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A study of the polycyclic nature of a lateritic soil profile from Guyana using micromorphology

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Laterites have been observed and described throughout the history of man's travels in the tropics. However, research in the genesis of laterite is still at a very much less advanced stage than in soils of the temperate zone.

Osmond [13] showed that micropedological methods have an important part to play in elucidating the dynamics of soil formation and of the processes that occur inside the soil body. The volume of literature dealing with soil micromorphology is rapidly increasing and the kinds of pedologic problems that are being elucidated are becoming continually more varied. The object of this paper is to cast some light on the genesis of a laterite profile in Guyana using the polarising microscope and the electron probe.

Although Buchanan [4] first coined the term laterite, Harrison [6] was probably the first to present detailed chemical analyses indicating some tendencies in laterite formation. Contributions have also been made in earlier years by Mohr [12], Pendleton [14-18], Prescott and Pendleton [19] and others whilst Alexander and Cady [1] and Maignen [11] have provided very useful research and reviews in recent years. The volume of literature on the micromorphology of laterites although very modest is increasing. Humbert [7] concluded from his studies that laterite was formed by the mobilisation of iron and its movement through channels in the weathering matrix to form concretions. These concretions coalesced and became indurated by connecting veins of precipitated oxides of iron. Kubiëna [8, 9] on micromorphological evidence has suggested that a similar process may obtain in the formation of laterite. Laruelle [10] studied six laterite profiles in the Congo and showed the presence of microflocculation centres caused by periodic dessication and that all the profiles showed some degree of equilibrium between zones of mobile sesquioxides and zones of fixation. Alexander and Cady [1] have examined many thin sections of indurated laterite from West Africa and suggest that the hardening of laterite is a function of the enrichment in iron, the active role of amorphous or microcrystalline oxides and alternate wetting and drying.

In this paper the term laterite is applied to the indurated subsurface horizon of a soil profile and lateritic profile applied to a soil profile in which the upper horizons consist mainly of pisolithic or nodular materials and overly, at depth, an indurated lateritic horizon.

Although laterites vary greatly in structure, there appear to be three major structural patterns [1, 11]; (a) indurated elements forming a solid mass of iron oxide or a cellular, or network, arrangement with mixed hard walls and soft channels — a pattern which has been called vesicular or vermicular laterite [20]; (b) the indurated elements are free concretions, nodules or concretions in an earthy matrix — sometimes called pisolithic laterite or pisolithic ironstone gravels; (c) the indurated elements cement pre-existing materials. The term plinthite has been coined by the U.S. Department of Agriculture [22] to cover types (a) and (b).

It is the authors' experience that many lateritic horizons in Guyana and parts of Australia are indurated ironstone gravels which have been formed by the cementing of a number of pre-existing pisoliths, nodules or concretions into a hard mass.

MATERIALS [1]

The laterite profile under discussion in this paper was examined in a quarry on St. Ignatius research station in the Rupununi savannas of Guyana. The quarry was the source for local road material in the area. At this site the following profile was exposed (Fig. 1):

0-36 cm	5YR4/2(D) dark reddish gray coarse gravelly sandy clay; well developed, fine, subangular blocky structure; slightly hard; 11% by weight of particles less than 2 mm; frequent, hard lateritic fragments in <2 mm fraction; gradual even change.
36-131	5YR5/6 yellowish red coarse gravelly sandy clay; apedal; loose; 15% by weight of particles <2 mm; few roots; gradual even change to
131-193	5YR5/8 yellowish red coarse gravelly sandy clay; loose; 21% by weight of fragments <2 mm; abrupt change to
+193	hard laterite crust of variable colour.

OBSERVATIONS ON PROFILE MATERIALS

The profile can apparently be divided into two major elements:

1. 0-6 ft. (193 cm) very closely packed uncemented ironstone materials varying from fine gravel to cobble size with minor amounts of sand, silt and clay size materials (Fig. 1). The coarse fragments appear to be juxta-

[1] The descriptive terminology in this paper is based on those suggested by the U.S. Department of Agriculture [2] and Brewer [3], for the macro- and micromorphological descriptions respectively. Munsell colour given for dry state.

posed in almost ped-like fashion so that the whole subsurface part of the profile is more closely packed than the normal river gravels. The contact with the indurated underlying laterite is unconformable.

When broken with a geological hammer the coarse fragments have porphyritic quartz grains set in a dark red ground mass. The quartz grains are generally rounded to subrounded and vary from less than 200 μ to greater than 5 mm in size. The broken face has the appearance of a coarse-textured sandstone and is thus a nodule and not a concretion. The groundmass colour varies from (10R2/1) reddish black of (10R3/3) dusky red. The nodules are not presently case hardened but have an irregular (2.5YR5/6) red weathering skin of variable thickness (Fig. 1).

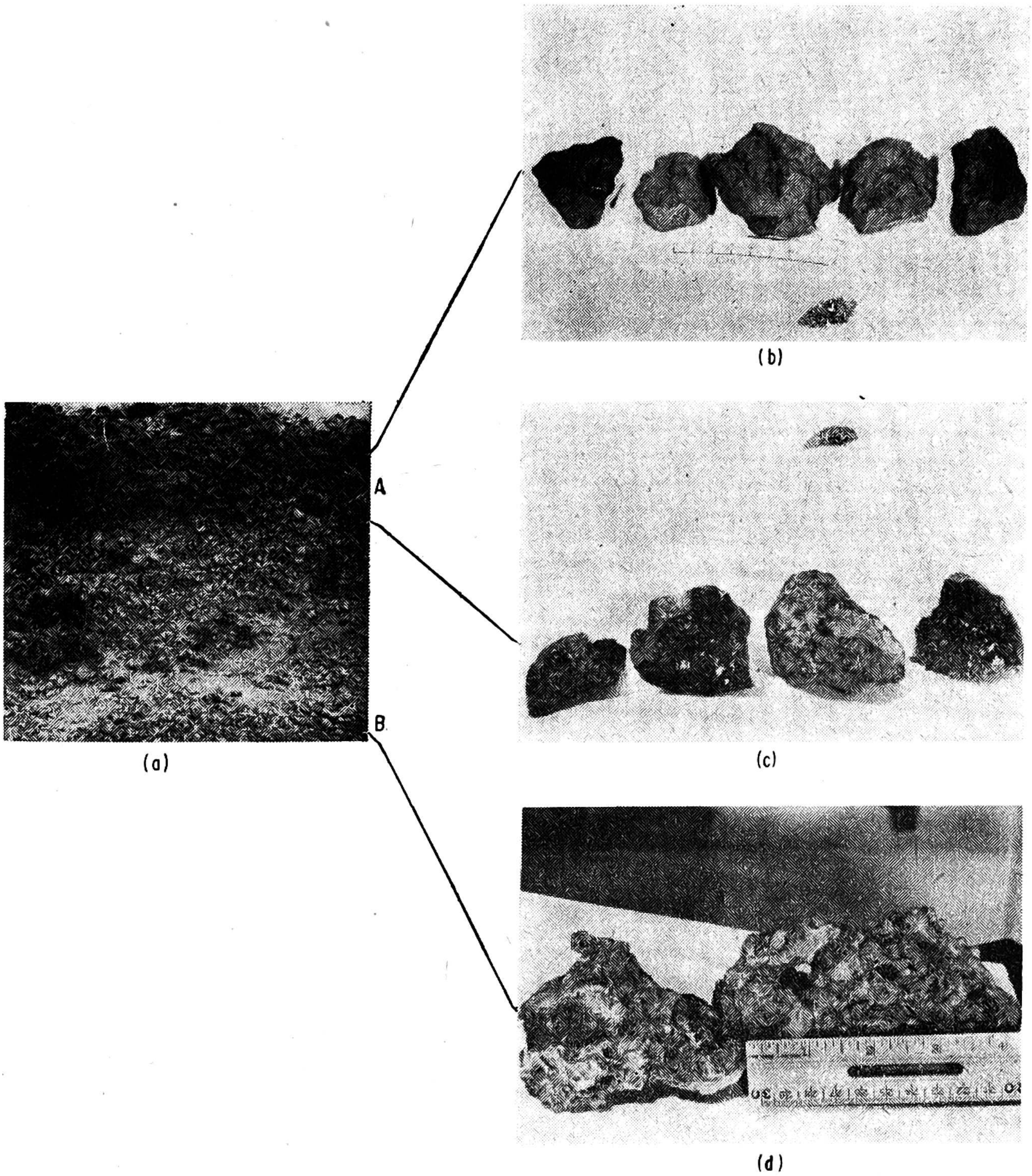

Fig. 1. Macromorphology of a Guyana laterite profile (*a*) showing laterite gravels (A), indurated laterite (B) *in situ* and in hand specimen (*b*, *c*, *d*).

2. 6-+7 ft. indurated vermicular laterite with metavoids and vughs ranging from 1 mm to greater than 15 mm minimum diameter. The matrix materials have a regular, unrelated and unoriented distribution pattern and show four distinctive colour/induration associations; (a) (10R2/1) reddish black, very hard; (b) (10R3/3) dusky red, hard; (c) (10R4/4) weak red, slightly hard to hard; (d) flecked (10R5/8) red and (7.5YR5/8) strong brown, loose to slightly hard (Fig. 1).

The voids are case-hardened with shiny (10R2/1) reddish black border up to 1 mm wide and wholly or partially filled with (10YR6/4) light yellowish brown sandy clay which is structureless, slightly hard and contains coarse sand size lateritic fragments.

From the above observations, it appears that two fundamentally different materials occur in the noncemented and cemented and indurated parts of the profile. If this is indeed the case, then it would not be unreasonable to assume that either (i) two different genetic soil forming processes obtained during the formation of the profile or (ii) that this is a polycyclic profile in which the uncemented horizons have been deposited on top of the cemented and indurated horizon some time after the formation of this horizon.

MICROMORPHOLOGY

Methods. A thin section was prepared from both the nodule and the cemented indurated laterite by cutting the samples with a diamond saw and from one fragment a thin section was made using the normal procedures and the cut face of the other fragment was made into a polished section for microprobe analysis. It was not expected that one would be an exact replica of the other but nevertheless, the likeness was such that most sites on the thin sections could be recognized in the polished section.

OBSERVATIONS USING THE LIGHT MICROSCOPE

In Table are presented micromorphological descriptions of the nodule and vermicular laterite. The two main constituents appear to be reddish or yellowish amorphous or cryptocrystalline groundmass with reddish (10R5/8) pellet-like botryoidal nodules with undifferentiated uniform fabric and sharp boundaries up to 4 μ diameter. At magnifications of $\times 500$ and higher these nodules appear to coalesce and form considerably larger dark red nodules with accompanying glaebular haloes. The fine nodules are probably high in hematite and the term hematitic micronodules is proposed for them at the present time. Aggregations of these nodules are very common in the reddish groundmass and much less common in the yellowish one (Fig. 2).

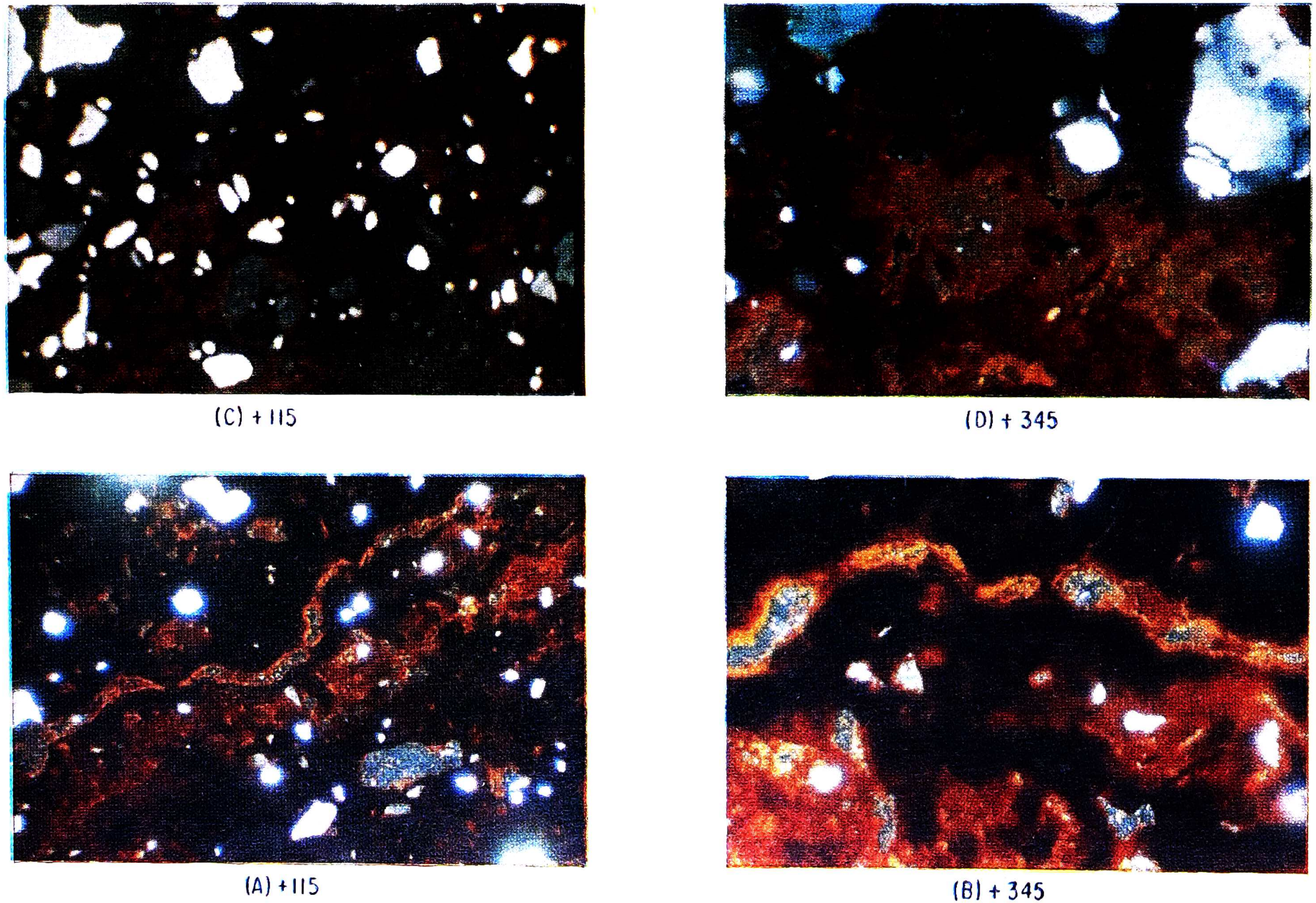

Fig. 2. Micromorphology of laterite (A, B) and lateritic gravels (C, D) from a profile in Guyana (crossed nicols).

Table. Micromorphological description of a nodule and vermicular laterite from a laterite profile in Guyana

	Nodule	Vermicular laterite
Skeleton	Porphyritic; uneven, mainly coarse (0.5-2mm); equant; subangular to angular; regular, unrelated unoriented distribution pattern; quartz grains only observed.	Weakly porphyritic; very uneven, mainly equant; subangular; regular, unrelated, unoriented distribution pattern; mainly medium (0.1-0.5 mm); quartz grains only observed.
Voids	Micro- to macro- metavughs (20-75 μ) and interconnected vughs; unrelated and unoriented distribution.	1. Large macro-metavughs in hand specimen. 2. Thin section; (a) common, coarse (<75 μ) metavughs and interconnected vughs, (b) few, meso-metaskewplanes, (c) few, simple and anastomosing macro-channels.
Plasmic fabrics	1. Dark red botryoidal nodules and glaebular haloes which at × 500 appear to be coalescing hematitic micronodules[a].	Mainly isotic: 1. Dark red botryoidal nodules and glaebular haloes composed of hematitic micronodules[a]. 2. Light reddish areas irregularly flecked with coalesced hematitic micro-nodules[a].
	2. Light yellowish areas with randomly distributed irregularly coalesced hematitic micronodules forming a marked irregular flecked pattern.	3. Elongate yellowish areas of continuous fabric commonly along voids or parallel to surfaces with frequent fine light yellow streaks parallel to elongation.
Cutans	Many vughs have a neo-cutan development composed of yellowish or light reddish nonpleochroic materials adjacent to walls of vughs; uncommon.	Neo-cutans and quasi-cutans of light reddish nonpleochroic materials adjacent to or related to some voids; uncommon.

[a] Explained in text.

The micromorphological evidence suggests that the nodule is essentially porphyritic with quartz crystals set in an amorphous to cryptocrystalline reddish groundmass with local areas of coalesced hematitic micronodules of varying density. On the other hand the laterite horizon consists of much fewer and less sorted quartz grains set in a reddish amorphous or cryptocrystalline groundmass with locally developed continuous yellowish stringers.

Lyle and Alexander (1962) have presented coloured micrographs of lithorelic structures in laterites, lateritic saprolites and in hardened laterite mainly from West Africa including Guinea, the Ivory Coast and Nigeria. They postulate that hardening is promoted by an enrichment in iron and subsequent crystallization and dehydration. Iron oxide minerals crystallize into continuous aggregates or networks and pseudomorphs after clay minerals, feldspars and gibbsite may be present. From their paper it appears that many of the profiles were developed in situ from underlying rocks — commonly basic. As the Guyana profile is developed from alluvial materials, such lithorelic structures would not appear. However, the coloured micrographs presented for hard laterite in Nigeria (site 3) and the Ivory Coast (site 7) show very similar features to those presented by the hardened laterite in Guyana. Skin and pore filling of goethite in a predominately hematitic groundmass indicates solution and reprecipitation of iron oxide. Concentration of goethite along stringers and channels with coalescing of laminated channel walls are features common to the West African and Guyana laterites. The cutan-like features are also common to both sites. Although no mention is made of features akin to lateritic micronodules the micrographs suggest that these may be a feature of the Guinea laterite. Humbert [7] although describing what appears to be pisolithic laterite suggests that iron concentration, crystallization and dehydration are the essential processes in the formation of pisoliths.

The micromorphology of the nodule indicates an essentially similar origin with respect to the formation of laterite micronodules but they lack goethitic stringers which are diagnostic for the hardened laterite. The pedogenetic processes may well differ in the upper and lower parts of the profile although it is difficult to ascertain the reason for this. Further, there is the possibility that this is a polycyclic profile and in fact, the nodules represent material that has been deposited on top of a denuded laterite profile. Much of the laterite in this part of Guyana consists of cemented lateritic pisoliths as described by Humbert [7] and thus have a different micromorphology to the nodules described here. No further explanation of this difference is given at this point until further field work can be done in the area.

ELECTRON MICROPROBE

Birks [2] has described the functions of the electron microprobe and Cescas *et al.* [5] have described its use in soil studies. The microprobe is based on the principle that a beam of electrons strikes a surface and produces X-rays having a specific wavelength for each element and the intensity of the socalled "reflection" is a function of the atomic number and amount of the element present. By using specific analyzing crystals, the X-rays produced by the elements may be separated according to wavelength with considerable accuracy. The advantage of this method is that a volume a few microns in diameter may be analyzed and compared with an equally small volume across a boundary.

The Electron Back Scatter diagram (E.B.S.) indicates general boundaries of chemically similar or dissimilar areas which may not be obvious with the light microscope. Figures 3 and 4 illustrate E.B.S. and the Al, Fe, Mg and Si distribution patterns for both the nodule and the laterite. As Mg is geochemically unstable and as random chemical analyses of

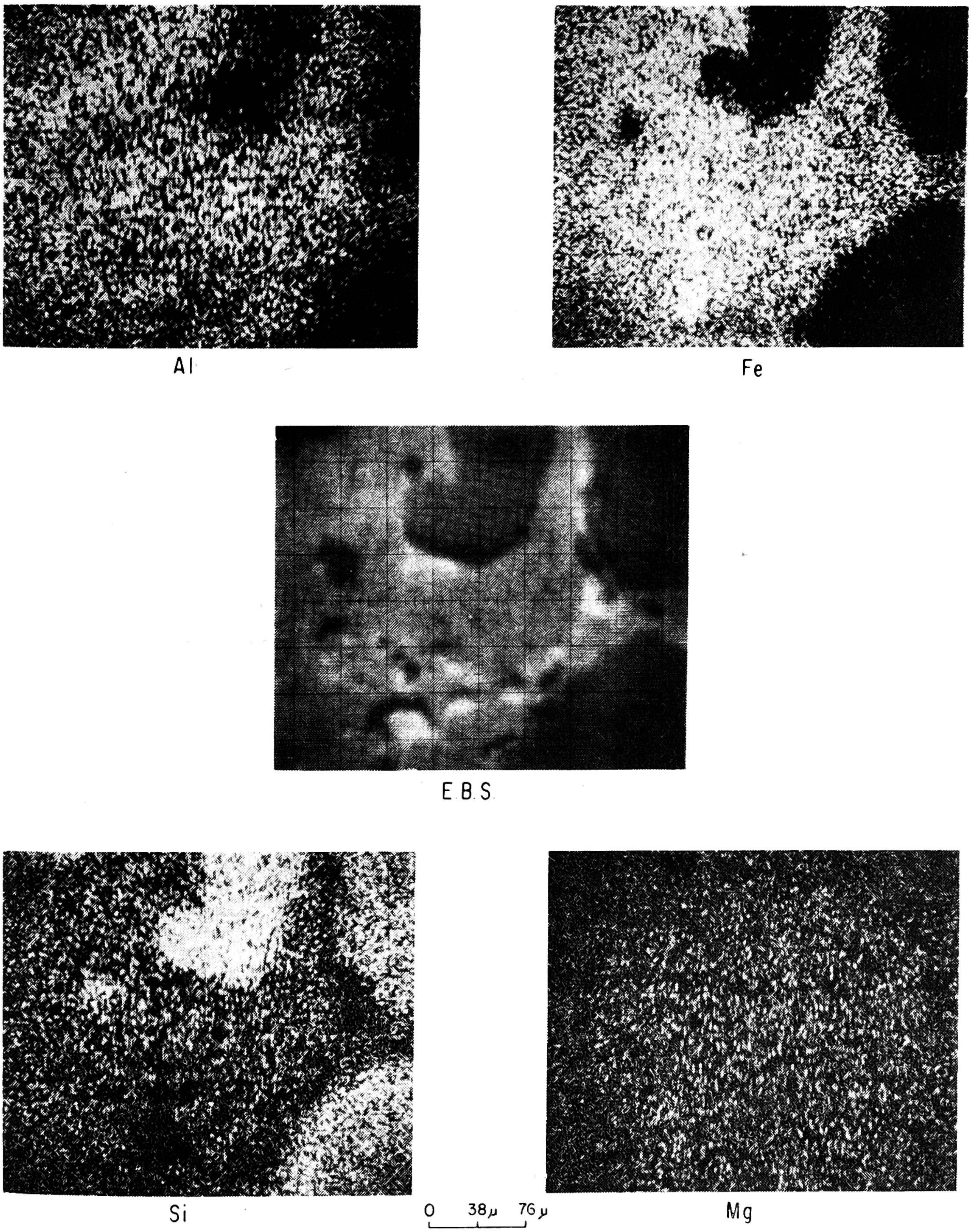

Fig. 3. Electron microprobe studies of laterite horizon from a Guyana laterite profile (approximately 16,000 counts).

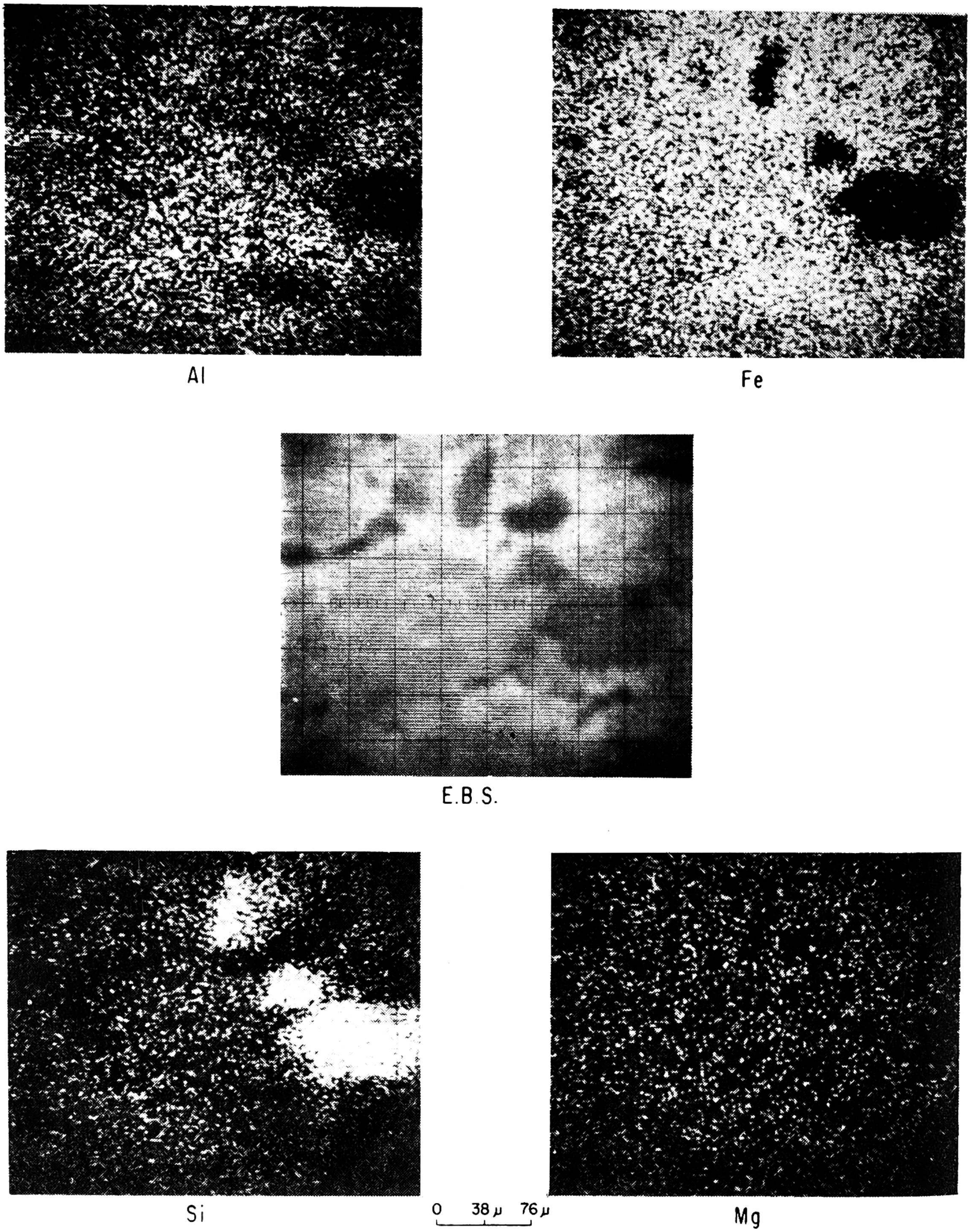

Fig. 4. Electron microprobe studies of a nodule from a Guyana laterite profile (approximately 16,000 counts).

these materials indicate that it is virtually absent, the micrograph for Mg represents the general "background" of the apparatus. The micrographs indicate that:

(i) Si is concentrated mainly as quartz and has a low concentration and is randomly scattered through the groundmass.

(ii) Although Al and Fe are generally evenly spread throughout the groundmass, Fe is in markedly higher amounts. However, in those sites where Fe tends to concentrate both Si and Al have lower relative concentrations. There is no "cutannic" concentrations of Fe around quartz grains.

(iii) The even distribution of Mg throughout the material even through quartz grains suggest that this is mostly "background".

In recent studies of the fixation of K by aluminosilicate gels Van Reeuwijk and de Villiers [23] showed that structural channels in the gels provide steric hindrance to the passage of cations according to their solvated size. There is no evidence from the micrographs nor from the light microscope that the distribution of the Fe has been conditioned by such a process during genesis. Also there is no indication from the electron probe micrographs of any difference in the fundamental distribution pattern of the chemical elements which would suggest that the nodule and the laterite have passed through different genetic processes.

CONCLUSION

Evidence from the field, the light microscope and the electron probe show that the laterite soil profile in Guyana is composed of two morphologically different elements; nodule and vermicular laterite. Although the basic fabric are similar a consensus of evidence suggests that this is a polycyclic profile.

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SUMMARY

The objective of this study was to make some initial studies of the nature, shape, size and arrangements of the constituents of a Guyana laterite. Hardened laterite is a very suitable and appropriate material for soil studies because formation of laterite necessitates the complete breakdown of all but some of the most resistant rock minerals and the building up of a dense body of ferruginous material commonly four feet or more in thickness.

An orientated piece of laterite was impregnated with plastic and after hardening and curing was cut with a diamond saw. Both cut faces were then polished with fine grinding powder and from the one a thin section was made for examination under the petrographic microscope, the other was polished and set in copper impregnated bakelite for study with the

electron probe. It is realized that both faces would not be exactly the same but it transpired that significantly similar sections were obtained.

The black and white micrographs shown in this paper indicate quite clearly the concentric nature of the laterite about voids. The colour micrographs suggest that the concentricity is a function of the different oxides of iron. The electron backscatter diagrams made from the polished section show the distribution of the elements Fe, Al, Si, and Mg through the section. Chemical analyses were carried out with the microprobe at the same time and the chemical analyses made at sites on a transect across the polished section are recorded in a table and the sites indicated on a scale drawing of the polished section.

The results of the electron probe study complement and verify the thin section record and an explanation of the unexpected accumulation of geochemically unstable Mg along a void is given.

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