THE MICROMORPHOLOGY OF OXISOLS

by

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Introduction .-

The Order Oxisols in Soil Taxonomy (Soil Survey-Staff, 1.975) brings together a group of soils which generally occur on gently undulating landscapes, which are highly weathered and so have a low CEC, have low weatherable mineral reserve in the 20 to 200μ , fraction and which have few or no translocated clay in the "B" horizon which has at least 15 % clay. The Order arises from the previous group of soils known as Latosols (Kellogg , 1.949) which through the years since its inception has lost its original meaning. The Oxisols are also nearly synonmous to Ferralsols (Van Wambeke, 1.974) of the FAO/UNESCO legend.

The concept of the Oxisols is equated to the intense weathering that the soil material has undergone (Buol et al, 1.973). This stage may be attained by the weathering of the material prior to and during transport or the presence of the soil on old stable landscapes. It may also be due to the fact that the parent rock is easily weatherable, as in the case of ultrabasic rocks. The latter type of Oxisols may be present on steeper landscapes. The intense weathering probably requires rather specific climatic conditions. A perudic, isohyperthermic soil climate is perhaps ideal but Oxisols are also found under a range of less wet and less hot present day climates. When such soils are present in dry environments, one could infer that the material was subhected to intense

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weathering in the past, either at the present site or at a previous site since many soils in S. America and Africa are formed in transported materials.

The definition of the Oxisols, being based on the CEC of the clay fraction, is almost purely mineralo-chemical and the soils belong to a specific weathering and soil formation stage -the oxic stage (Tavernier et al, 1.972). Previous studies on such soils have indicated that some of their micromorphological properties also differentiates them from other groups of soils. One of the earliest studies of the micromorphology of such soils was by Uehara et al (1.962) who evaluated the structural types of some Hawaiian latosols. Some of these latosols are classified as Andepts today. Earlier, Laruelle (1.956) had also studied the microstructure of some soils of Zaire. Some of these soils may be Oxisols and one of his conclusions was that the plasma tended to coagulate.

Later studies revealed other important properties of the nature of the plasma. Uehara et al, (1.962), Eswaran (1.967) and Stoops (1.968), have all commented on the isotropic nature of the plasma. Later Bennema et al (1.970) observed that the plasma developed a "cloudiness" when proceeding from Ultisols to Oxisols and they concurred with the suggestion of Kubiena (1.962) who stated that the limit of the latosols corresponds to rotlehm with associated crystallisation of iron. Bennema et al (loc cit) also traced the evolution of the plasma and related it to the SiO_2/Al_2O_3 ratio. Similar conclusions were made by Eswaran (1.972) who also related the plasmic fabric types to the free iron content of the soil as Stoops (1.968) indicated that the free iron masked the optical properties of the plasma. Eswaran (1.972) concluded that the isotic and asepic plasmic fabric types of the oxic horizon could be attributed to (a) the high free iron content, (b) type and amount of clay minerals (c) absence of internal stres ses due to low COLE values. Other workers (Lepsch et al, 1.974 : Verheye, 1.975) have made similar observations on Oxisols in other parts of the world.

Soil Physicists (Wolf, 1.975) are beginning to look at the micromorphology of Oxisols to explain the peculiar moisture release characteristics of these soils. Employing the scanning electron microscope (SEM), Tsuji et al (1.975) have shown that Oxisols have a higher proportion of intra-aggregate pores as compared to some Inceptisols or Vertisols. They attribute the higher retention of moisture at 15 bar suctión by the Oxisols to these pores Soil moisture release studies (Uehara et al, 1.975) also indicate that at low suctions, the material behaves like sands or sandy loams and this is attributed to the very stable - sand sized clay aggregates visible in thin sections (Lepsch et al, 1.974). Preliminary micromorphological observations indicated that this appeared to be a characteristic feature of many oxic horizons and Eswaran et al, 1.976, proposed the term "Agglutinic" to describe this specific related distribution pattern.

Material and Methods .-

Oxisols from Brazil, Malaysia, Madagascar and Zaire are employed in this study. Petrographic size thin sections were made of selected horizons and when-necessary, the soil material was also examined with the SEM. The physico-chemical and mineralogical characteristics were evaluated by conventional techniques.

Results and Discussion .-

Grains .-

By the time a soil material reaches the oxic stage of soil formation, the weatherable primary minerals are altered or dissolved. During the weathering process, the liberated iron may coat other weatherable minerals and as a result, retard the weathering of these minerals. A few such relicts may be detected in oxic horizons. A similar phenomena takes place during the formation of gibbsitic or sesquioxidic nodules; entrapped primary weatherable minerals may be present in these nodules. In most cases, presence of weatherable minerals in oxic horizons may be attributed to such mechanisms.

At this stage of soil formation, only resistant minerals are present. The most frequent is quartz and in soils formed on basic rocks, ilmenite and magnetite may be present in significant amounts. In plate I, some micrographs of oxic horizons under incident light are shown. In (a), the particles with the metallic lustre are grains of ilmenite and magnetite. Under plane polarised light, they are not discernable due to the isotic fabric of the plasma. Even quartz is not stable in the environment to which the oxic horizon material is subjected to. Under the SEM, the quartz surface appear etched. Two characteristic type of each features (Plate II, a,b,c,d) are shown. One appears as out-growths whilst the other is as dissolution pits. The etch patterns shown typical crystallographic symmetry, In thin sections cracks may be seen in quartz and in many cases these are infilled to give rise to features termed runiquartz (Eswaran et al, 1.975). The arrow in Plate IIb points to a runiquartz.

Crystals of secondary minerals forming the grains is another feature of the oxic horizon. Due to the mode of formation, intercalary crystals are rare as most of the secondary minerals occur agregated together forming pedological features. Gibbsite and iron and manganese glaebules illustrate such features. The silt-and sand-sized secondary minerals are invariably euhedral (Eswaran et al, 1.973 ; 1.977). These secondary grains are stable as long as the environment during their formation persists. A change in invironment causes the breakdown and in some cases transformation. Silicification of gibbsite to form kaolinite has been reported (Jackson, 1.969) but no SEM or micromorphological studies exist though the initial destruction of gibbsite has been illustrated (Eswaran et al, 1.977).

Plasmic Fabric .-

The plasmic fabric types (Brewer, 1.964), observed in soils, are due to several reasons. Clay mineralogy, the related distribution pattern and presence or absence of cementing agents determine the types. Ma-and omni-sepic fabrics are shown by soils with a high COLE values; allophanic and halloysitic soils have an isotic plasmic fabric and soils with kaolinitic clays show intermediate characteristics. As 2:1 minerals or allophane is absent in Oxisols, the most frequent plasmic fabric type is insepic with occasional vo-and skel-sepic.

However, the oxic stage is also accompanied by a high free iron content; Oxisols on granite have 6-10 % free Fe_2O_3, basalts about 20 % and on ultrabasic rocks, about 30-40 %. It has been shown (D'Hoore, 1.954; Follett et al, 1.965) that the iron settles on clays and as a results, the optical properties of the clays is masked (Stoops, 1.968; Eswaran, 1.972). In these cases, the plasmic fabric grades to argillasepic or isotic. Consequently, with increasing free iron content, which reflects increasing weathering conditions, the expression of the plasmic fabric decreases.

Plate III shows the s-matrix of four different Oxisols. In the granite derived Oxisols (a) from Malaysia, the plasmic fabric is isotic with local in-, skel-and vo-sepic domains. In the soil on gneiss from Madagascar (b) the plasmic fabric is basically argillasepic though some stress oriented domains are present. The soil on basalt from Malaysia (c) has an in-sepic, argillasepic type whilst it is completely argillasepic in the soil from Brazil (d). In some variants of the last type of Oxisol, plasma separations running in a concentric manner but confined to just below the surface of the aggregates has been noticed (Lepsch et al 1.972). Verheye et al (1.975) employ the term ooidsepic to described this feature. This specific orientation of the plasma may have been attained during transport of the sediment.

In conclusion, it can be said the Oxisols have a poorly expressed plasmic fabric but this is not a mutually exclusive characteristic as soils grading to this stage may already have this property.

Voids. -

Voids (Brewer, 1.964) are of biological or pedological origin and the former are of little importance for the present objectives. The type of the latter voids and their distribution and configuration depend on (a) the related distribution pattern (b) the clay mineralogy and (c) the presence of cementing agents.

An oxic horizon has by definition more than 15 % clay and so there are no oxic horizons with granic or - phyric NRDPs. Consequently, void patterns characteristic for these NRDPs are absent. Most of the Oxisols have a plasmic or plasmi-porphyric NRDP. Those with high free iron tend to develop an agglutinic SRDP which is discussed later. This SRDP results in a high amount of large packing voids between the aggregates (Plate IIId) and within the aggregates there is a significant amount of intra-aggregate pores (Plate IVf) which retain water at high suctions. This indirectly also suggests that the stability of the aggregates is high. However, continuous cultivation of such soils tends to destroy the aggregates. Moura et al (1.976) have shown that the abundance of voids of more than 50 were found to be greatly reduced from values of 25 to 34 %, to 10 to 22 % in a Eutrustox after 15 years of cultivation.

Many Oxisols do not show the typical agglutinic SRDP as in Plate IIId, but frequently local areas with such SRDP may be presentina plasmic NRDP. The consequence is to increase the porosity of the soil. Bennema et al (1.970) have shown that Oxisols have twice as great a porosity as Ultisols of similar clay content.

Related Distribution Pattern .-

Two types, the normal related distribution pattern (NRDP) and specific related distribution patter (SRDP) are recognised by Eswaran et al (1.976). The more frequently occuring NRDP in oxic horizons are plasmic and porphyric (Plate IIIb and a) and some intergrades to granic and phyric.

At the oxic stage of soil formation, the free iron tends to cement the clay into pseudo -silt and-sand. Cementation may also lead to aggregate formation, where the aggregates are 1-5 mm diameter (Plate IIId). In the field, the soil structure is frequently described as "crumb, granular or massive" and the consistence of such materials is fluffy and loose. In thin sections they have a specific related distribution pattern which Eswaran et al (1.975) have termed "agglutinic" (Plate IIId). Tendency to form agglutinic SRDP (1) increase with the free iron content (oxidic families), (2) appears to better expressed in Oxisols with ustic soil moisture regimes (3) in soils with udic soil moisture regimes, is confined to the upper B horizons. Agglutinic SRDP with an ooidsepic plasmic fabric seem to be confined to materials that have been transported . Plate IV shows the morphology of the aggregates comprising the SRDP. The aggregates are formed by a close packing of clay platelets as seen in Plate IV (c,f) and some intra-aggregate pores are seen in (f).

The agglutinic SRDP is a specific feature of many oxisols especially those having "acric" properties and several physico-chemical properties fo the soil are related to this feature. The particular moisture release and retention characteristics (Tsuji et al, 1.975; Uehara et al, 1.975) are portrayed to a maximum in soils with this SRDP. Thin section observations indicate that fine roots do not penetrate the aggregates but merely surround them and as a result, the effective volume of the soil that could be tapped for nutrients is reduced. As the aggregates release the water slowly, they have the capacity to entrap nutrients. To test this, Moura (1.970) extracted the bases on a natural sample and compared it with similar extraction on sample that was ground to a fine powder. There was a significant increase in the amount of exchangeable Ca and Mg in the latter. The agglutinic SRDP also suggests that the soils behave like sands with respect to their moisture retention capacity. These soils are excessively drained and drought conditions are easily attained in such soils. As soils with agglutinic SRDP also have a high free iron content, there is considerable phosphate fixing capacity, inability to retain applied nutrients and a relatively high zero point of charge (ZPC).

Pedological Features .-

A range of pedological features (Brewer, 1.964), may be present; none of these characterise oxic horizons though a few are more frequent in oxic horizons. Galebules of gibbsite are frequent in Oxisols developed on acid to intermediate rocks and few on basic and ultrabasic rocks. Plate IIIb, shows gibbsite veins traversing the s-matrix of the soil. Gibbsite formation may be so extensive, as in a Gibbsiorthox, that the whole s-matrix is composed of silt-sized crystals of gibbsite, resulting in a gibbsi-phyric SRDP as shown by Eswaran et al (1.977). Petroplinthic nodules are frequent in some Oxisols and in Plate Ic, a large haematitic nodule is seen under inci cent light. In Plate Id, large bands of goethite, present cutanically to voids in the nodule are seen. SEM micrographs of these crystalline minerals are presented by Eswaran et al, (1.973; 1.977).

Translocated clay as argillans are rare in the oxic horizon and if present occupy less than 2 % of the area. With depth however, they may increase as in some Tropeptic subgroups. Papules of translocated clay may be present and these frequently show evidences of destruction.

The acric great groups have an additional feature which is specific for this group of soils. Belgian Pedologists working in Zaire have called them "variole" or "small pox" and Malaysians refer to them as clay balls. These are spherical to subspherical bodies of up to 4 cms diameter, compact and firm. They do not differ from the rest of the soil material in colour, texture or free iron content but have a distinctly higher bulk density. In one Acrorthox in Malaysia, the oxic horizon has a bulk density of 1.12 whilst the clay balls have 2.0. In thin sections, the soil material has an agglutinic SRDP and the clay ball, a plasmic. The matrix of the clay ball is compact and no voids are discernable though with the SEM a few fine voids can be seen. Plate Va, b, c, shows SEM micrographs of the soil material and (d, e, f) the fracture surface of the clay ball. The compact matrix of the clay ball is very evident in Plate Vf.

Conclusions.-

As would have been evident in the foregoing discussion, the oxic horizon cannot be defined by a single micromorphological property. However there is a collection of properfies which seem to characterise this diagnostic horizon. These define the Oxic Syndrome. Other soils may have some or all of these properties but have additional features not compatable with the oxic nature.

The syndrome for any diagnostic horizon is characterised by a set of features it should have and others which are absent or present in insignificant amounts.

The oxic syndrome :

(a) May have any NRDP except granic or phyric.
(b) Has a poorly expressed plasmic fabric, - insepic, argillasepic or isotic.
(c) Has only traces of weatherable minerals comprising the grains.
(d) Has only traces of translocated clay unless present as papules.
(e) May have an agglutinic SRDP.

SUMMARY

Oxisols are a group of soils whose geographic distribution is confined to the tropics. Their definition in Soil Taxonomy is almost purely mineralo-chemical. An attempt is made to summarise existing information on the micromorphology of these soils. Soils from Brazil, Malaysia, Madagascar and Zaire are employed to show the homogeniety of the microfabric. The micromorphological properties are also related to other physico-chemical properties of the soils. Finally, the authors propose the term "oxic syndrome" to group the several different micromorphological properties which are characteristic for this group of soils.

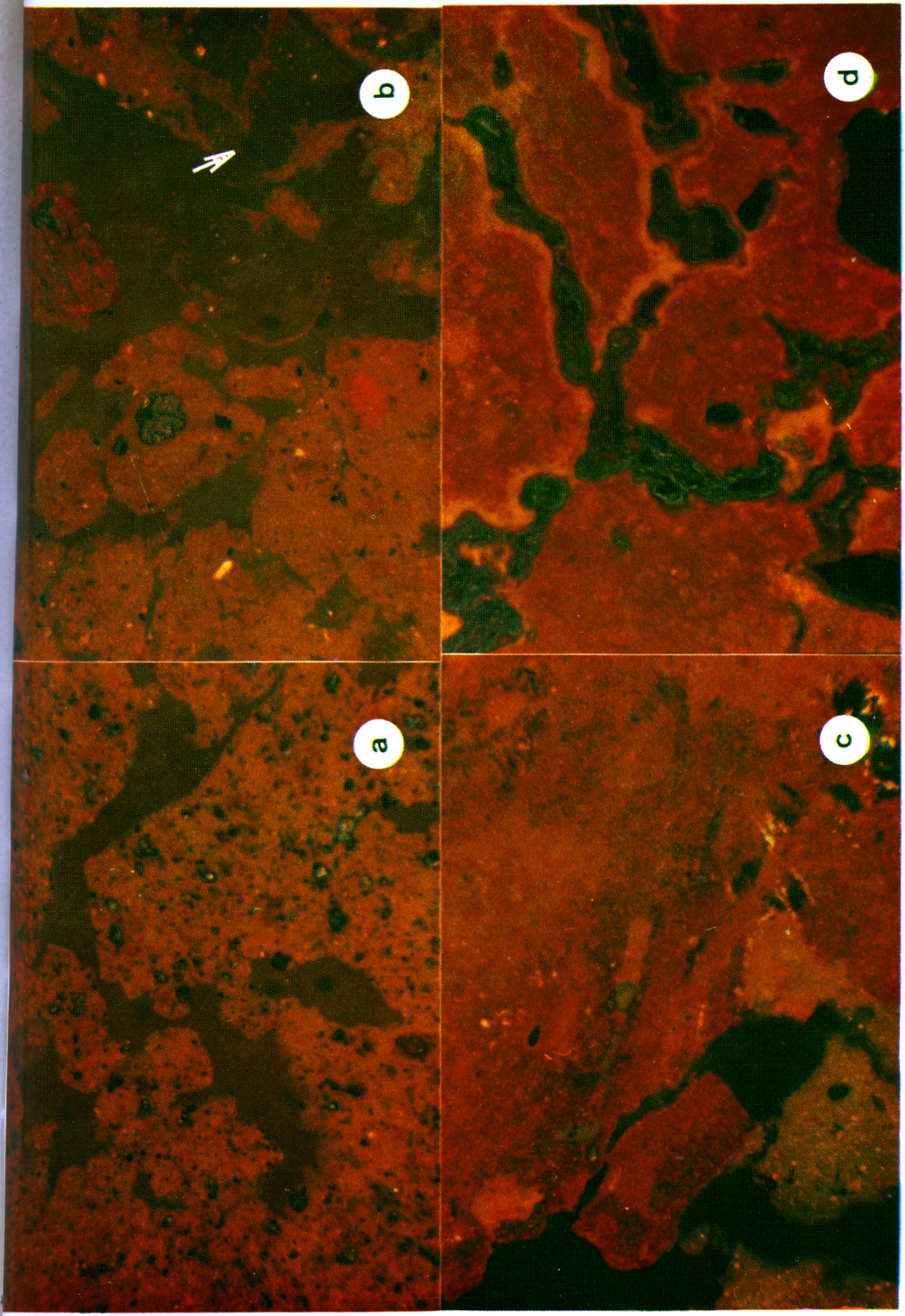

Plate I

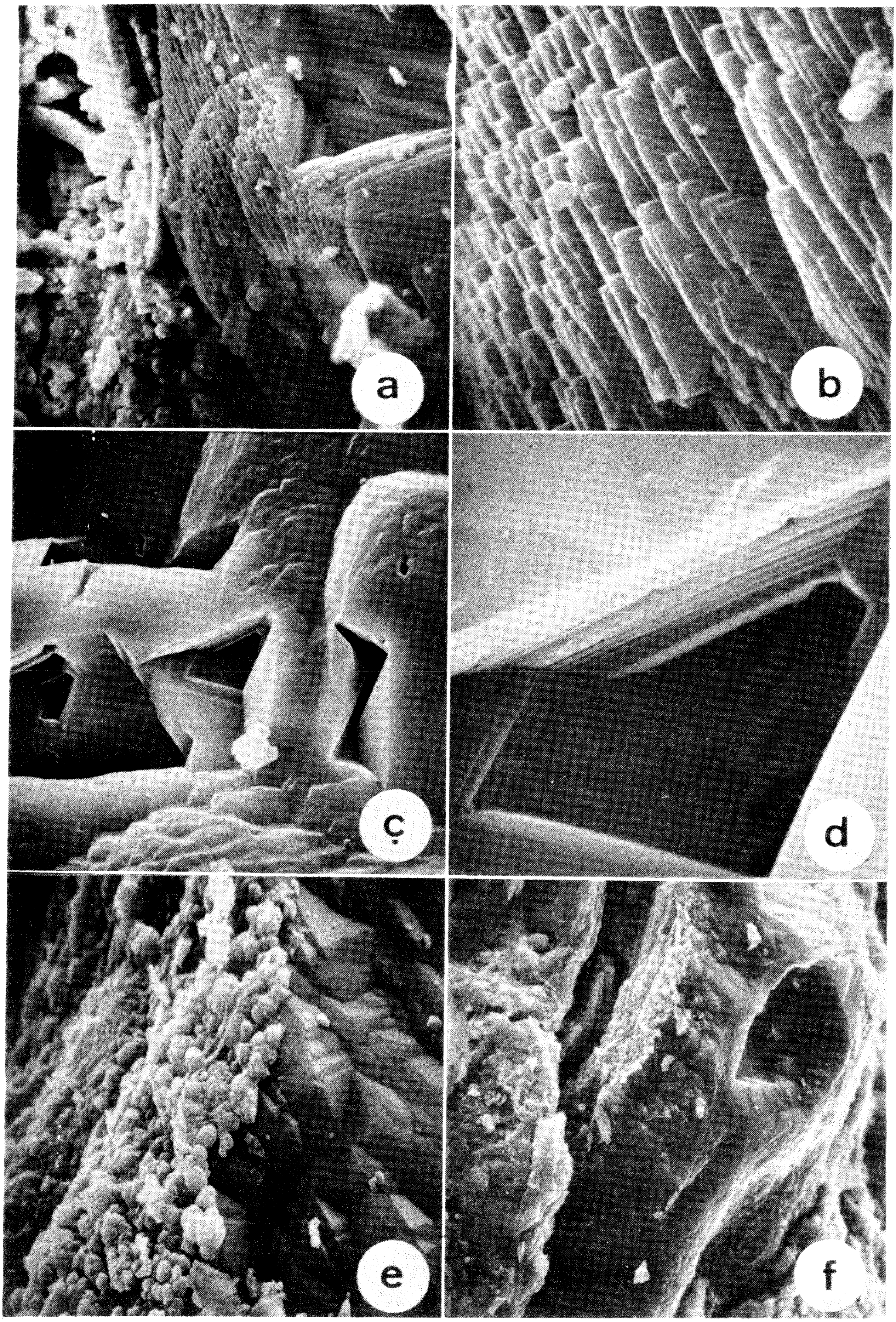

Plate II

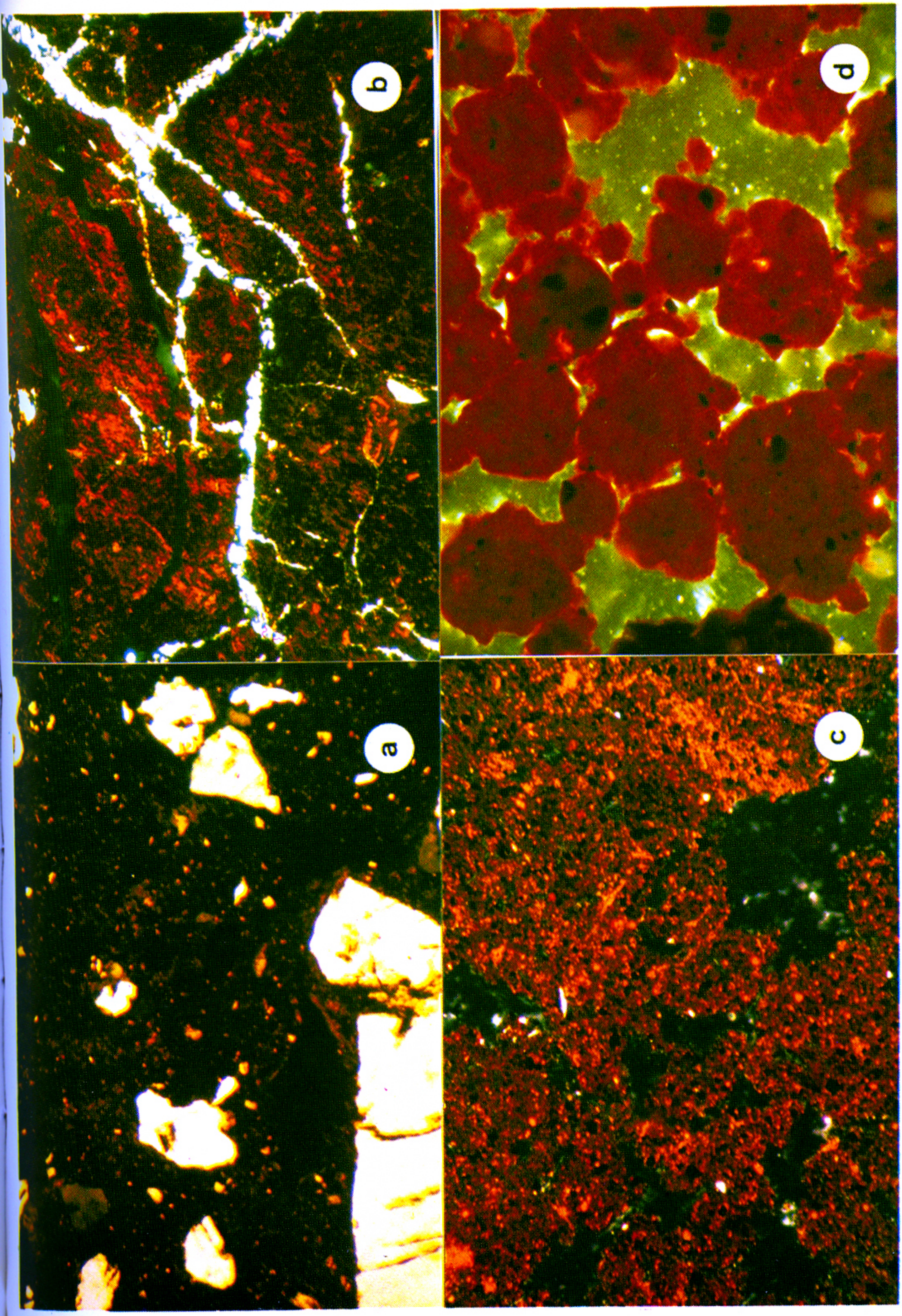

Plate III

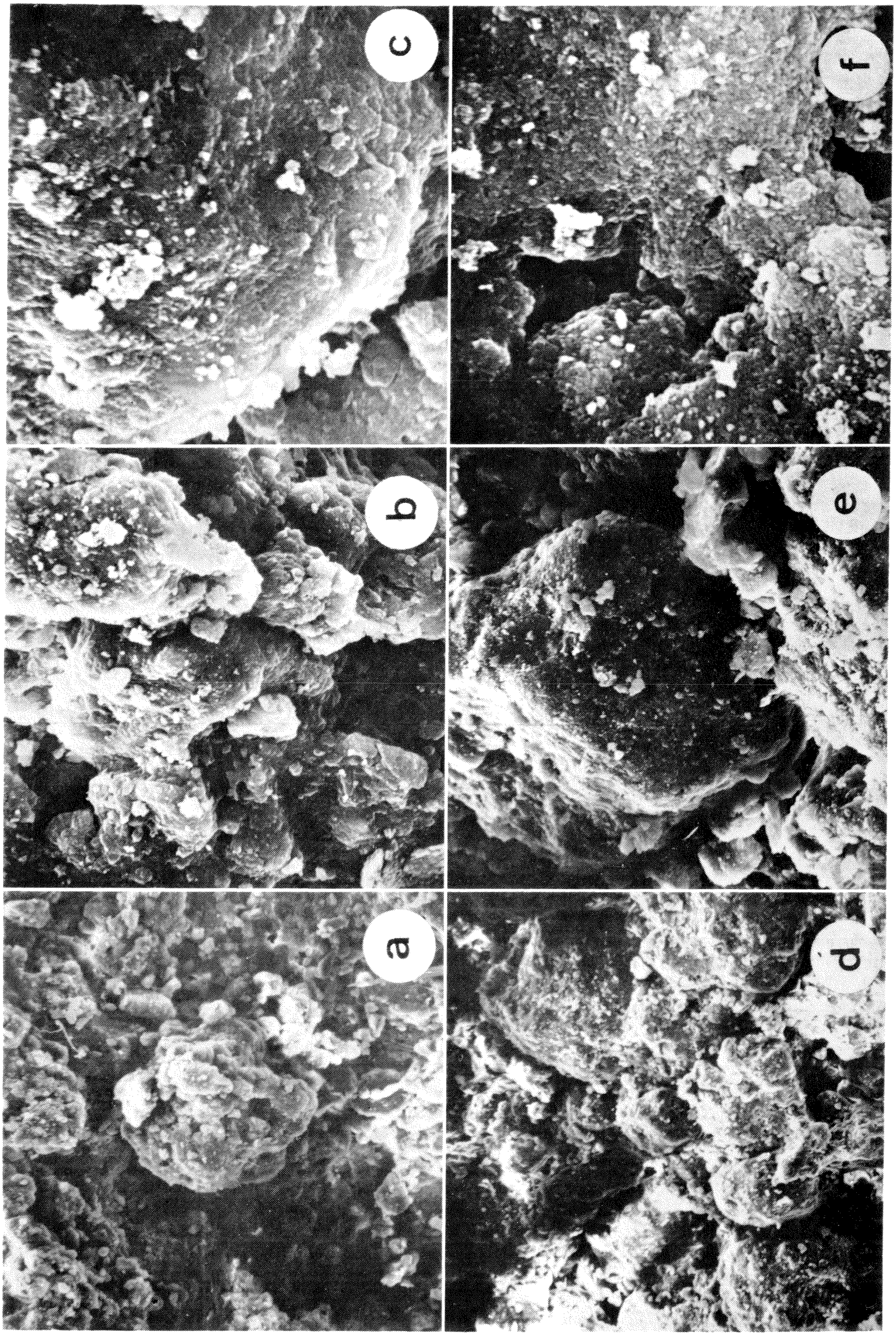

Plate IV

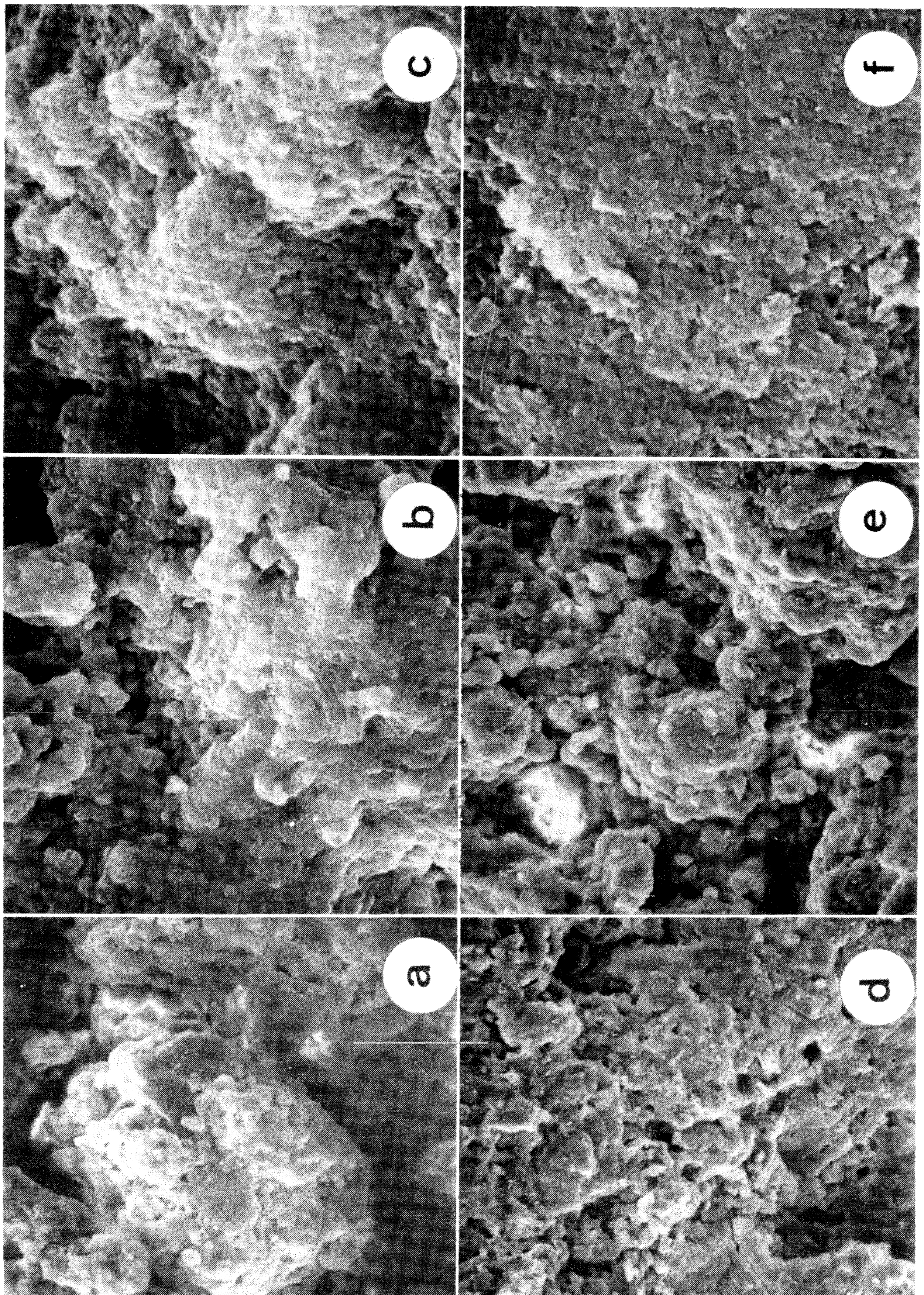

Plate V

Literature Cited .-

Bennema, J., A. Jongerius and R. C. Lemos. 1.970. Micromorphology of some oxic and argillic horizons in South Brazil in relation to weathering sequences. Geoderma 4. 333-355.

Brewer, R. 1.964. Fabric and mineral analysis of soils. John Wiley. New York. 470 pp.

Buol, S. W. Hole, F. D. and McCracken, R. J. 1.973. Soil genesis and classification. Iowa State Univ. Press. Ames. 347 pp.

D'Hoore, J. 1.954. Etude statistique des teneurs en Fe_2O_3 libre sur limon et argile. 2nd. Inter-African Soil Conf. Leopoldville. 26 1-274.

Eswaran, H. 1.967. A micromorphological study of some soils from the West Coast of Peninsular Malaysia. M.Sc. Thesis. Univ. Gent. Belgium. 79 pp.

Eswaran, H. 1.972. Micromorphological indicators of pedogenesis in some soils derived from basalts from Nicaragua. Geoderma, 7. 281-285.

Eswaran, H. and N. G. Raghumohan. 1.973. The microfabric of petroplinthite. Soil Sci. Soc. Amer. Proc. 37. 79-81.

Eswaran, H., C. Sys and E. C. Sousa. 1.975. Plasma infusion - A pedological process of significance in the tropics. Anales Edaf. y Agrob. 34. 665-673.

Eswaran, H. and C. Baños. 1.976. Related distribution patterns in soils and their significance. Anales de Edaf. y Agrobi. 35. 33-45.

Eswaran, H. , G. Stoops and C. Sys. 1.977. The micromorphology of gibbsite forms in soils. J. Soil Sci. 28. 53-60.

Follett, E. A. C. 1.965. The retention of amorphous colloidal ferric hydroxide by kaolinites. J. Soil Sci. 16. 334-341.

Jackson, M. L. 1.969. Weathering of primary and secondary minerals in soils. Proc. 9th Int. Congr. Soil. Sci. Adelaide. IV. 281.

Kellogg, C.E. 1.949. Preliminary suggestions for the classification and nomenclature of great soil groups in tropical and equatorial regions. Comm. Bur. Soil. Sci. Tech. Commun. 46. 76-85.

Kubiena, W. L. 1.962. Die taxonomische Bedeutung der Art und Ausbildung von Eisenoxydhydratmineralien in Tropenboden. Z. Pflanzenernahr. Dung. Bodenk. 98. 205-213.

Laruelle, J. 1.956. Quelques aspects de la microstructure des sols du nord-est du Congo belge. Pedologie. 6. 38-57.

Lepsche, I.F. and S.W. Buol, 1.974. Investigations in an Oxisols-Ultisol toposequence in S. Paulo State Brazil. Soil Sci. Soc. Amer. Proc. 38. 491-496.

Moura, W.F. 1.970. Studies of Latosol Roxo (Eutrustox) in Brazil; Clay mineralogy, micromorphology, effect of ion release and phosphate retention. Ph. D. Thesis. North Carolina State Univ. 57 pp.

Moura, W.F. and S.W. Buol. 1.975. Studies of a Latosol Roxo (Eutrustox) in Brazil: Micromorphology effect on ion release. Experientiae. 21. 161-177.

Soil Survey Staff. 1.975. Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. U.S.D.A.; S.C.S. Agric. Handbook No. 436.

Stoops, G. 1.968. Micromorphology of some characteristic soils of the lower Congo (kinshasa). Pedologie. 18. 110-149.

Tavernier, R. and H. Eswaran. 1.972. Basic concepts of weathering and soil formation in the humic tropics. Proc. 2nd. ASEAN Soil Conf. Indonesia. 383-392.

Tsuji, G.Y., R.T. Watanabe and W.S. Saki. 1.975. Influence of soil microstructure on water characteristics of selected Hawaiian soils. Soil Sci. Soc. Amer. Proc. 39. 28-33.

Van Wambeke, A. 1.974. Management properties of Ferralsols. Soils Bulletin 23 FAO, Rome. 129 pp.

Uehara, G., K.W. Flach and G.D. Sherman. 1.962. Genesis and micromorphology of certain soil structural types in Hawaiian Latosols and their significance to agricultural practice. Trans. Joint. Meet. ISSS. New Zealand. 264-269.

Uehara, G. and J. Keng. 1.975. Management implications of soil mineralogy in Latin America. In. Soil management in tropical America. Publ. Soil Sci. Dept. N. Carolina State Univ. 351-363.

Verheye, W. and G. Stoops. 1.975. Nature and evolution of soils developed on the granite complex in the subhumid tropics (Ivory coast). II. Micromorphology and mineralogy. Pedologie. 25. 40-55.

Wolf, J.M. 1.975. Soil-water relationships from Puerto Rico and Brazil. In. "Soil management in tropical" Publ. Soil Sci. Dept. N. Carolina State Univ. 145-154.