MICROMORPHOLOGY OF SOME SOILS DEVELOPED ON MARINE CLAYS IN PENINSULAR MALAYSIA

by

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Introduction.-

Recent clayey marine alluvium occurs as a continuous band on the west coast of Peninsular Malaysia and on the east coast, it alternates with sandy beach deposits and other estaurine formations. The marine clay deposits extend to a distance of one to ten kilometers inland and agriculturally are one of the most important areas. In the morthern part of the country, these soils are cultivated with rice; in the central, they are under oil palm, and sometimes coconuts intercropped with cocoa and in the southern part, they are mostly under coconuts, though many areas are changing to oil palm. Except for rice, which is irrigated, the soils for the perennial crops are drained and in both cases good management, requires an accurate control on drainage or irrigation depending on the crop.

Under non-cultivated conditions, the soils generally have a high water table. Draining them or irrigating them changes this situation and induces new pedo-chemical processes to operate which may be a permanent features as in the case of drainage or periodic as in the case of irrigation. These new conditions will have a consi

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derable affect on the mineralo-chemical and other agro-pedological properties, some of which may be adverse for agriculture as many of these soils have pyrite. Consequently our long term objectives of these studies is to monitor these changes.

The present study is an initial characterisation study; the present objectives being only to provide basic information on these soils. As a result, we have sampled some benchmark pedons of the Soil Survey of Malaysia. This paper presents the micromorphological aspects of this project.

Material and methods .-

Four pedons were selected and the soils varied in their drainage properties. The classification according to Soil Taxonomy (USDA, 1.975) which reflects this difference in the ground water regime is:

Pedon No.	Soil Series	Taxonomy	Depth to ground water table (m).
1	Sedu	Histic Sulfaquept	0.8
2	Sungai Sebatu	Typic Sulfaquept.	1.0
3	Kangkong	Sulfic Tropaquept.	1.3
4	Briah	Typic Tropaquept.	1.5

The difference in drainage is due to slight difference in elevation and the physiographic position of the soil. Pedon 1 and 2 occur at about the same elevation of about 5 m above sea level, except that the former is in depressions. In addition, there is some admixture of riverine materials in the latter as shown by the presence of large mica flakes in the field. Kangkong Series is present at elevation of 5–10 m. whilst Briah is at 10 to 20 m. Briah Series frequently is mapped in the estuarine area and as a result some admixtures with riverine alluvium is also suspected.

All the soils are clayey and in the field, it is frequently difficult to decide if the parent material is marine or riverine or admixtures of both as in the case of Pedon 2. Such a distinction is necessary as the marine clays have variable amounts of pyrite which is absent in the riverine deposits.

Pits were dug to a depth of 1.25 to 1.5 m. Profile description and sampling was done by one person while two others were involved in continuous bailing out the water. Undistrubed samples were taken in Kubiena boxes and bulk samples in plastic bags. Thin sections were made from the undisturbed samples by conventional procedures. By the time they were transported and impregnated in Belgium, many of the samples had shrunk through air-drying. Oxidation of pyrite to jaroite had also taken place and at least in one case some gypsum had crystallised on ped faces. These artefacts are unavoidable. In one case, the sulphuric acid liberated during the oxidation of pyrite had completely corroded the aluminum-zinc sampling box.

Some of the features observed in thin section were studied with the scanning electron microscope (SEM). For this fresh samples from the sampling box were employed.

Results and discussion .-

(a) Pedon 1 : Sedu Series - Histic Sulfaquept.

This is an actual acid sulphate soils. The surface organic rich horizon just meets the depth requirements of a histic epipedon. The B_{21g} horizon is about 25 cm thick and there is some jorosite mottles. In addition, large voids and some ped faces are coated with a black organic coating. The $(B)_{22g}$ horizon extends to about 60 cm and has a high amount of jarosite mainly in root channels. The C_G horizon commences at about 85 cm, with colours of grey (N/6) and no jarosite. No gypsum was noticed in the field but on opening the sample box in Gent a few crystals could be seen.

Framboids of pyrite are present in all the horizons and as these are better represented in Pedon 2 (Plate IIa, b, c, d), they will be considered later. The black organic coatings observed in the upper part of the profiles are shown in Plate Ia, the micrograph being taken with parallel light. In thin sections they appear reddish black in transmitted light and are composed if iron complexed with organic matter. They are present, frequently subcutanic to voids and they also coat ped faces. Plate IIe is a SEM micrograph of such a coating. It is cracked due to dessication. Associated with the coatings and frequently penetrating the soil matrix are fungal hyphae. These are shown in Plate IIf.

Biorelicts composed of decaying roots are common in all horizons. These are also invaded by fungal material. Organic matter staining masks the plasmic fabric. As a result, despite the fact that the clay is dominantly montmorillonite, clay separation is poorly expressed. Related distribution is plasmic according to the terminology of Eswaran et al (1.976). Grains are few and are mostly quartz. Planar voids are more abundant in the deeper horizon whilsts in the solum channels of biological origin are frequent.

The channel walls in the upper part of the profile are frequently coated with jarosite. Plate Ib shows the accumulation of jarosite in a channel. Some of the jarositans may be 0.5 cm thick and in the field are canary yellow in colour. Plate IIIa,b,c, show the SEM micrographs of jarosite. X-ray diffraction analysis indicated that they belong to the variety natro-jarosite $NaFe_3 (SO_4)_2 (OH)_6$ but the term jarosite is used in the text. The jarosite crystals in PlateIII a,b,c, belong to the hexagonal system and none, which pseudomorphed pyrite were found. All the SEM micrographs of jarosite published todate (Van Dam et al, 1.973 ; Miedema et al, 1.973; Eswaran et al, 1.974) have the same crystal habit and so it appears to be the most common habit. Miedema et al (1.973) have shown thin section micrographs of jarosite where there is little doubt that it is developed directly from the pyrite framboids. In some instances, the jarosite framboids even retain a nucleus of unaltered pyrite. Such pseudomorphs have not been examined with the SEM.

Although it was stated earlier that gypsum was found in the air-dry samples in the boxes, only very small amounts were found in thin sections. The arrow in Plate Ib, shows a small accumulation of gypsum associated with the jarosite. Consequently the induced crystallisation of gypsum appear confined to ped faces. Plate III d,e,f, show such gypsum crystals. A more detailed account of the crystallography of these tabular crystals is given by Stoops et al, (1.977). Gypsum is also present in the acid sulphate soils studied by Miedema et al, (1.973) but their crystals have a different habit.

Further oxidation of jarosite leads to liberation of the iron and this iron seems to be complexed by the organic matter forming the ferri-organans.

Pedon 2 : Sungai Sebatu Series - Typic Sulfaquept.

There is no histic epipedon in this profile and the horizon of jarosite accumulation is better expressed. As there is some admixture with riverine material, there are some differences in the micromorphology when compared to Pedon I. Large muscovite flakes and fine sand sized quartz are present giving a grani-plasmic NRDP. The amount of organic staining is much less in the upper part of the profile and the ferri-organans are rare. Jarositans are of the same type as in Pedon I both in thin section and under the SEM.

There is a very high amount of pyrite in the C_G horizon. The pyrite framboids are either scattered in the s-matrix or congregate in root channels. Their forms in thin sections resemble previous published work (Eswaran 1.967; Miedema et al, 1.973; Van Dam et al, 1.973; Eswaran et al, 1.974) and so no micrographs are included here. The question that arose was if these were current formations. Previous workers have assumed this due to their association with roots. To confirm this, decaying roots were split open and examined with the SEM. Plate IIa,b,c,d show the results of this study. The rounded aggregates in Plate Ia,b, are the pyrite framboids composed of a packing of single pyrite crystals each showing the typical pyritohedral form as illustrated by Eswaran et al, 1.974. Crystals need not aggregate together as framboids only. The arrow in Plate IIa points to a case where four crystals are present in a single root cell. Higher magnification of these are shown in Plate IIc,d. These crystals again have the pyritohedral form. These differ from the pyrite crystals of Holland (Miedema et al, 1.973) which were pentagonal dodechedral. Perfect cubes of pyrite, characteristic for sedimentary pyrite were never encountered.

Pedon 3 : Kangkong Series - Sulfic Tropaquept.

With improvement in drainage, the jarosite layer goes deeper down the profile or as in Pedon 3 is absent. In this case, oxidation of pyrite leads directly to preci -

pitation of the iron which coats the ped faces or the face of a freshly dug pit. The reddish brown colour or "ochre" as it is sometimes termed is very characteristic and is employed to define the "sulfic" great groups by the present authors.

The micromorphology of the lower part of the profile resembles the previous two profiles and the upper part of the profiles has properties of the Briah Series. The most striking difference is the absence or scarcity of the organic staining. Plasmic fabric is very well expressed and is ma-omnisepic (Plate Ic). The NRDP is typically plasmic, grains are few and composed of silt sized quartz. In the cambic horizons neo- and quasi-ferrans are common. They are associated with channels, which are the dominant void types.

All the pedons contain diatoms but were not very evident in the previous two due to masking or coating with organic matter. They are best represented in this pedon. Plate Id, shows a thin section micrograph taken under transmitted light and outlines of the diatoms can be vaguely made out. Plate IV shows some of the types of diatoms encountered in this pedon. The diatom shown in Plate IVc belongs to the genus Coscindodiscus whilst that in Plate IVe and f belong to the genus Melosira. Plate IVe is the obverse side and (f) the top side of the same diatom. The genus of the other diatoms could not be determined. The two diatoms mentioned above date from Tertiary to recent and so cannot be employed as characteristic fossils.

These diatoms however seem to be characteristic for marine deposits in Peninsular Malaysia as none of these species been detected in riverine material. Their presence is now employed as an evidence for the origin of the parent material. Diatoms are present in all four pedons indicating their origin.

Pedon 4: Briah Series - Typic Tropaquept.

This is the best drained member of the four pedons. The A_1 horizon does not exceed 10 cm and beneath is a thick cambic horizon with strong prismatic structures breaking down to coarse angular blocky. Mottles are abundant in the cambic horizon and these are composed of iron. Close to the C_g horizon, at about 1. 2 m, some faint, fine jarosite mottles are present.

Plate Ie shows the fabric of the cambic horizon. The NRDP is grani plasmic, grains being silt-sized quartz. The plasmic fabric is ma-omni-sepic. There are two types of voids which seem to be characteristic for the solum. Planar voids as those in the upper right hand corner of the micrograph are perhaps created during the drying of the soil material during prior to impregnation. The well developed plasmic fabric and the ability to form these planar voids reflect the high COLE value of the soil which is due to the presence of swelling colloids. The second type of void are channels which have a sperical to elliptical shape. In some of these, remnants of roots are still present.

As observed in the field, reallocation of iron is an active process in the cambic horizon. The most prominent features are neocutans (Plate Ie). There is a decreasing concentration of iron from the void wall into the s matrix. This gives the impression that iron has diffused into the s-matrix which is not correct. Oxygen has diffused into the soil material and the precipitation of iron is a function of the partial pressure of oxygen. Consequently, the differences in the concentration of iron reflects the gradient of oxygen in the system. The thickness of the neo-ferran is great in the cambic horizon which is only periodically saturated with water. In the C_g horizon which is almost continuously saturated with water, the neo-ferran is present as a thin band (Plate If).

This is further evidence that in the formation of the neo-ferran, iron does not diffuse into the matrix but oxygen does. However, concentration of iron can build up in a neo-ferran by diffusion of ferrous iron to the channel wall where iron is continuosly being depleted by its precipitation in ferric forms. Two other subsequent processes further modifies this pedological feature. If the percolating soil solution is rich in ferrous iron, precipitation on void wall leads to formation of ferran. Ferran-neoferrans are other pedological features present in the soil. On the other hand, iron may be stripped from the void wall when organic acids percolate through, resulting in a quasi-ferran. A first stage of this is seen in Plate Ie.

In less compact parts of the s-matrix, where there is a greater proportion of plasma, the partial pressure of oxygen may be sufficient to precipitate iron during periods of the year. These are the sites for nodule formation. A large sesquioxidic nodule is seen in Plate Ie.

With the precipitation of iron, the plasmic fabric is masked. This is well illustrated in Plate Ic, e,f,. Stoops (1.968), Eswaran (1.972) and Buol et al (1.977) altribute this as one of the mechanism for the poor expression of plasmic fabrics in highly weathered, iron rich soils.

In the C horizon of the Briah Series, some microstratifications are present. Plate If, shows quartz grains with a banded preferred distribution pattern. This micrograph also relates the effect of the NRDP in the plasmic fabric. In the plasmic NRDP zones, the plasmic fabric is masepic but in the plasmi-granic NRDP of the bands , the plasmic fabric is skel-omni-sepic.

Genesis of micromorphological features as a function of drainage conditions .-

The four pedons are developed on similar pyritic marine clays. The micromorphological features observed seem to show the changes taking place upon drainage. The most obvious field feature is the increase of sesquioxidic mottles and the decrease of jarosite mottles with drainage. The jarosite mottles moves progressively deeper in to the profile and the sesquioxidic mottles replaces it. The second field feature , also reflected in thin section is the organic staining on the soil material. In the sulfaquepts, there is a large supply of organic matter which complexes with iron and forms the ferri-organans. The organic matter also masks the plasmic fabric. With improved drainage, the ferri-organans move deeper into the profile or become absent and organic staining is negligible.

In thin sections, changes in plasmic fabric and development of sesquioxidic features are the most prominent changes with drainage. There is a progressive development of the expression of the plasmic fabric. In these soils with a similar colloid composition and NRDP, the plasmic fabric should have been similar. It is poorly expressed in the poorly drained members due to organic staining. As postulated by Eswaran (1.972), in the last two pedons, maximum development of the plasmic fabric is in the cambic horizon. It is not due to differences in COLE between the horizons, but rather due to the fact that under natural conditions, it is the cambic horizon that experiences most shrink-swell.

The mechanism of the neo-ferran formation was discussed before. Studying the thin section, it appears that once a nucleus for the precipitation of iron is present, further precipitation takes place at the same point. As a result ferrans or nodules grow by accretion. This is possibly due to two reasons. First, as in the case of a neo-ferran, there is an oxygen gradient which causes movement and precipitation of iron. In a nodule however, once a compact matrix is formed, this mechanism may no longer operate; yet the nodule increases in size. This implies that iron settles preferably on surfaces that are already enriched with iron. A similar situation that prevails in concretion (e.g. Eswaran et al, 1.977), where the concentric fabric is developed periodically. The interesting feature in soils, is that concretion and nodules in soils generally belong to a specific size fraction, or are only rarely encountered in a thin section where glaebules in all stages of formation are present. This implies that once a few centres of precipitation are formed, later precipitation seems confined to these centres. In these cases the previously precipitated iron acts as centres on which mobile Fe^{2+} is fixed and subsequently oxidised by "valence induction" as described by Selwood (1.948) and Selwood et al (1.949).

SUMMARY

The micromorphology of four pedons forming a drainage sequence on marine clays with pyrite, were investigated show the changes induced upon drainage. The most obvious field changes was a progressive increase in the depth at which jarosite mottles occured and a simultaneous increase in the amount and size of sesquioxidic mottles.

In thin sections, the plasmic fabric showed a better development in the better drained members as in the others, humified organic matter tended to mask the optical properties of the plasma. In the Sulfaquepts, organic matter also complexed iron and ferri-organans are abundant in the upper parts of these pedons. Diatoms are present in all the pedons and seems to be a characteristic feature of the marine clays in Malaysia.

SEM micrographs of pyrite, jarosite, ferri-organans, fungal mycelia, gypsum and diatoms are presented.

Plate I. Thin-section micrographs at magnification X 80.

(a). $(B)_2$ horizon of Sedu Series showing ferri-organan (arrow). Plain light.

(b). C_2g horizon of Sedu Series showing jarositans with small, local accumulation (arrow) of gypsum. Crossed nicols.

(c). Cambic horizon of Kangkong Series showing intense development of plasmic fabric and neo- and quasi ferrans. Crossed nicols.

(d). Diatoms in C_g horizon of Kangkong Series. Plain light.

(e). Diffuse nodules and neoferrans in cambic horizon of Briah Series. Crossed nicols.

(f). Microstratification in C horizon of Briah Series (arrow). Crossed nicols.

Plate II.

(a, b, c, d). SEM micrograph of split root showing accumulation of framboids and single crystals of pyrite.

(a) X 500 ; (b) X 1, 000 ; (c) X 2, 000; (d) X 5, 000.

(d) SEM morphology of ferri-organan (c. f. Plate Ia). X 2, 000.

(f) Fungal hyphae in void. X 5, 000.

Plate III. (a, b, c). Crustals of natro-jarosite forming. jarositans (c. f. Plate Ib).

(a) X 1, 000 ; (b) X 5, 000; (c) X 10, 000.

(d, e, f). Large tabular crystals of gypsum accumulating on ped faces.

(d) X 500; (e) X 2, 000; (f) X 2, 000.

Plate IV. Diatoms in marine deposits.

(a) X 500; (b, c, d, e, f) X 2, 000.

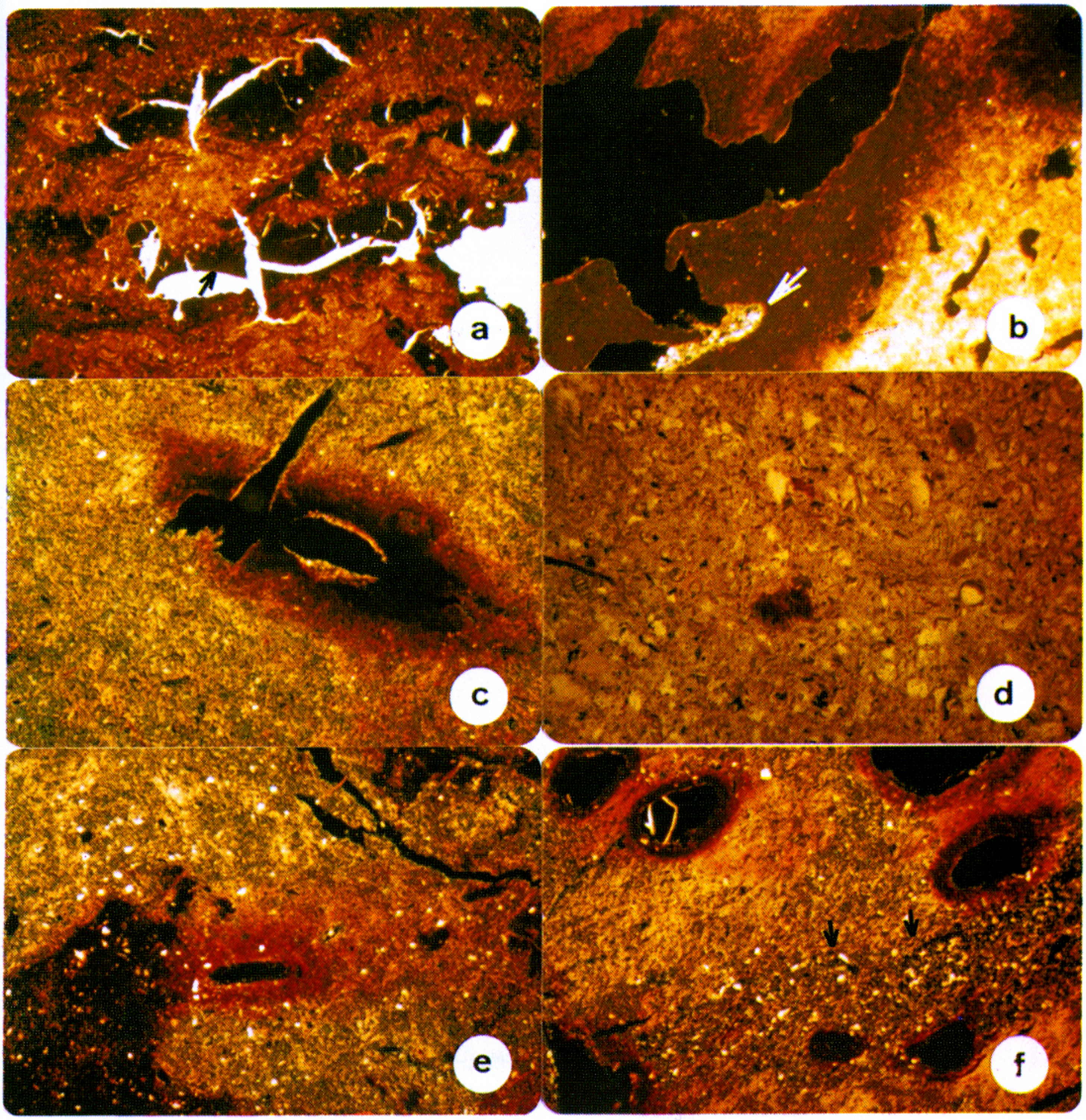

Plate I

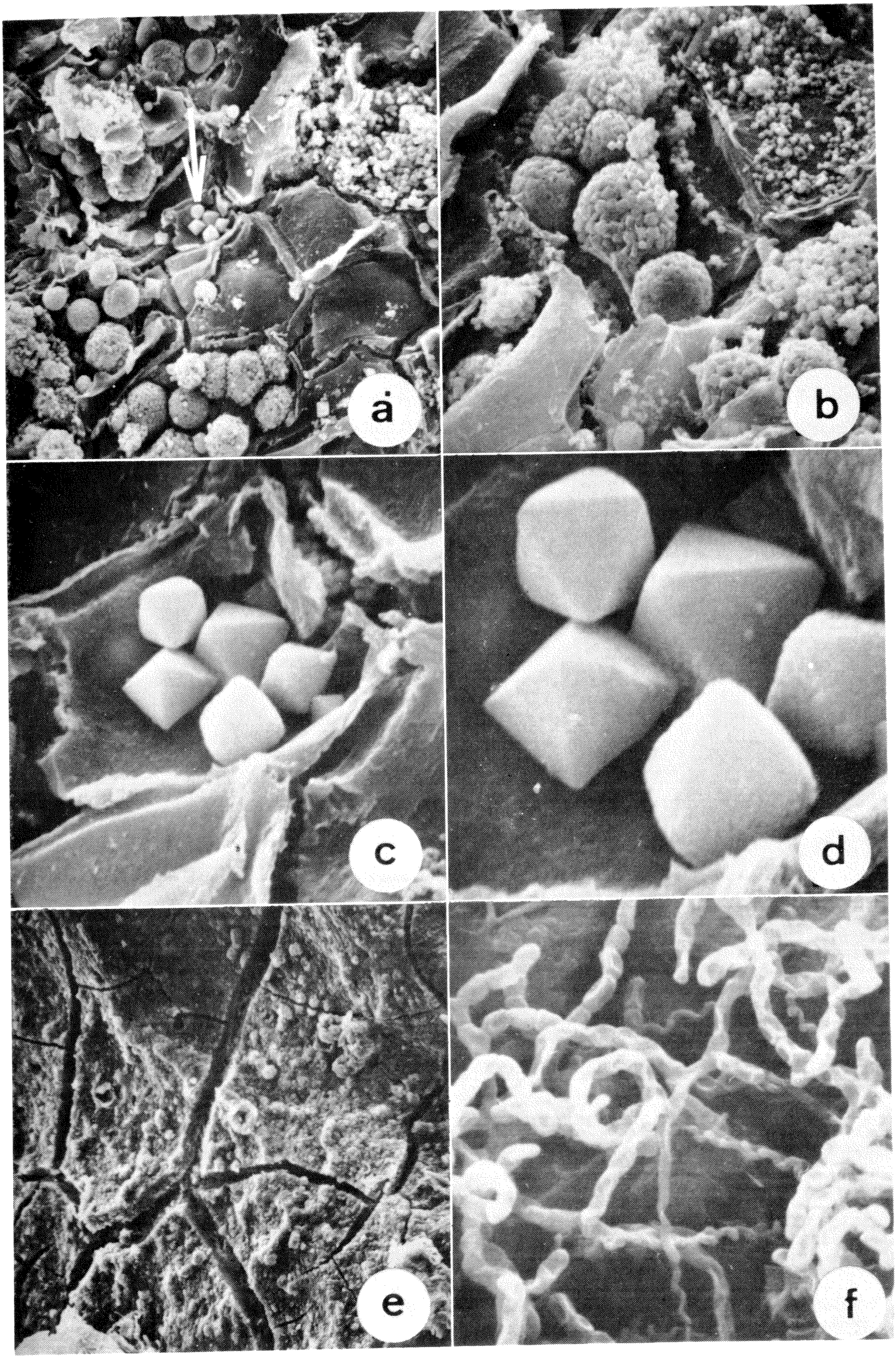

Plate II

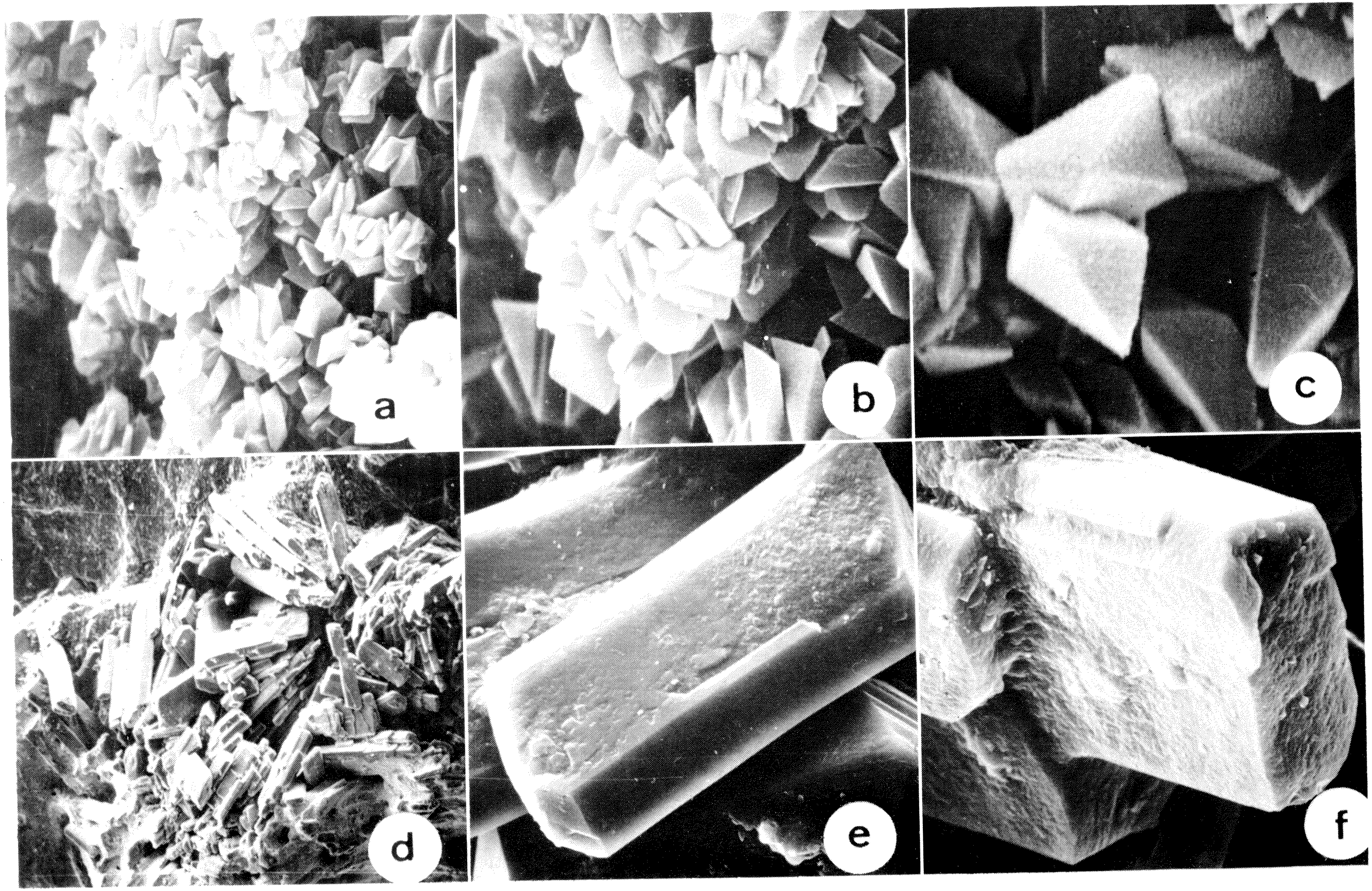

Plate III

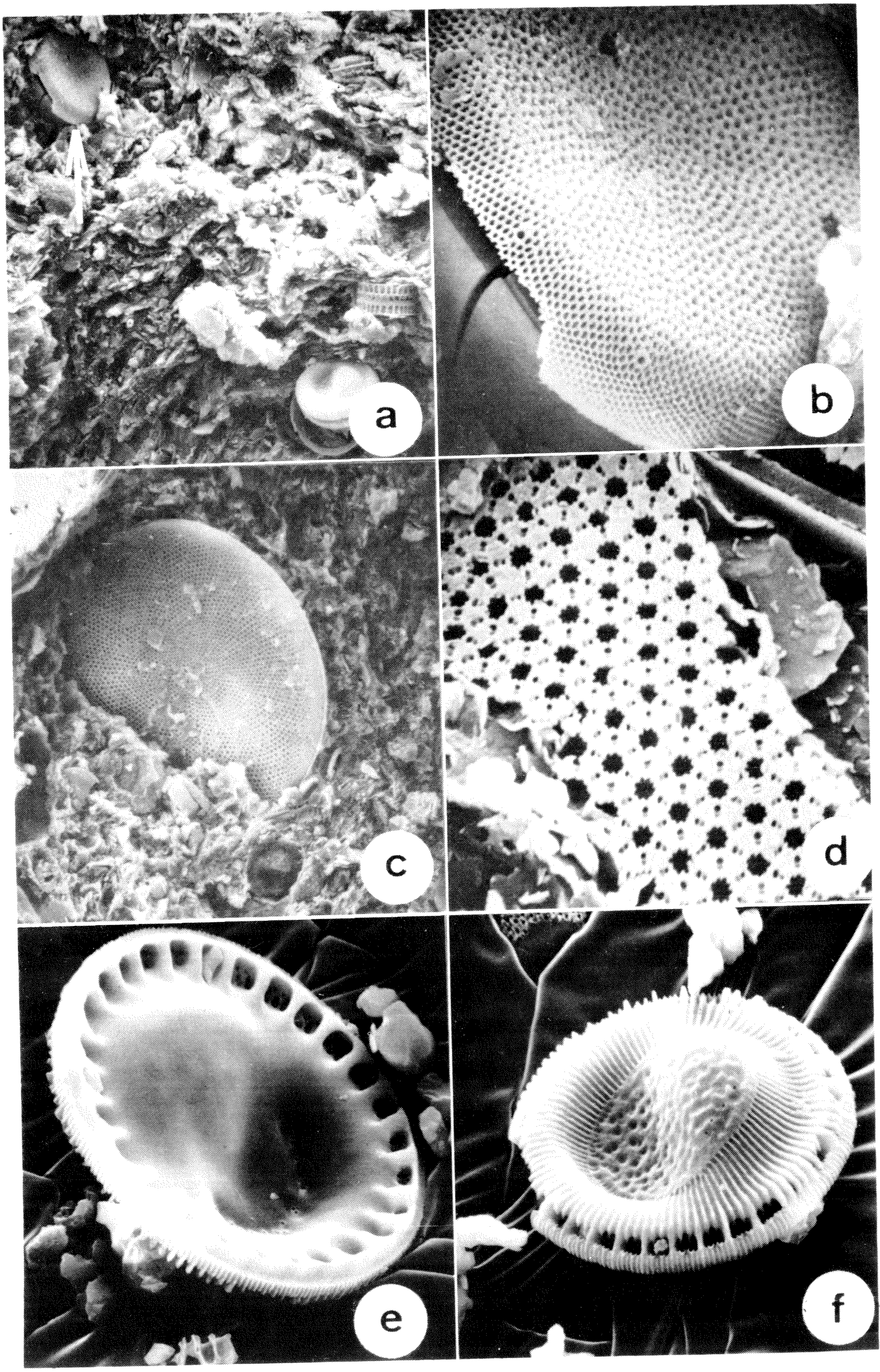

Plate IV

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