape corresponds to the parts where the soil material was pushed up. Vertical cracks are present in the upper part of the soil. They do not penetrate the zone of the slickensides, unless it was a very dry year.

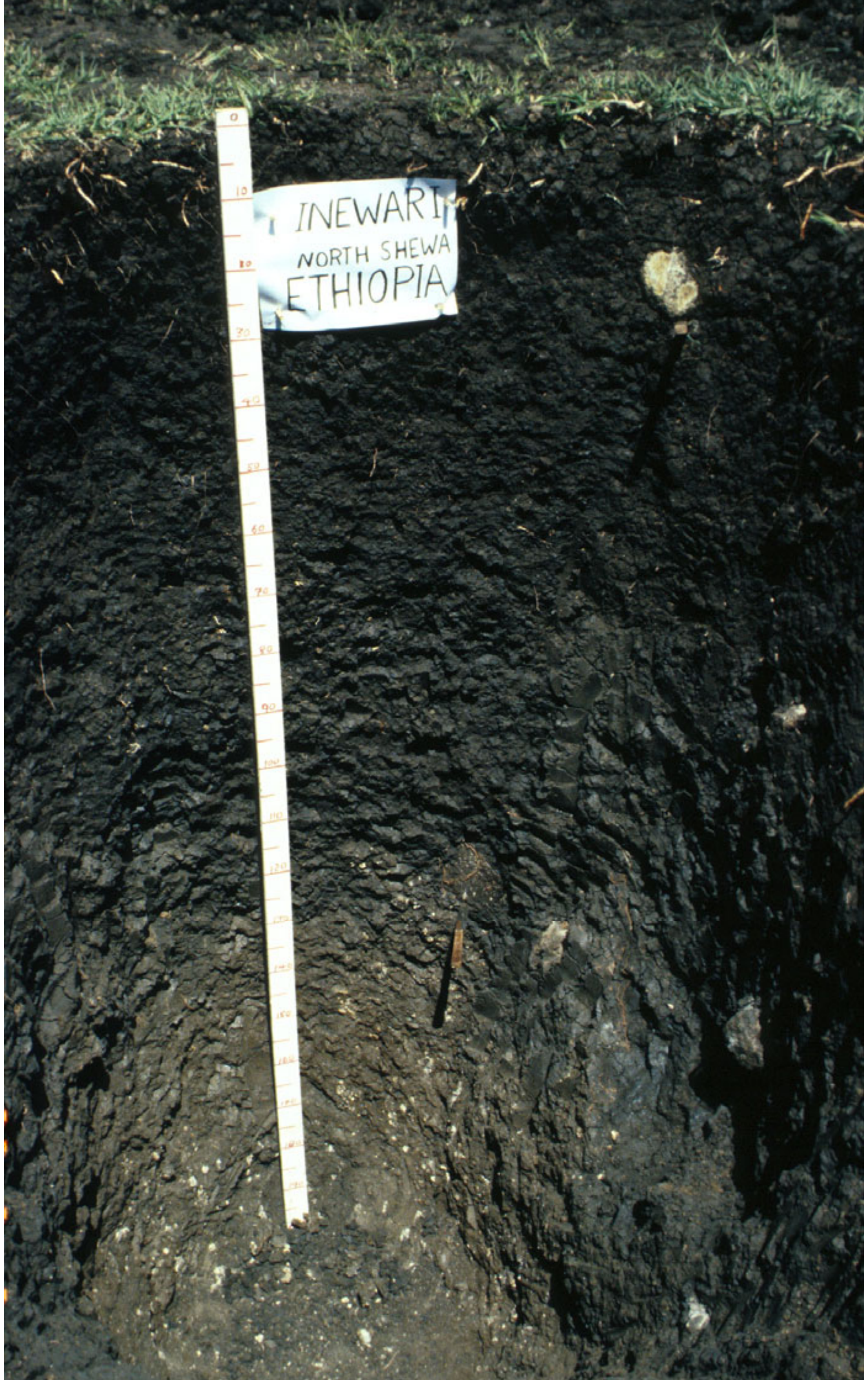
24 - The microhighs are marked by the presence of white carbonate concretions (Beinroth, 1965), littered on the soil surface. These concretions are exposed on upper part of the diatreme or the chimney (illustrated later).

25 - Profile face of the Lake Charles Series, Texas, showing a section corresponding to the block diagram in (23). The right half of the bowl is shown. On the right part, the slickensides tilt upwards and beneath are the lime-concretions, which are pushed up forming the chimney or diatreme.

26 - The best time to observe a gilgai landscape is the day after a rain. Water ponds on the micro-lows or the basins. Burleson Clay in Texas after a rain. These circular depressions are sometimes referred to as 'normal gilgai.'



27 - Slickensides, the glossy surface seen in the picture, are an obligatory requirement for Vertisols. Other examples are provided in the following sections. In Soil Taxonomy, the phrase "Slickensides close enough to intersect" has been interpreted as "intersecting slickensides". Slickensides do not intersect.



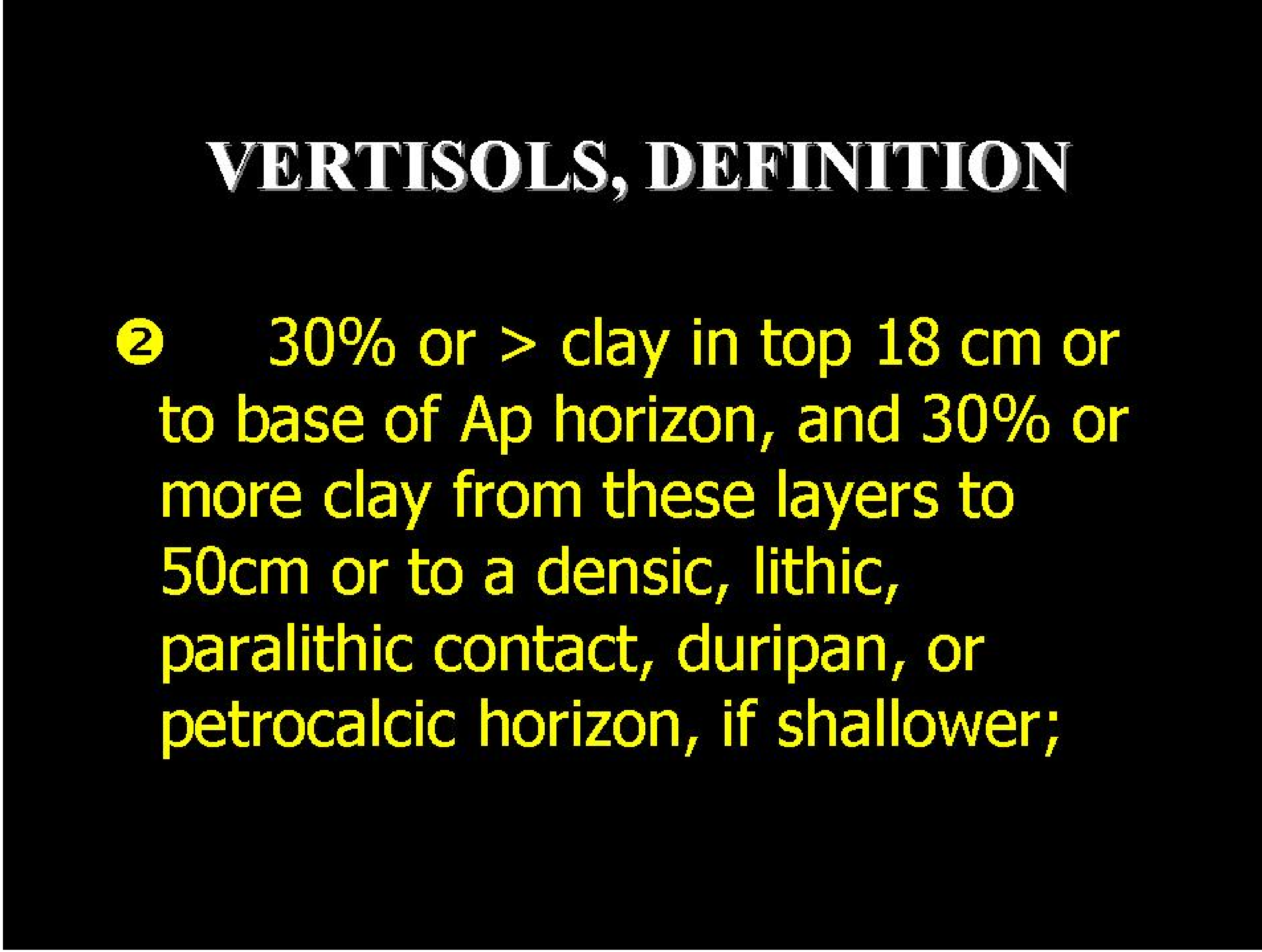
28 - In some Vertisols, as in this soil from Ethiopia, sphenoids may be the only expression of vertic features. Slickensides may be poorly expressed or absent.

29 - Though not a requirement in the definition, cracks are omnipresent in Vertisols during the dry season. They are the first indicators on the field for such soils.

VERTISOLS, DEFINITION

➊ A layer 25 cm or > thick within 100 cm of surface, with slickensides or wedge-shaped parallel epipeds, with their long axis tilted 10-60° from the horizontal;

30 - Definition of Vertisols. The term sphenoids refers to the "wedge-shaped structural aggregates."



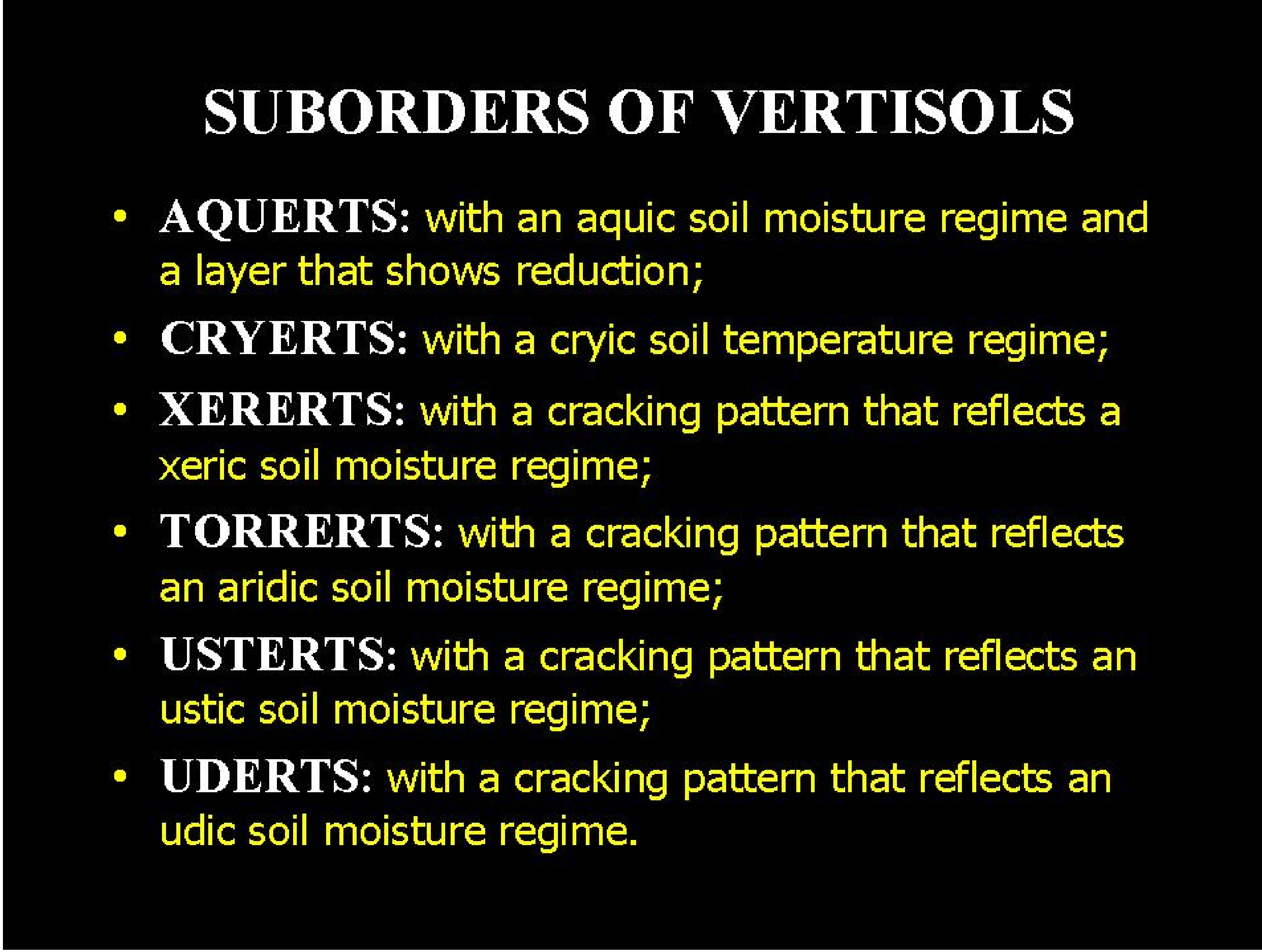
31 - Definition of Vertisols. The different impermeable layers are defined in Soil Taxonomy.

VERTISOLS, DEFINITION

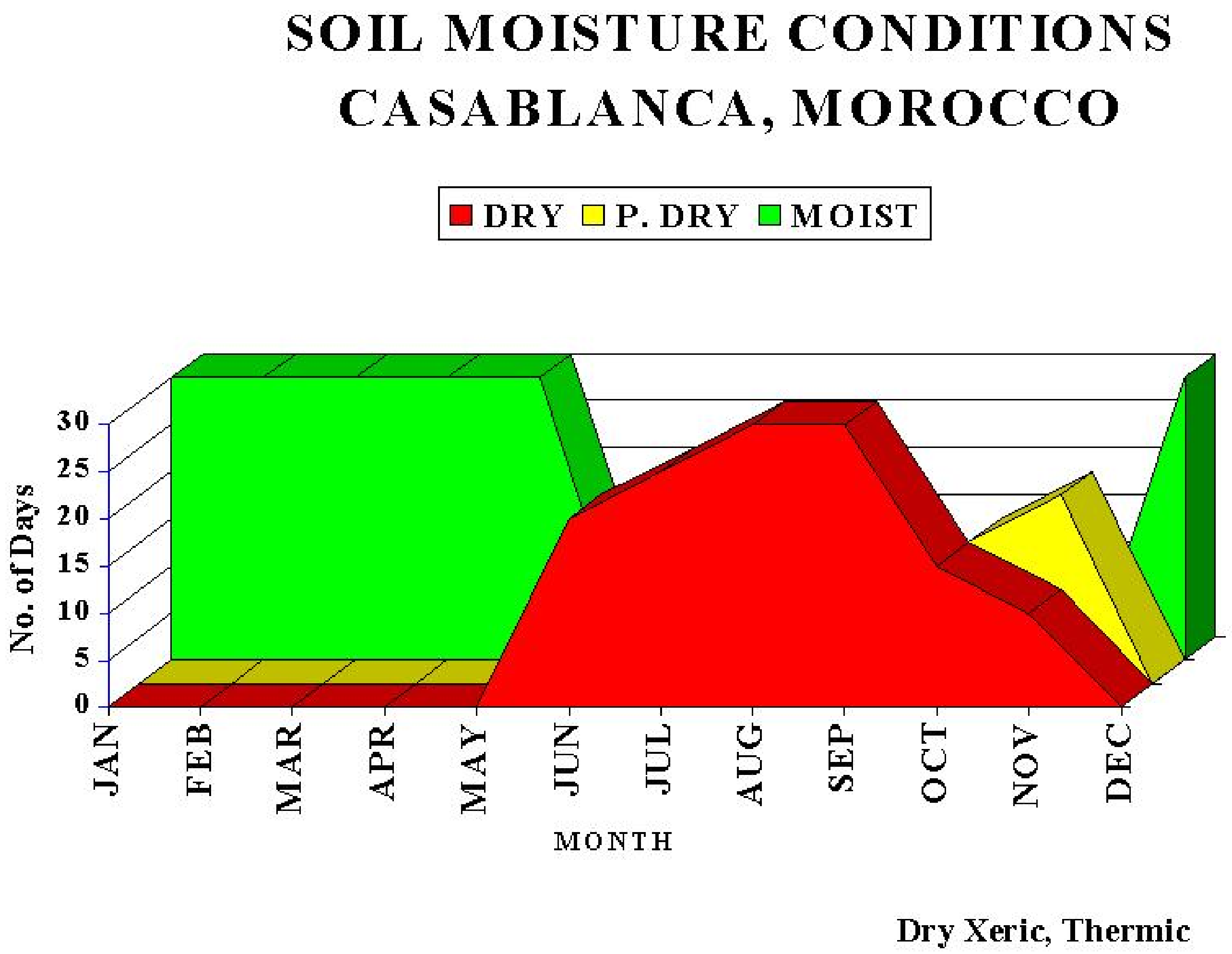
❸ Cracks that open and close periodically;

A crack is a separation between gross polyhedrons. It is considered open if it controls the infiltration and percolation of water in a dry, clayey soil.

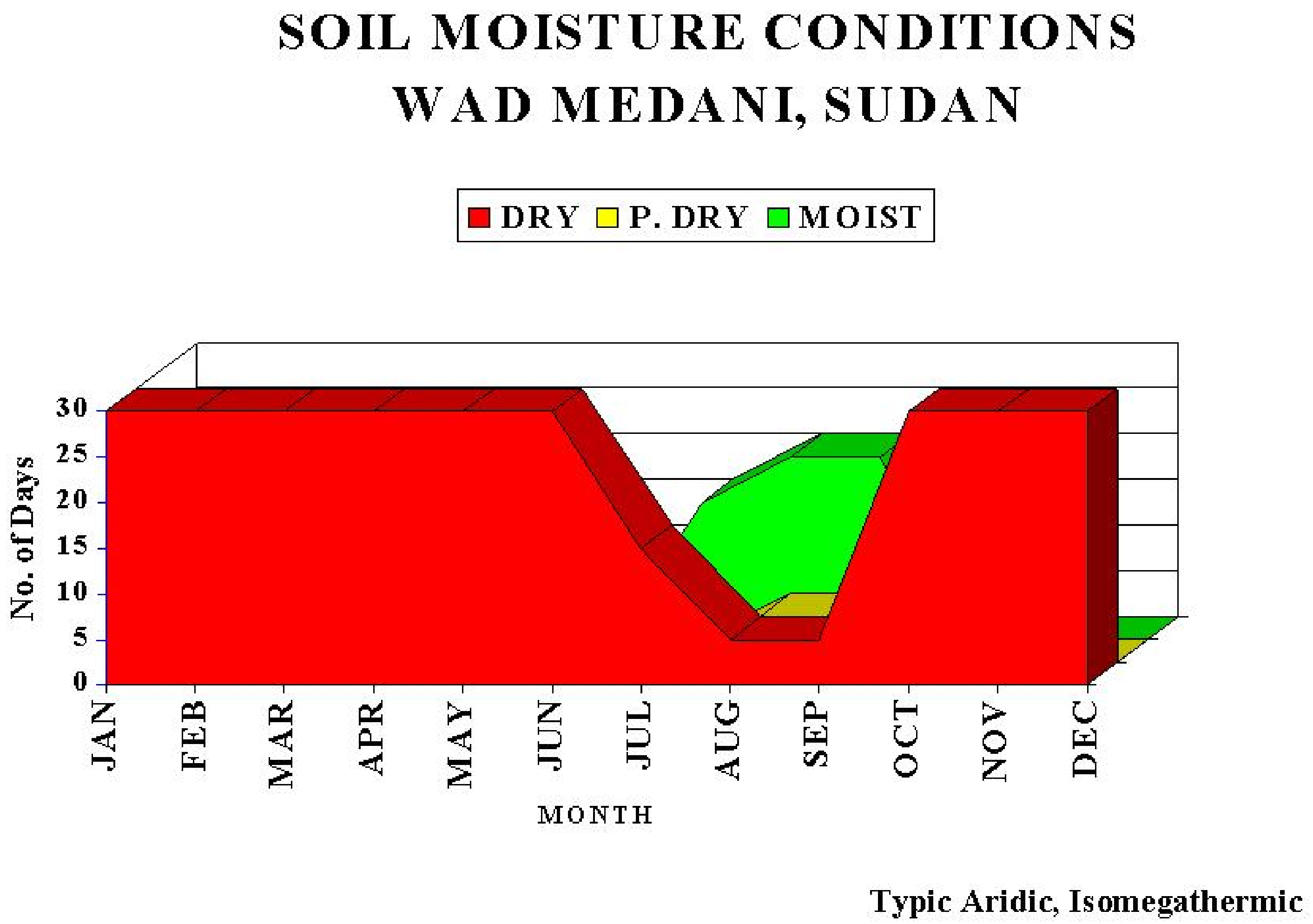
32 - Definition of Vertisols; definition of a crack. The period during which the cracks remain open or closed is used to define the suborders.



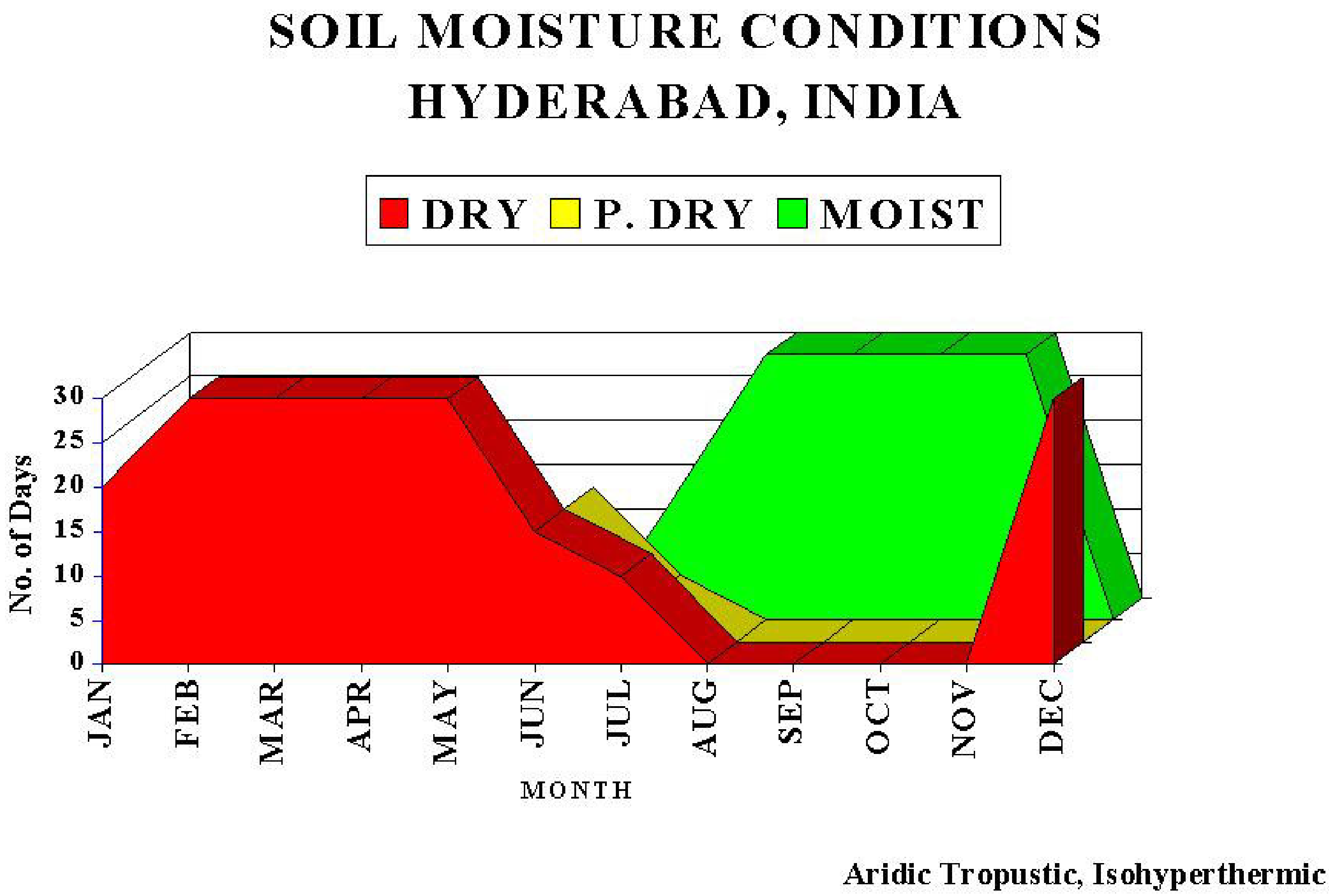
33 - Suborders of Vertisols.



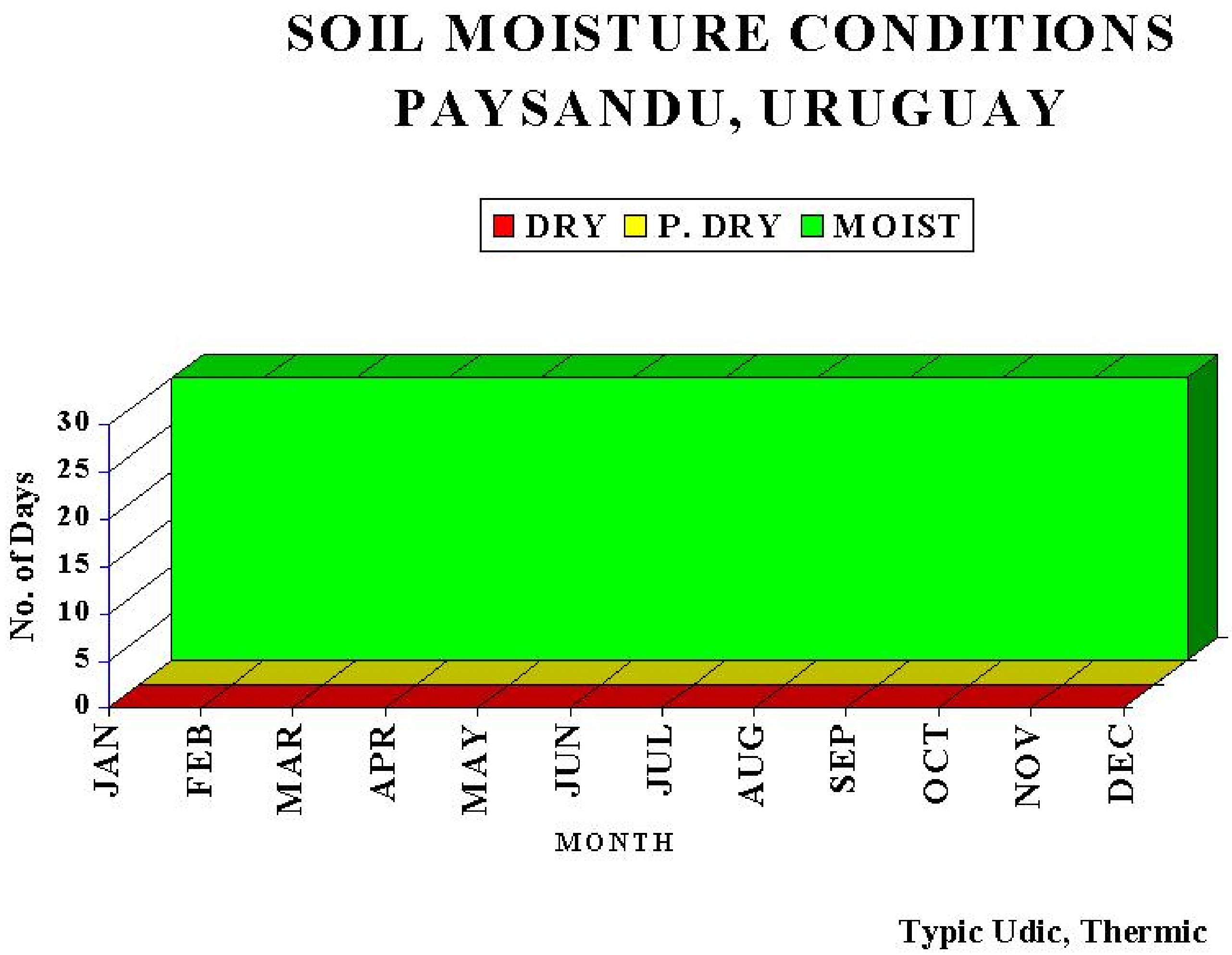
34 - Soil moisture conditions typifying Xererts. The soil moisture control section is moist during the winter months and dry during the summer months. The green and red areas represent the period during which the cracks remain closed or open, respectively.



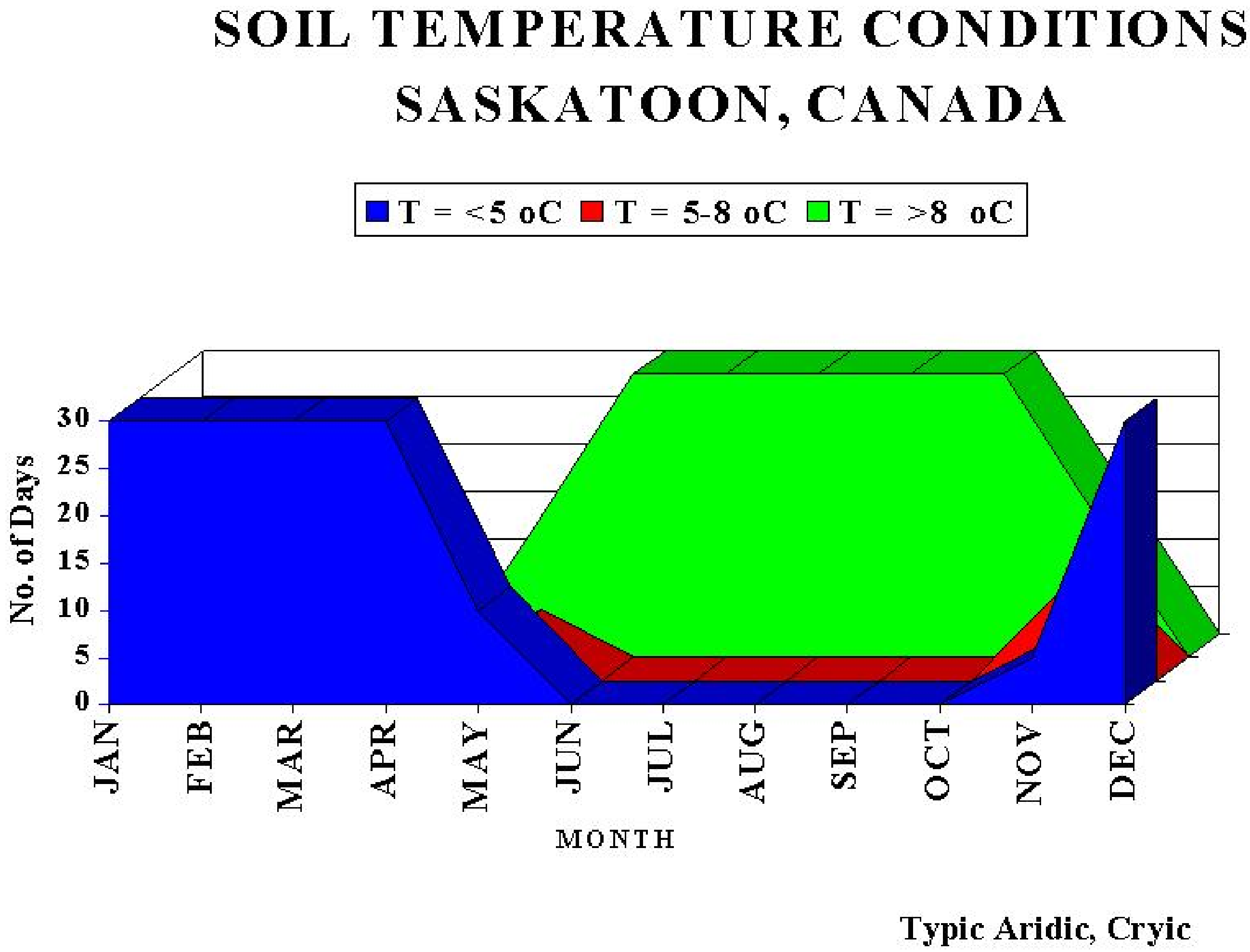
35 - Soil moisture conditions typifying Torrerts. The 'moist period' is not long enough to support most annual crops. This is also the period when the cracks remain closed.



36 - Soil moisture conditions typifying Usterts. Although the monsoon rains commence in the middle of June in Hyderabad, India, the cracks only close about the beginning of July.



37 - Soil moisture conditions typifying Uderts. There is no period during the year when the cracks are open for more than a few consecutive days. Though the cracks are not evident (as in many Aquerts), the slickensides are usually distinct.



38 - Soil temperature regime typifying a Cryert. In this diagram, the blue color represents the period when the soil temperature is < 5 ^{o}C, the green is the period when it is 5-8 ^{o}C and the red denotes the period when the soil temperature is > 8 ^{o}C.

Great Groups of Aquerts

- Sulfaquerts
- Salaquerts
- Duraquerts
- Natraquerts
- Calciaquerts
- *Dystraquerts*
- Epiaquerts
- Endoaquerts

Subgroups

- Sulfaqueptic
- Aridic
- Ustic
- Aeric
- Leptic
- Entic
- Chromic
- Typic

39 - Great Groups and subgroups of Aquerts. Each great group has several subgroups. The Dystraquerts are used as an example to illustrate the kinds of subgroups.

Great Groups of Usterts

- Dystrusterts
- Salusterts
- Gypsiusterts
- *Calciusterts*
- Haplusterts

Subgroups

- Lithic
- Halic
- Sodic
- Petrocalcic
- Aridic
- Udic
- Leptic
- Entic
- Chromic
- Typic

40 - Great Groups and subgroups of Usterts. The subgroups of the Calciusterts are presented as an example.

Great Groups of Uderts

Subgroups

- Dystruderts
- *Hapluderts*

- Lithic
- Aquic
- Oxyaquic
- Leptic
- Entic
- Chromic
- Typic

41 - Great Groups and subgroups of Uderts. The subgroups of the Hapluderts are listed, as an example.

Great Groups of Torrerts

- Salitorrerts
- *Gypsitorrerts*
- Calcitorrerts
- *Haplotorrerts*

Subgroups

- Halic
- Sodic
- Leptic
- Entic
- Chromic
- Typic

42 - Great Groups and subgroups of Torrerts. The subgroups of the Haplotorrerts are listed, as an example.

Great Groups of Xererts

- *Durixererts*
- Calcixererts
- Haploxererts

Subgroups

- Halic
- Sodic
- Aquic
- Aridic
- Udic
- Haplic
- Chromic
- Typic

43 - Great Groups and subgroups of Xererts. The Durixererts are used to illustrate the kinds of subgroups.

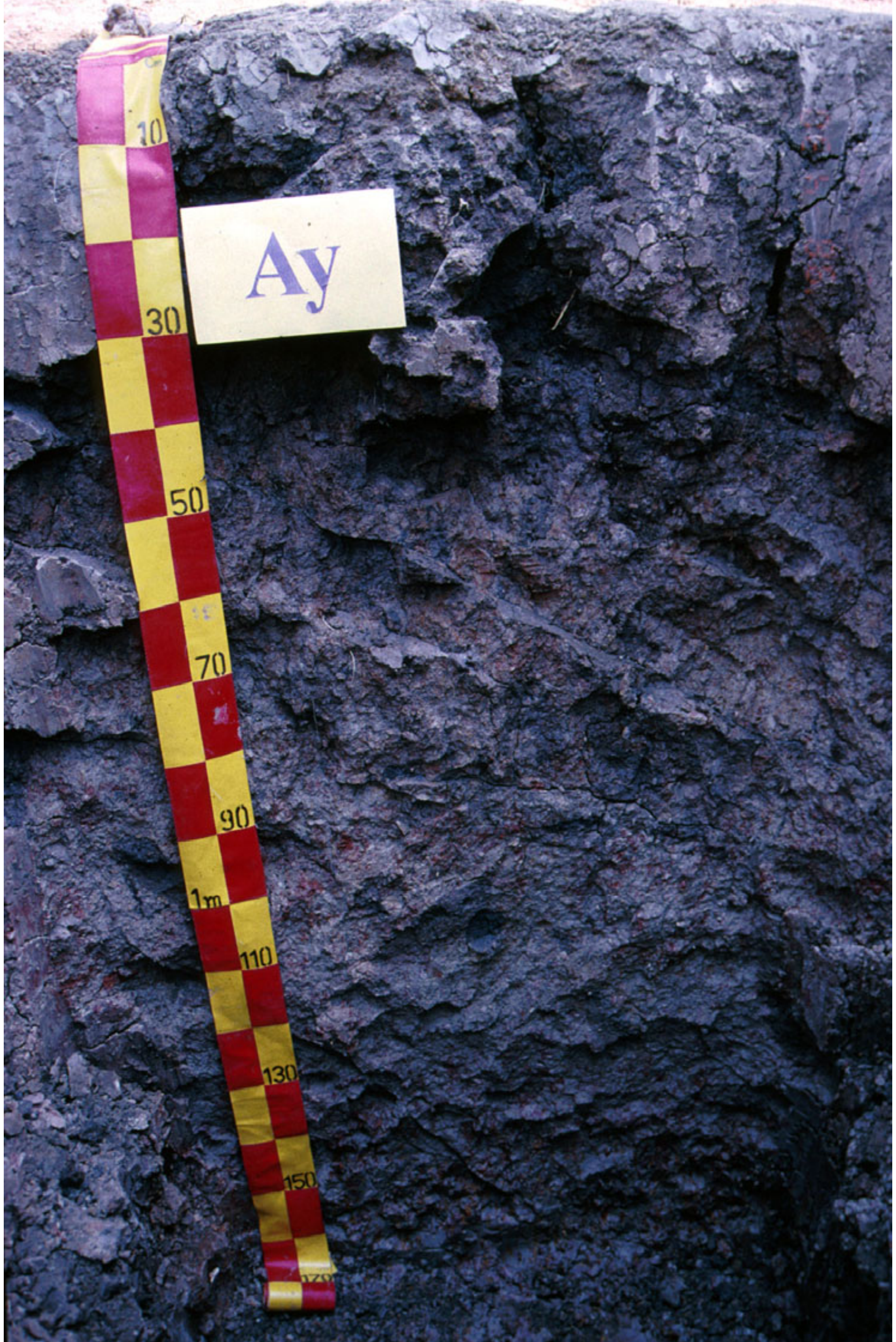
Great Groups of Cryerts

- Humicryerts
- *Haplocryerts*

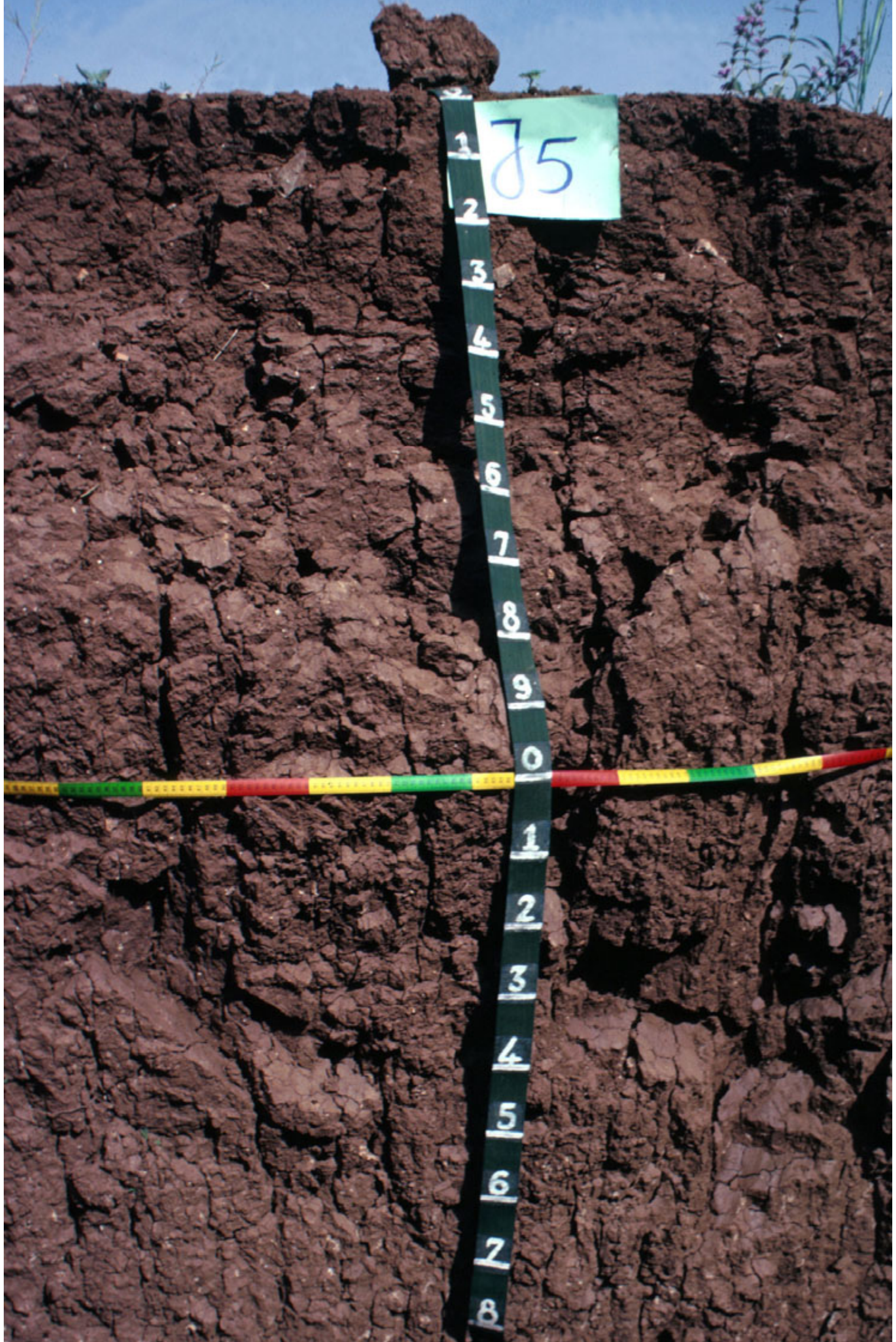
Subgroups

- Sodic
- Chromic
- Typic

44 - Great Groups and subgroups of Cryerts. The subgroups of the Haplocryerts are provided as an example.

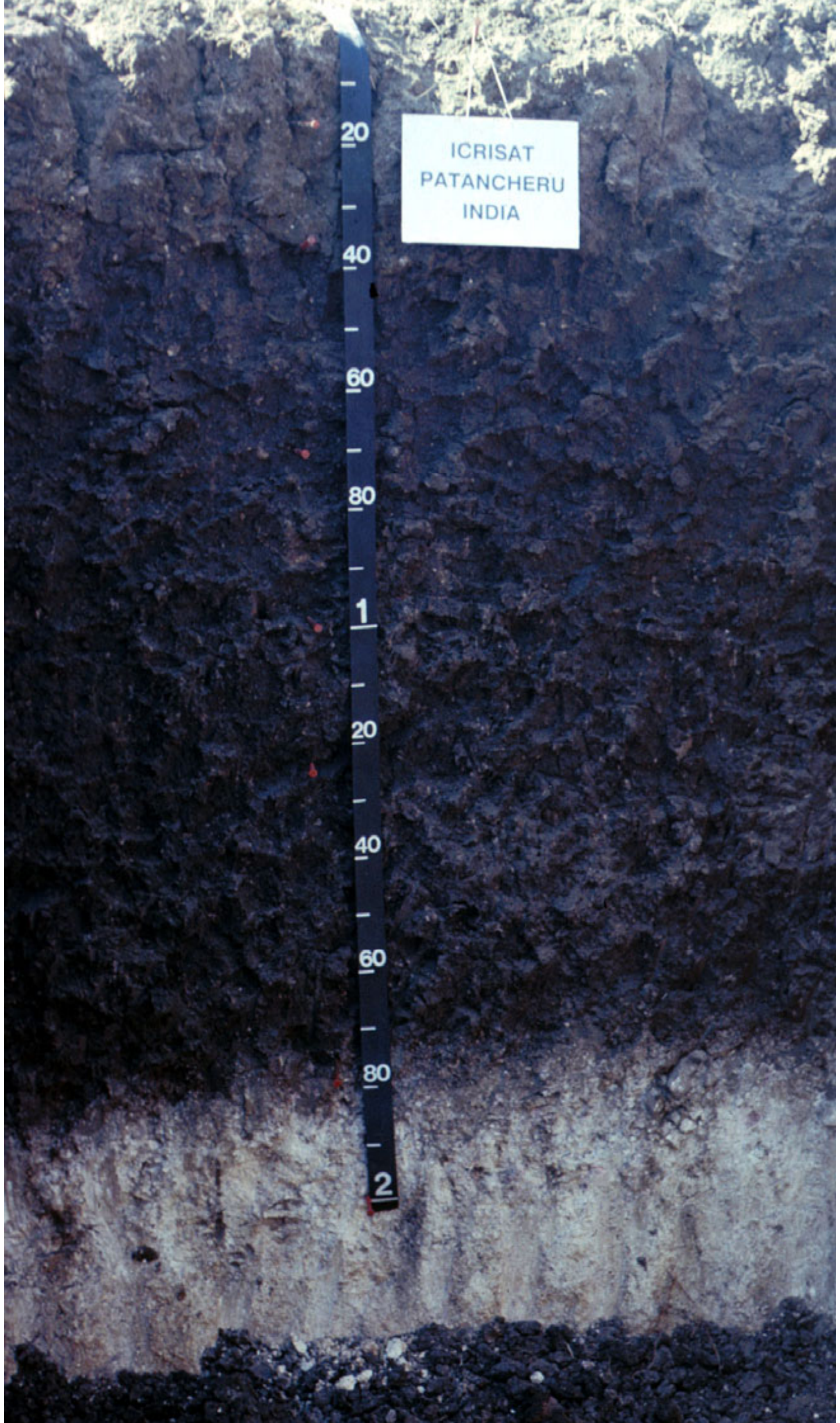


45 - Example of an Aquert. A Sulfaqueptic Dystraquert from Thailand. Jarosite mottles are present at about 1-m depth. In the wet season, the whole soil is reduced.

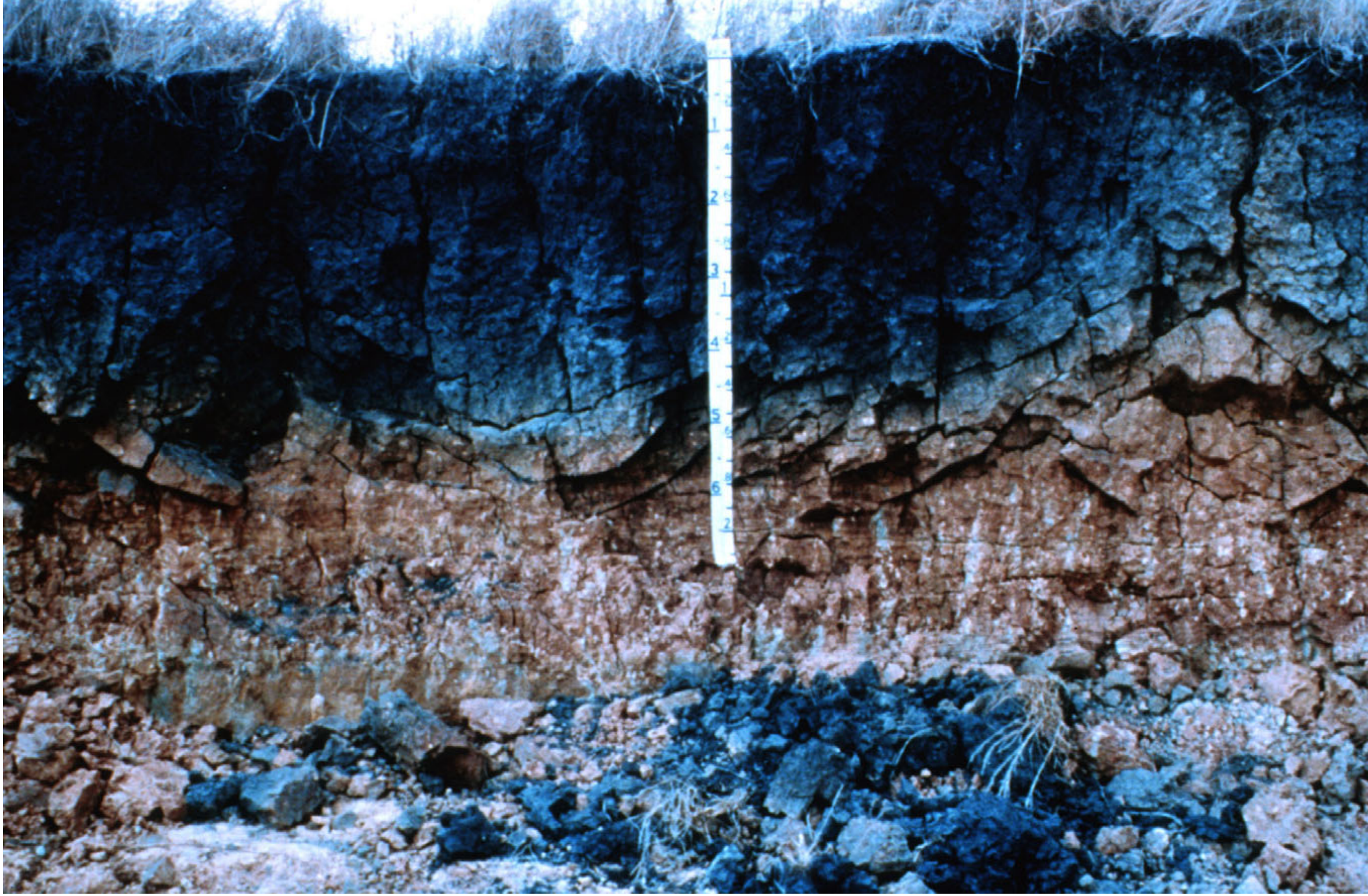


46 - Example of a Xerert from Jordan. Typic Haploxerert.

47 - Example of a Torrert, Sudan. Typic Gypsitorrert. Gypsum crystallizes on the slickensides.



48 - Example of an Ustert. Typic Calciustert, Hyderabad, India. Typical Vertisol of the Deccan Plateau.



49 - Example of an Udert. Typic Hapludert (Victoria Series), Texas. The bowl structure and the arrangement of the slickensides is very evident in this picture. On the right, the reddish subsoil material extrudes to the surface to form the chimney or diatreme.

50 - Weathering products of basalt and other basic rocks is a common material for the formation of Vertisols, if other conditions are favorable. The material must have the capacity to form and sustain a colloid with high amounts of smectites. Picture shows columnar basalt outcrops on a small hill in Nagpur, Central India.

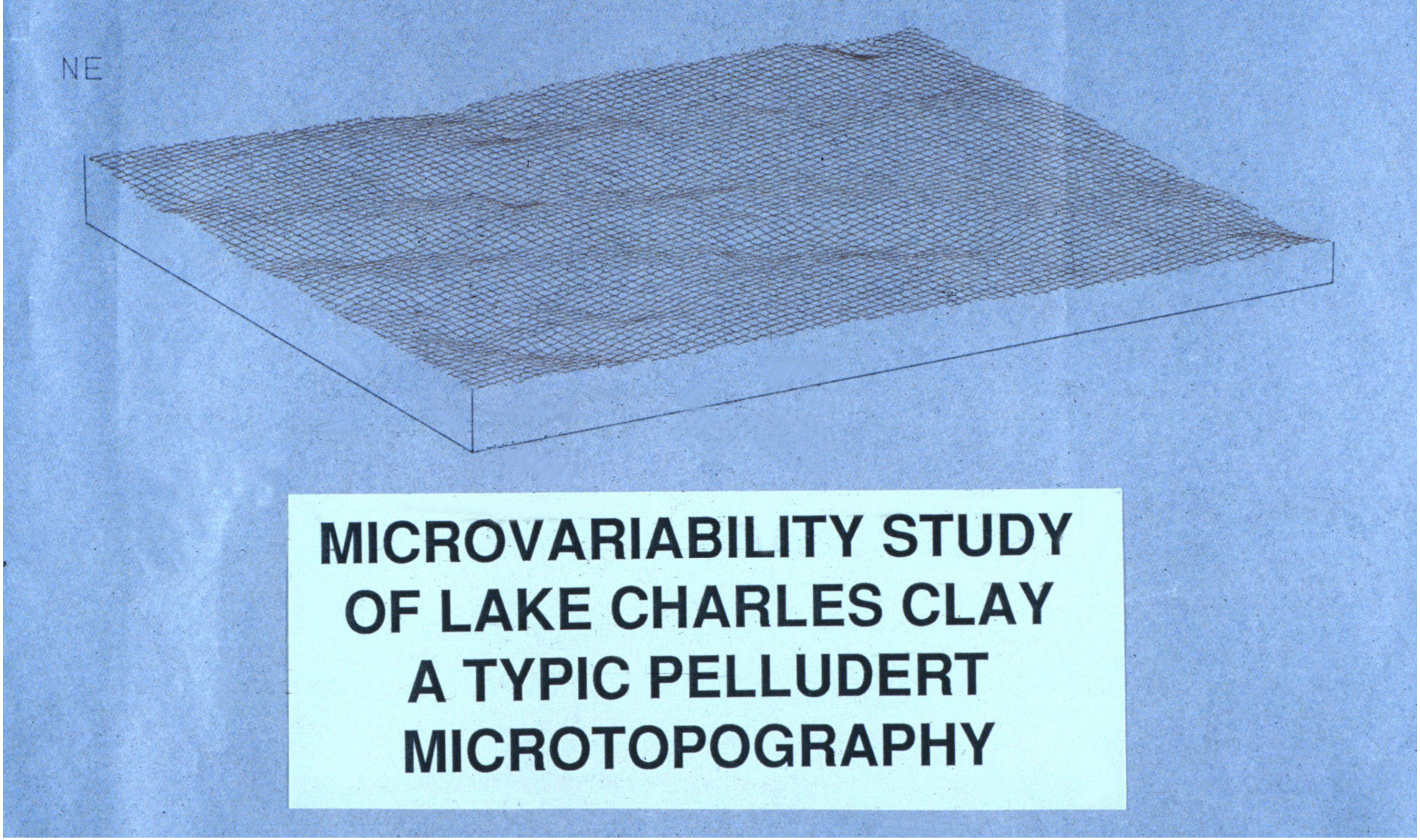
51 - The other common material for Vertisol formation, particularly in semi-arid climates, is weathering products of limestones and other calcareous materials such as marls. Picture shows a landscape in Tunisia. On the steeper slopes, the soils are Lithic Haploxerolls and on the depressions, the soils are Typic Haploxererts.

52 - Picture is of the Ruzizi Valley in Burundi. This narrow valley in a semi-arid climate receives weathering products from the volcanic uplands. The soils are Typic Haplusterts.

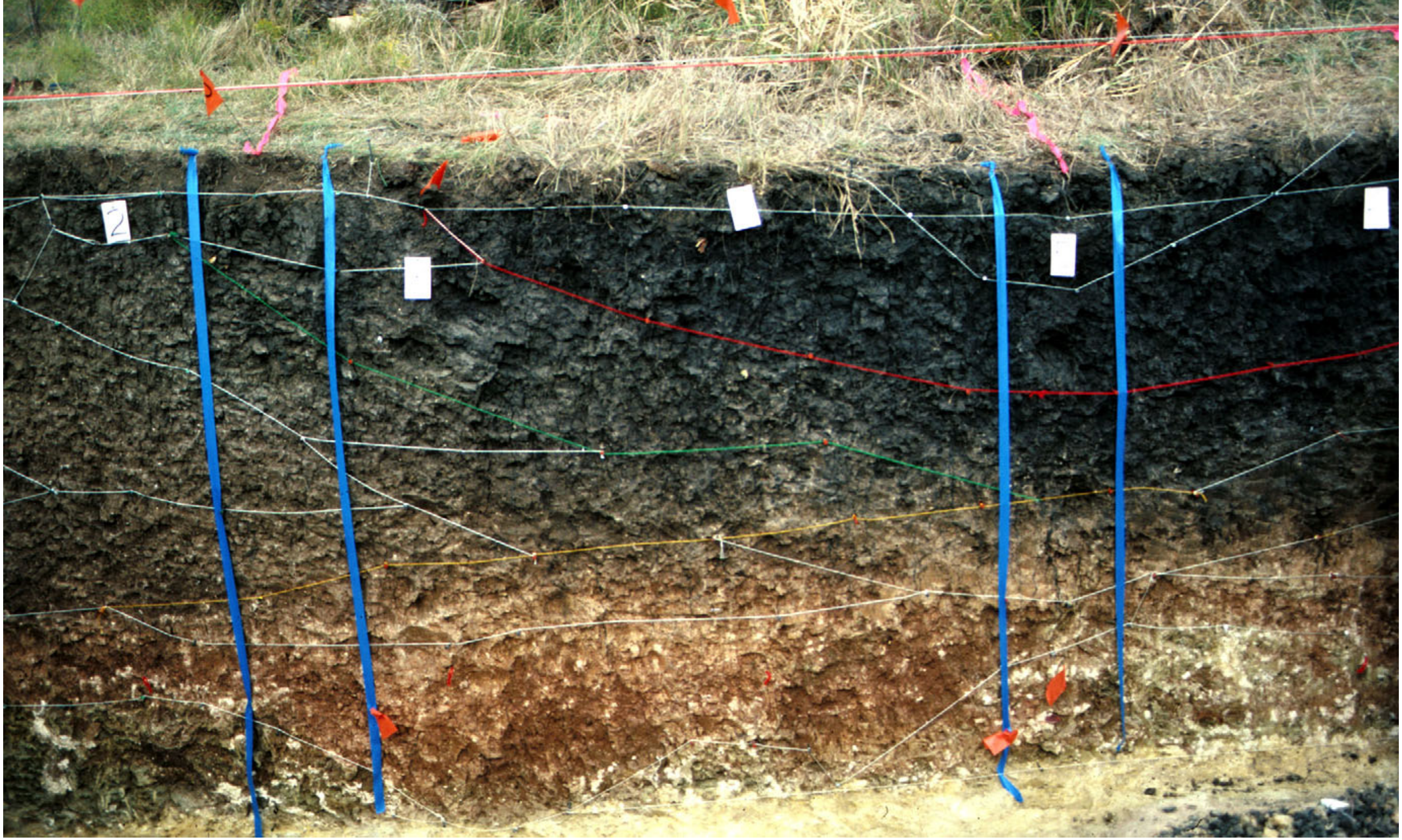
53 - The Murray Darling Basin in Eastern Australia is a large contiguous area with Vertisols. In the northern part of the basin, the soils are Haplusterts and Calciusterts. In the southern part, these soils merge with Haploxererts. The base rich sediments with high amounts of smectites are ideal for Vertisol formation.

54 - A similar valley is the Kafue Valley in Zambia where Vertisols occur in the lower parts of the valley and Ustalfs at the edges. Termite mounds, on the left of the picture, are common in such climates. The person with the red hat is standing on a micro-low and the other person is on a micro-high.

55 - Temporal variations in soil moisture conditions and the depth of the wetting front are important for the expression of the vertic properties. Picture shows a Torrert in Yemen with slickensides very close to the surface. The major flux of moisture in this soil is confined to the upper about 25 cm and so the swell/shrink related features are not expressed deeper in the soil.

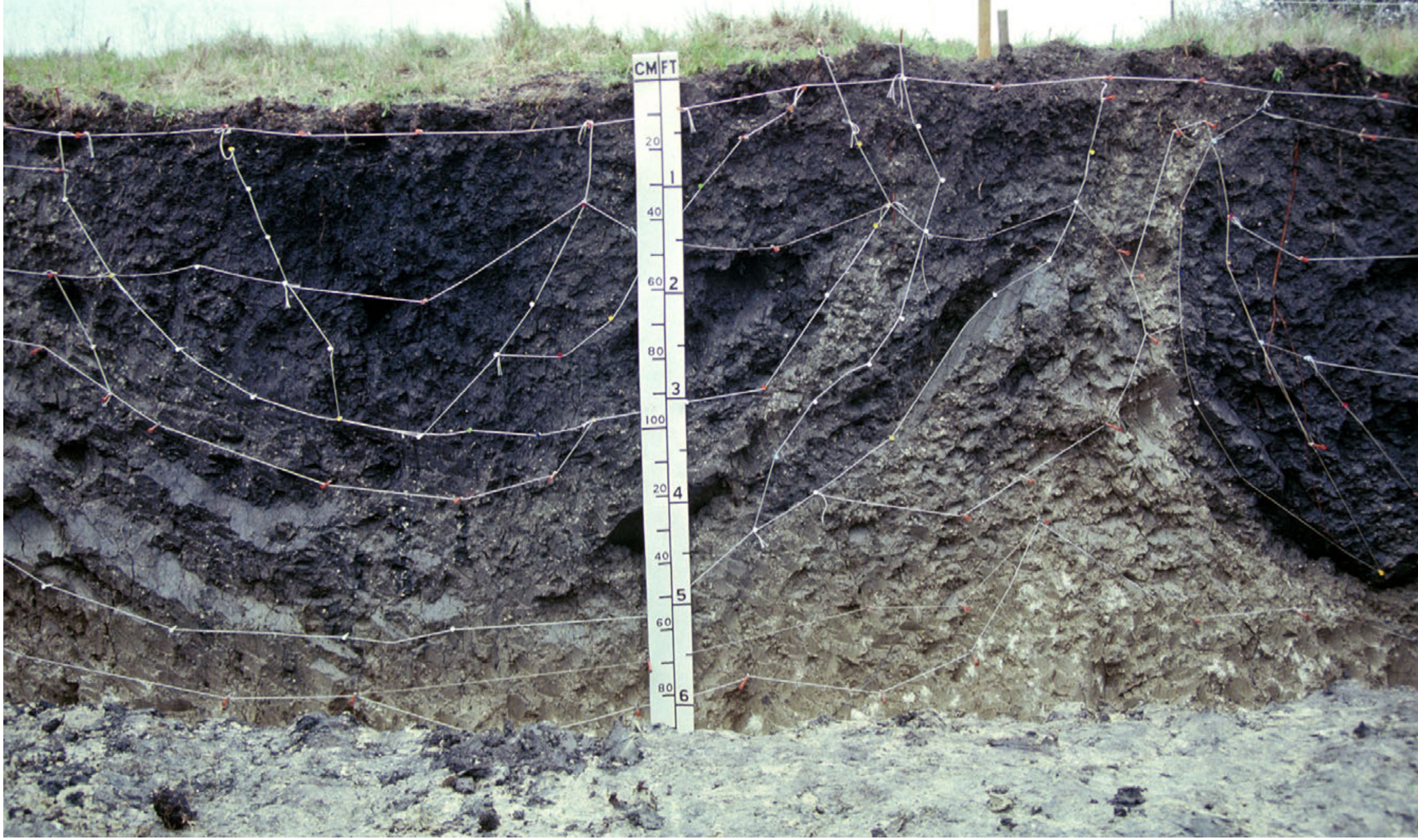


56 - Micro-variability in soil properties, both vertically and horizontally, is a characteristic feature of Vertisols. This is illustrated in the following five pictures. Williams et al. (1996) provide the details of the methodology. Site selection for the study is a first step. Picture shows a model of the soil surface at a site in Texas. The gilgai micro-relief is evident. This is a first step in the study.

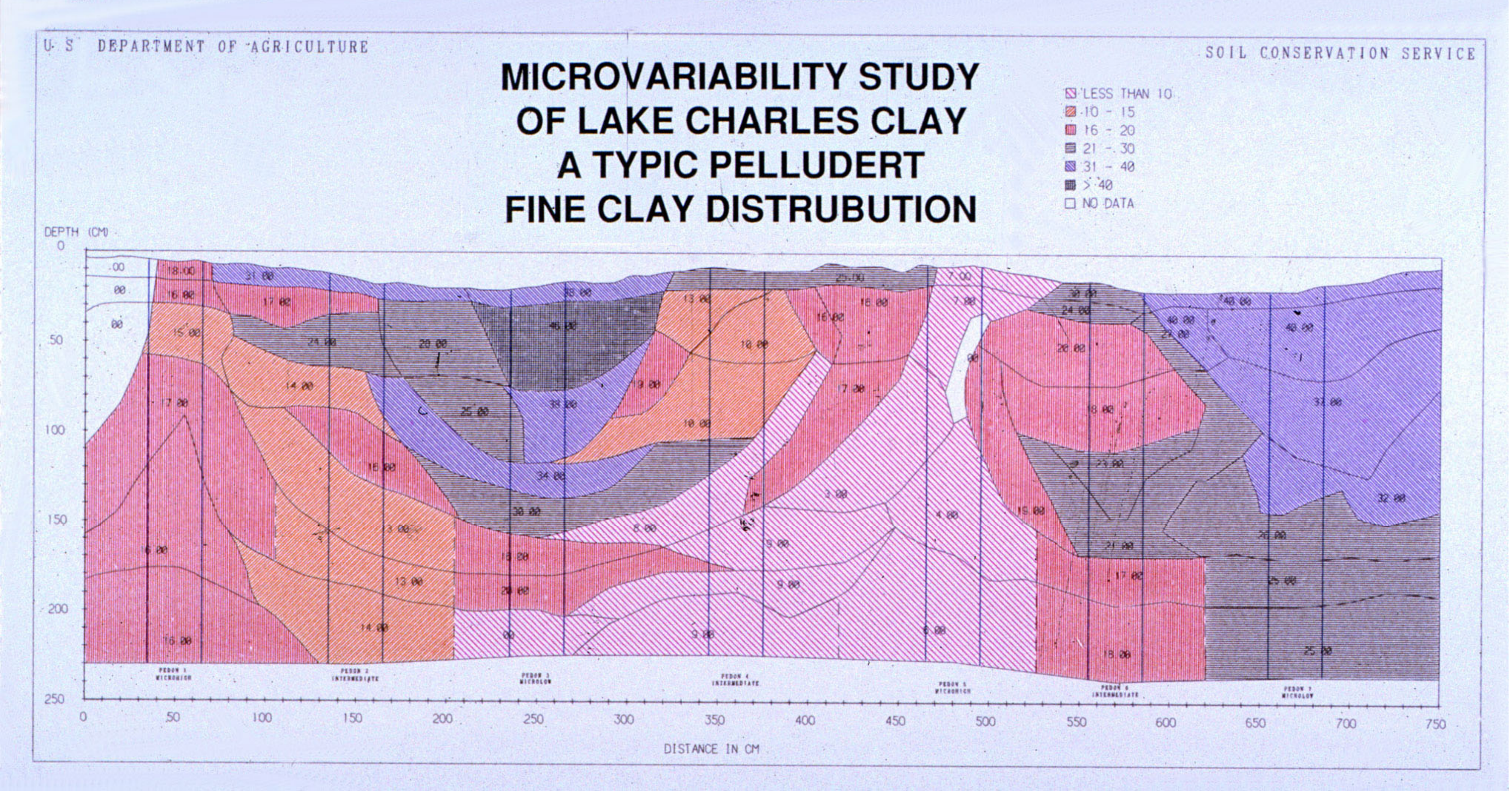


57 - A long trench (15 to 25 m) is ideal for such studies. The face of the trench is examined and variations are marked out using nails and string. Several vertical strips are also demarcated for description and sampling. Sufficient points on the trench face are described and sampled so that geo-statistical analysis can be applied later with the data. Picture shows the micro-low.

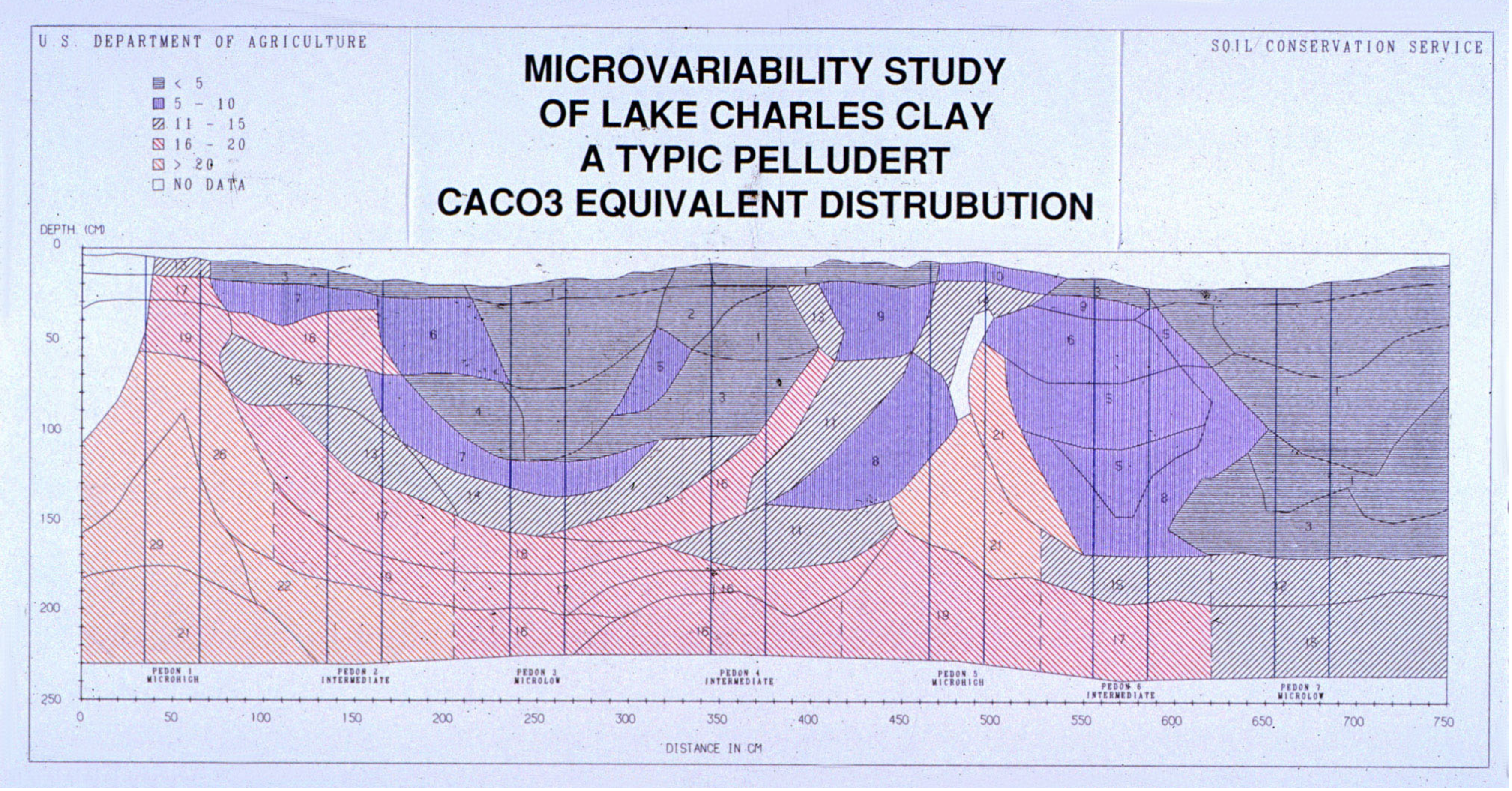
58 - Picture shows the micro-high (center of picture) of the trench cross-section. Numbers refer to vertical sections that were sampled for the study.



59 - A close-up picture to show micro-variability (Williams et al. 1996) that requires detailed study to understand the genesis of the soil. One or more samples per polygon defined by the strings were sampled for detailed analysis and later plotted using GIS. The bowl is clearly expressed. On the right, the subsoil material is pushed up to form the diatreme.

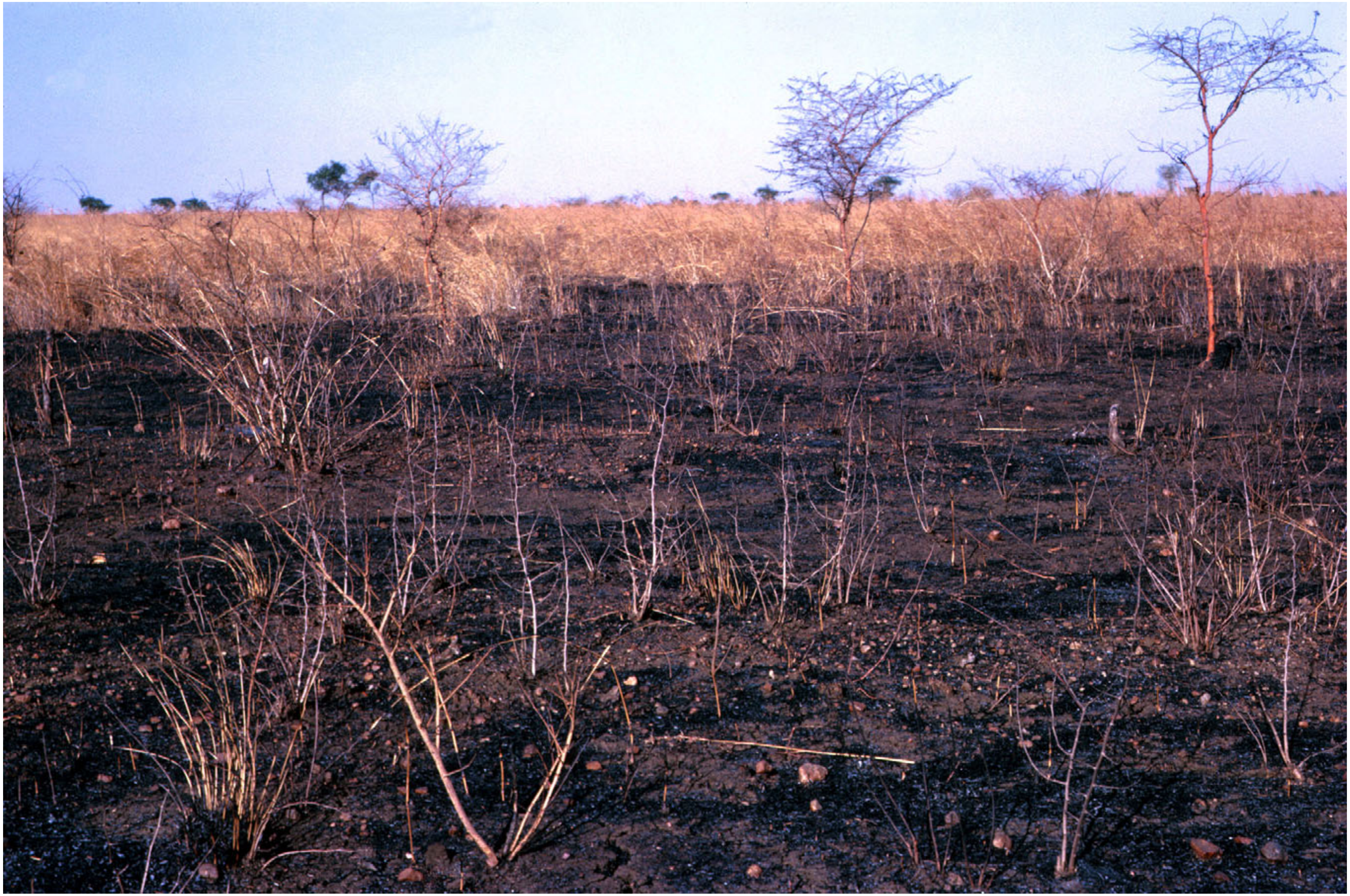


60 - Data were subjected to GIS analysis. Plot shows distribution of fine clay across the surface. The distribution of the fine clay follows the general morphological features. The center part of the bowl has the highest amount of fine clay.



61 - Plot shows distribution of carbonates. The carbonate distribution and the earlier plot of fine clay distribution, both show that the diatreme material is of similar composition as the subsoil. This suggests that the subsoil is pushed upwards to form the diatreme.

62 - Lajas Valley, Puerto Rico. In semi-arid environments, the vegetation is grass and shrubs. The landform may be flat to gently undulating an this is the common site for Vertisols. They may, however, occur on slopes of up to about 32%.



63 - The woody vegetation is generally sparse. During the dry season, they are prone to fires and as a result many of the shrubs are deformed.

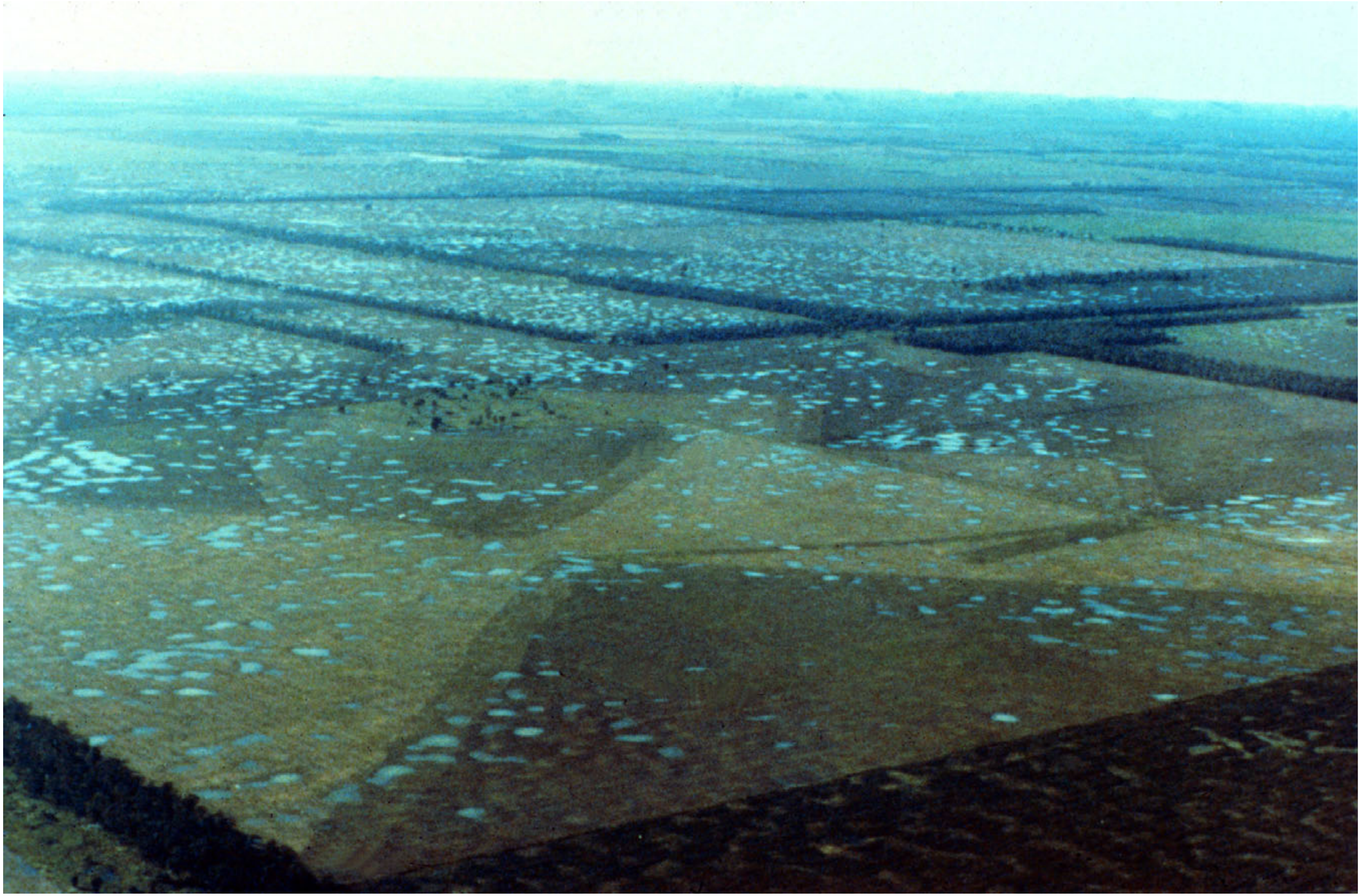
64 - The displacement of fences or telephone poles usually is an indicator of the presence of Vertisols as in this picture from Texas.

65 - Cultivated fields, such as the wheat field shown on the picture, also provide indicators for the presence of Vertisols. The growth is uneven and sometimes some patterns may be made out. These patterns reflect the micro-variability in the soil – differential availability of moisture as determined by the gilgai micro-relief.

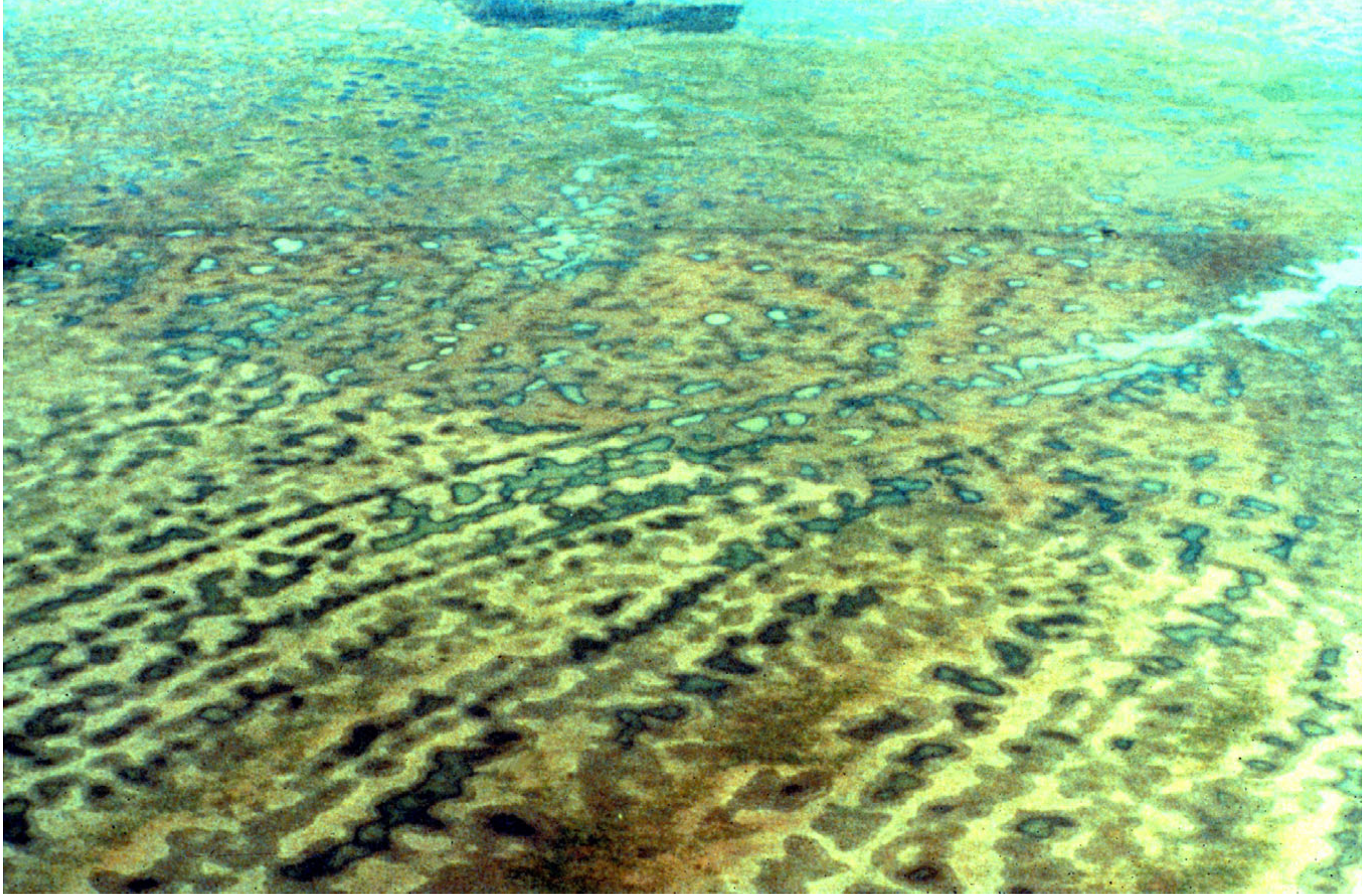
66 - In arid environments, organic matter is low and the fields have a reddish appearance. This picture from the northern parts of the Gezira Plains in the Sudan shows the flat alluvial plains. The green vegetation on the horizon marks the Nile valley.

67 - Close to Khartoum, Sudan, the climate is drier and the soil moisture regime is aridic. The Torrerts are only used for agriculture if irrigation is available. Non-irrigated areas have a surface similar to other desert soils, littered with stones. The stones are also coated with desert varnish.

68 - In semi-arid environments, typically the trees are short and widely spaced with tall grass vegetation in between. This vegetation type is sometimes referred as Sudanese Savannah.



69 - When flying over Vertisol areas, other features may be observed as shown in this and the next two pictures taken from a plane of the Condo Mine area of Australia. After a rain, the water remains for longer time in the micro-depressions. A pockmarked appearance results.



70 - As in slide 69, the micro-depressions appear to be arranged in a linear fashion, resembling linear gilgai.

71 - At ground level (#69), the linear arrangement is more evident.

72 - In general, the micro-depressions have a random arrangement. From a distance, the field appears speckled.

73 - Short summer rains provide the ideal conditions to see the gilgai micro-relief. In this picture from Australia, the ponded micro-lows are in good contrast to the burnt-out vegetation on the micro-highs. Continuous cultivation erases this micro-topography. Note the tilted fence.

74 - Onset of vegetation at the beginning of the wet season shows the patterns very well. The circular depressions are exaggerated at this site on a Laewest Soil in Calhoun County, Texas (Typic Hapludert).

75 - A similar (#74) vegetation pattern is seen at College Station, Texas.

76 - On a dry soil, presence of hard, fine, angular peds is usually an indicator of Vertisols. Some times, these structural elements may be so numerous that they may cover the surface to a depth of a few centimeters and even mask the early fine cracks. Such a grumulose structure gave the earlier name of Grumusols to such soils.

77 - Appearance of cracks during the dry season takes place when the soil moisture tension in the upper 10-cm exceeds 15 kP. When organic matter content is high, the surface cracks are not so evident and appear merged as in this Vertisol from Darling Downs, Australia. The granular material on the soil surface may fall into the cracks and become incorporated into the subsoil. This process is termed self-mulching. This incorporation of surface soil material into the subsoil is not as important as was originally believed.

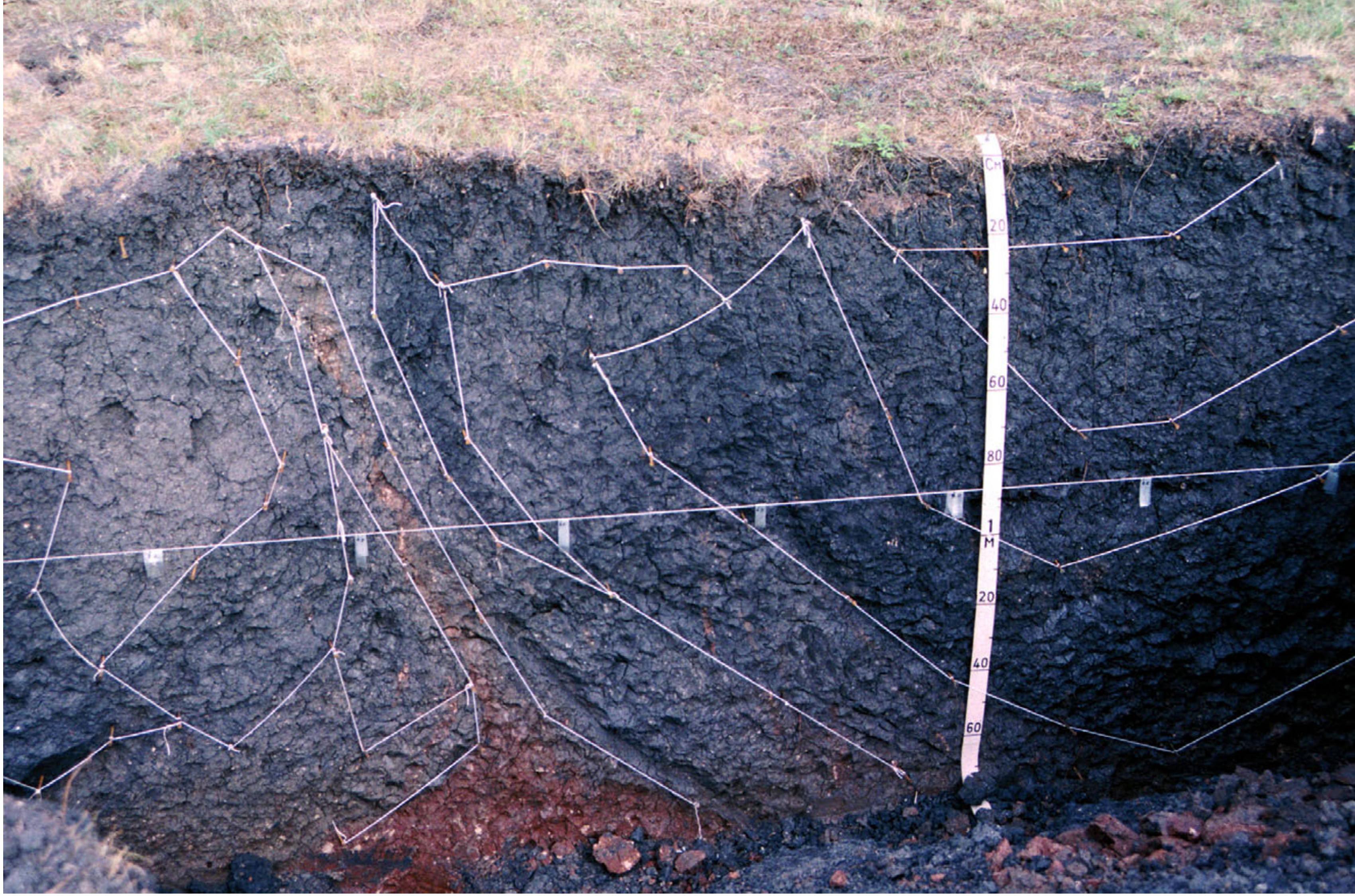
78 - The cracks, as in this picture of the Tirs of Morocco, are wide and separate the polygons. Cracks as wide as 25 cm have been observed.

79 - Commonly, the cracks are about 5 cm wide as in the Heiden soil from Tarrant County, Texas. At the point the cracks meet, the hole may be as much as 10 cm in diameter.

80 - The cracks traverse around vegetation. The soil around roots is relatively slightly moister and so the cracks form away from the clusters of the grass.

81 - In irrigated soils, as in the soil from the Gezira close to Wad Medani, Sudan, the soil surface has a layer of irrigation silt. The cracking pattern of such soils is different and generally the cracks are not so wide.

82 - In South India, tank silt from ponds (tanks) is added to the soil surface and thickness of more than 25 cm may result. In such surfaces, the cracks have a different form than those in typical Vertisols. When water is added to such a soil, the cracks do not close; after a period, the soil material slumps into the crack. In contrast, in a Vertisol, the cracks close after a rain.



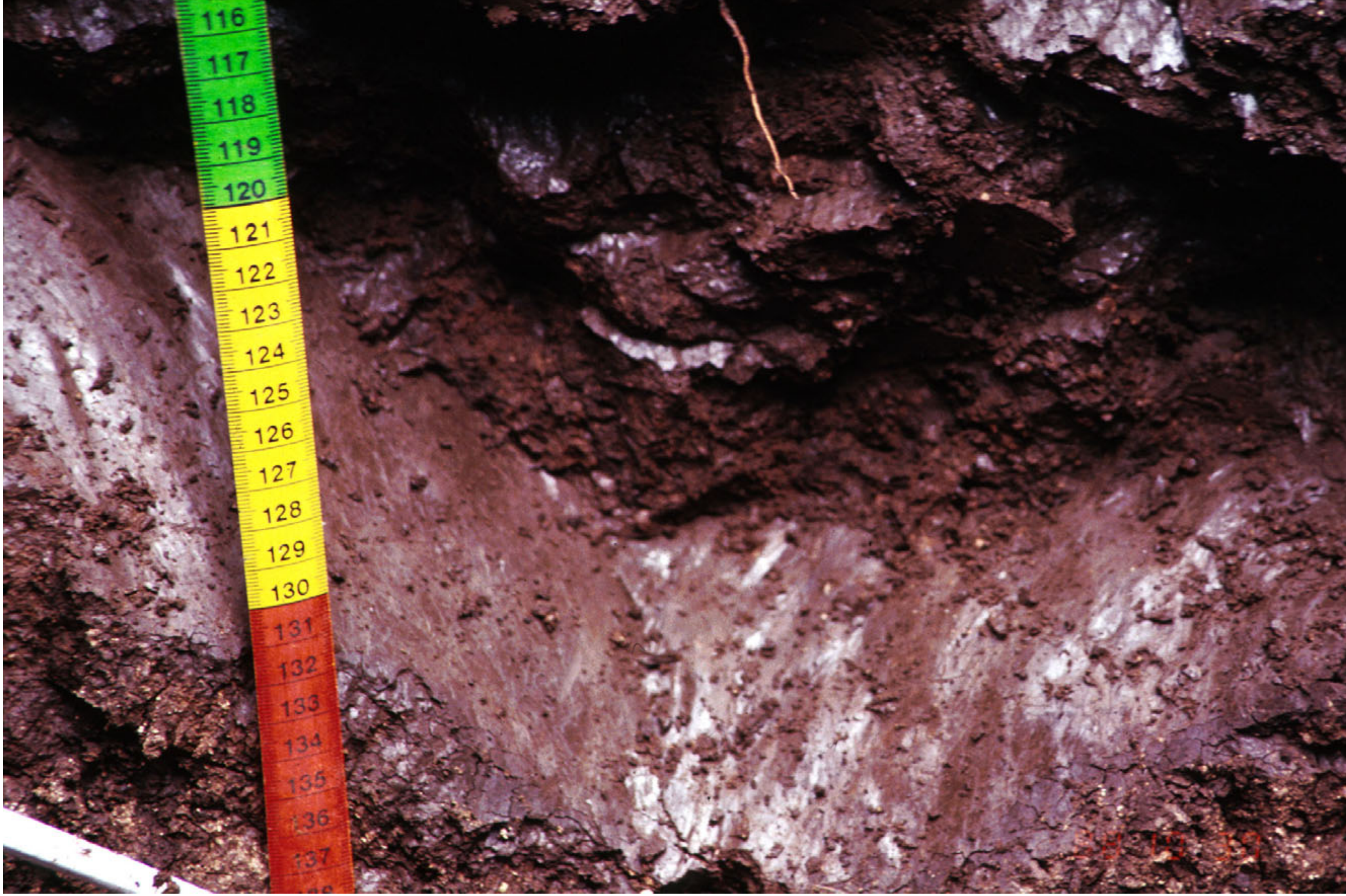
83 - The gilgai micro-relief as expressed by the micro-highs and micro-lows are also expressed in the subsoil. This and the following pictures express this. Picture of the Leray Series, Texas.

84 - Picture of a Vertisol in Bulgaria. The "bowl" shaped structure is evident. A layer of carbonate concretions borders the bowl. On the left side of the picture, the carbonates come close to the surface. This chimney-like feature is called a 'diatreme'. The diatreme is evident in this picture as it is contrasting with respect to the enclosing material. In many soils, it may not be so clear but can be differentiated.

85 - The bowl and diatreme are very distinct in this picture of the Lake Charles Soil from Texas.

86 - Another view of the Lake Charles soil. The morphology of the bowl varies across the landscape. The two bowls shown in this picture have totally different morphologies. Studies on this aspect of genesis have just begun.

87 - When the subsoil material is not contrasting, the bowl can still be recognized by the arrangement of the slickensides in this Haplustert from Philippines.



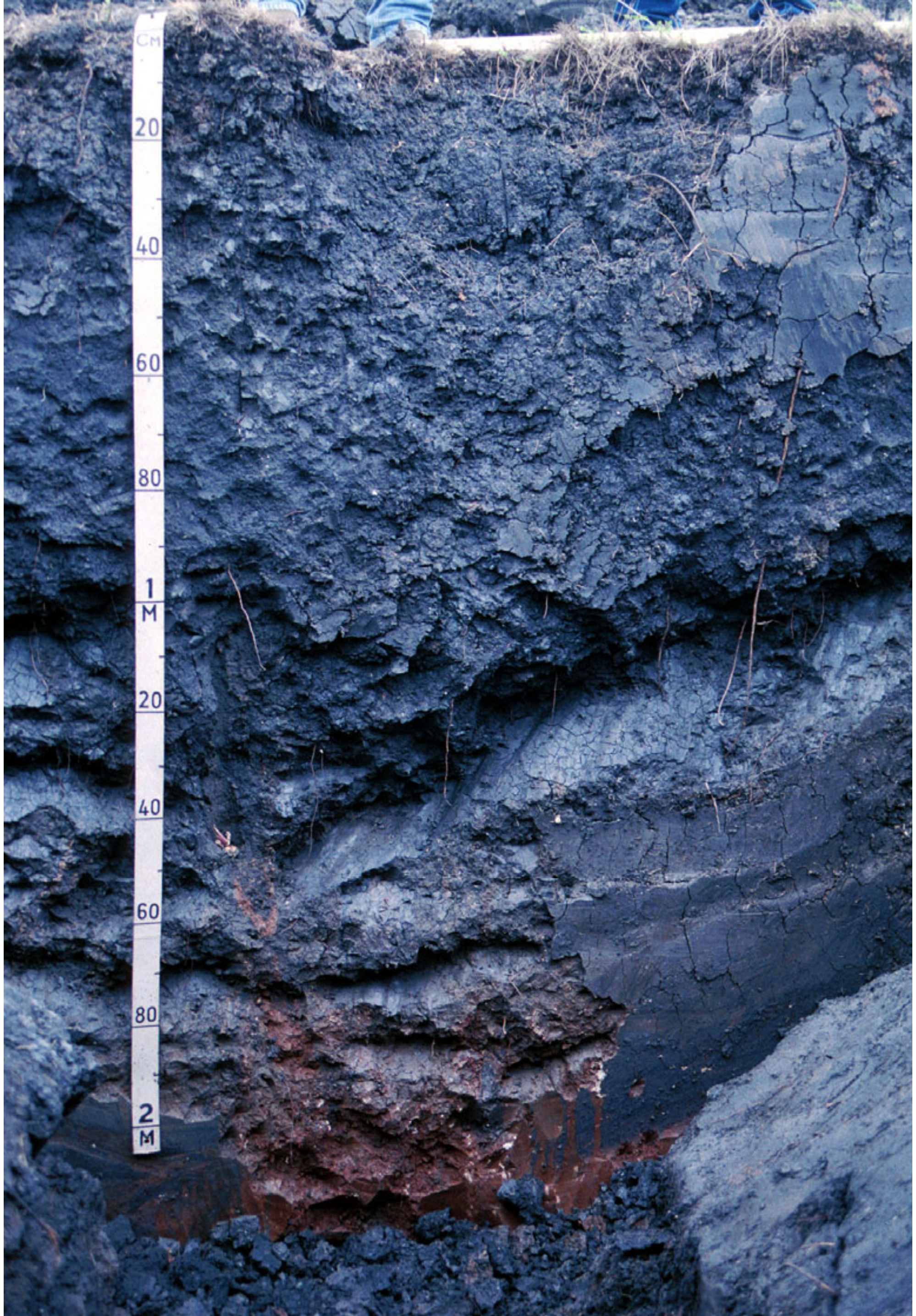
88 - The slickenside is recognized by its shiny surface, which is sometimes grooved. The striations on the slickenside result from shearing. Picture taken close to the bottom of the bowl of a Vertisol (Akot Series, India).

89 - A close-up of a slickenside in the lower part of the bowl. Note the color of the slickenside surface (reduced) and the soil beneath (oxidized). Cameron County, Texas.

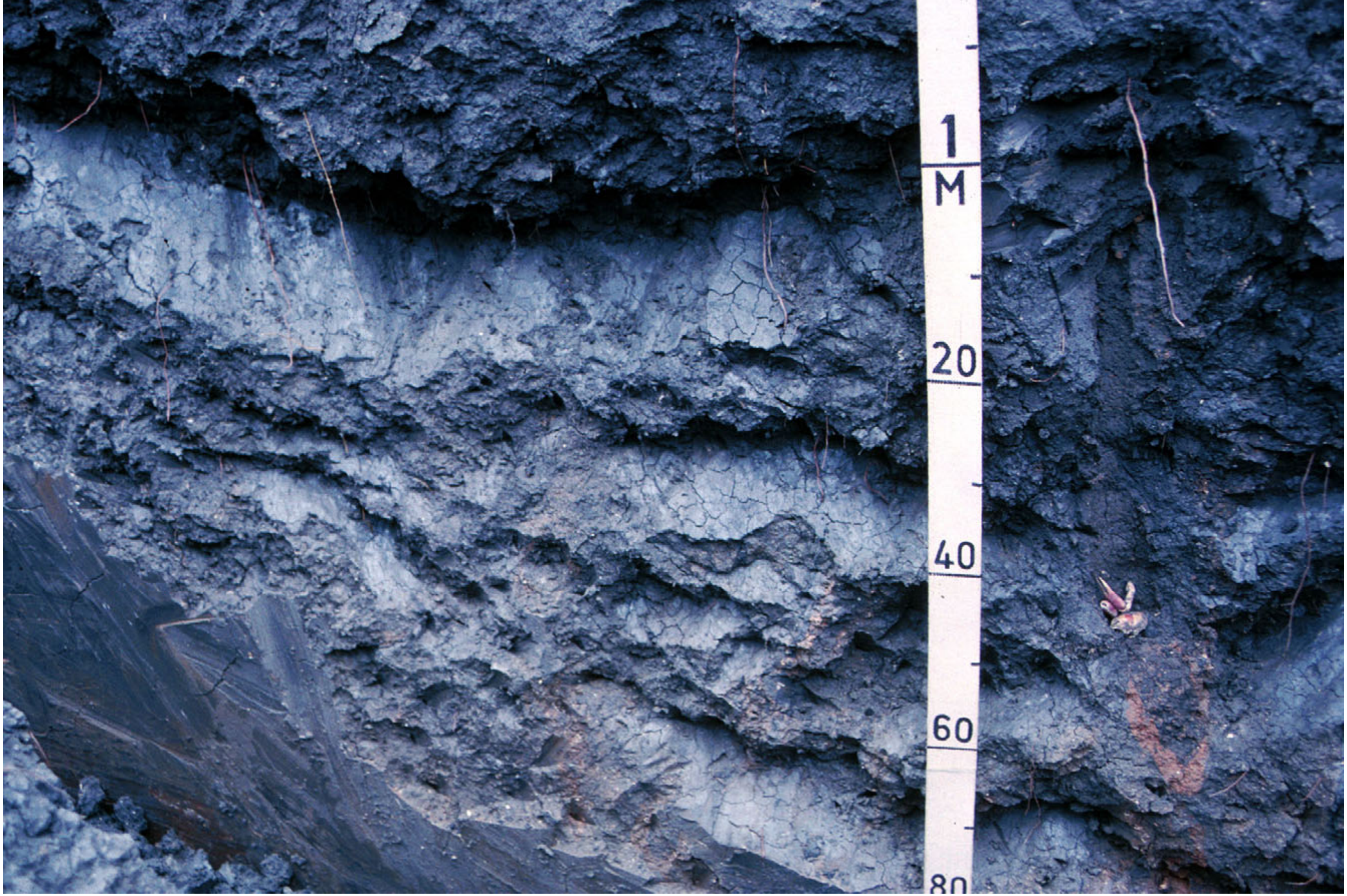
90 - Slickensides may comprise large blocks as in this Alathur series, an Aquic Haplustert, Tamil Nadu, S. India.

91 - In wet Vertisols, Aquerts, the soil matrix and the slickenside show gray colors due to reduction.

92 - At depth, the amount of organic matter is low. The reduced surface then appears white as in this Harlingen clay in Cameron County, Texas.

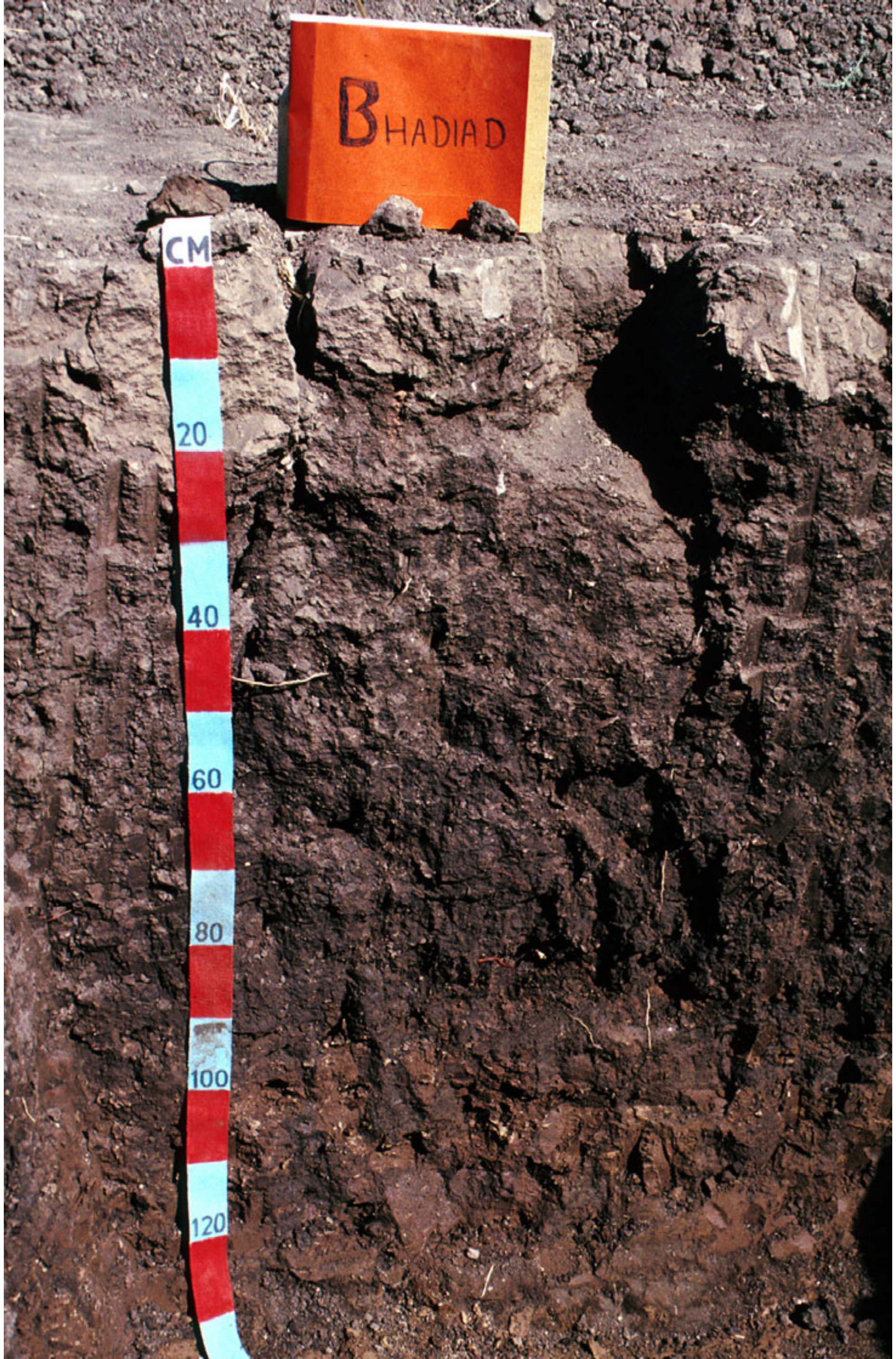


93 - In a large bowl, minor differences in the morphology of slickensides may be seen as shown in the following three pictures of an Endoaquert from College Station, Texas. Picture of the left part of the bowl.



94 - Picture of the central part of the profile (# 93).

95 - Picture of the right part of the profile (#93) showing a very well expressed slickenside.



96 - When the upper part of the soil has high amounts of exchangeable sodium, columnar structures develop. The columns are large as in this Sodic Haplotorrert from Gujurat, India, and the cracks are generally very wide.

97 - In some Vertisols, slickensides are not prominent as in this Haplustert from Burundi. Structural elements called sphenoids or wedge-shaped aggregates dominate the morphology and define the soil.

98 - Just below the surface, in this soil from Burundi, stress deformed structural elements are common. In addition, there are horizontal cracks. Sphenoids are not well defined in the upper 25 cm of the soil.

99 - At depths below 25 cm in the soil from Burundi, the sphenoids are well expressed. They are about 5-8 cm in length but are not large enough or well expressed to be called slickensides.

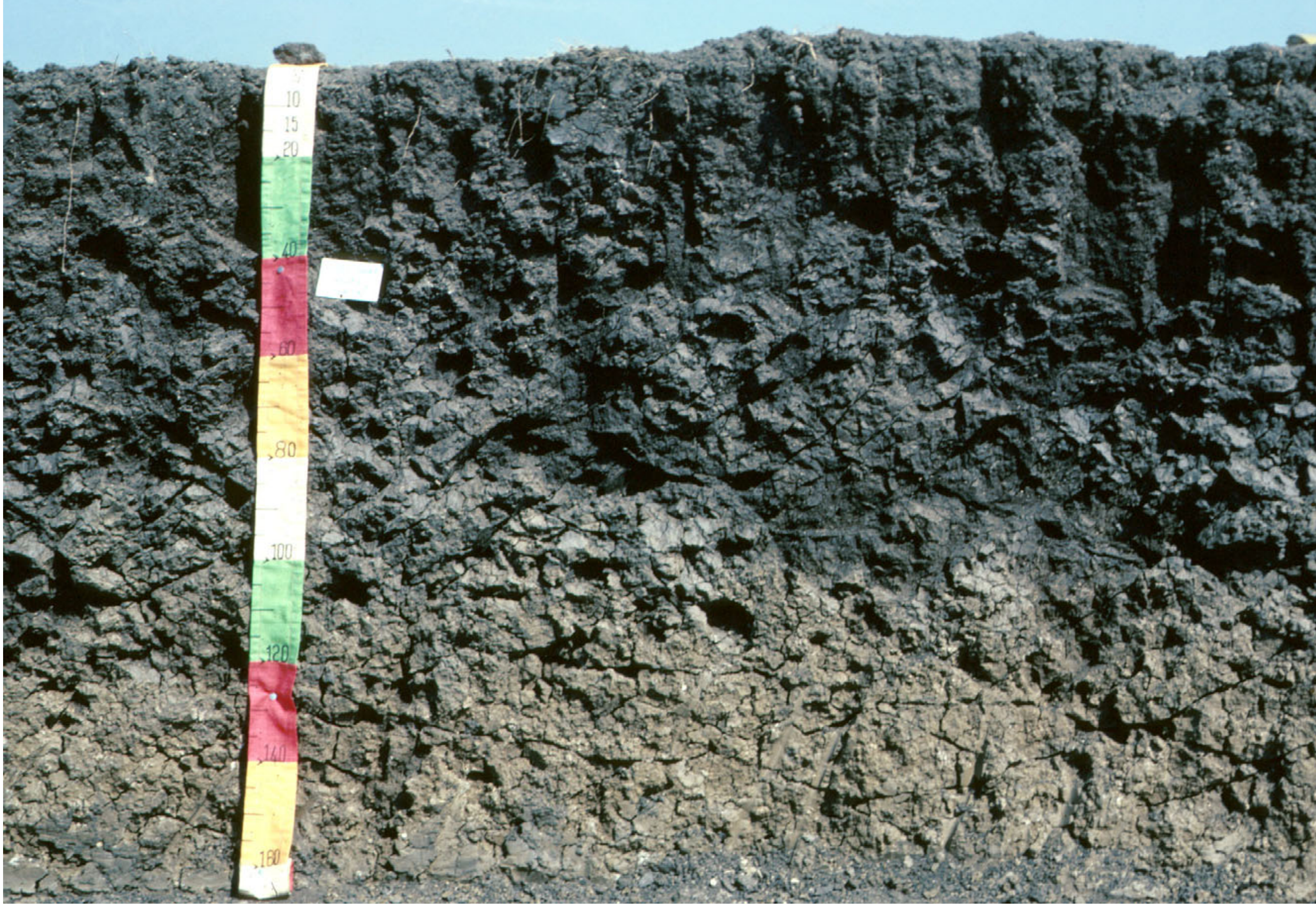
100 - Between the massive surface zone and the zone of slickensides, is a zone with angular to subangular blocky structural elements. Some of these, particularly in the lower part of the zone, are sphenoids if they have a wedge shape.

101 - In Sodic Haplotorrerts as this soil from the Okawanga Delta, Botswana, the massive columnar structures extend to about 40 cm. Below this is the zone with angular and subangular structural elements.

102 - In this Sodic Haplustert, belonging to the Tirs of Morocco, some salt encrustation is seen at the lower part of the columns.

103 - In very clayey soils where the clay is almost 100% montmorillonite, the slickensides are present very close to the surface.

104 - In Vertisols at high altitude or cold climates, organic matter accumulation in the soil surface is common and some may even have a mollic epipedon. This soil, a Typic Hapludert is from Debra Birhan, Ethiopia. These humic Vertisols lack the high COLE values in the surface horizon due to the high organic matter content.



105 - Subsoil features are most evident when there are contrasting materials. In this Typic Haplustert from the Kafue Flats of Zambia, the material is uniform and so special features are not present. Below the slickenside zone (at 100 cm), the structure is angular blocky or in some cases, massive.

106 - In the soil from College Station in Texas, the substratum is a reddish clay loam and so the contrast with the overlying vertic material is obvious.

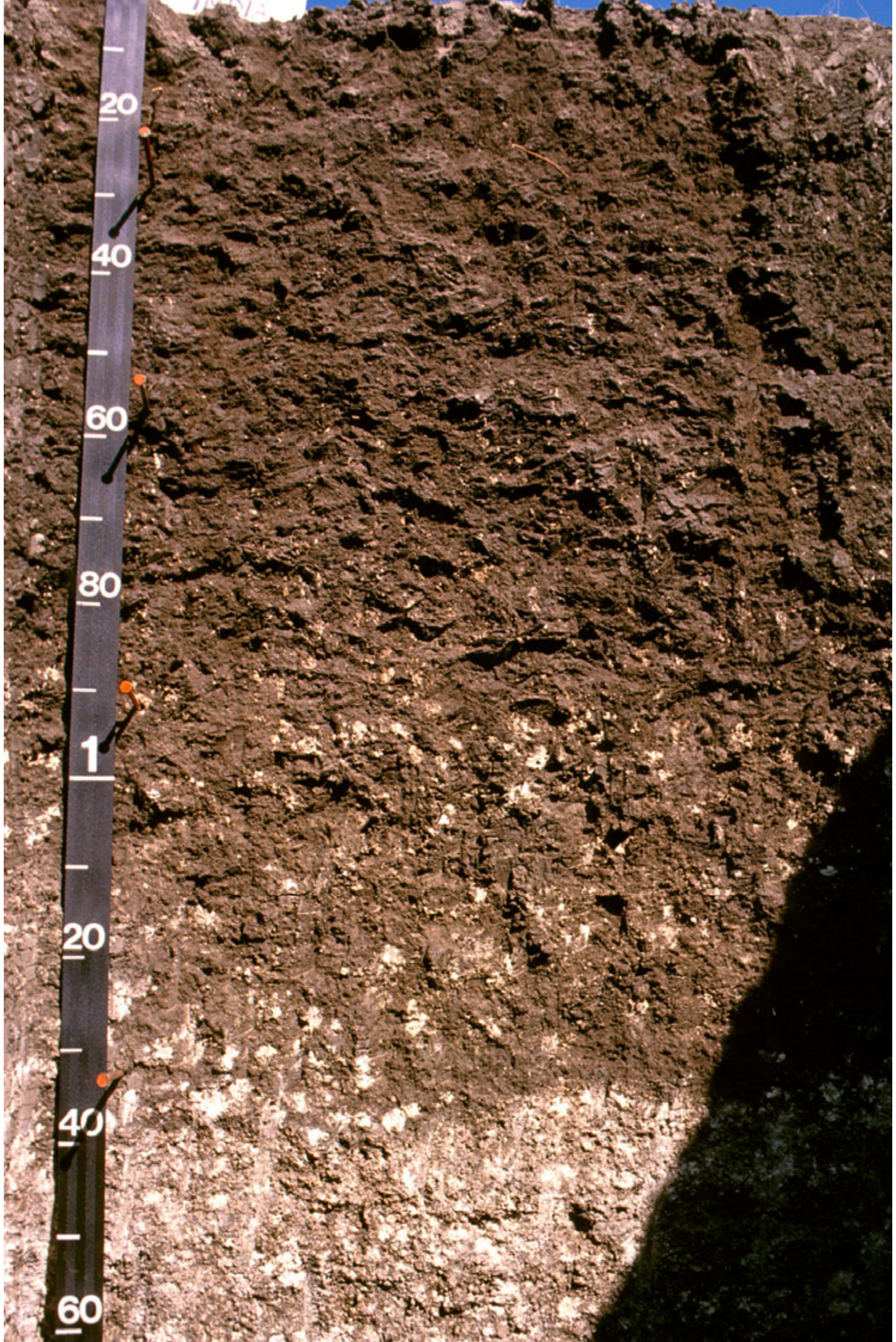
107 - In marly materials, the substratum is granular marl. During the formation of the bowl, the marl is pushed sideways; laterally, it is pushed up to form the diatreme as in this soil from Texas.

108 - In another view of the soil (#107), the marl forms and outlines the bowl very clearly.

109 - When there is a supply of carbonates, a layer rich in carbonate forms below the zone of slickensides, as in this Calciustert from Tamil Nadu, India.

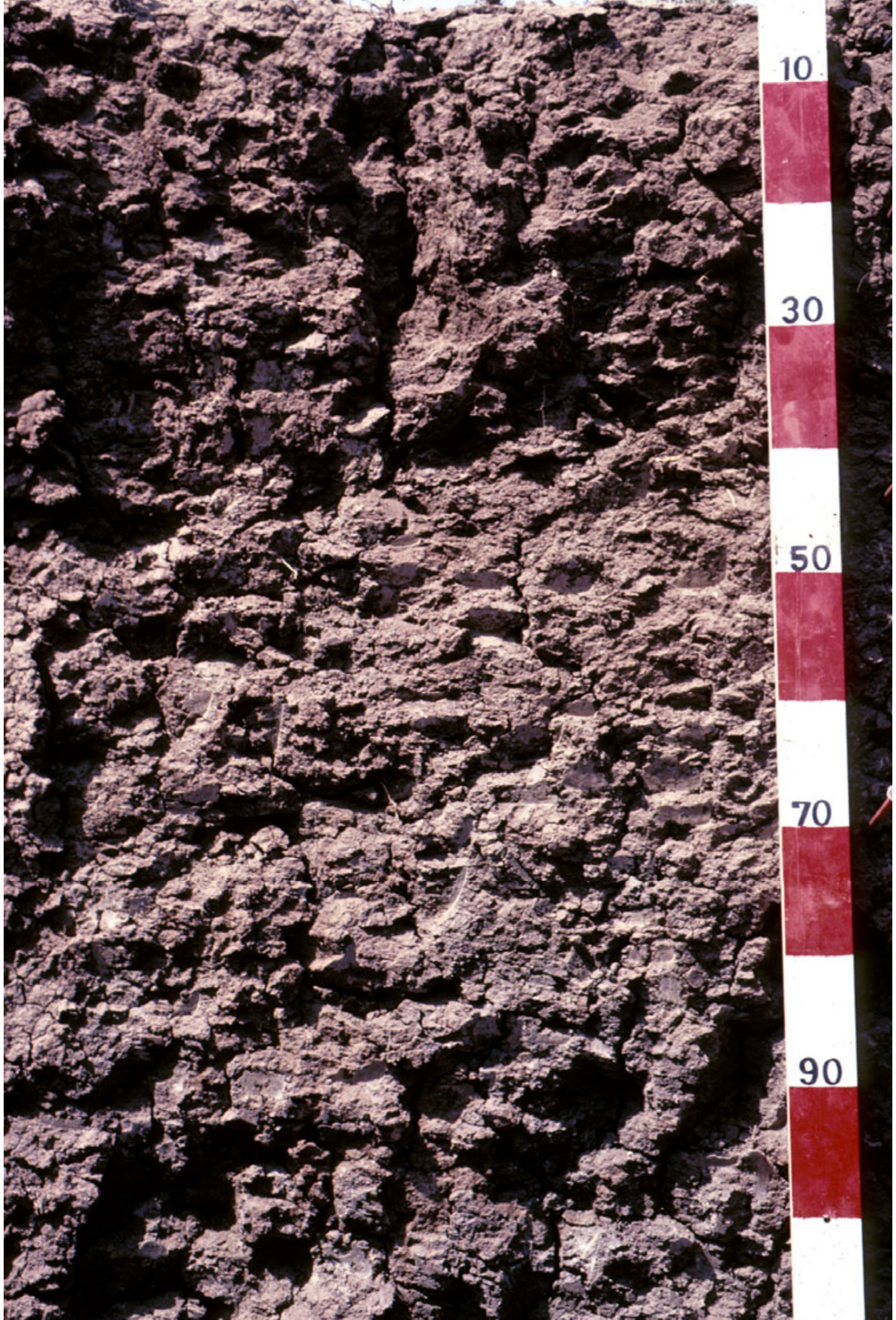
110 - Sometimes, there is contrasting material below the vertic material. The lower material as in this soil, is loamy, with mixed mineralogy clays, and hence no vertic properties. Vertisols with lithological discontinuities are common in alluvial areas.

111 - In this Gypsitorrert, there is gypsum in the subsoil. The soil is from Port Augusta, Australia. On close examination, gypsum crystals may be seen on the slickensides.



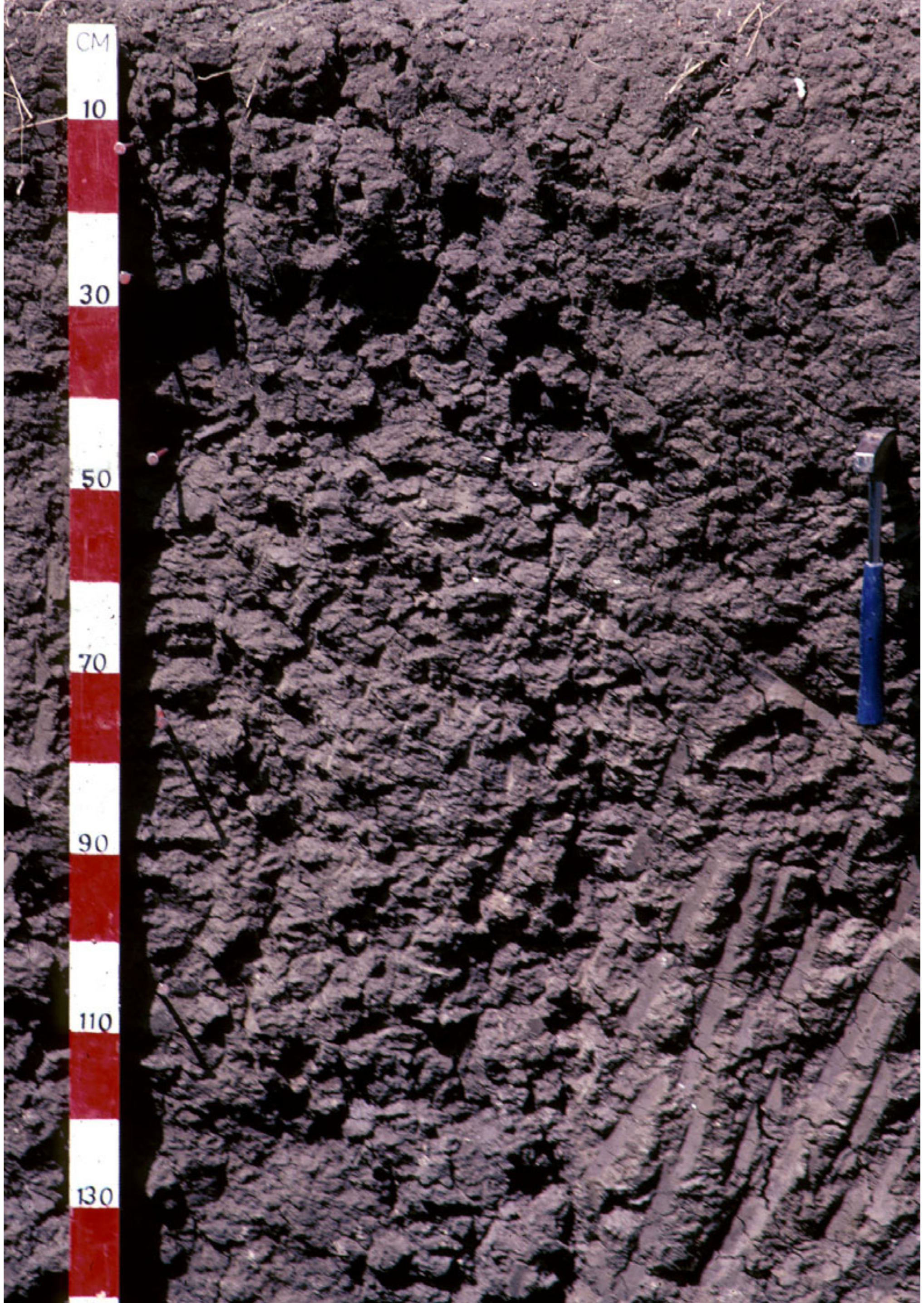
112 - In this Typic Calciustert (Kovilpatti series, Tamil Nadu), between the zone of slickensides and the calcic horizon, there is a zone with soft powdery lime. Some slickensides are present in the zone with powdery lime.

113 - Typic Haplotorrert on Jordan developed on basalt. (S82FN-500-014) on road from N. Shuna to Jordan River.



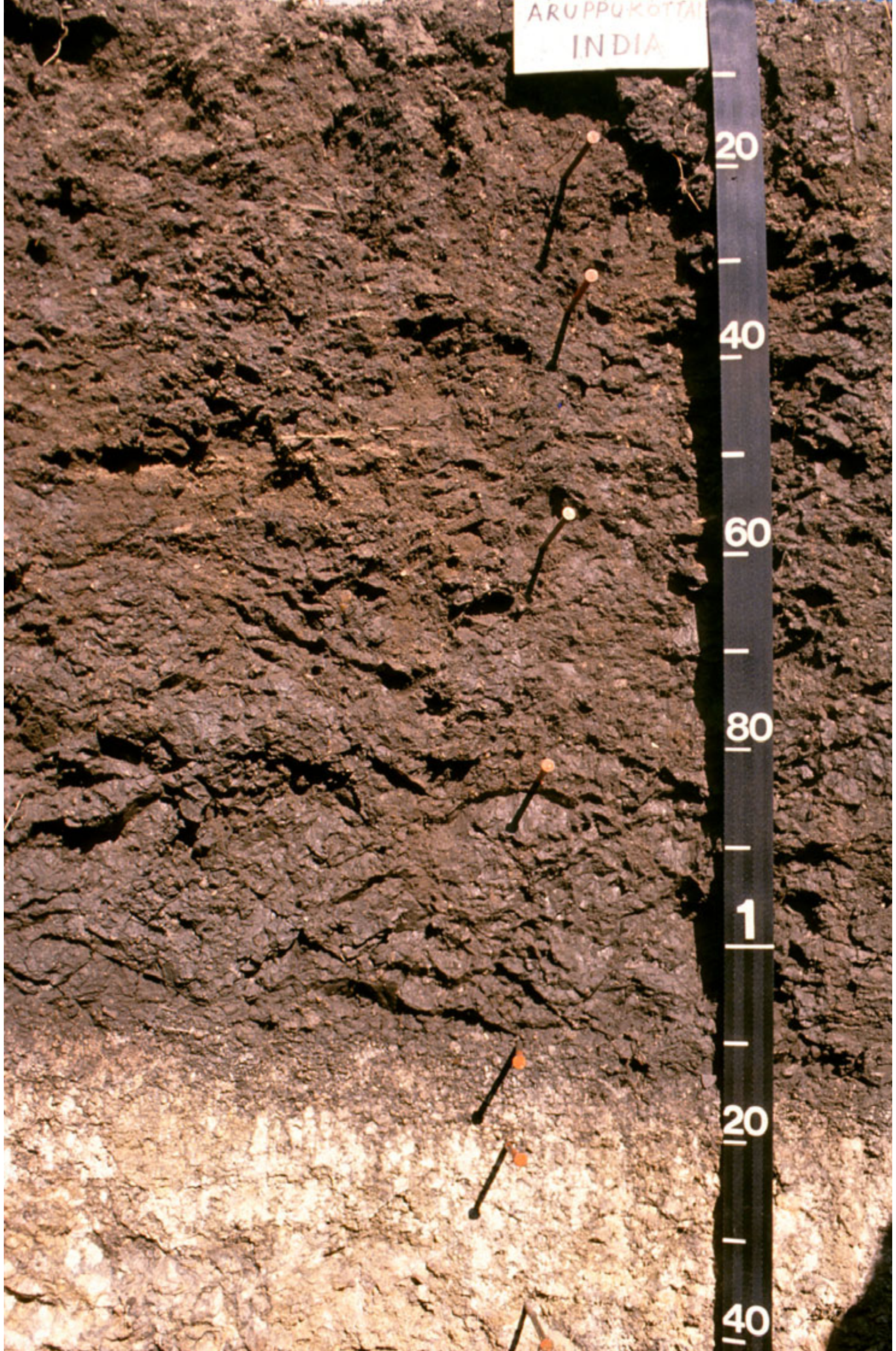
114 - Aridic Haplustert (S81FN-835-005) located at Gedaref field station, Sudan.

115 - Aridic Haplustert (S81FN-835-003) in sugar plantation between Sennar and Wad Medani, Sudan.



116 - Aridic Haplustert (S81FN-835-006) near Gedaref, Sudan.

117 - Typic Haplustert (S81FN-835-008) 1 km from Jebel Abu Naam, close to railway, Sudan.

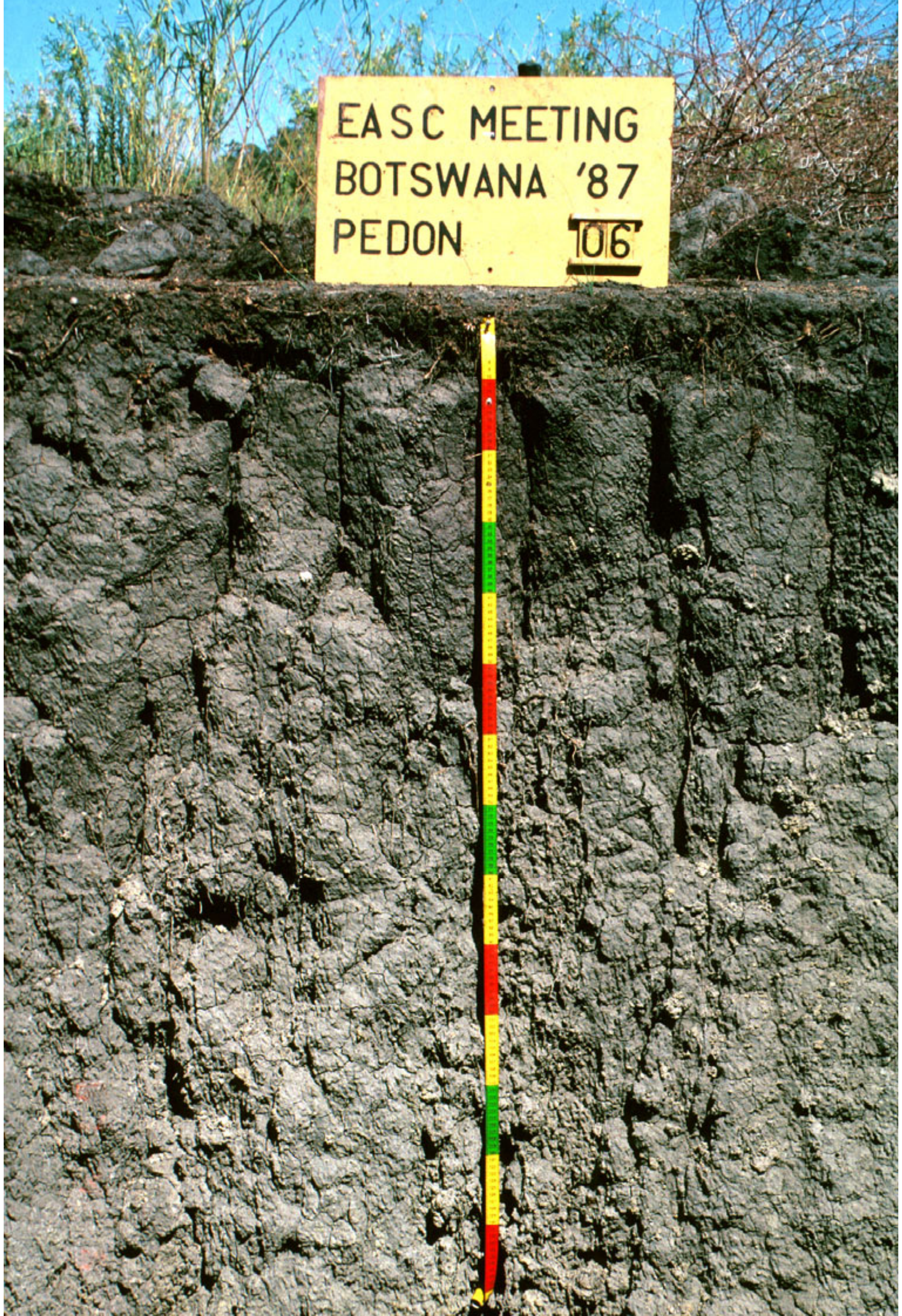


118 - Sodic Haplustert from India
(S90FN-455-11)

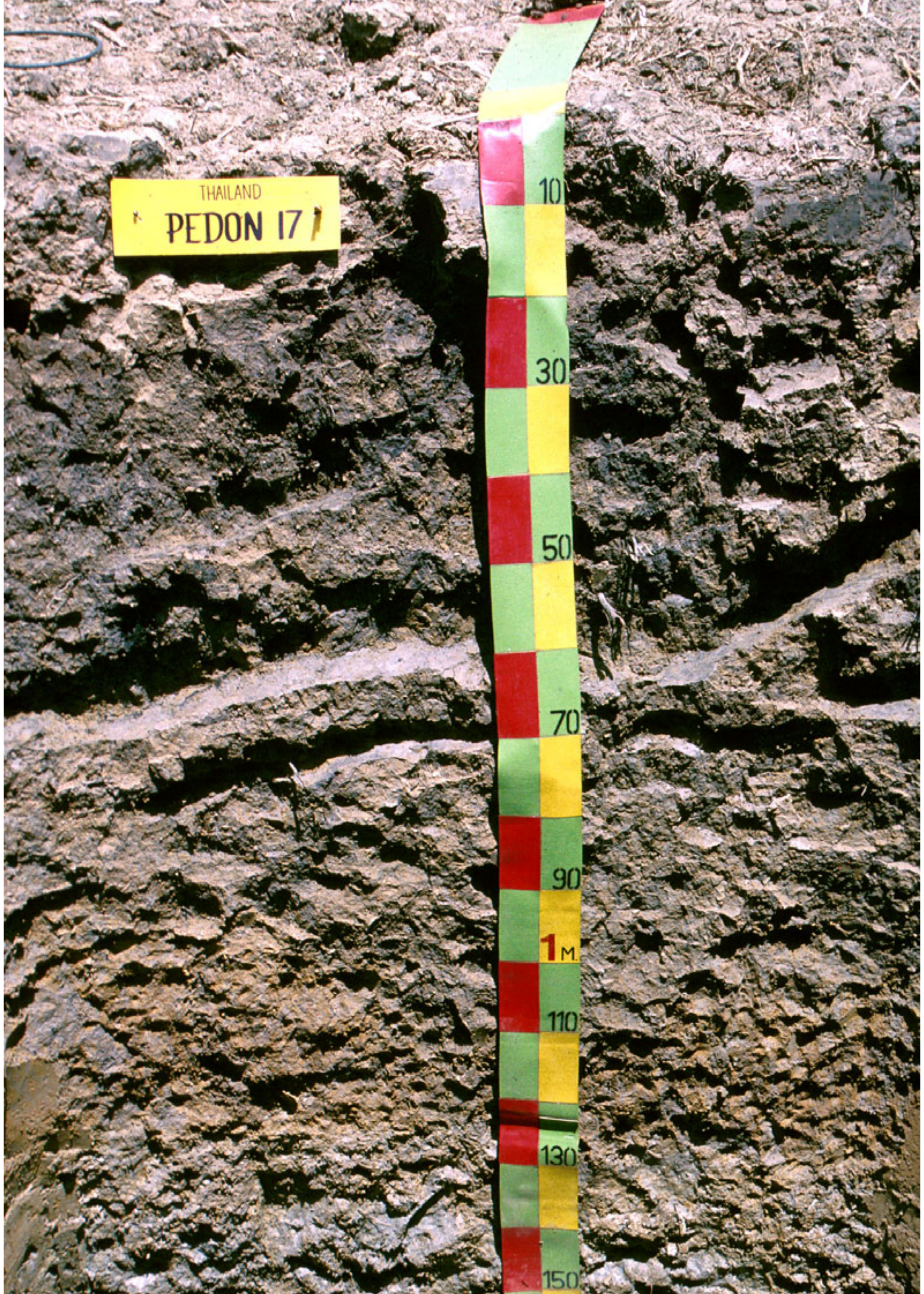
119 - Typic Haplustert. Magaldan Series from Philippines.

120 - Calcic Haplustert from Tamil Nadu, India (Dasarpatti series).

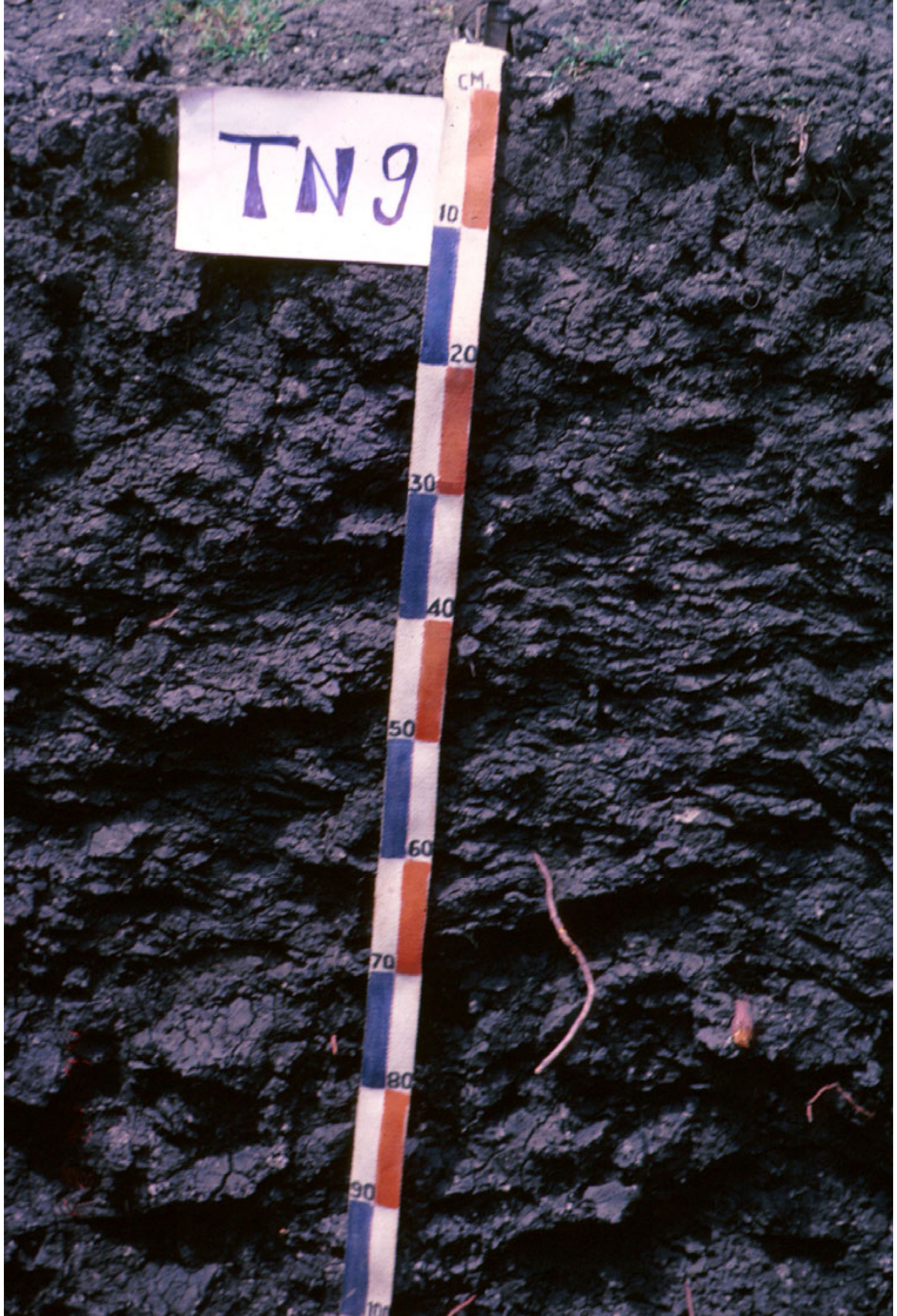
121 - A Vertic Haplustalf from Thailand.



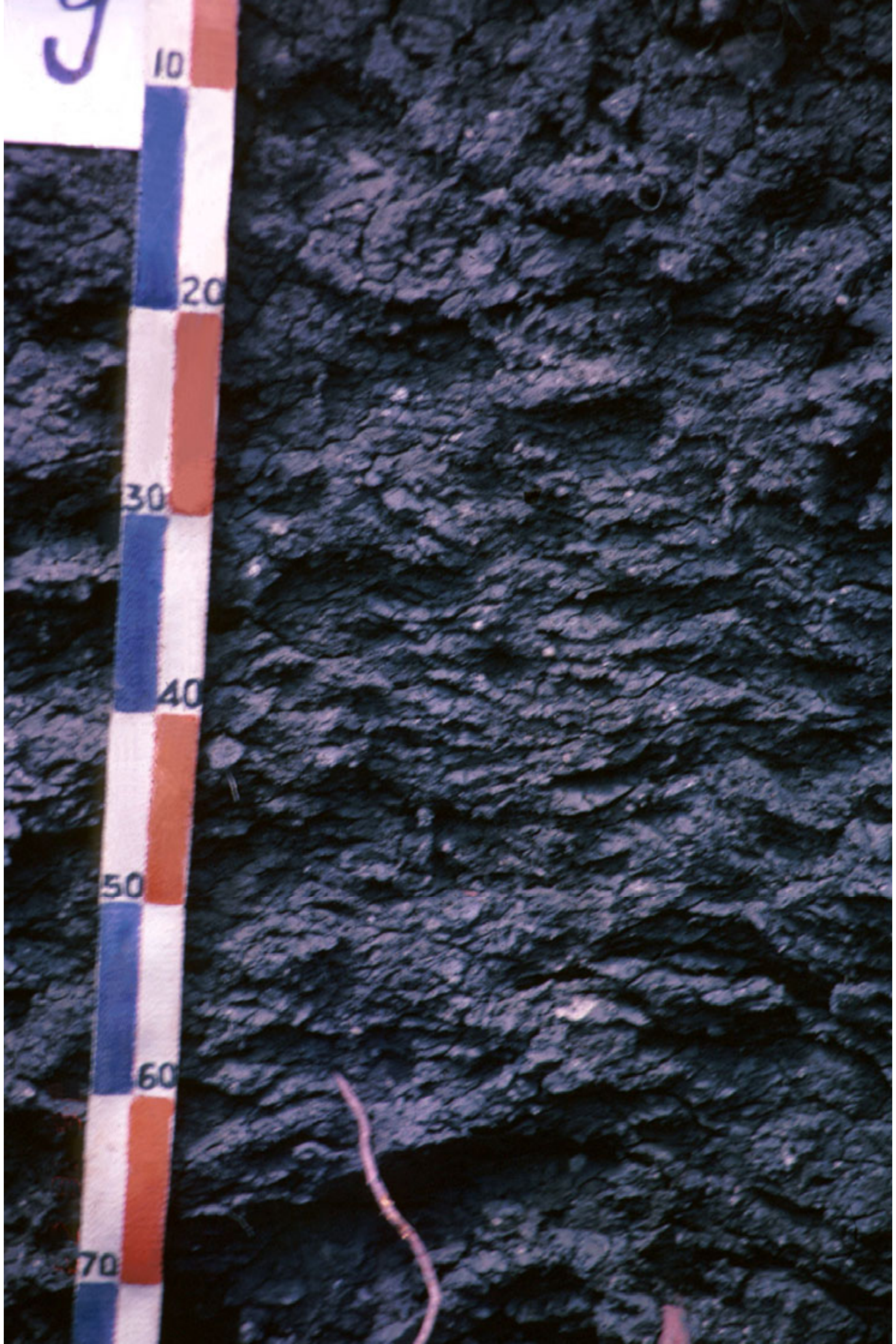
122 - A Sodic Haplotorrert from Botswana (B6).



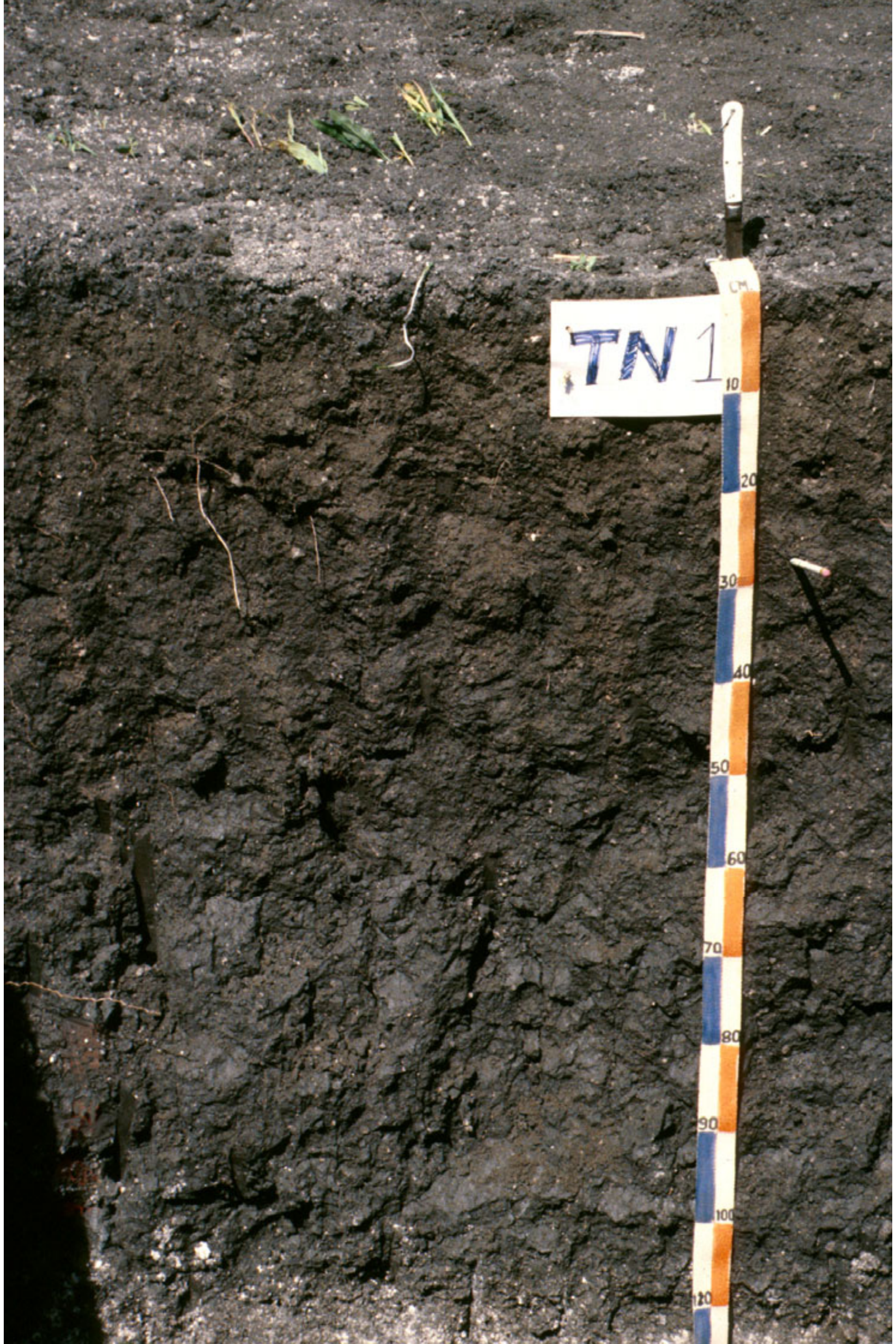
123 - A Typic Haplustert from Thailand (T17).



124 - A Typic Haplustert from Tamil Nadu, India with Sphenoids.



125 - Close up of sphenoids in profile #124.

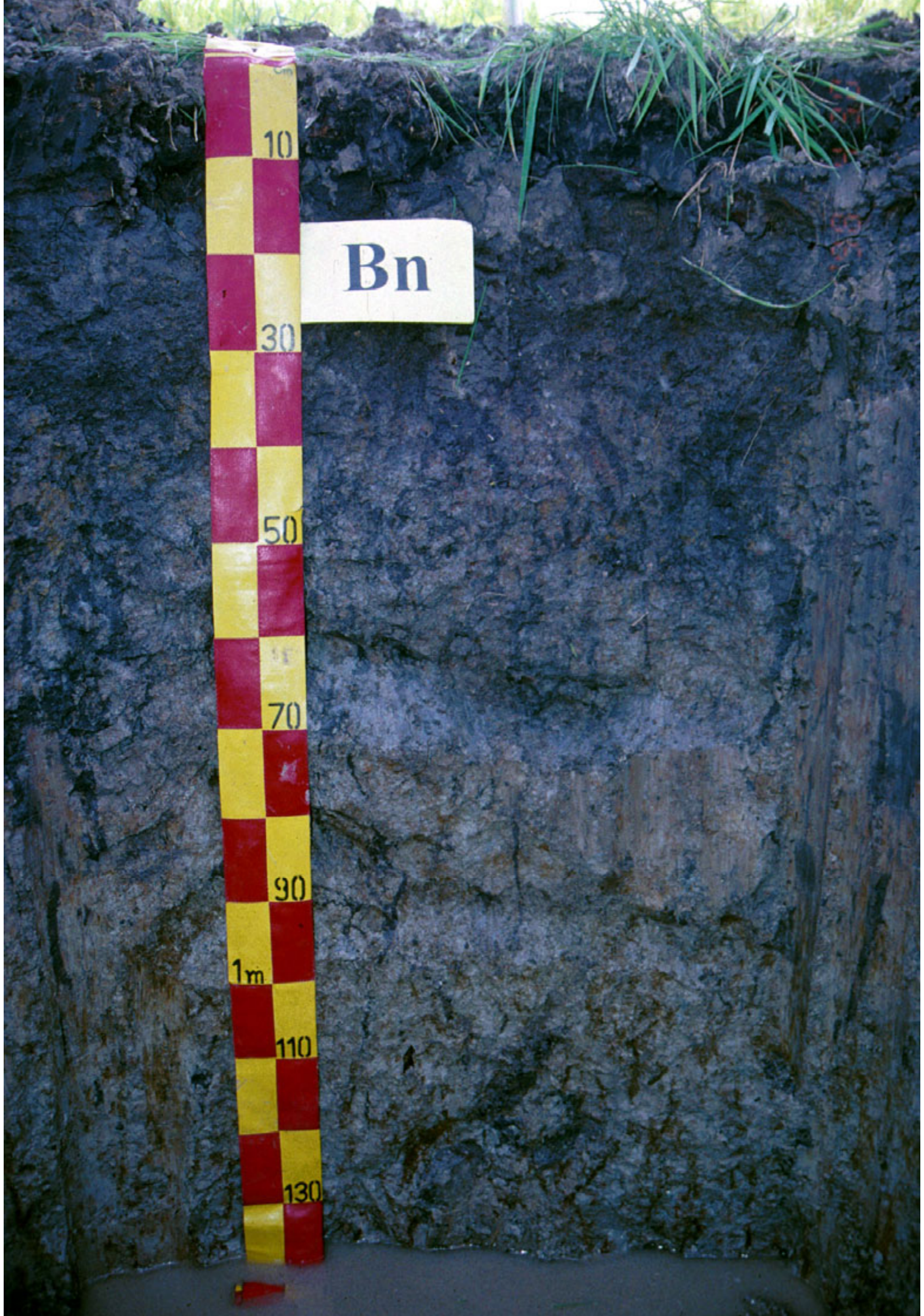


126 - A Calciustert from Tamil Nadu, India.

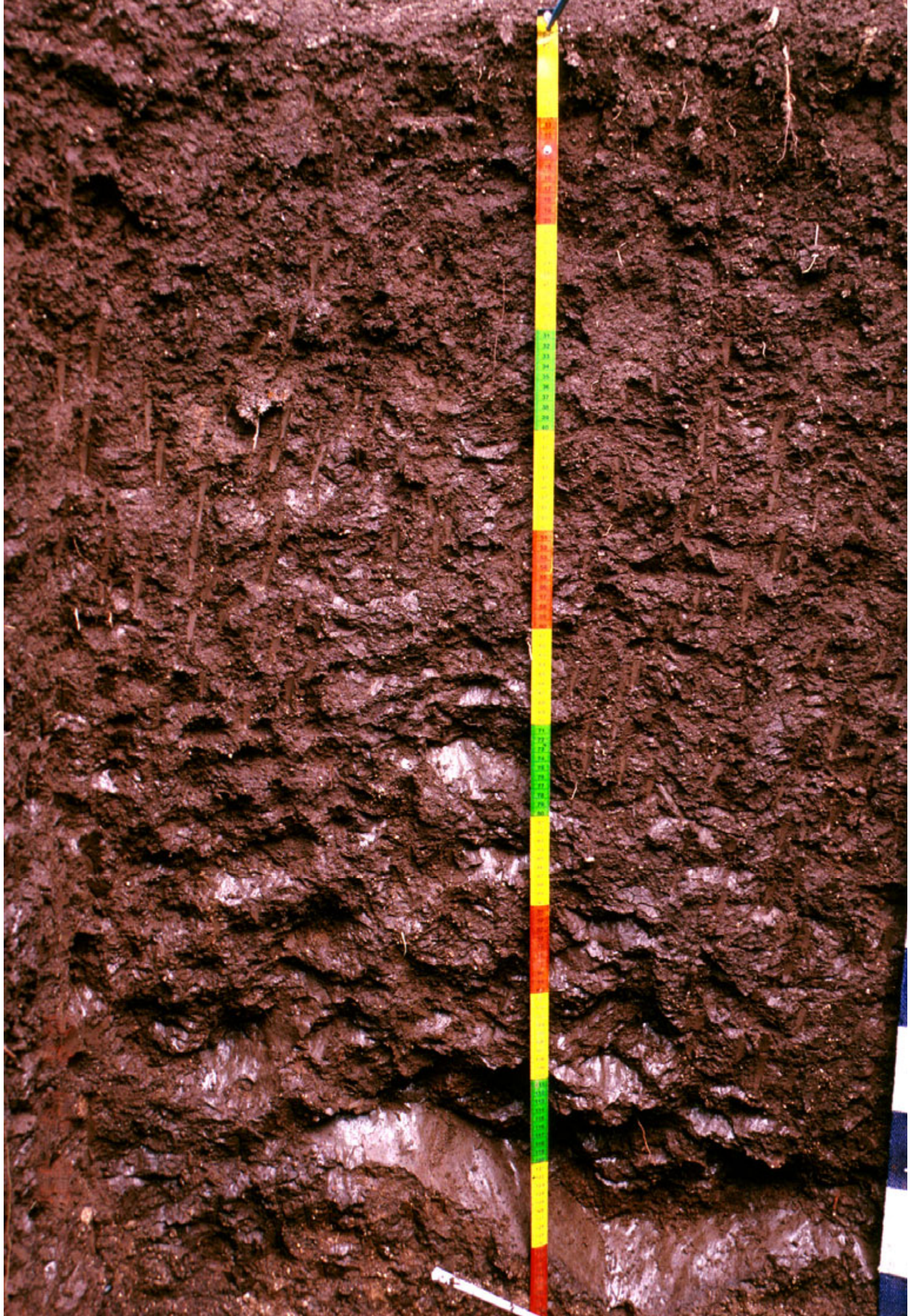
127 - A Typic Haplustert from Pangasinan, Philippines.

128 - An Entic Haploxerert near Kaniva, Victoria, Australia.

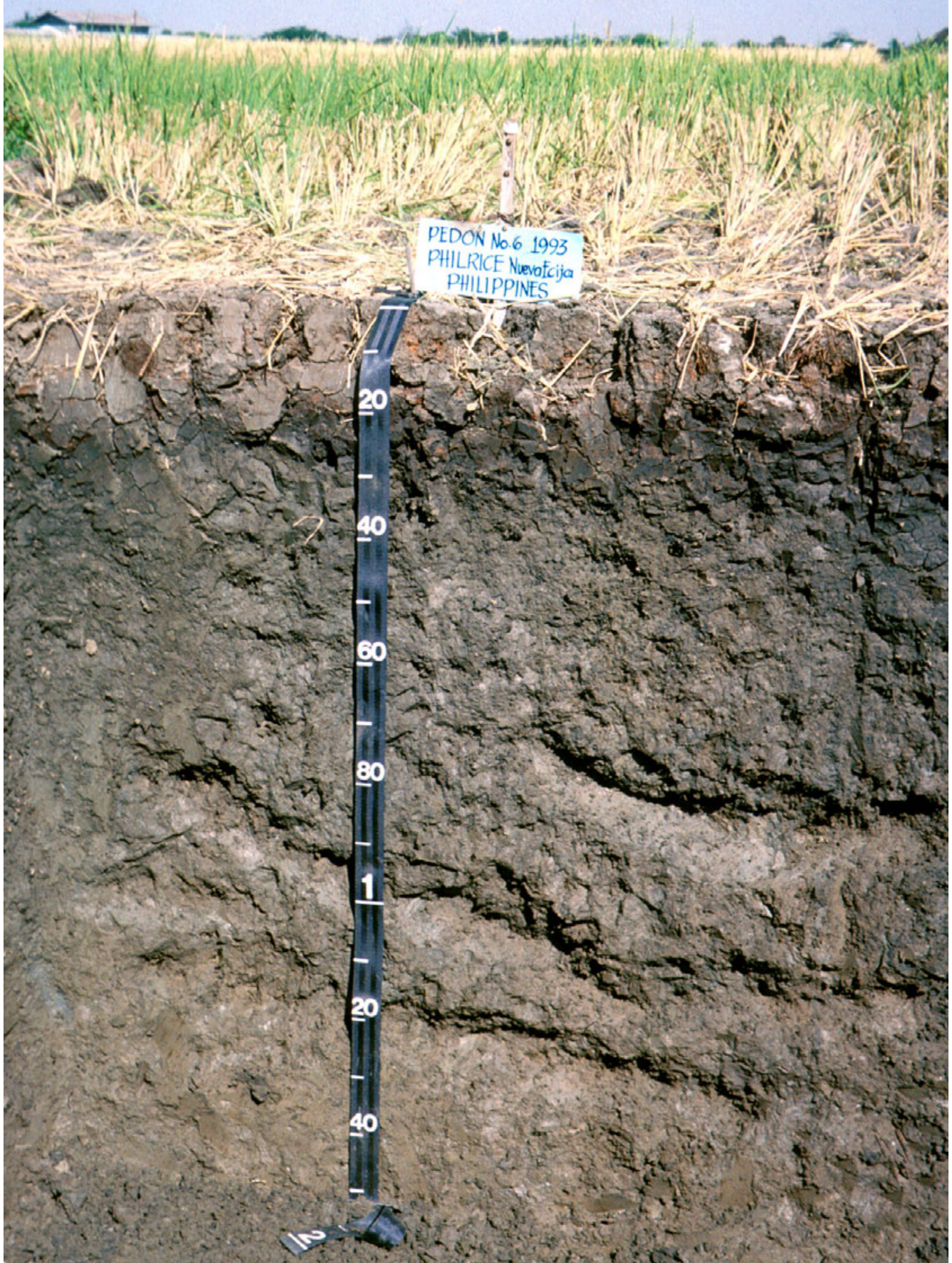
129 - A Typic Haplustert, Kafue Flats, Zambia.



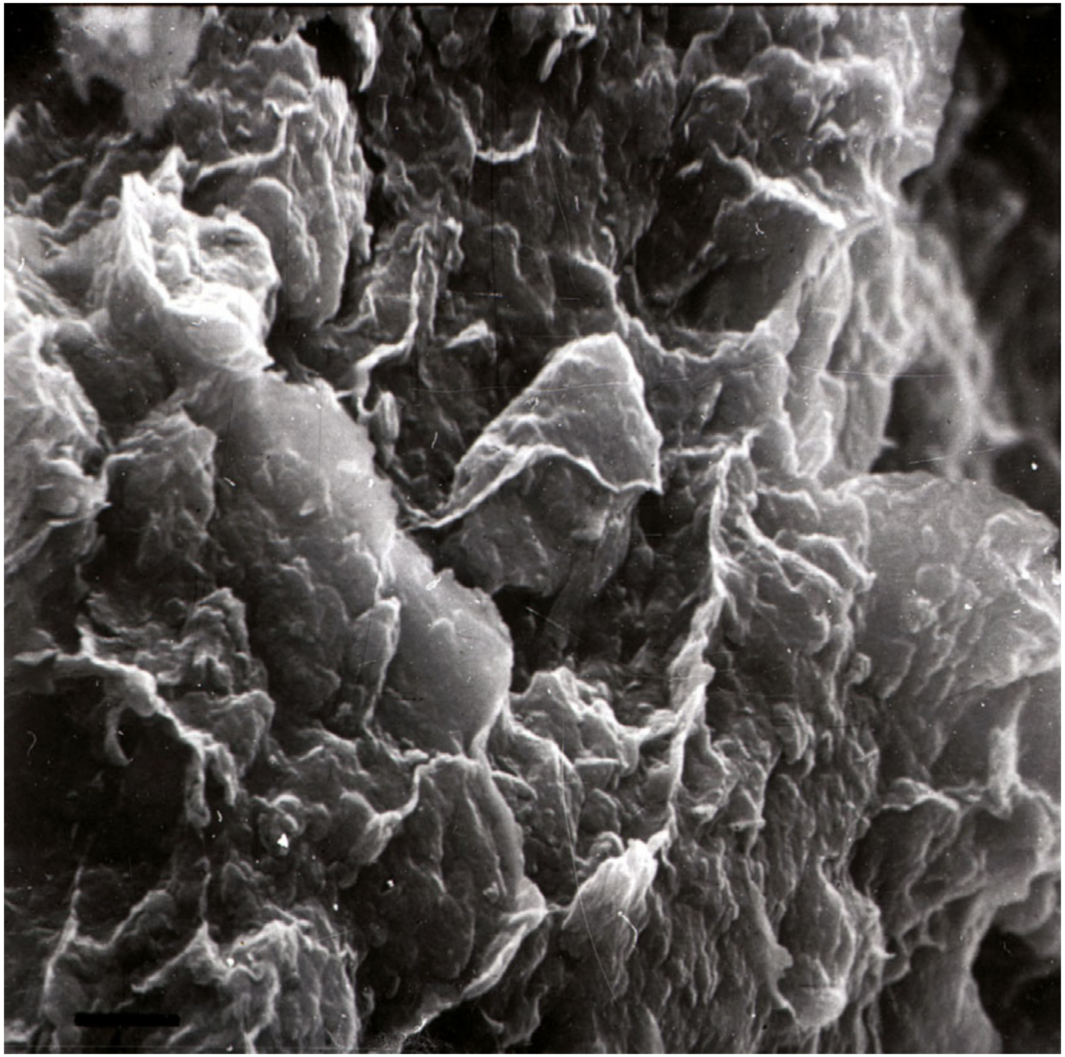
130 - An Ustic Dystraquert, Thailand.



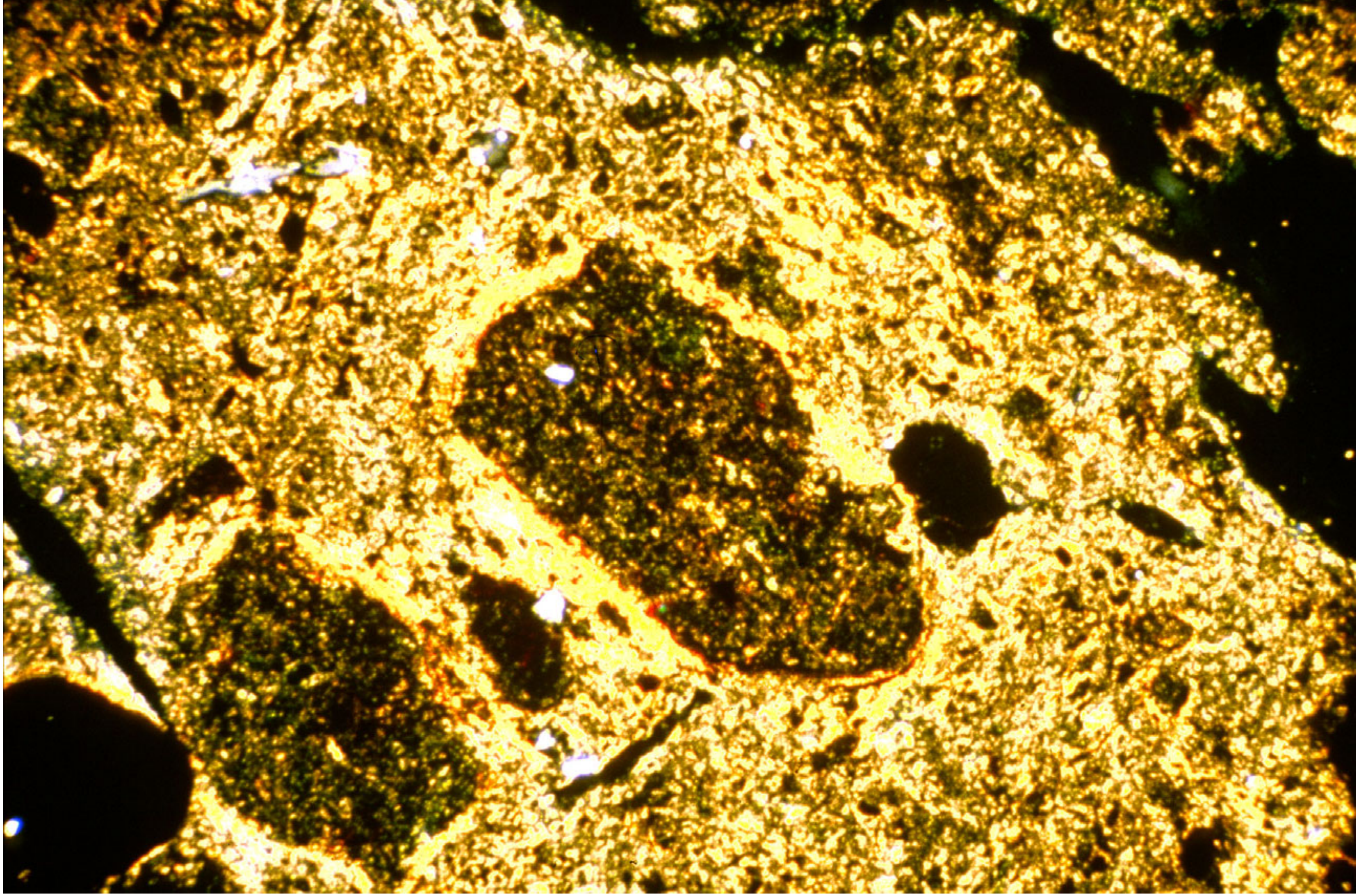
131 - A Chromic Haplustert from Akola, India.



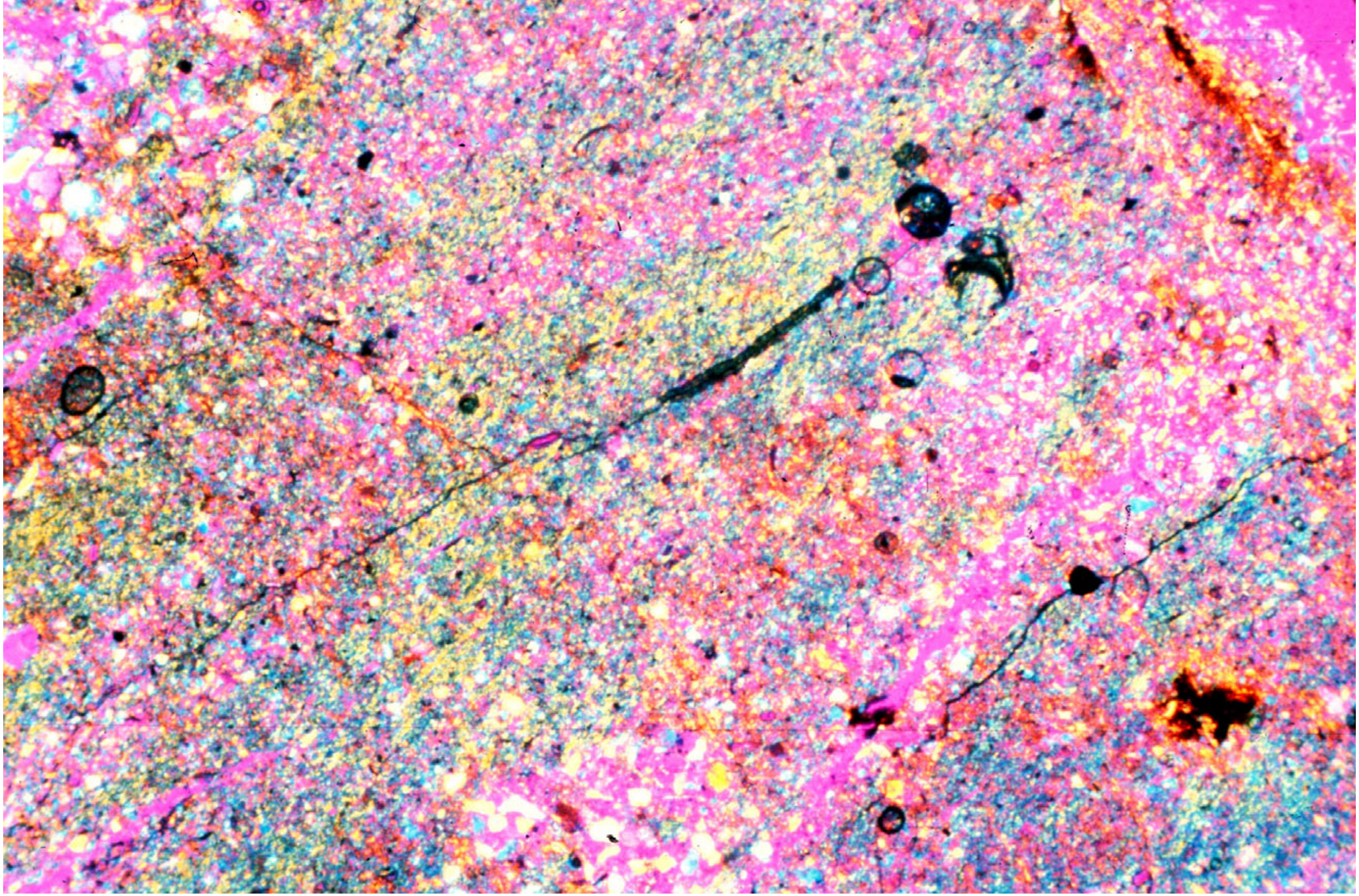
132 - An Ustic Epiaquert from Nueva Ecija, Philippines.



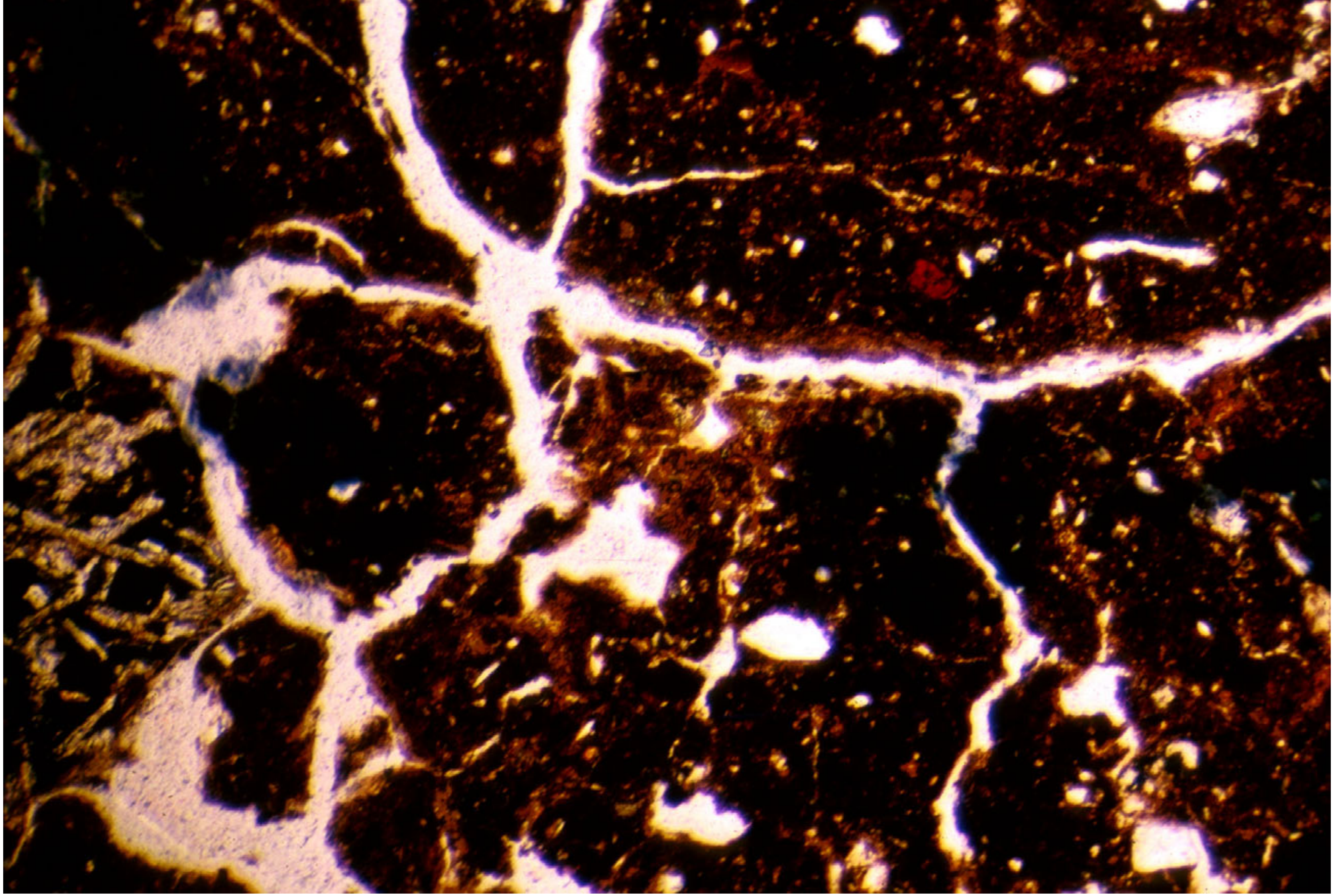
133 - Scanning electron Micrograph (SEM) of a sample of a soil with smectite.



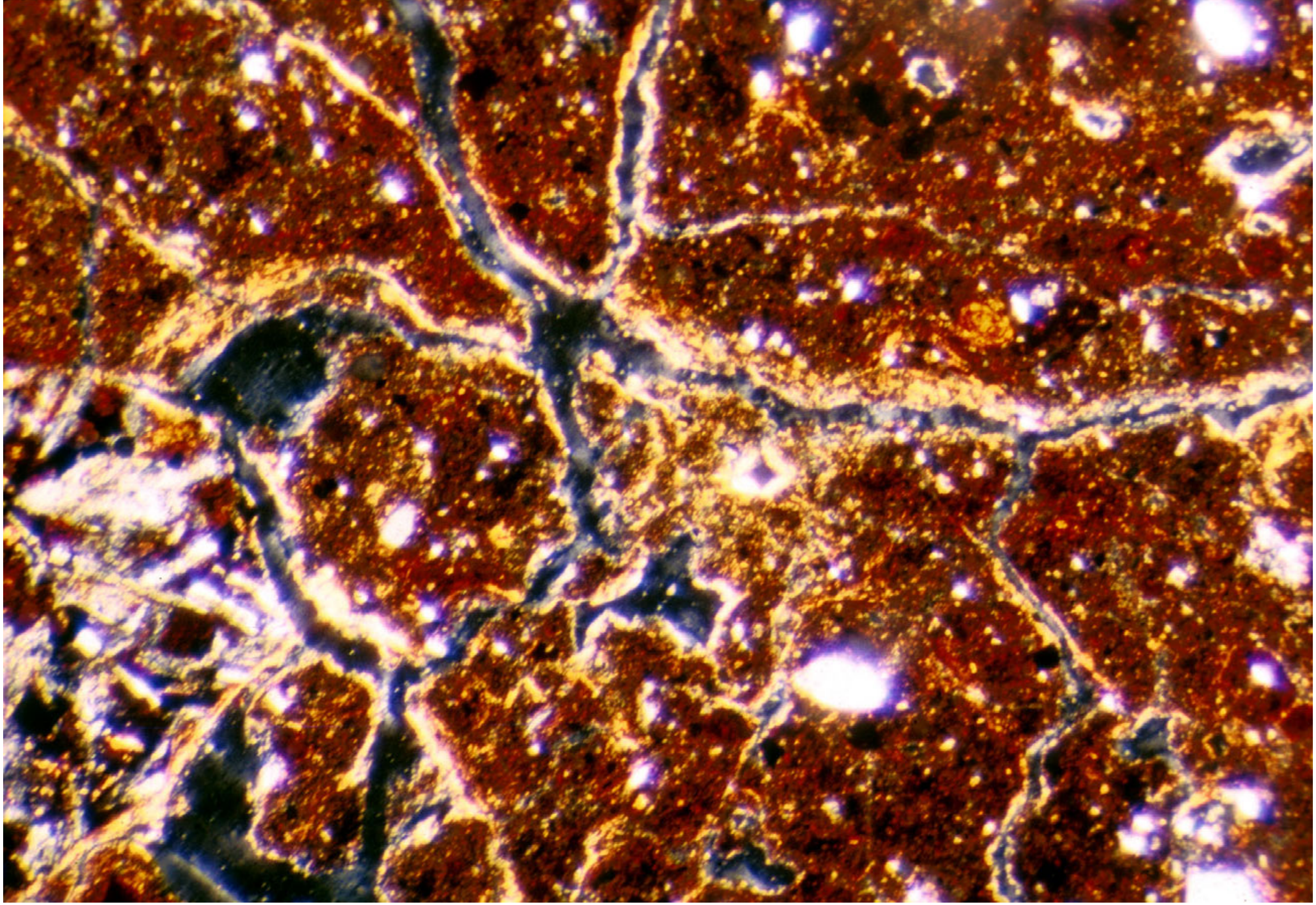
134 - Stress orientation of the plasma is clear in those Vertisols with low organic matter and low amounts of free iron. This sample is from the subsoil of a Sulfaqueptic Dystraquert.



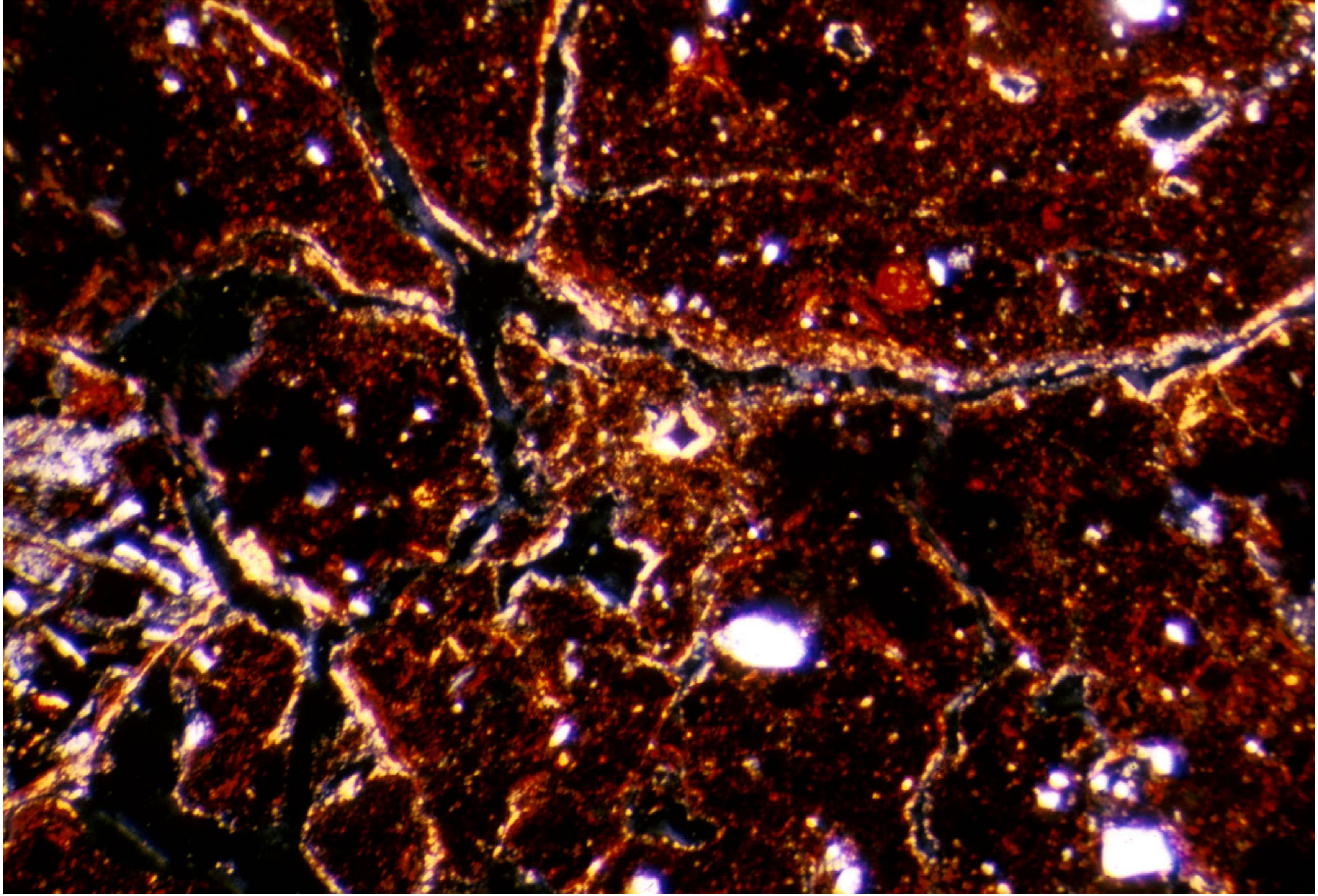
135 - Under polarized light, stress orientation is seen better if a gypsum plate is used in viewing the thin-section.



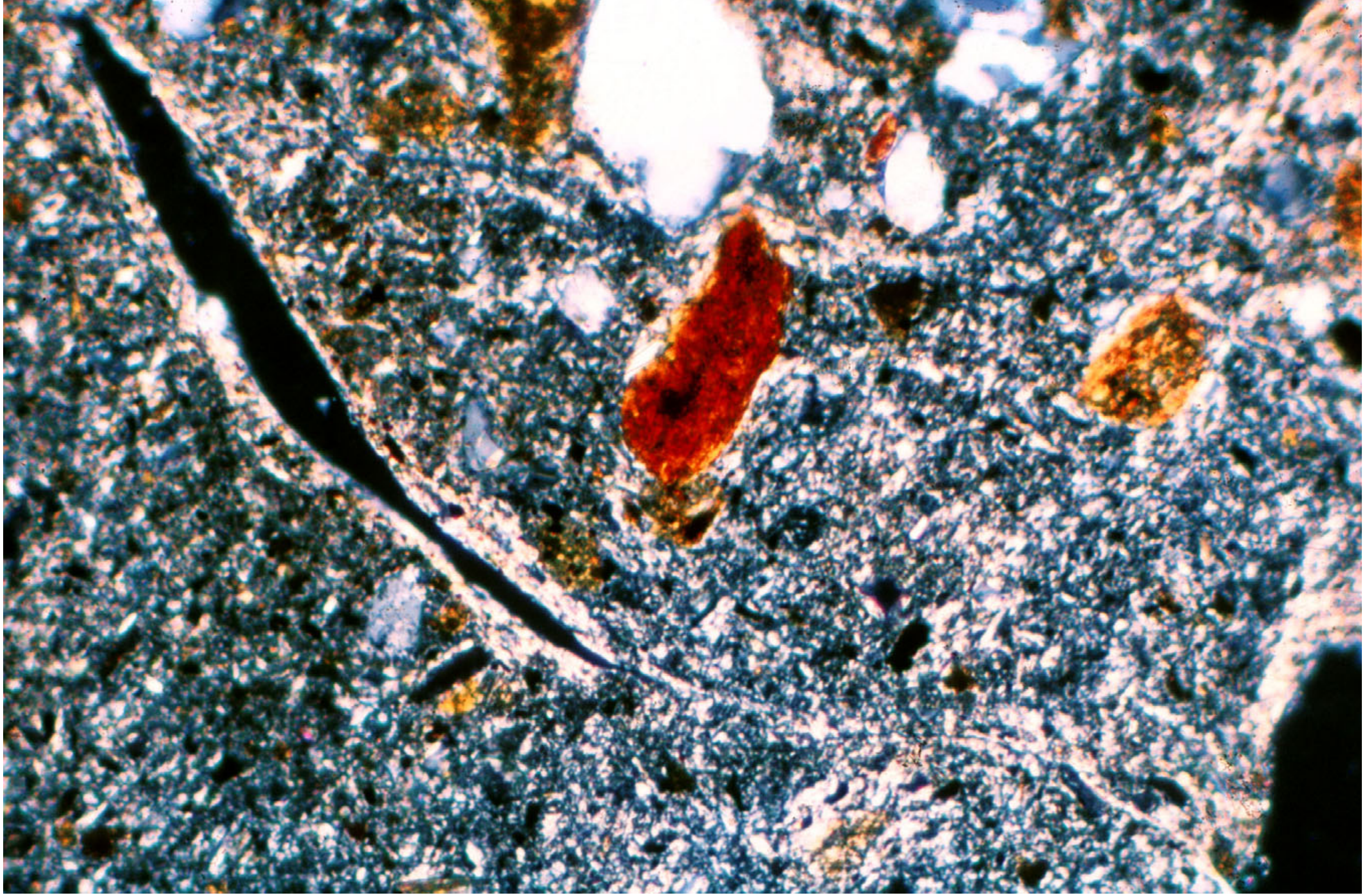
136 - In organic matter rich Vertisols, as in this one from Ethiopia, the high amount of organic matter masks the stress orientation of the plasma. Under plane light, the cracks are very evident.



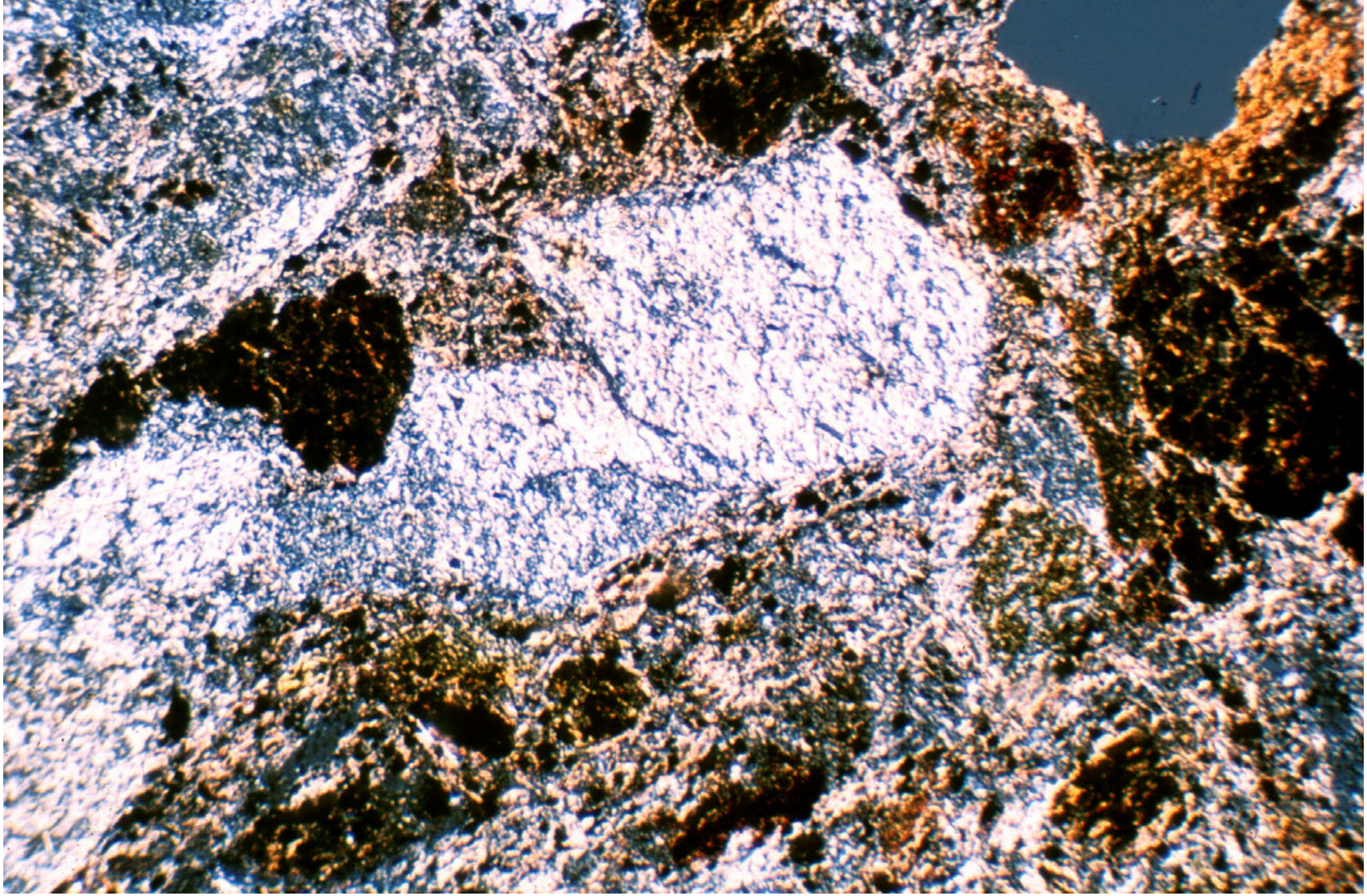
137 - A similar situation is seen in reddish Vertisols, which have high amounts of free iron that mask the stress orientations. However, the cracks are clear.



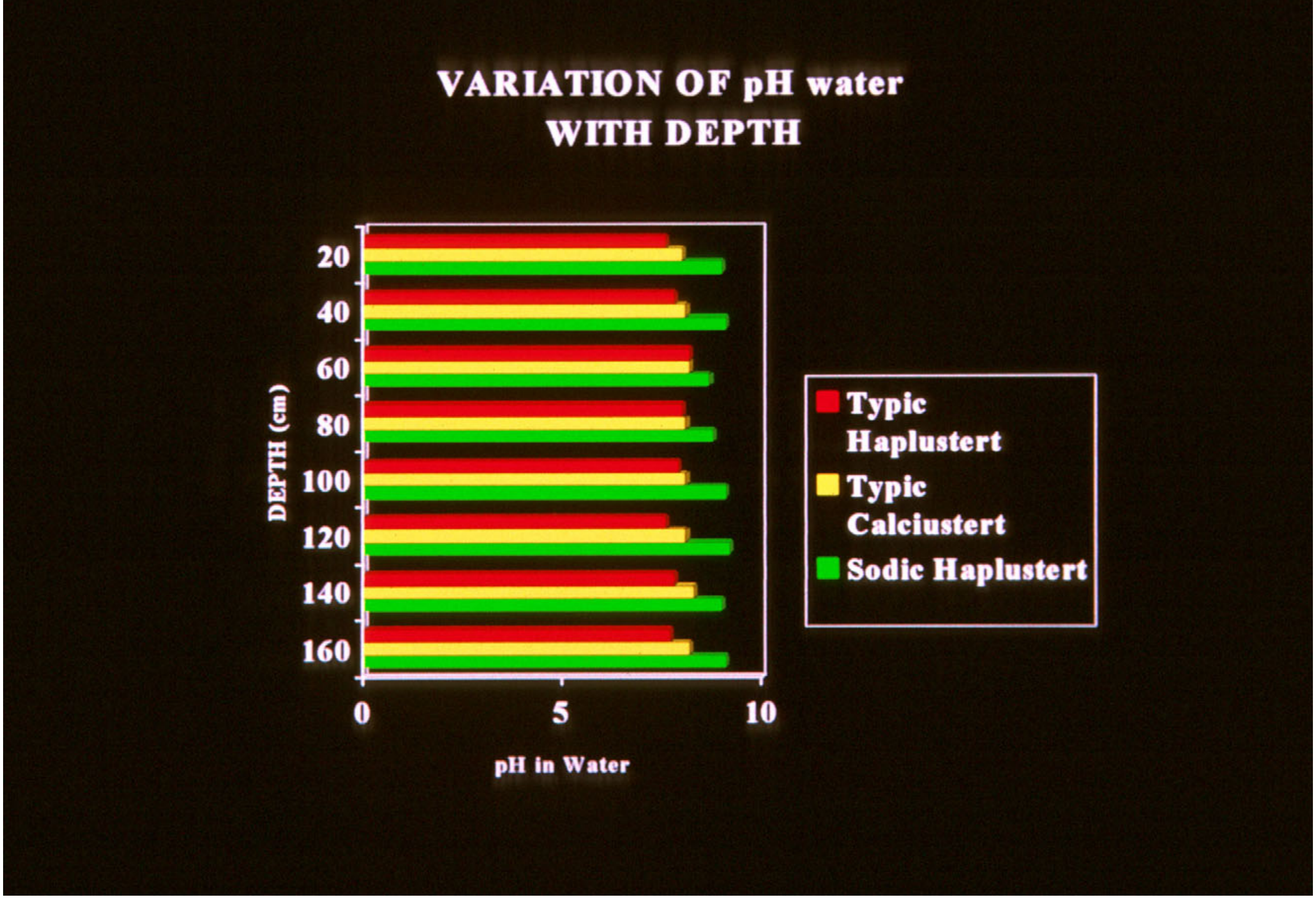
138 - At the edge of the cracks, the orientation of the plasma may be seen. The plasma here has less free iron.



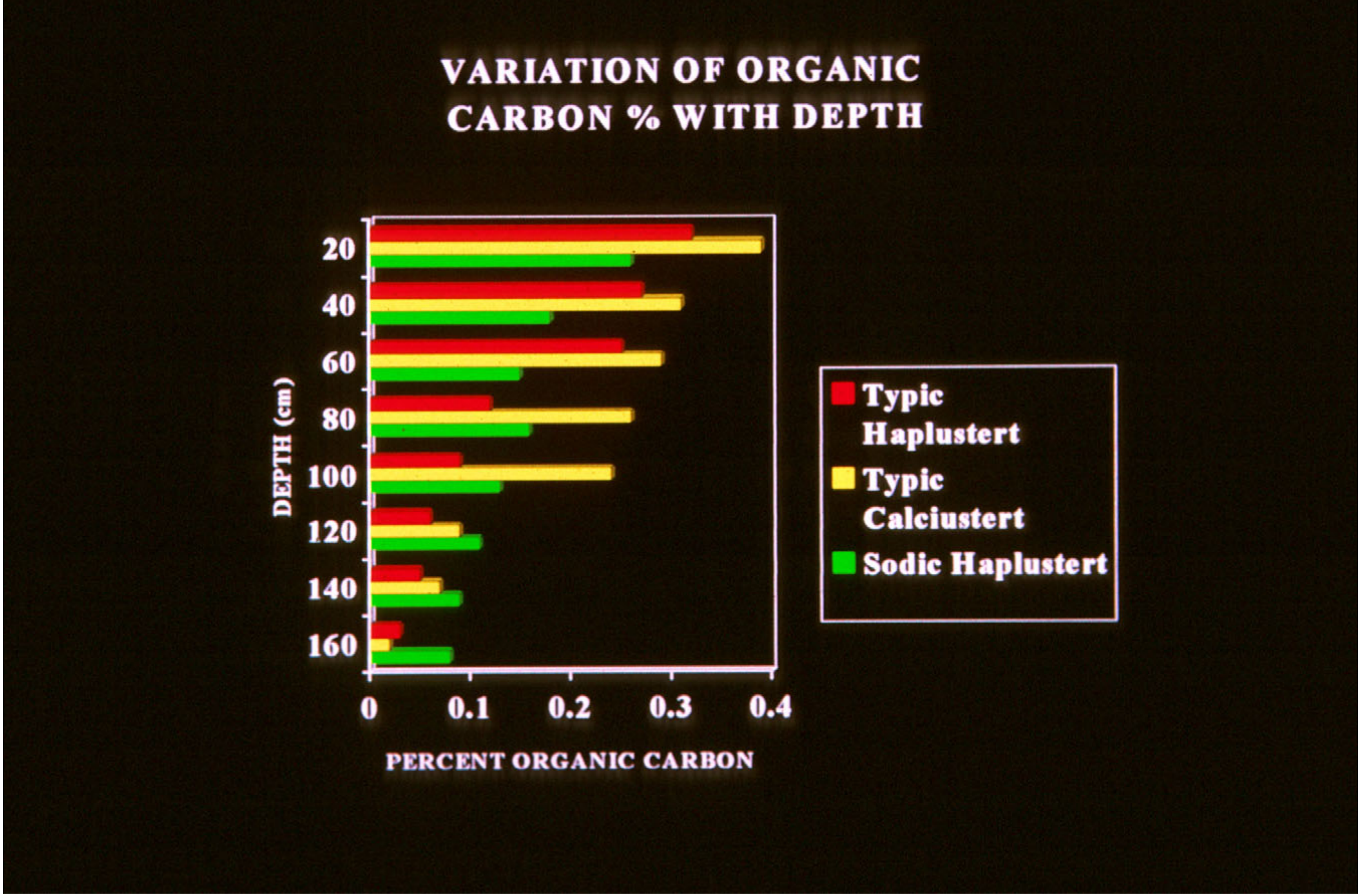
139 - In acid Vertisols, some clay movement may take place. The voids in the subsoil have a thin lining of cutans.



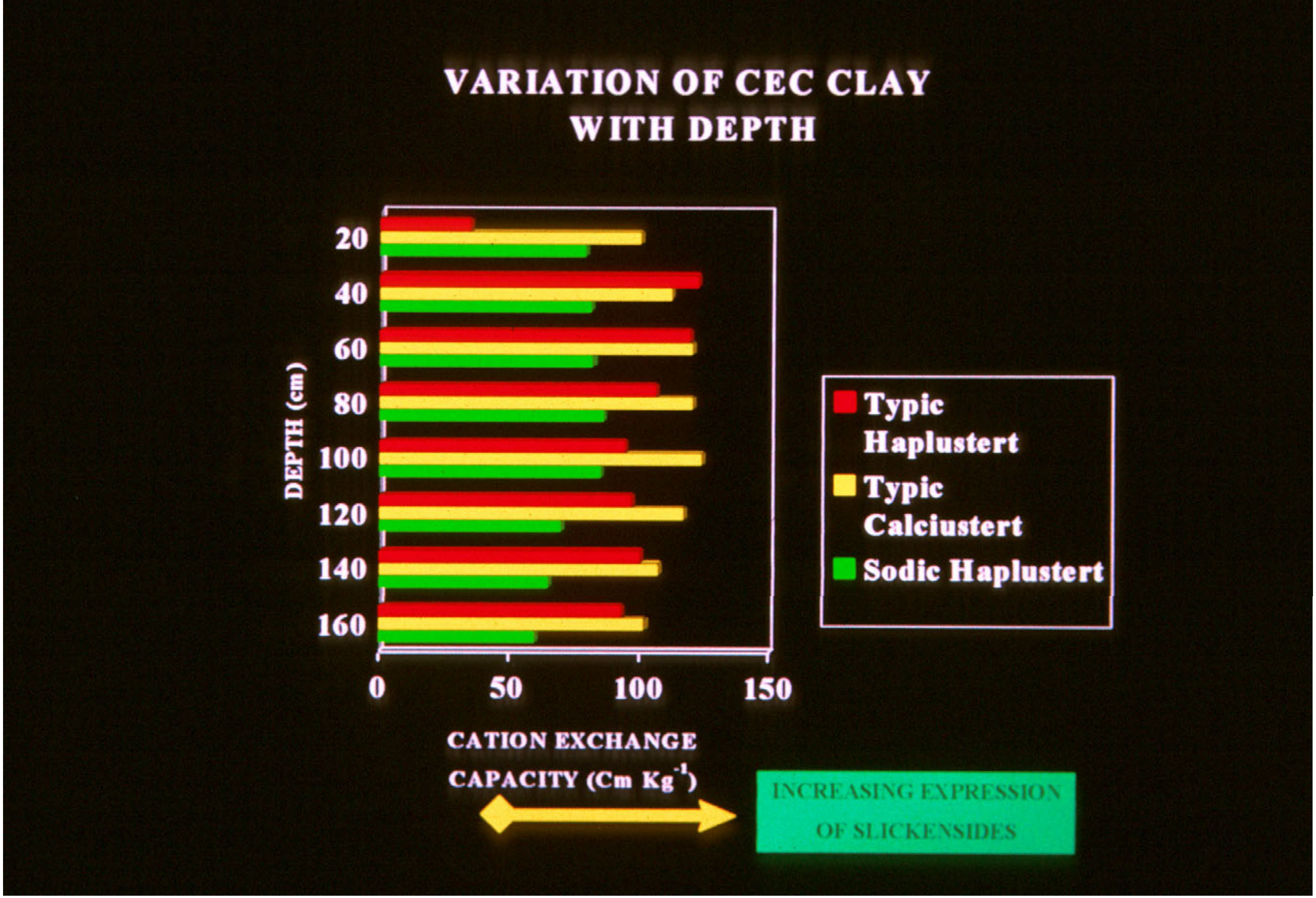
140 - Intense lattice-like orientation of plasma (omni-sepic fabric) may be seen in some Vertisols as in this soils from the Czech Republic.



141 - Vertisols may be acid, neutral, or alkaline. The majority of Vertisols are neutral or alkaline as they are mostly derived from calcareous or base-rich materials. Acid Vertisols may result from acidic parent materials, a more humid paleo-climate, strong seasonal leaching, or ferrolysis. There is generally and increase of pH with depth corresponding to an increase of $CaCO_3$ and other salts. Acid Vertisols with pH values of 4.5 or less are recognized in Soil Taxonomy as Dystraquerts, Dystrusterts, or Dystruderts. The pH of the three soils are high with the flood-plain soil having a pH >9.0.

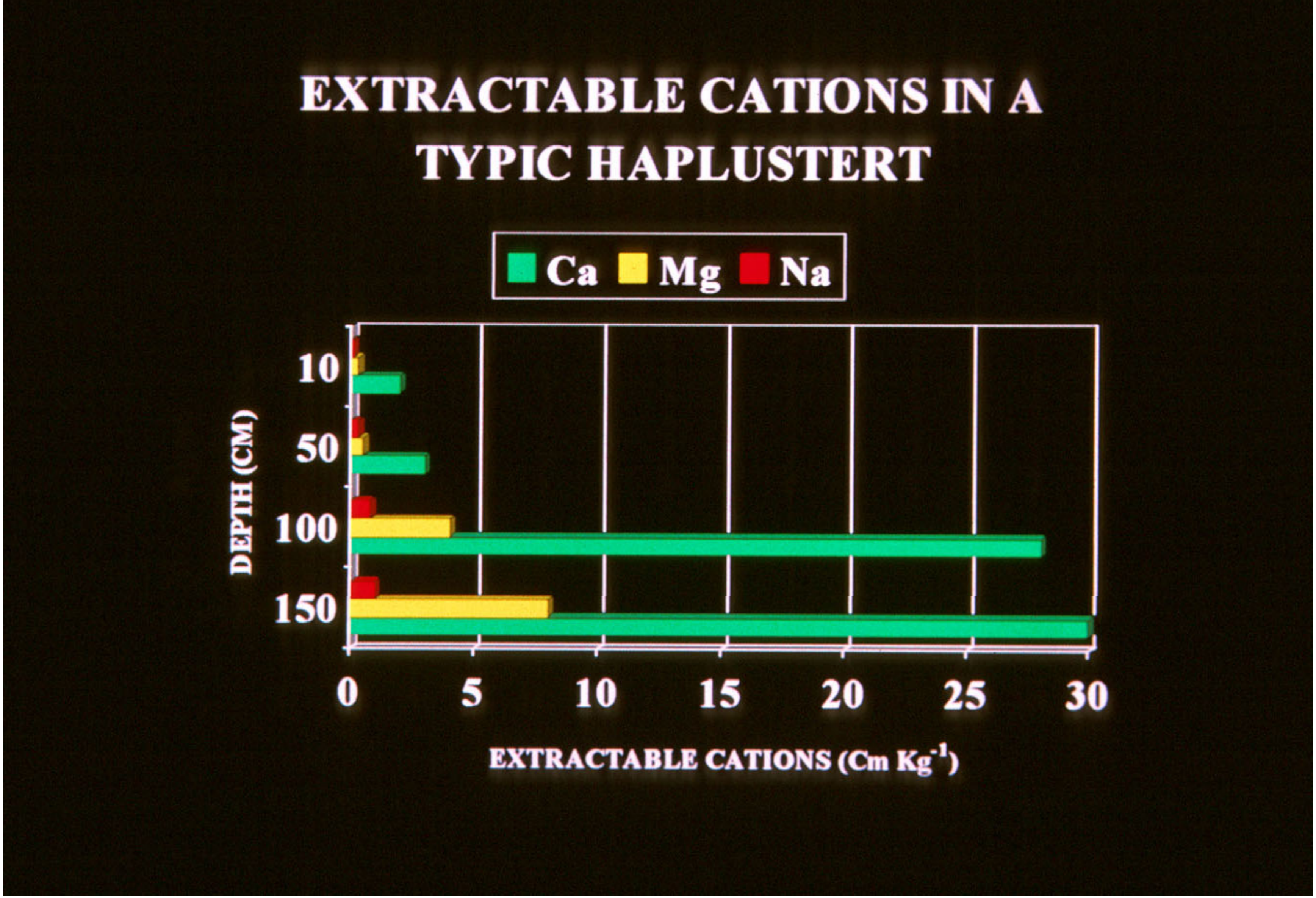


142 - Organic matter is an important constituent of Vertisols as it affects their morphological, chemical, and physical properties as well as their management. Organic matter contents range from 0.5 to 10 percent (3 to 6 percent org. C) but are typically from 0.5 to 5 percent. The differences are due to climatic conditions, cropping history, or natural vegetation. A dark color is not necessarily indicative of a high organic matter content in Vertisols as some dark Vertisols contain less than 1 percent organic matter. This is generally attributed to strong clay-organic complexes of smectite and humic substances (Coulombe et al., 1996).

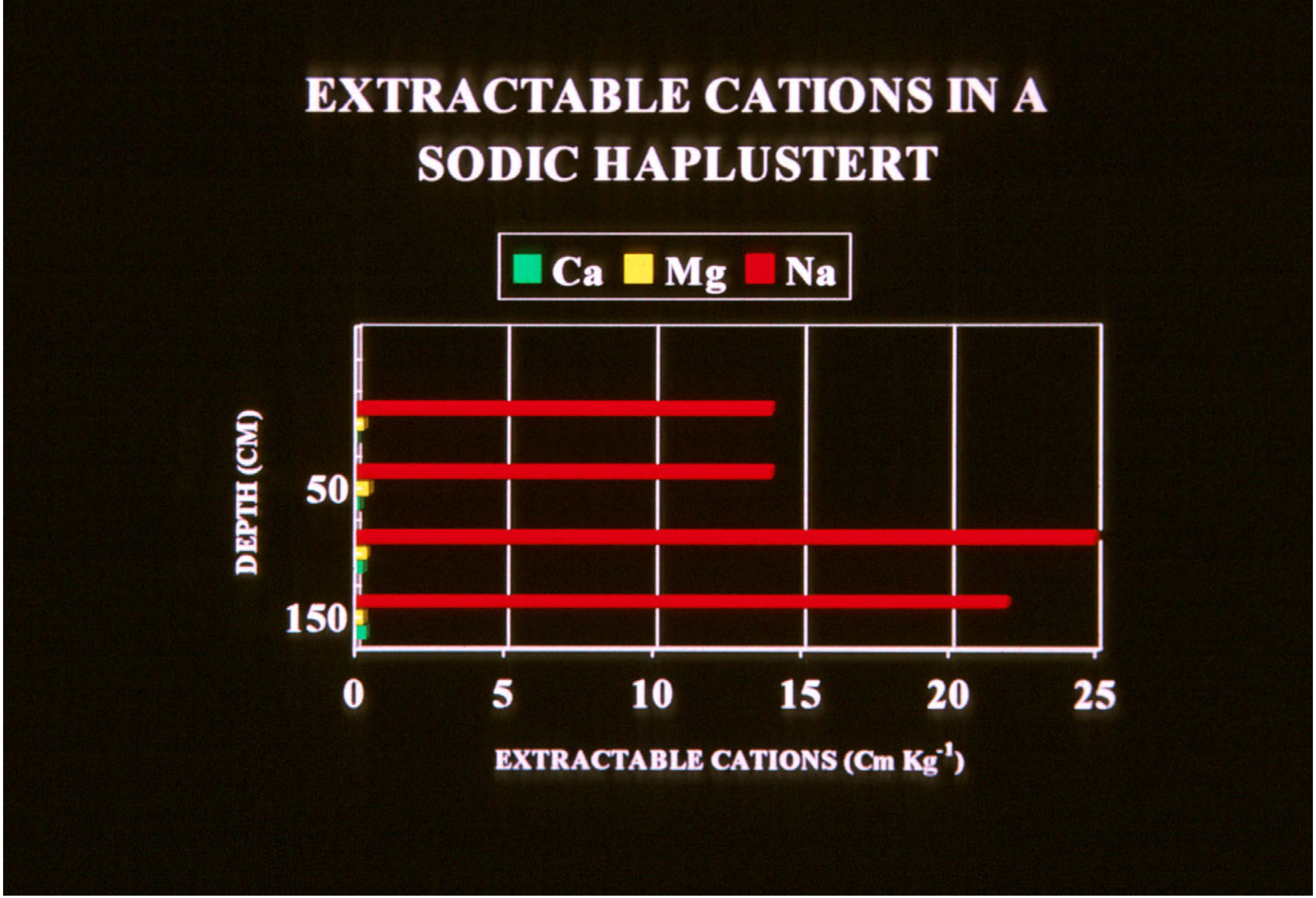


143 - **Cation Exchange Capacity:** The cation exchange capacity (CEC) varies considerably depending on the organic matter content and the amount of smectitic clay. Generally, however, Vertisols have a high CEC ranging from 20 to 45 cmol kg-1(soil) or more. In neutral Vertisols the exchange sites are occupied mainly by calcium and magnesium and to a lesser extent by potassium and sodium. Alkaline Vertisols in which sodium occupies 15 percent or more of the exchange complex are differentiated as sodic subgroups in Soil Taxonomy. Aluminum, magnesium, and exchangeable acidity replace calcium and magnesium under acid conditions (Coulombe et al., 1996).

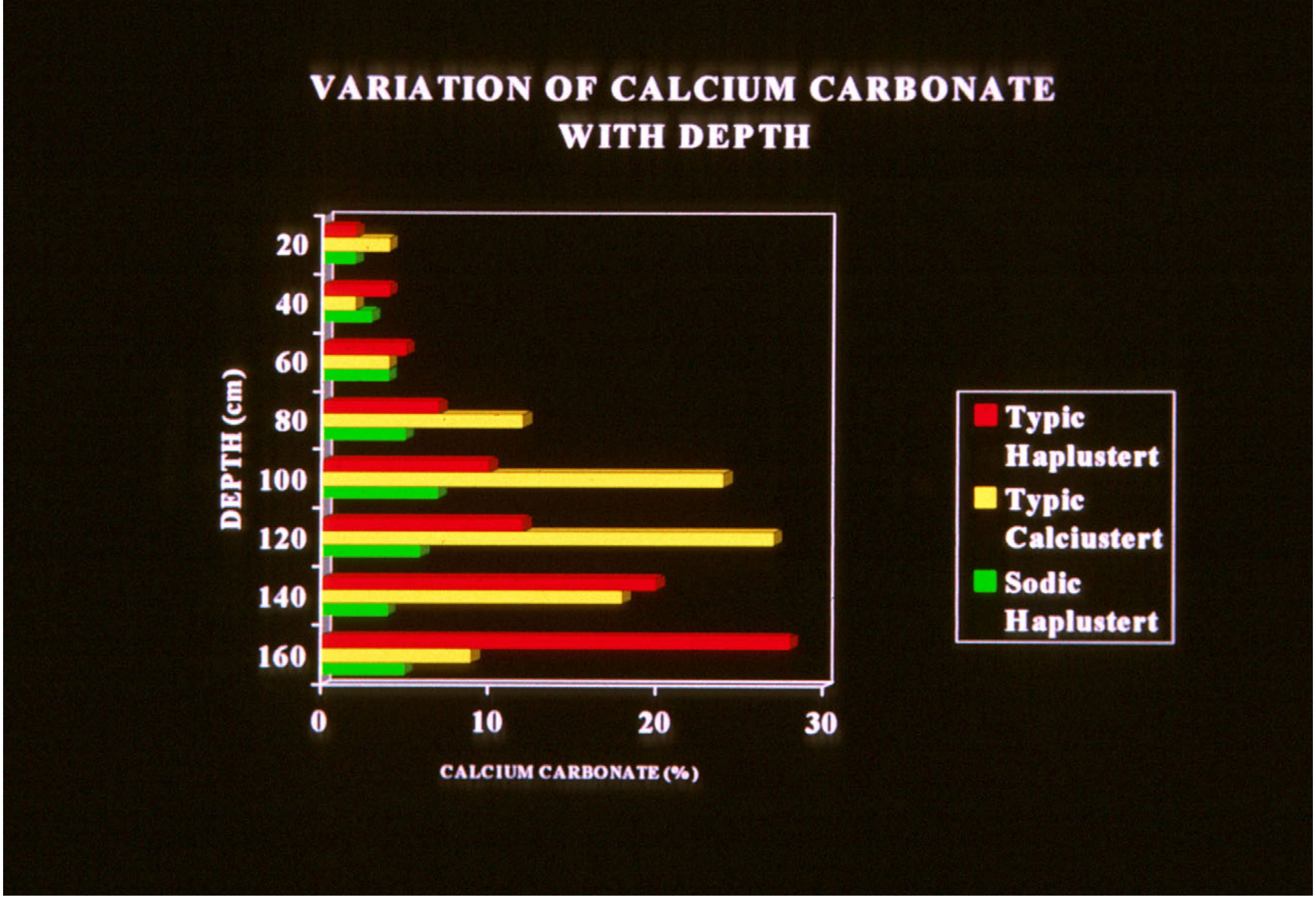
The variations in CEC between the three soils are due to differences in clay content and type of dominant clay. Due to the presence of some chlorites, the CEC is greater than 100.



144 - The depth functions of the extractable cations also varies between soils as seen in this slide of the Typic Haplustert and the next (#145).



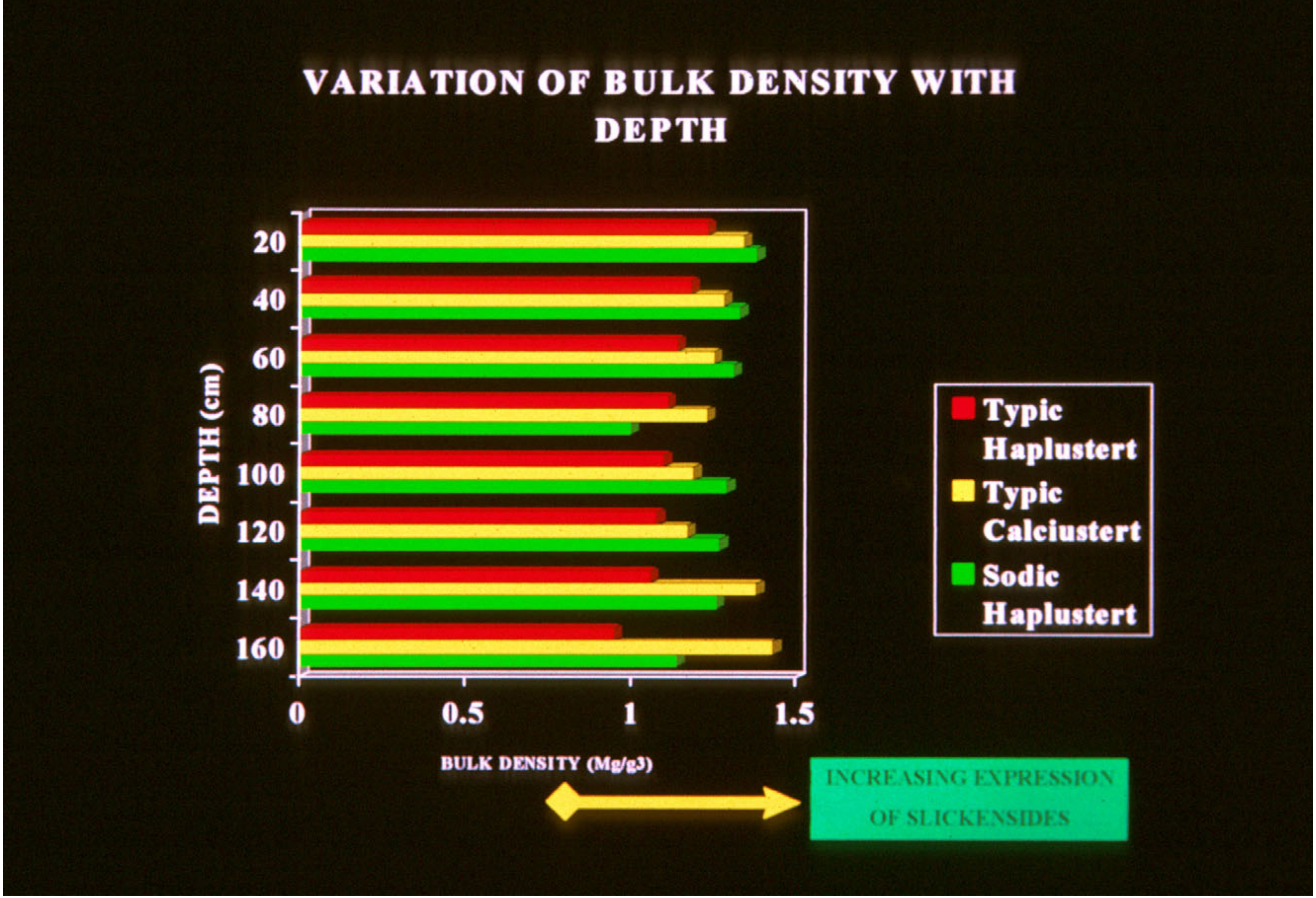
145 -Extractable cations in a Sodic Haplustert.



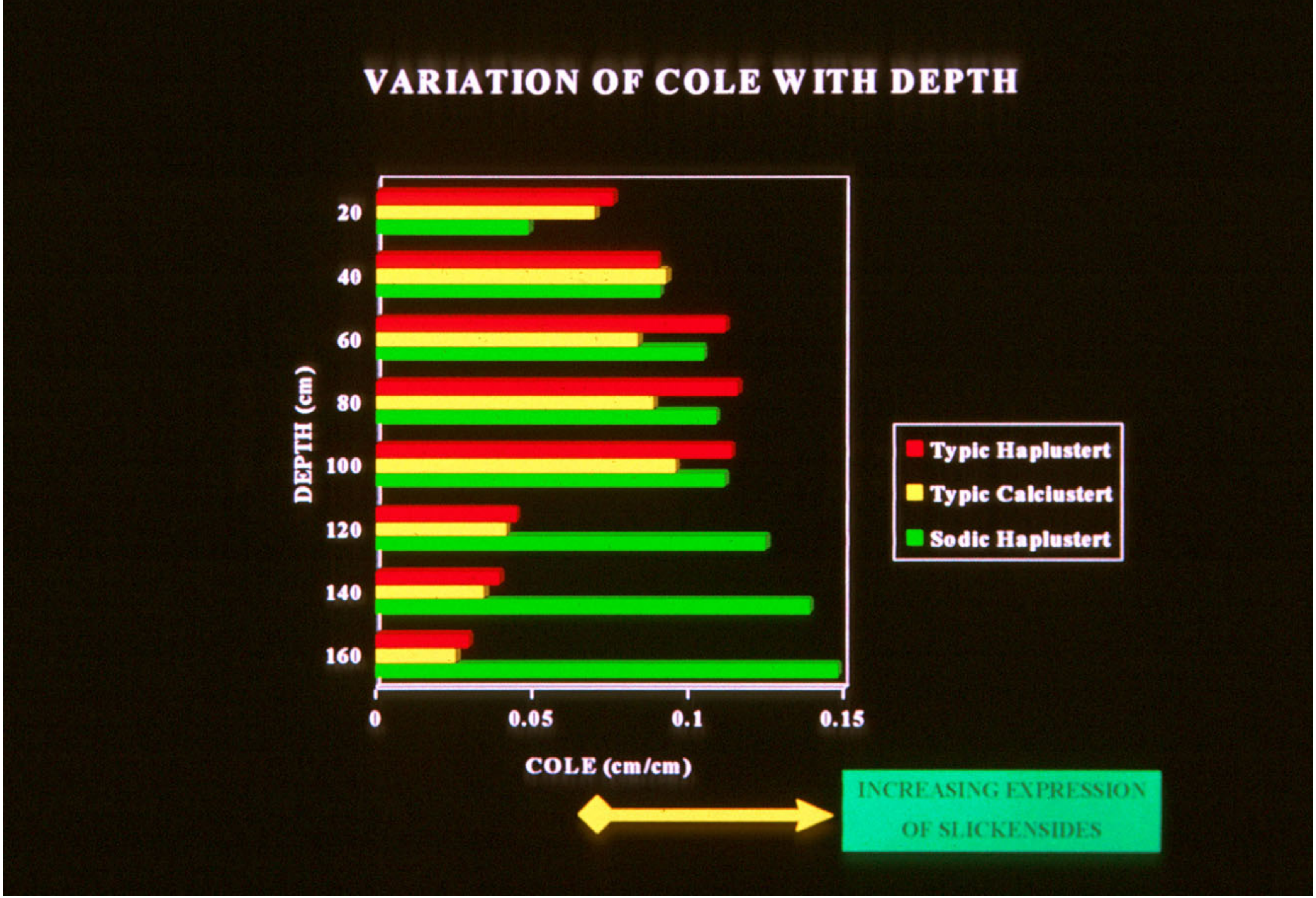
146 - Many of the arid and semi-arid Vertisols are calcareous. However, a calcic horizon is only present in the Calciusterts.

147 - **Plant Nutrients:** The kind and amount of plant nutrients vary considerably as a result of differences in the environmental conditions, particularly the composition of the parent material. An important feature of most Vertisols is their high base saturation with calcium and magnesium as the dominant components of the absorption complex. Potassium and available phosphorus are generally low. Nitrogen content is closely related to the organic matter content. Manganese is normally present in small amounts, but may be relatively high in soils derived from basalt; it often occurs as iron-manganese concretions. Vertisols with an illite component in the clay fraction tend to fix potassium and ammonium in non-exchangeable form. Crops on Vertisols normally do not show nitrogen deficiency. In comparison, in a well-drained Alfisol, it is easily induced as shown by this crop of sorghum on an experimental field.

148 - Measuring bulk density is most important in the study of physical properties of Vertisols. A saran coated clod is used to measure bulk density.

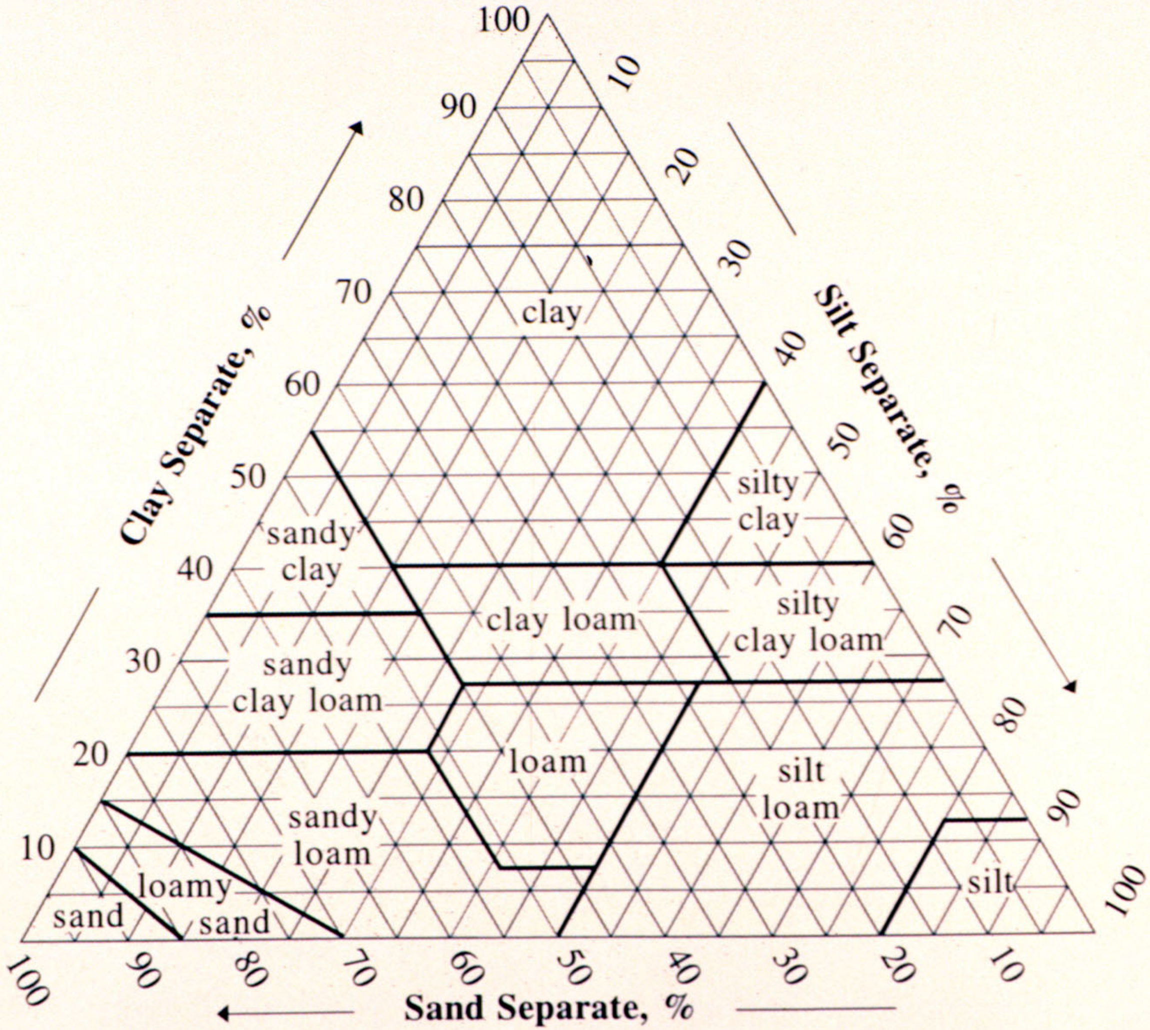


149 - Bulk Density: Vertisols are characterized by a high bulk density, which is defined as the mass of soil per unit volume. It varies with the moisture content of the soil. Values reported for Vertisols by Coulombe et al. (1996) range from 0.9 to 1.2 Mg m3 at 0.33 MPa (field capacity) and 1.6 to 2.0 Mg m3 at 1.5 Mpa (permanent wilting point).

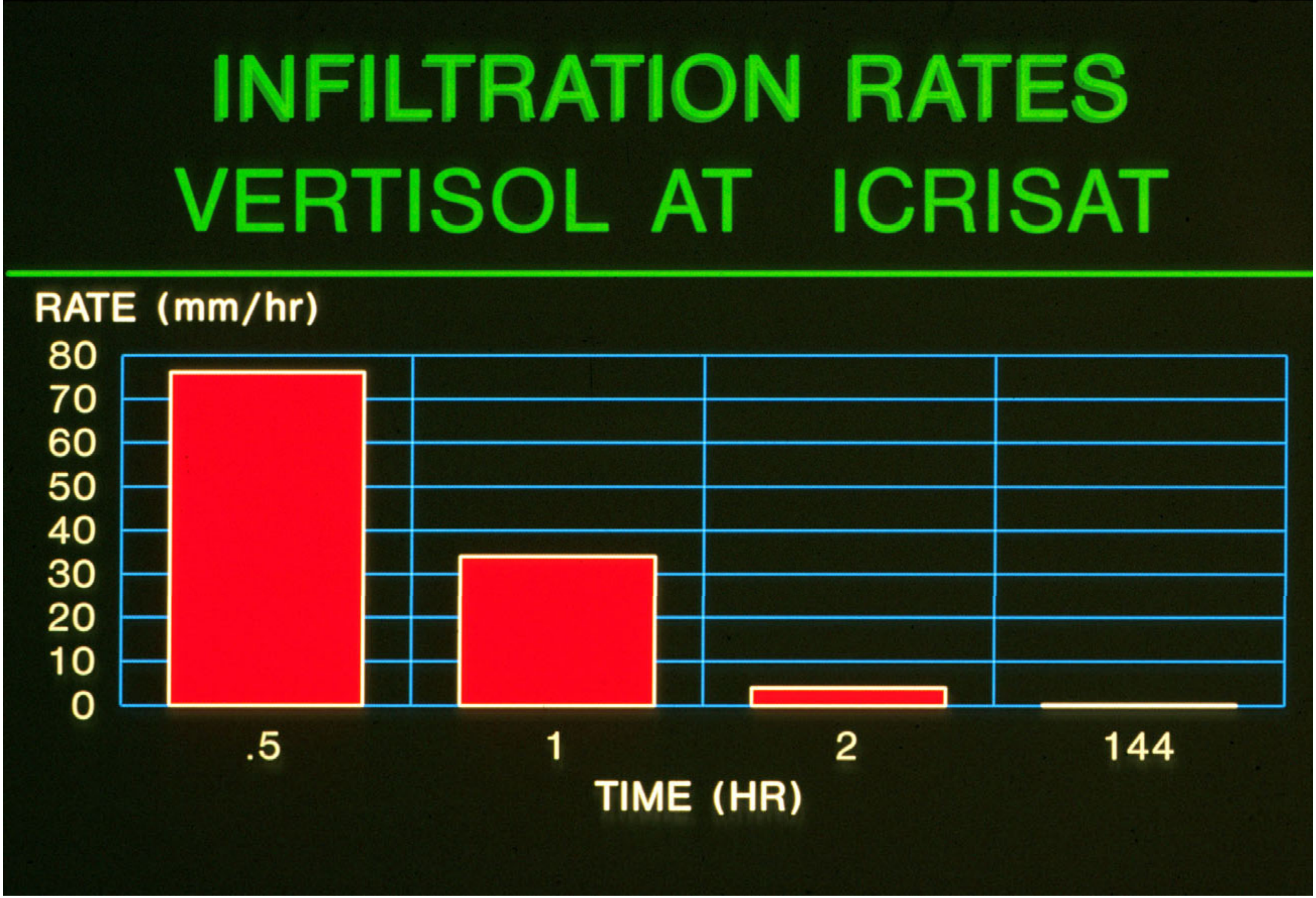


150 - COLE: COLE, the coefficient of linear extensibility, is the ratio of the difference between moist length and dry length of a clod, to its dry length (Soil Survey Staff, 1996). It is a measure of the swell-shrink potential of the soil. COLE values in Vertisols range from 0.07 to 0.20 cm cm1 (Coulombe et al., 1996).

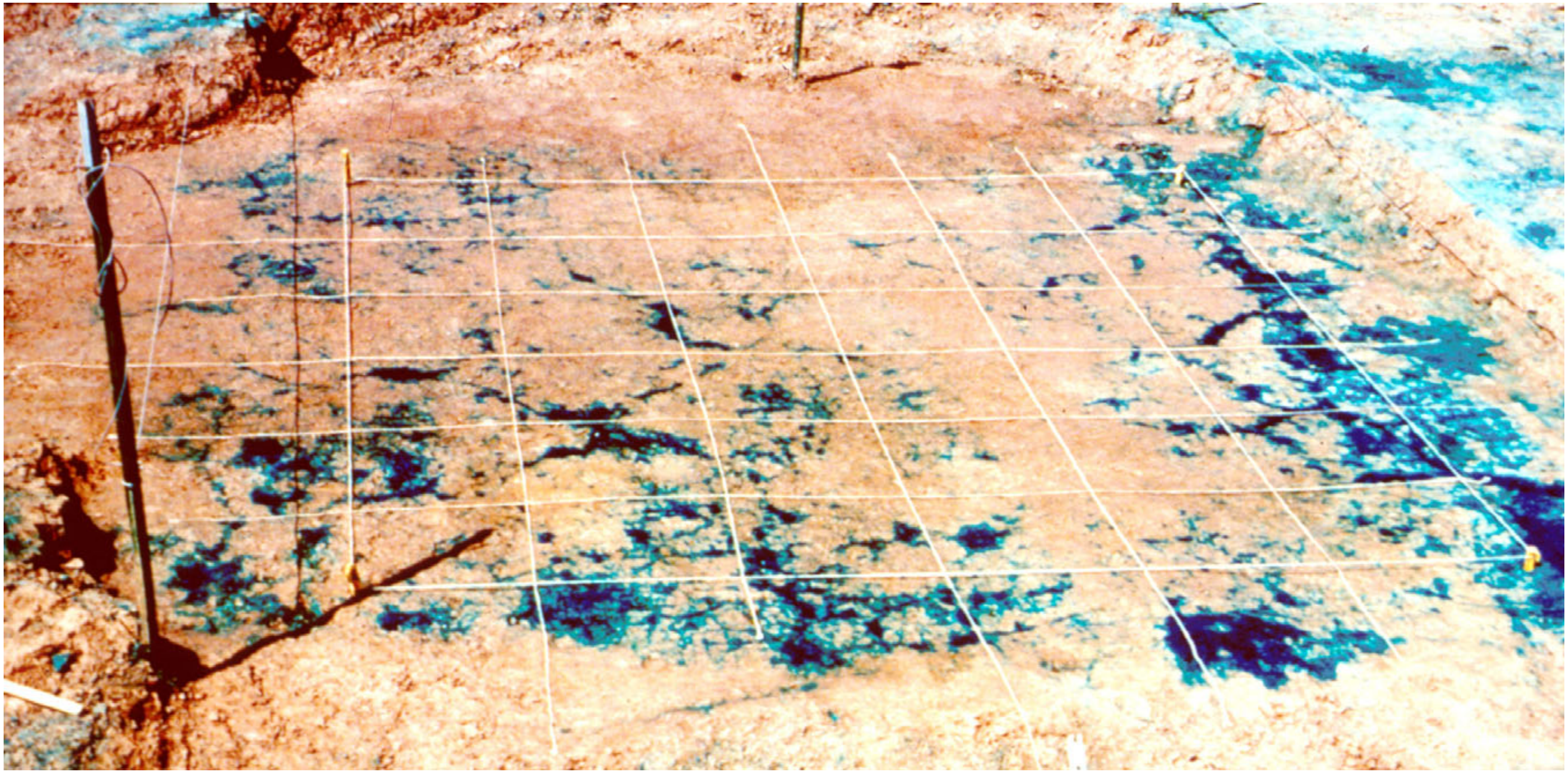
USDA Textural Triangle



151 - Texture: The texture of Vertisols is generally clay and occasionally silty clay or loam. By definition, the clay content of Vertisols must be at least 30 percent, but may be as high as 90 percent. Total fine clay (<0.2m) usually accounts for as much as 80 percent of total clay. Smaller clay-size particles have high specific surface areas (from 100-400 m2 g-1 up to 800 m2 g-1) and consequently increased swell-shrink potential (Coulombe et al., 1996). On account of pedoturbation, the clay content of most Vertisol pedons remains uniformly high throughout the profile to a depth of at least 1 m.

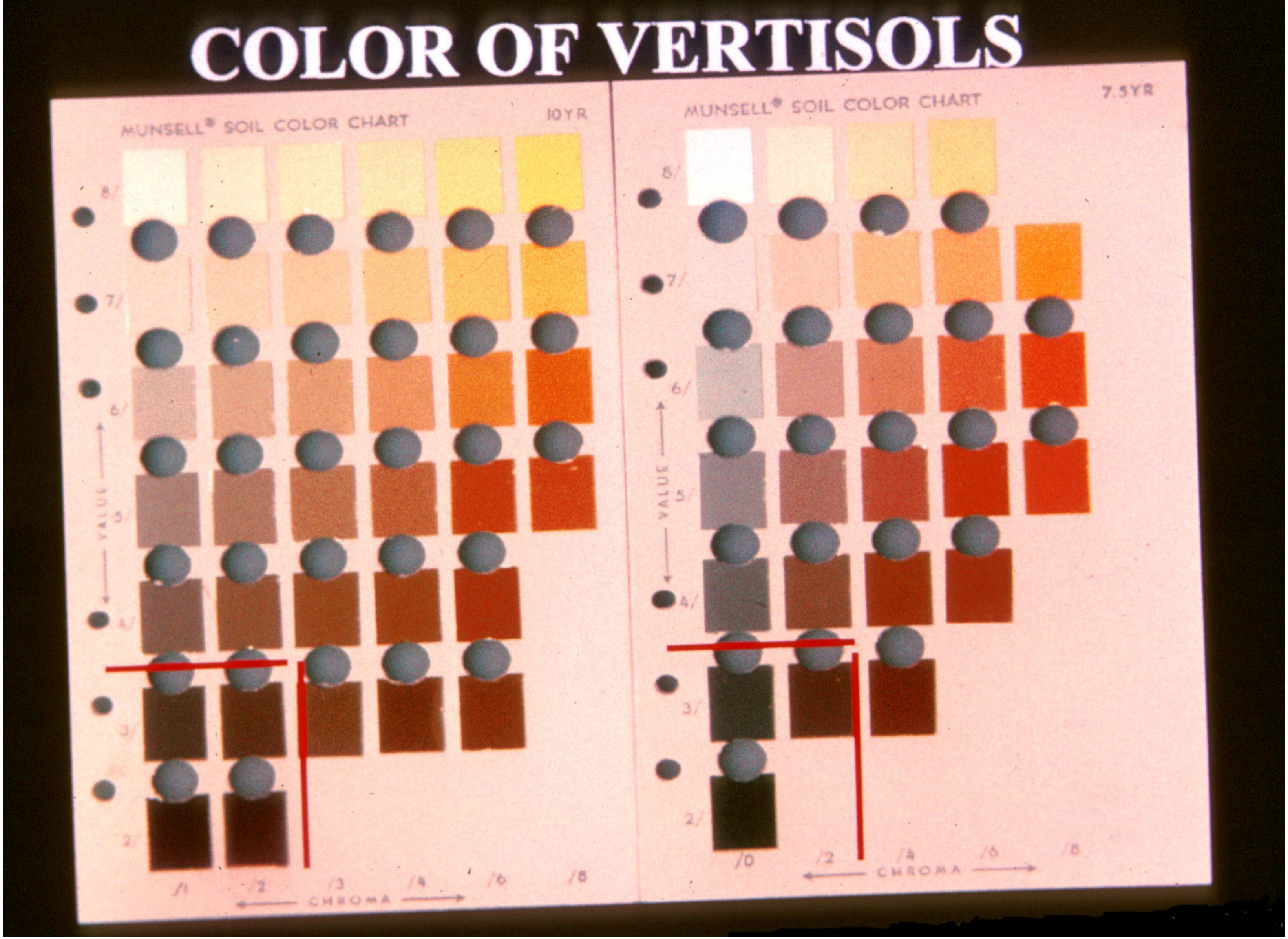


152 - Infiltration rates in Vertisols are a function of porosity and cracks. Porosity is very low due to the very compact nature. Much of the infiltration is through the cracks as shown in the slide.



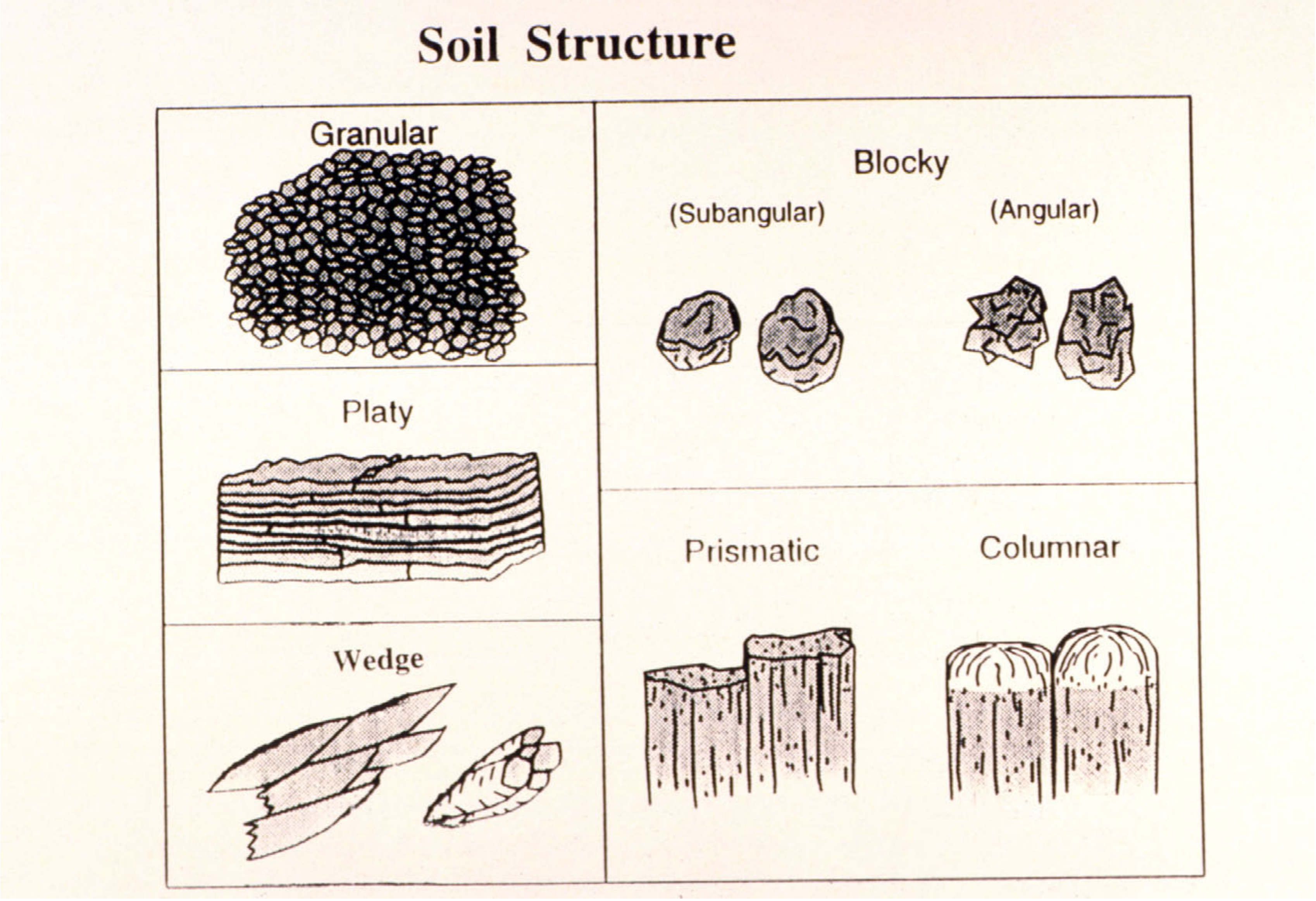
153 - The cracking pattern is seen clearly when a dye is added to the soil. In this experiment, a blue dye is added to the soil surface. About 10 cm of the soil is then scraped out to study penetration of the dye.

154 - As in photo #153, the penetration of the dye into the soil is seen in a vertical cut.



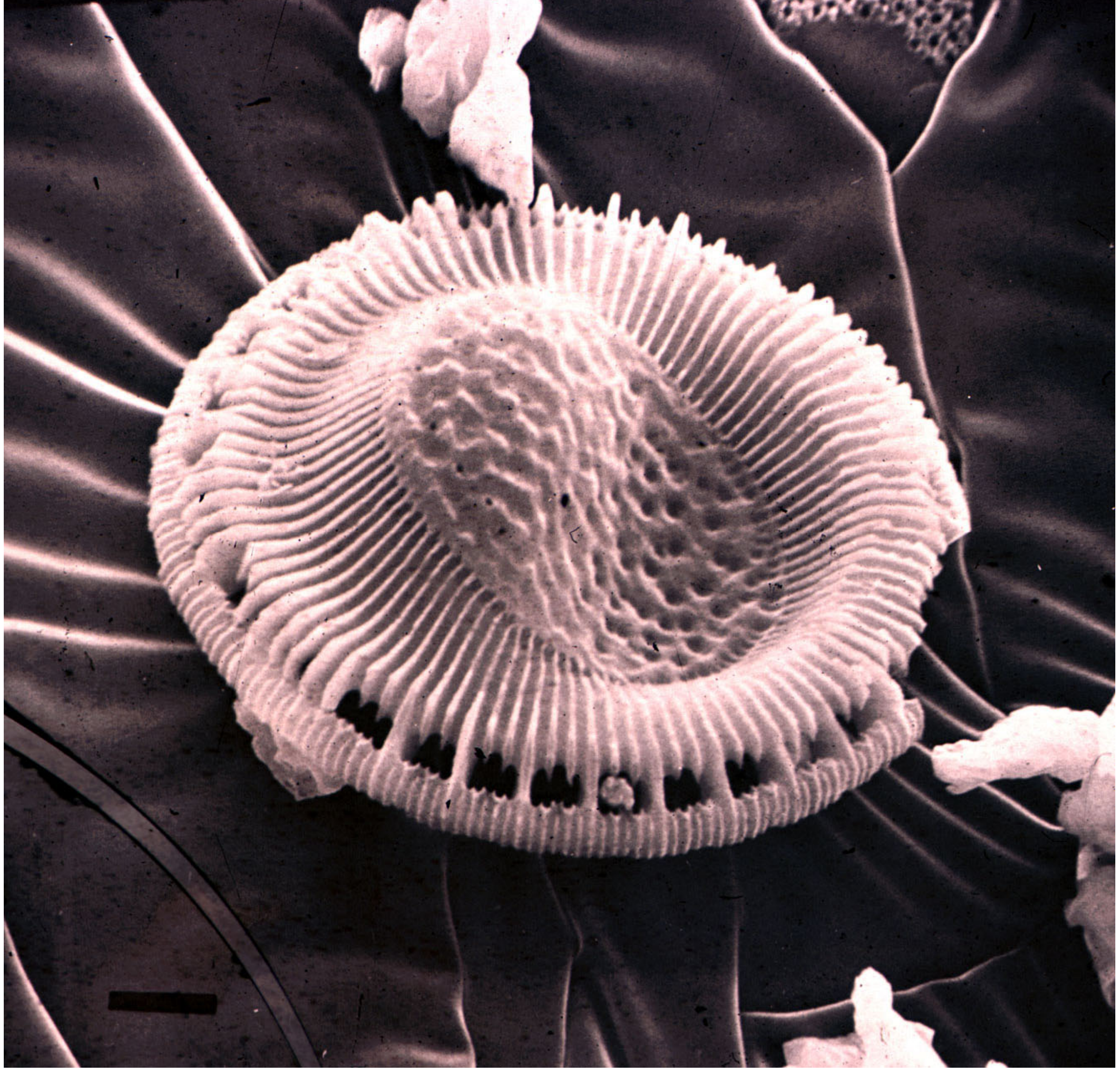
155 - Color: The colors of Vertisols have most frequently hues of 2.5Y and 10YR, but range from 5Y to 2.5YR. Values and chroma are characteristically low, regardless of hue. Dark-colored Vertisols are considered the norm. Color variability is attributable to differences in topographic position, mineral composition of the parent material, and climate. Earlier versions of Soil Taxonomy differentiated pellic and chromic great groups, but this distinction has been deleted as it proved to be of low diagnostic value. The color of the Pellic subgroups are demarcated on the lower left-hand corner of each chart.

156 - **Consistence:** The consistence of Vertisols varies from plastic and sticky when wet, and friable when moist, to hard when dry. Consistence is critical to the management of Vertisols, but there is only a narrow window of favorable soil moisture and, therefore, consistence conditions that allow workability and trafficability. The timing of tillage practices is thus of utmost importance. Considering their place among all soils of the world, Vertisols tend to be concentrated at one end of the consistence spectrum (Dudal, 1965).
On the Gezira Plains, the climate is more favorable and the soils have been irrigated for several hundred years. The soils are blacker and have higher organic matter content. During early rains, the consistence is adequate for land preparation.

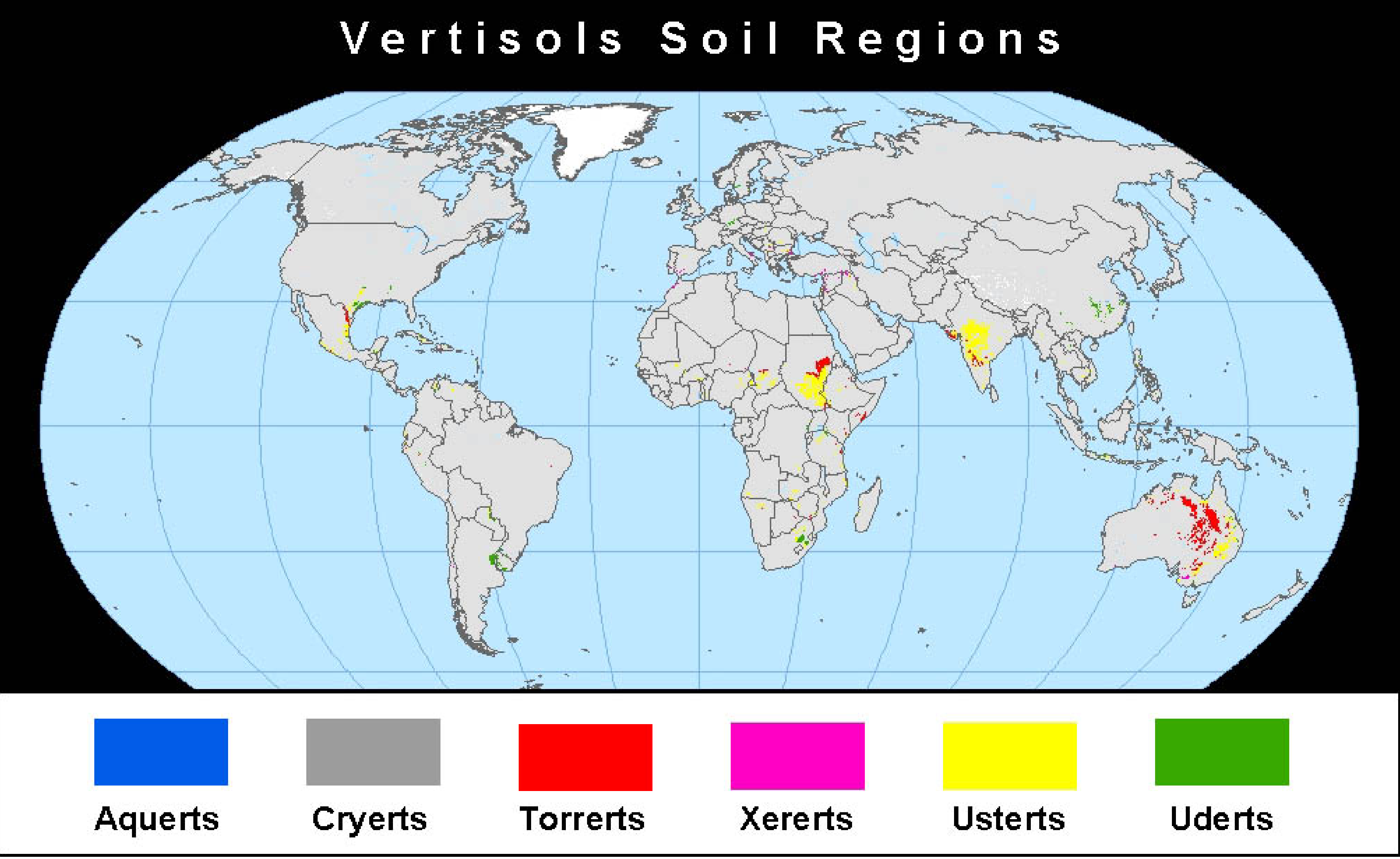


157 - Structure: many of these structural elements occur in Vertisols.

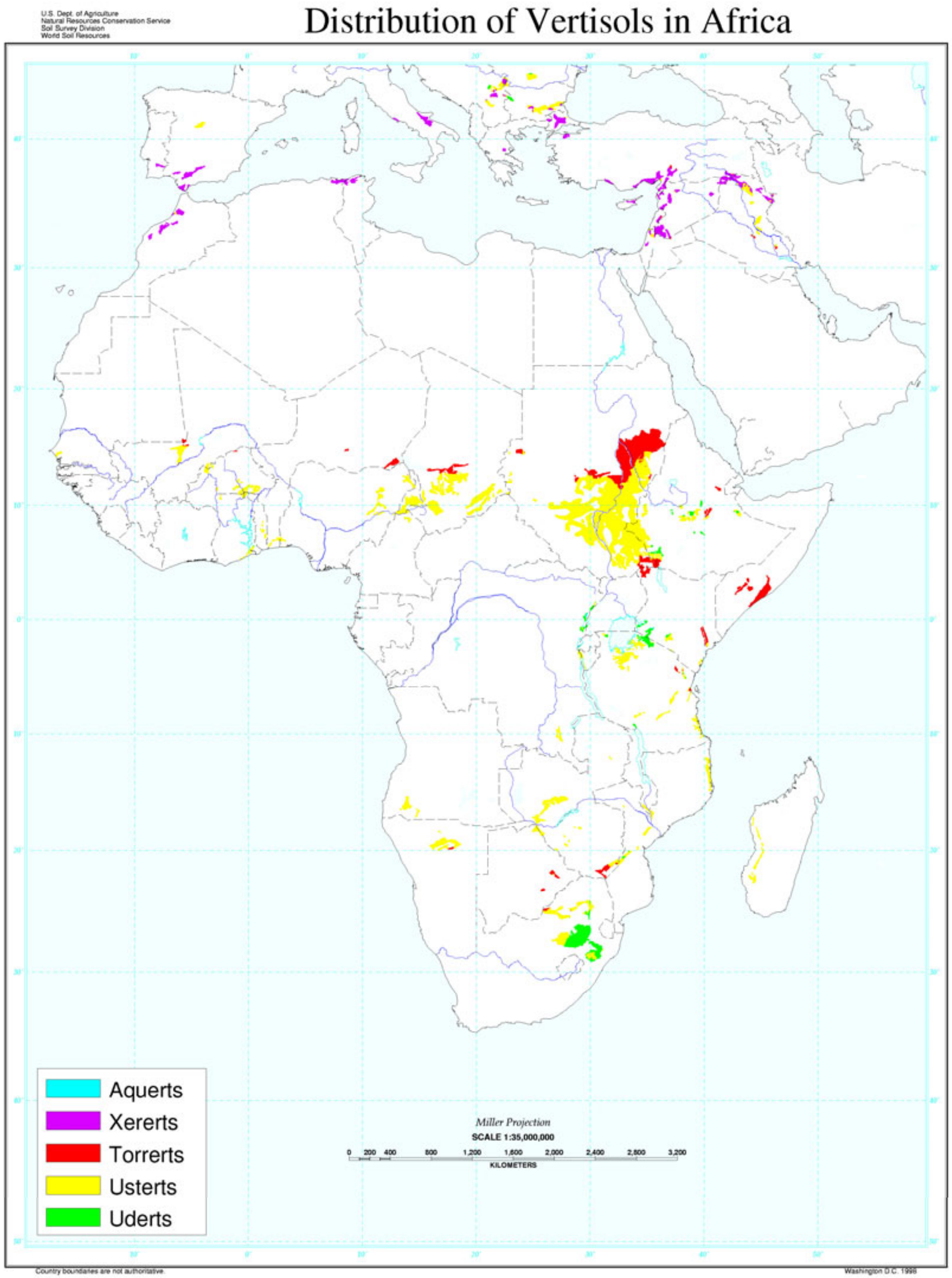
158 - Termite mounds are rare on Vertisols. However, on these Vertisols near Darwin, Australia, tall mounds are seen. The sand of these mounds is magnetic, the magnetite coming from the high magnetite concentration in the soil.



159 - Vertisols on some coastal marine alluvium may have diatoms. SEM micrograph, x 15,000.

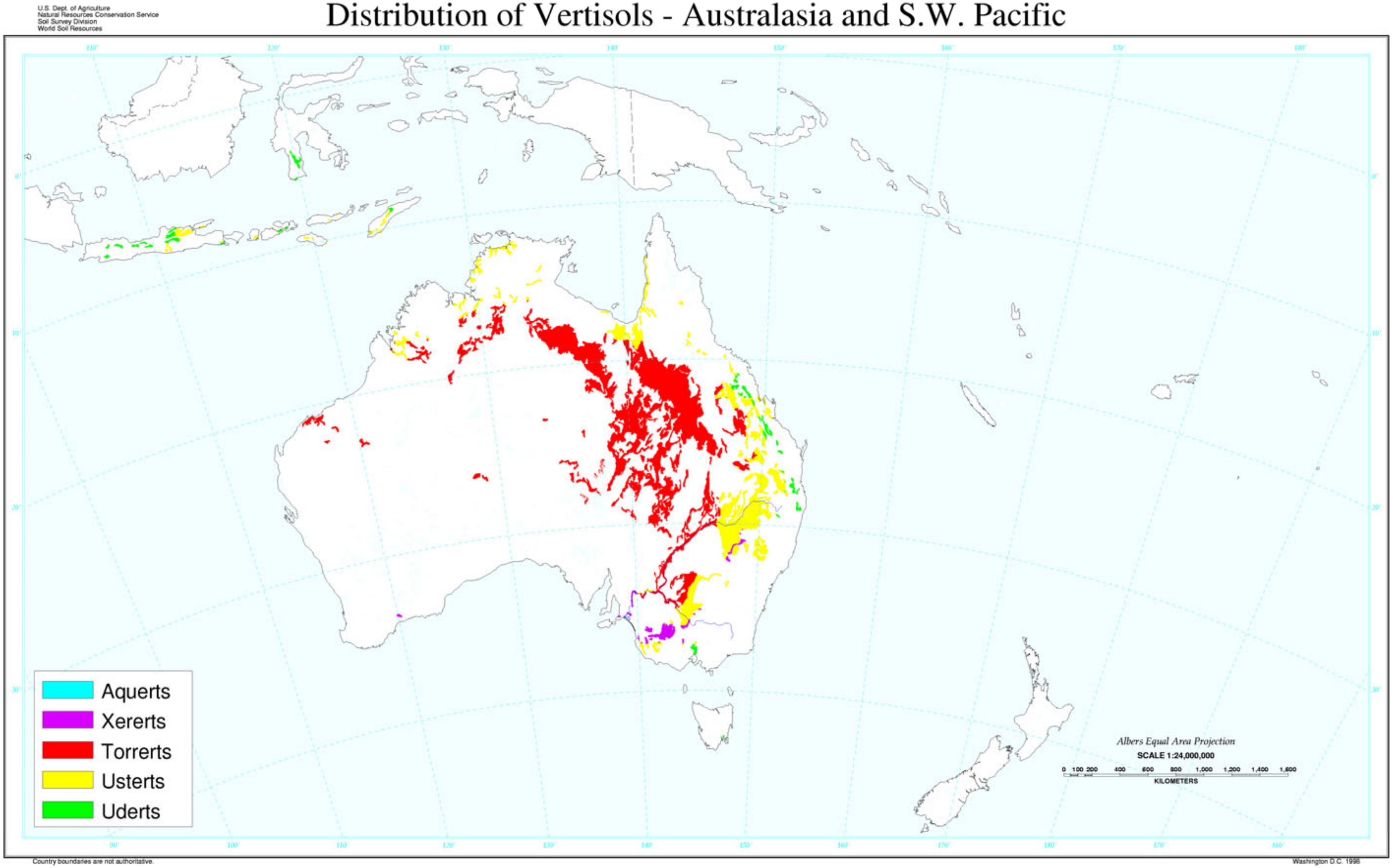


160 - Global distribution of Vertisols. Large contiguous areas are shown. Small areas, as on the volcanic islands, cannot be shown on a map at this scale.



161 - Vertisols of Africa. The large contiguous areas are in the Sudan, parts of East Africa, Zimbabwe, and in South Africa. Large areas also are present in Madagascar but there are few studies on these soils.

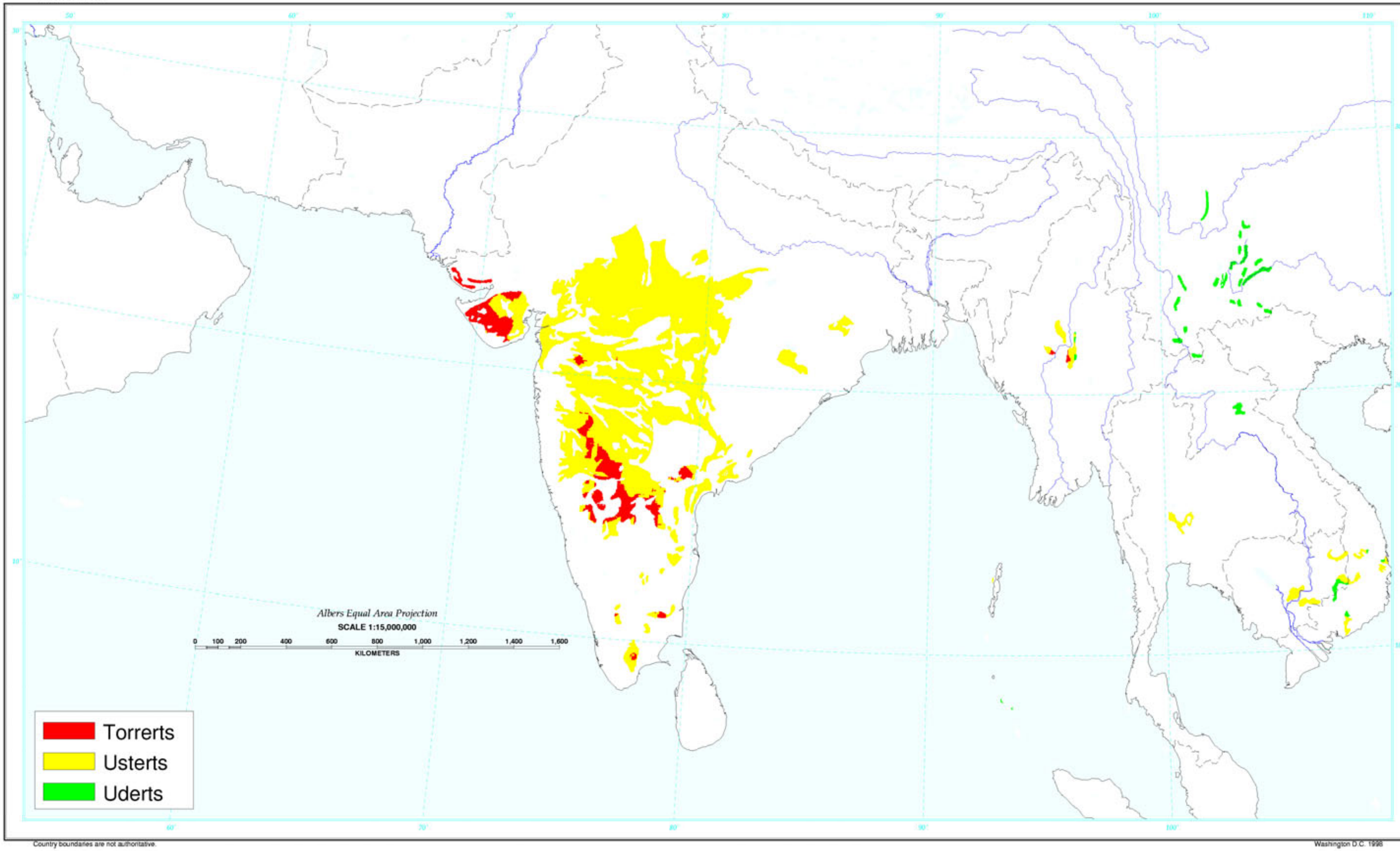
Distribution of Vertisols - Australasia and S.W. Pacific



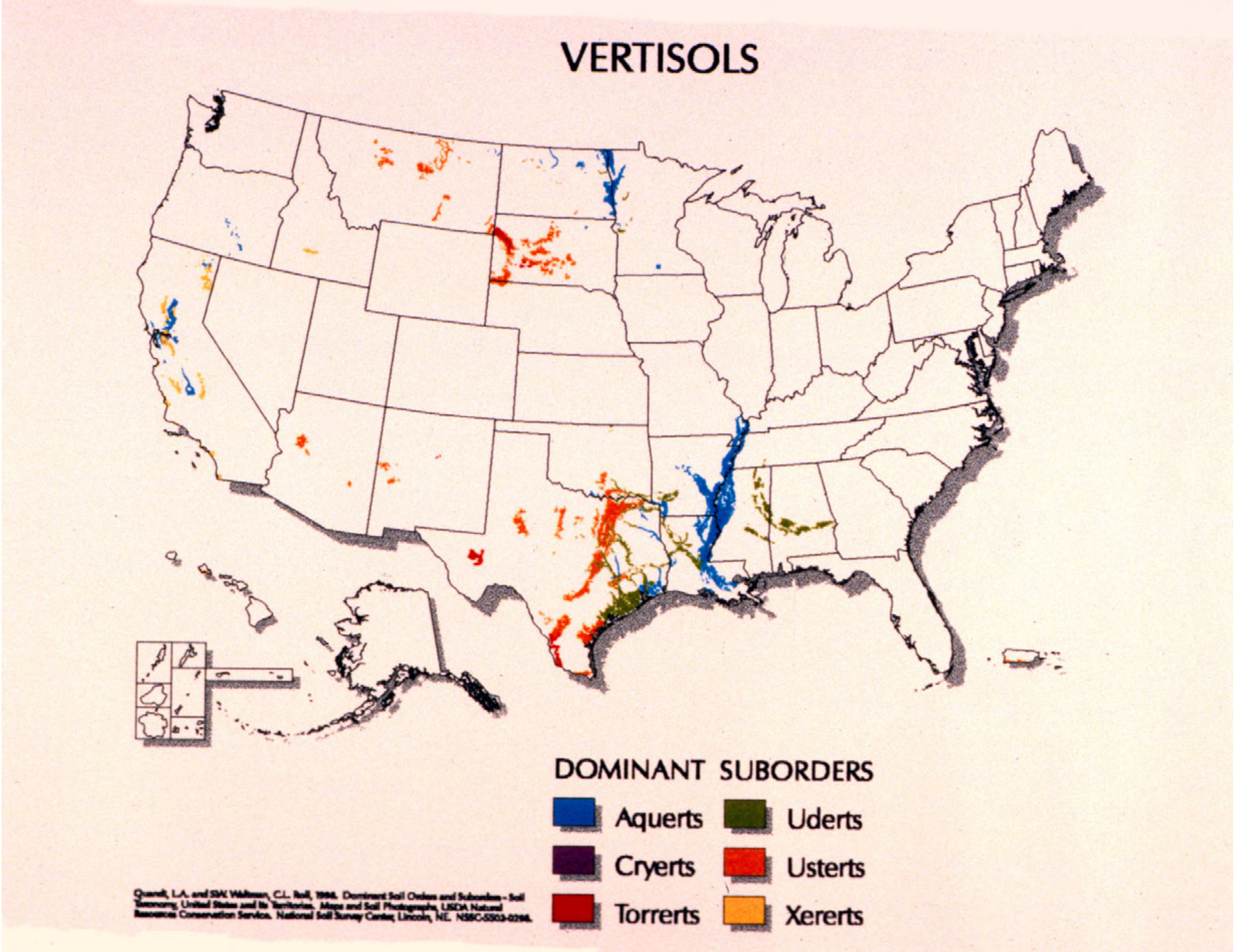
162 - In the Australasia region, Australia has the largest extent. Australia has extensive areas of Usterts, Torrerts, and Xererts.

U.S. Dept. of Agriculture
Natural Resources Conservation Service
Soil Survey Division
World Soil Resources

Distribution of Vertisols - Indian Sub-Continent



163 - The Deccan Plateau is the home of Vertisols in India. Associated soils are Mollisols and Inceptisols. At the fringes, Vertisols occur in association with red Alfisols.



164 - Most of the US Vertisols occur in the south-central part of the country. Small areas are also in the northern states.

Global Distribution of Soils

Soil Order	Area (m km^2)	Percent
Gelisols	11.87	9.07
Histosols	1.53	1.17
Spodosols	4.59	3.51
Andisols	0.98	0.75
Oxisols	9.81	7.50
VERTISOLS	3.16	2.42

165 - Summary of global distribution of soils to show the relative amounts of different kinds of soils (part 1).

Global Distribution of Soils

Soil Order	Area (m km^2)	Percent
Aridisols	15.46	11.82
Ultisols	10.55	8.07
Mollisols	9.16	7.00
Alfisols	13.16	10.06
Inceptisols	19.85	15.18
Entisols	23.43	17.91

166 - Global distributions of soils (part 2).

Vertisols [1]

Orders	Suborders	Area (km^2)	Extent (%)
Vertisols		181,482	1.99
	Aquerts	55,469	0.61
	Cryerts	0	0
	Torrerts	10,025	0.11
	Uderts	30,934	0.34
	Usterts	74,120	0.81
	Xererts	10,934	0.12

[1] Extent and percent for United States and Territories, Commonwealths, and Island Nations served by the Natural Resources Conservation Service.

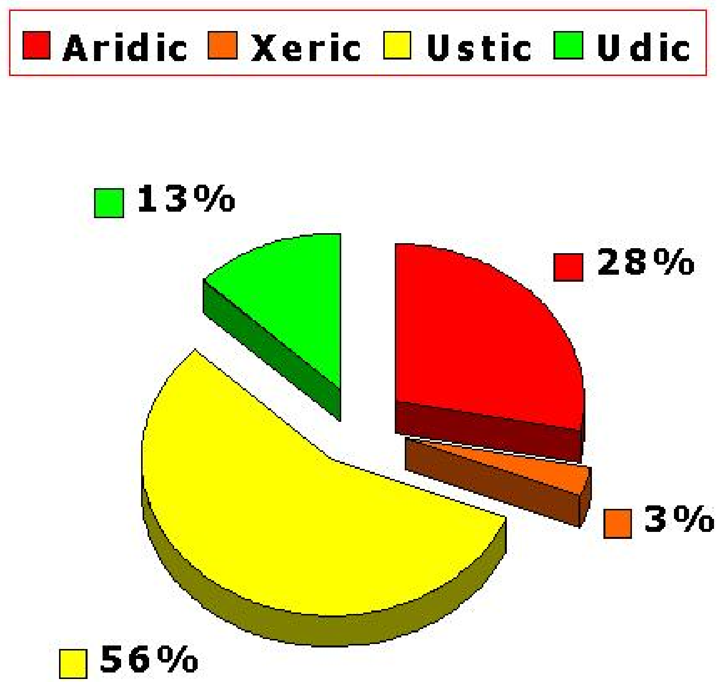
167 - Distribution of suborders of Vertisols in the United States.

Distribution of Vertisols (I)

Ecosystem	AREA (m Km^2)	Percent
Tropical	1.49	1.14
Temperate	1.64	1.26

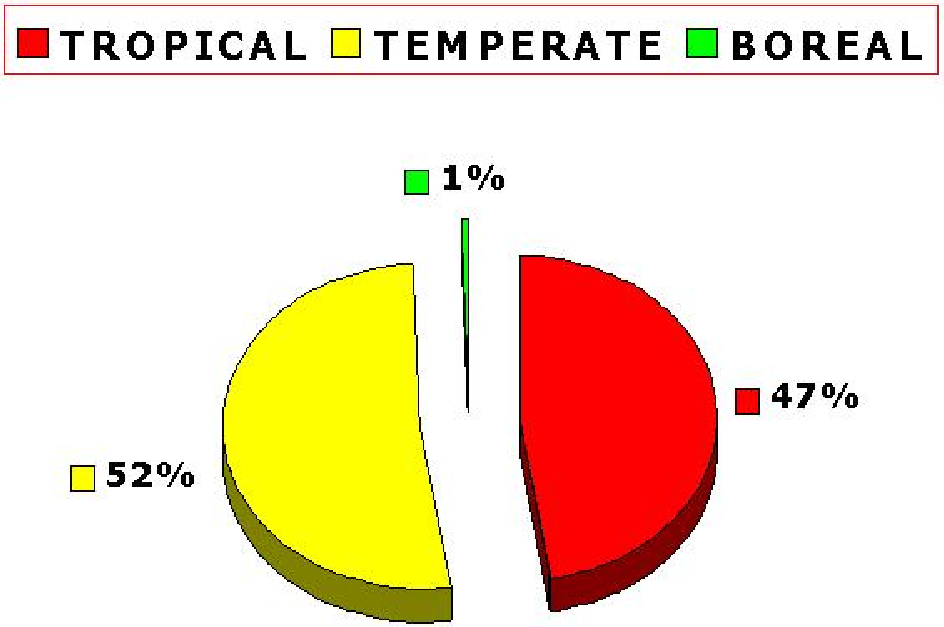
168 - Most of the Vertisols occur in the tropical and temperate ecosystems.

Distribution Of Vertisols
Function Of Soil Moisture Regimes



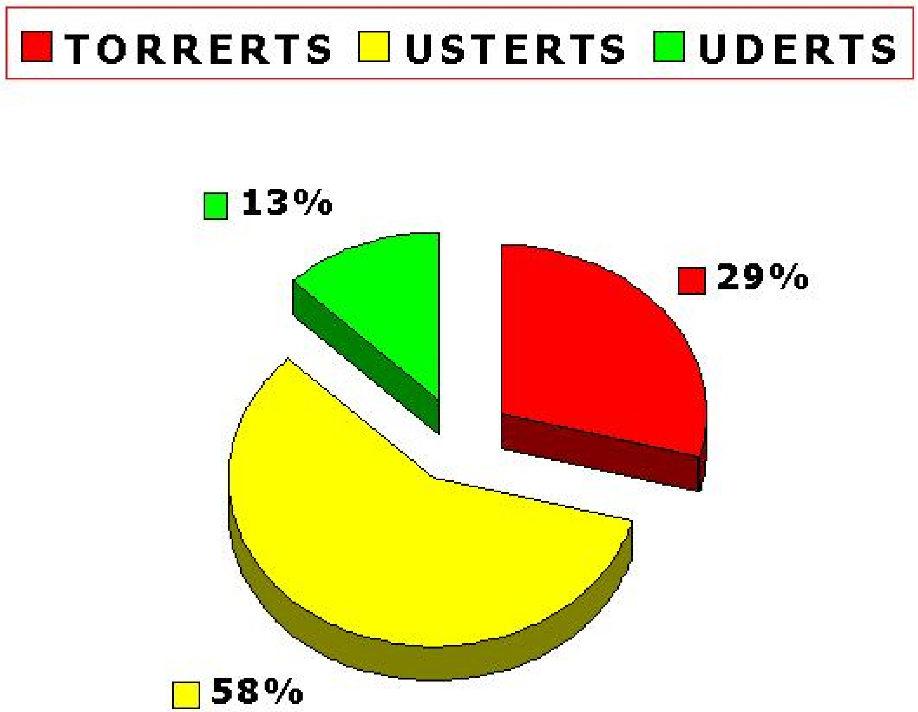
169 - Distribution of Vertisols according to soil moisture regimes.

Distribution Of Vertisols Function Of Ecological Regions



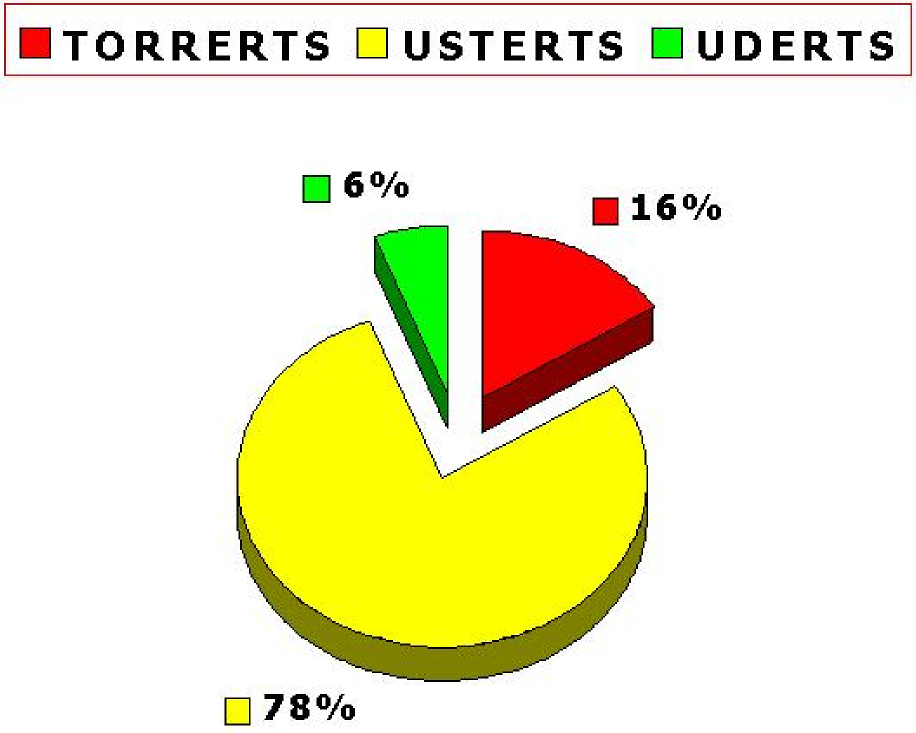
170 - Distribution of Vertisols according to ecosystems.

Distribution of Vertisols Function of Suborders (Global)



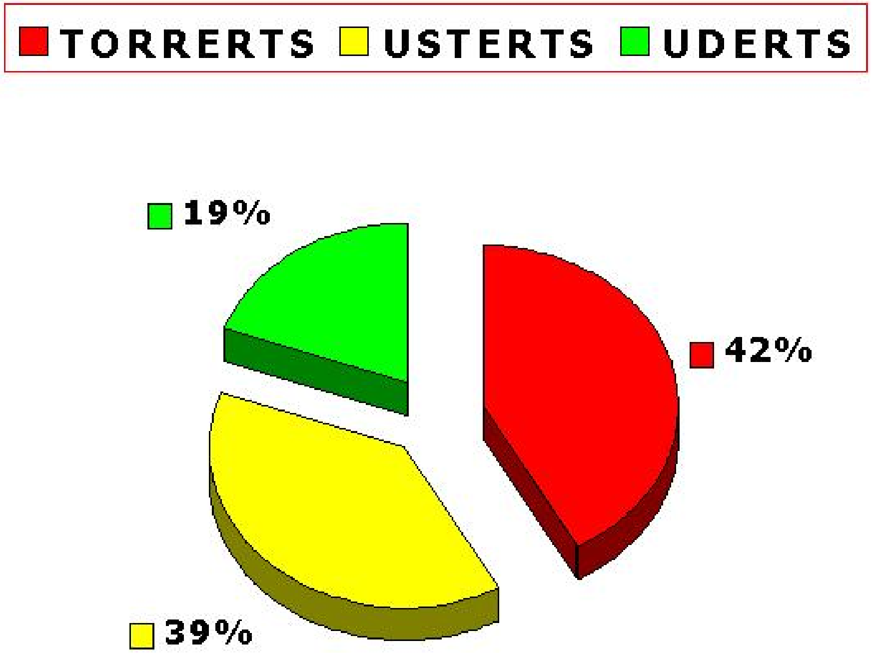
171 - Distribution of Vertisols according to soil suborders.

Distribution of Vertisols
Function of Suborders (Tropical)



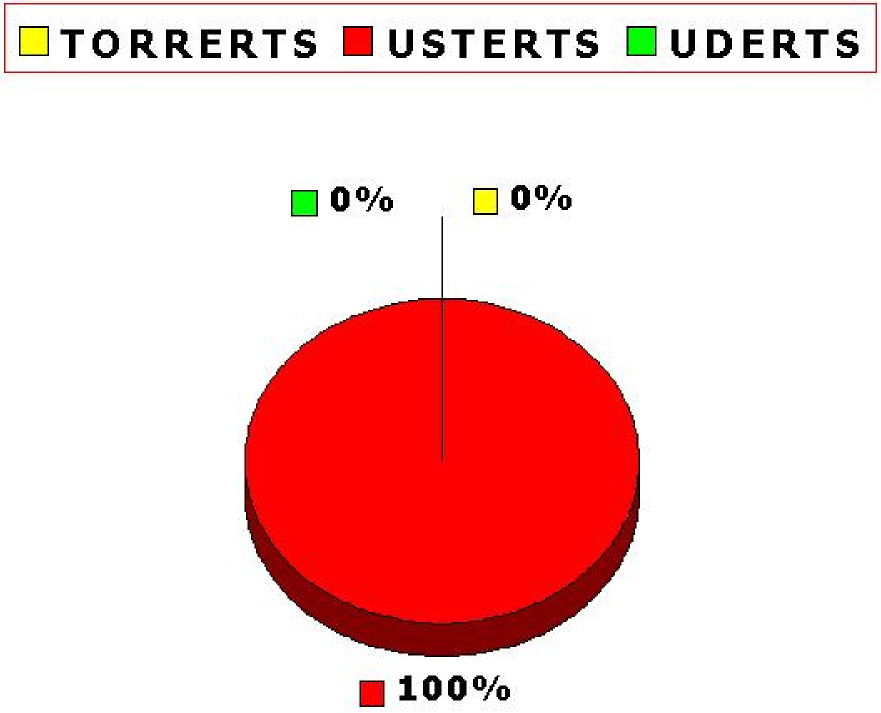
172 - Distribution of Vertisols according to soil suborders in the tropics.

Distribution of Vertisols Function of Suborders (Temperate)



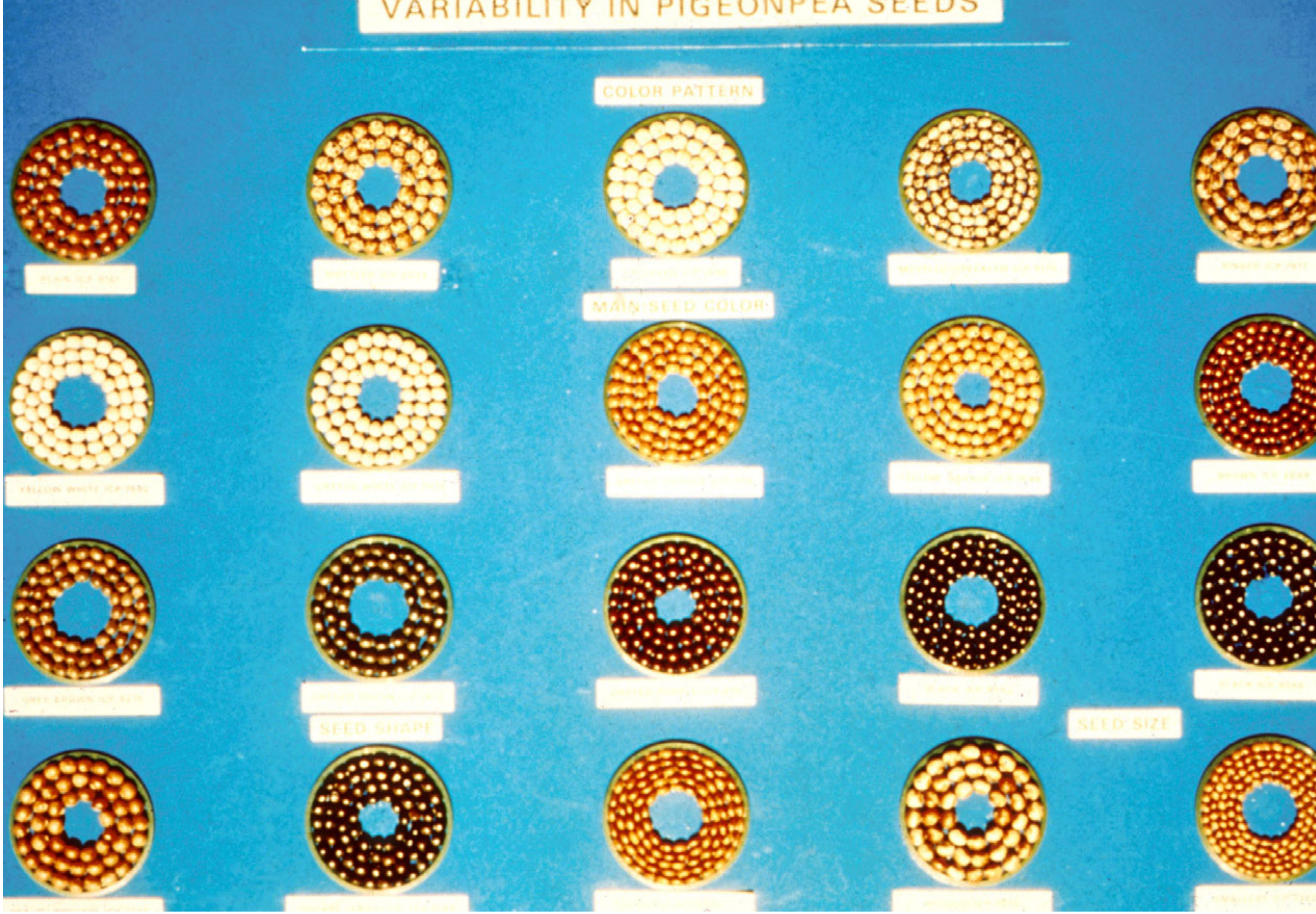
173 - Distribution of Vertisols according to soil suborders in temperate regions.

Distribution of Vertisols Function of Suborders (Boreal)



174 - Distribution of Vertisols according to soil suborders in boreal regions.

175 - Sunflower is a common oil-crop on Vertisols of the semiarid regions. Moisture stress is a major constraint at the end of the rainy season. Irrigation stabilizes and enhances yield.



176 - The quality of the grain is a function of the genetic variability. The picture shows different varieties of chickpea. Chickpea is also a crop of the semi-arid to arid tropics. It has higher tolerance to moisture stress in comparison to sorghum and sunflower.

177 - Crop breeding enables selection of the crop based on several criteria. Quality of the product is becoming increasingly important. The photo shows groundnut pods and kernels of a good selection. Groundnuts are not the ideal crops for the heavy, clayey Vertisols but are grown in some countries. Harvest losses, with pods remaining in the soil, are high.

178 - In much of SE Asia, rice is grown on Vertisols. These are some of the best rice growing soils as they are easily puddled. When irrigation is available, two crops of rice are grown on this soil. If irrigation is not available, the land is used for grazing during the dry season.

179 - Land being prepared for sugar cane in Guyana. Though the soils are Aquerts and the climate is humid, sugar cane is grown to meet the countries sugar needs though this is not the best crop for these conditions. Deep ditches control the depth of the water table.

180 - Vertisols were called "black cotton soils" because it was one of the best crops for such soils. Most of the world's cotton, particularly in the developing countries, is grown on Vertisols.

181 - A major pest in the tropics of sorghum and corn is the red hairy caterpillar. The outbreak is during the early part of the rainy season. The caterpillars prefer the young shoots.

182 - There are many pests affecting crop production. Photo is an example of a blister beetle that damages pigeon-pea flowers. Yields may be reduced 20 to 50% by this pest.

183 - Chickpea is an important crop in the post-rainy season. Heliocoverpa is a serious pest in chickpea. This pest damages pods and reduces production up to 60%.

184 - In many developing countries, a wooden plough is used to till the land.

185 - ICRISAT has done research to improve the efficiency of the bullock-drawn ploughs while maintaining the economics. The Tropicultor is increasingly being used by Indian and African planters.

186 - Water tank. Excess water during the rainy season is collected in the reservoir for use during the dry season. Land shaping is an efficient means of collecting excess water.

187 - Fraternidad Soil in Puerto Rico. This is an example of cultivation on Vertisols. Sugarcane is being grown here. Deep ditches are provided to take away the water during the rainy season. Due to the low internal hydraulic conductivity, the soil is quickly saturated with water that must be removed to reduce crop loss.

188 - Safflower, in India, is also traditionally a post-rainy season crop. Typically grown on Vertisols, it is a relatively recent oil-seed crop.

189 - An example of inter-cropping. On the broad-bed, four rows of soybean are inter-cropped with one row of sunflower.

190 - Multiple cropping in India. At the background is sugar-cane. Corn, beans and onions are in the fore-ground.

191 - An experimental field at ICRISAT showing a sorghum/pigeon pea inter-crop experiment. Such research helps to develop technologies that could be used by farmers with few additional investments.

192 - In countries where livestock is important, managed pastures of Rhodes grass is developed.

193 - For horticultural crops and orchards, pits are dug in Vertisols and filled with red soils to provide better rooting and water movement. Example from Kenya.

194 - Aquaculture in the Lajas Valley, Puerto Rico. Due to the self-sealing property of Vertisols, the subsoil becomes impermeable to water after wetting. This facilitates the establishment of aquaculture industry. This is an alternative, non-traditional use of Vertisols.

195 - The biggest problem of sloping Vertisols is sheet and rill erosion. Appropriate land management must be designed to get rid of excess water during the rainy season and to conserve moisture during the dry season.

196 - Land shaping is an essential technology for sustained use. Grassed furrows take out excess water, trap soils and nutrients, and act as buffer strips.

197 - An example of good land management technology in Australia.

198 - Providing for wildlife and biodiversity is also an important component in sustainable agriculture. Good ecosystem management is beneficial in the long term.

199 - Aquaculture is a good alternative to traditional crop production. Picture shows tilapia culture in a pond on Vertisols. The system provides protein and an additional source of income for resource poor farmers. In addition, the nutrient-enriched pond sediment can be used as fertilizers when the pond is cleaned.

200 - A market in India. Vertisols play a critical role in meeting the food needs of global population. A variety of crops can be grown and being high quality soils, if there is adequate water, yields are generally good.