Bulletin de la Société belge de Géologie	99-1	pp. 79-92	Bruxelles 1990
Bulletin van de Belgische Vereniging voor Geologie	99-1	pp. 79-92	Brussel 1990

COMBINED MICROMORPHOLOGICAL AND MINERALOGICAL STUDY OF A LATERITE PROFILE ON GRAPHITE SERICITE PHYLLITE FROM MALACCA (MALAYSIA)[1]

by

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SUMMARY

A complete lateritic profile over graphite sericite phyllite in the state of Malacca (Peninsular Malaysia) was studied using micromorphological, mineralogical and chemical analyses. Special attention was given to separate the heterogeneous samples into different phases (e.g. matrix, mottles, nodules) prior to analysis.

Kaolinite is the dominant mineral throughout the profile, besides sericite, goethite, hematite and gibbsite. Kaolinite shows the least defects in the most weathered horizon. In the saprolite gibbsite occurs as rosettes, formed by in situ desilicification of the kaolinite matrix ; in addition it crystallizes in larger pore spaces at different levels. The goethite shows a rather high Al-substitution, in agreement with the relative free leaching condition. Free iron and aluminum increase in the following order : matrix, mottles, hard nodules.

Pedoplasmation seems to be mainly due to bioturbation and different cycles are necessary to obtain the final homogeneous matrix characteristic of oxic materials. Study of the internal fabric of saprolite fragments and nodules indicates that at least the petroplinthite layer is of colluvial origin.

SAMENVATTING

Een volledig laterietprofiel, ontwikkeld op grafiet-sericiet-fylliet uit de omgeving van Malakka (Maleisië), werd mikromorfologisch, mineralogisch en chemisch onderzocht. De verschillende fasen (bijvoorbeeld de matrix, de vlekken en de nodulen) van heterogene monsters werden manueel afgescheiden en afzonderlijk geanalyseerd.

Doorheen gans het profiel domineert kaoliniet, naast sericiet, goethiet en gibbsiet. In de sterkst verweerde horizont vertoont kaoliniet het minst struktuurdefekten. In de saproliet komen gibbsietrosetten voor, onstaan door in situ desilicificatie van de kaolinietmatrix ; bovendien kristalliseert gibbsiet ook uit in grote poriën op verschillende niveaus. Goethiet vertoont een tamelijk hoge Al-substitutie, overeenkomstig met zijn vorming in een vrij uitlogend milieu. Het gehalte aan vrij ijzer neemt toe van de matrix via de vlekken naar de harde nodulen.

Pedoplasmatie wordt in hoofdzaak veroorzaakt door bioturbatie ; verscheidene cycli zijn echter noodzakelijk om uiteindelijk een homogene grondmassa te verkrijgen. De studie van het intern maaksel van saprolietfragmenten en nodulen wijst er op dat, op zijn minst de petroplinthietlaag een colluviale bijmenging bevat.

KEY WORDS

Weathering, pedoplasmation,laterite, Malaysia.

SLEUTELWOORDEN

Verwering, pedoplasmatic, lateriet, Maleisië.

1. INTRODUCTION

Although laterites and lateritic gravel cover a large part of the continents in the tropics, their genesis

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and evolution are not yet well understood. This is partially due to the very complex and polygenetic nature of this material, and to the fact that mainly only results of bulk analyses are available. It is becoming more clear that it is necessary to study the complete weathering profile, from the rock till the soil surface, using petrographic techniques supported by chemical, physico-chemical and mineralogical analyses of the different phases separately. Fabric analyses are in most cases the only way to understand the relation between the components and to establish a relative chronology in the case of polygenetic materials.

This paper summarizes the results of such a combined study of a laterite profile on phyllite from the state of Malacca, Peninsular Malaysia.

2. MATERIAL

In Peninsular Malaysia, laterite occurs extensively in the states of Malacca, Johore, Negri and Kedah. Generally, the laterite is found in association with low grade metamorphic rocks such as phyllites, but important deposits are also known to occur overlying andesite and basalt. In Malacca, laterites not only occur over phyllites, but also over quartz-micaschist and talcbearing rock (Othman, 1982).

The laterite profile was sampled on a road cut along the road from Ayer Keroh to Jasin, about 10 km east of the town of Malacca (Peninsular Malaysia). The area is rather flat and lowlying ; the highest point being only 266 m above sea level (Bukit Kecil). The laterite profile is situated on a slope of about 7° of a low rounded hill. It has developed on graphite sericite phyllite, most probably of the Lower Paleozoic (Devonian). This region has an Afi-climate according to the classification of Köppen, with an annual precipitation of about 2200 m and mean temperatures ranging from 25°C to 32°C. The Malacca coast experiences a clear and fairly regular dry season in January-February. This period also carries a high probability of days with moisture stress. After the dry season the rainfall increases up to November. A schematic section of the profile is shown in Fig. 1.

Eight samples were collected, representing the different stages of weathering and lateritization. In the laboratory, subsamples were manually separated according to the different colors in the soft samples (L2 - L4) and the degree of cohesion in the harder laterites (L5 - L7). They are indicated by subsidiary numbers.

Profile description :

L 8 : massive laterite (taken from a profile across the road) consisting of hard red (10R 4/7) (sub)rounded nodules, 4 - 15 mm in diameter (L8-3), slightly hard red (10R 4/8) cemented material (L8-2) and interstitial loose bright reddish brown (5YR 5.5/6) material (L8-1). LI.L 7 : massive laterite on top of the profile, composed of hard reddish brown (2.5YR 3.5/7) rounded to subrounded nodules (2 - 10 mm in diameter, few of them larger than 30 mm) (L7-5), soft compact matrix with different colors : red (10R 4.5/8) (L7-4), orange (7.5YR 7/6) (L7-3), dull yellow orange (10YR 7/4) (L7-2 and L7-1) and loose soft orange (7.5YR 6/6) interstitial material (L7-6).
L 6 : upper part of the petroplinthite zone : hard subrounded and rounded red (10YR 4.5/6) nodules (2 - 20 mm in diameter) (L6-H) with dull orange (7.5YR 7/4) loose interstitial material (L6-L).
L 5 : lower part of the petroplinthite composed of hard subangular to subrounded red (10YR 4/6) nodules (1 - 15 mm in diameter) (L5-H) in a dull orange loose matrix (L5-L).
L 4 : upper plinthite zone : soft compact orange (2.5YR 6/6) (L4-1) and dull yellow orange (10YR 7/2) mottles (10 - 30 mm in size) with weak to moderate impregnation (L4-2) with slightly hard subrounded reddish brown (10R 5/4) nodules (2 - 10 mm in diameter) (L4-3).
L 3 : lower plinthite : light gray (7.5 Y 8/1) soft compact matrix (L3-2) with light gray (10YR 8/1) mottles (L3-3) which commonly occur near the phase L3-1, and soft reddish orange (10R 6/6) nodules with diffuse boundaries, 10 - 20 mm in diameter (L3-1).
L 2 : soft weathered phyllite : soft compact grayish white (N 8/0) (L2-4), light brownish gray (5YR 7/2) (L2-3), olive gray (N 5.5/0) (L2-1) matrix with soft, dull orange (5YR 6/3), elongated nodules, 1 - 10 mm (L2-2).
L 1 : coherent soft weathered phyllite, olive gray (N 5.5/0).
In addition, a sample of the hard phyllite was taken (4).

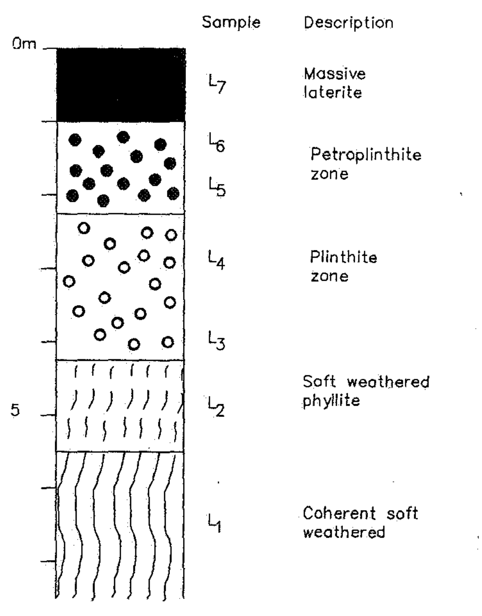


Figure 1 : Schematic section of the studied profile and localization of the samples.

Table 1a. Particle size distribution.

Sample	Sand				Silt		Clay	Fe_{DCB}	Fe_{DCB}/ Clay
	>500µm	500–250	250–125	125– 50	50 – 20	20 – 2	< 2 µm		
L5	47.5	0.0	0.5	1.5	2.65	14.57	33.3		
L4	10.0	1.0	1.0	2.0	5.95	23.85	56.2	5.00	0.089
L3	0.5	0.5	0.0	0.5	6.03	24.22	68.2	2.50	0.037
L2	0.0	0.5	0.5	1.5	6.51	34.85	56.1	1.55	0.028
L1	1.5	0.0	1.0	1.5	16.31	38.33	41.4	1.87	0.045

Table 1b. pH, extractable bases and C.E.C.

Sample	pH (H2O)	pH (KCl)	ΔpH	Ca*	Mg*	K*	Na*	Sum*	C.E.C.*	B.S. %	C.E.C.#
L6	5.4	4.1	−1.3	0.04	0.04	0.03	0.03	0.14	5.28	2.7	
L5	5.3	4.1	−1.2	<0.01	0.03	0.01	0.02	0.07	7.08	1.0	21.3
L4	5.3	4.1	−1.2	<0.01	0.02	0.02	0.02	0.07	3.48	2.0	6.2
L3	5.3	4.1	−1.2	<0.01	0.03	<0.01	0.02	0.07	4.48	1.6	6.6
L2	4.9	3.9	−1.0	0.02	0.03	0.03	0.03	0.11	3.82	2.9	6.8
L1	5.0	4.1	−0.9	0.02	0.02	0.03	0.04	0.11	1.62	6.8	3.9

* in meq./100g soil
\# in meq./100g clay

3. METHODS

Particle size distribution was determined on untreated samples by wet sieving for the sand fraction, and sedimentation balance for the silt and clay fractions. pH was determined in a 1 : 1 soil/water ratio, and in a 1N KCl-solution.

Free iron Fe(d) was determined according to Mehra and Jackson (1960), active iron Fe(o) according to Schwertmann (1964). Al substitution in goethite was measured according to Schulze (1984), after concentration of the Fe-oxides (the term iron oxides stands here for all members of the system Fe_2O_3 - H_2O) in the samples (Norrish and Taylor, 1961, Kämpf and Schwertmann, 1982). Some samples were, in addition, analyzed by Mössbauer spectroscopy with a program based on the distribution of magnetic hyperfine fields (sextets) and of quadrupole splits (doublets) as proposed by Vandenberghe *et al.* (1986).

The crystallinity of kaolinite was determined on non-oriented powder mounts of dithionite-citrate-bicarbonate-treated clay samples, after Hinckley (1963) and Plançon *et al.* (1989). Kaolinite contents were estimated by thermal gravimetry (TG).

Thin sections (60 X 90 mm) of undisturbed samples were prepared after impregnation with polystyrene according to the procedures of the Laboratory for Mineralogy, Petrography and Micropedology of the State University Ghent. Micromorphological descriptions were made according to Bullock *et al.* (1985).

4. RESULTS

4.1. CHEMICAL AND MINERALOGICAL ANALYSES

The results of the routine soil analyses and the selective extractions of Fe, Al and Si are presented respectively in table 1 and 2. Quantitative data for Al-substitution in goethite are given in table 3., where the results of Mössbauer spectroscopy are also summarized.

The heavy minerals of the sand fraction consist mainly of opaques (93 - 100 %). Amongst the transparent grains, tourmaline is dominant (73 - 82 %), except in L2 where it represents only 42 %, as a result of the presence of a large amount (30 %) of sillimanite which is absent in the other zones.

Table 2. Fe, Al, Si extracted by DCB (d) and oxalate (o) (in %).

Sample	Fe(o)	Fe(d)	Fe(o)/Fe(d)	Al(o)	Al(d)	Al(o)/Al(d)	Si(o)	Si(d)	Si(o)/Si(d)
L8–1	0.21	8.94	0.023	0.36	1.45	0.25	0.07	0.28	0.25
L8–2	0.07	21.30	0.003	0.20	1.28	0.15	0.06	0.48	0.10
L8–3	0.15	27.49	0.005	0.27	1.58	0.17	0.09	0.66	0.14
L7–6	0.07	6.25	0.010	0.24	1.07	0.22	0.04	0.34	0.12
L7–5	0.18	20.96	0.009	0.26	1.18	0.22	0.10	0.64	0.16
L7–4	0.09	13.34	0.007	0.30	1.00	0.30	0.10	0.45	0.22
L7–3	0.12	5.90	0.020	0.40	1.08	0.37	0.12	0.49	0.24
L7–2	0.05	4.33	0.012	0.23	0.81	0.28	0.09	0.16	0.50
L7–1	0.04	4.28	0.010	0.25	0.76	0.33	0.10	0.40	0.25
L6–H	0.07	22.11	0.003						
L6–L	0.05	4.84	0.010						
L5–H	0.05	17.65	0.003						
L5–L	0.04	7.95	0.005						
L4–3	0.10	14.57	0.007	0.07	0.62	0.11	0.03	0.22	0.14
L4–2	0.03	1.47	0.020	0.09	0.31	0.29	0.02	0.15	0.13
L4–1	0.10	6.74	0.015	0.09	0.47	0.19	0.03	0.18	0.16
L3–3	0.02	2.01	0.010	0.09	0.35	0.26	0.02	0.68	0.03
L3–2	0.01	0.53	0.020	0.09	0.15	0.60	0.04	0.15	0.27
L3–1	0.05	6.10	0.008	0.09	0.47	0.19	0.04	0.16	0.25
L2–4	0.00	0.16	0.000	0.06	0.15	0.40	0.02	0.17	0.11
L2–3	0.03	2.04	0.015	0.06	0.14	0.36	0.01	0.37	0.03
L2–2	0.08	3.44	0.020	0.06	0.32	0.19	0.05	0.18	0.28
L2–1	0.02	1.50	0.013	0.04	0.14	0.29	0.00	0.22	0.09
L1	0.00	1.87	0.000						

1	2	3	4
L8-3	24	26	74
L8-1	24	88	12
L7-5	16	62	38
L7-2	28	95	5
L6-H	18	20	80
L6-L	18		
L5-L	33		
L5-H		14	86
L3-1	15		

Table 3 : Al subsitution in goethite (by XRD) and proportions of goethite and hematite (from Mössbauer data).

1. Sample
2. Al sub. (XRD)
3. Goethite (%)
4. Hematite (%)

Andalusite is also relatively common (8 - 21 %) throughout the profile, whereas the other minerals (rutile and zircon) represent each less than 10 %. The light minerals in the sand fraction are mainly quartz and gibbsite.

In the silt and clay fractions a regular decrease of sericite and an increase of kaolinite are noticed from L1 to L3. In the L4, the quantity of sericite suddenly increases, but decreases again towards the upper zones of the profile. Thermogravimetric and XRD-analyses on the clay fraction of bulk samples indicate that the maximum kaolinite content is found in L3, where the highest proportion of low defect kaolinite also occurs (table 4). Using transmission electron microscopy, no distinct morphological differences were observed between the different fractions. No broadening of the 1.0 nm peak of sericite was observed throughout the profile, in contrast to the findings of Zauyah (1987) in a comparable profile from the region of Karak. Other types of 2:1 clays were not detected.

4.2. MICROMORPHOLOGY

The parent rock (4) is a graphite bearing sericite phyllite showing clear foliation. Few grains of quartz and thin prisms of tourmaline are observed. Dark red microgranular iron-oxide segregations occur in a few fissures parallel to the foliation, and as coatings on some voids.

In the saprock (L1), part of the sericite is transformed to kaolinite with a mozaic-like extinction pattern. Locally, the rock fabric is disturbed by channel infillings with a crescentlike fabric, which are much richer in sericite than the surrounding groundmass (Pl. I, 2). Rare limpid yellowish kaolinitic clay coatings occur in channels. The granular hematitic segregations become more pronounced, and infillings and coatings of gibbsite (crystals up to 12O µm long) occur in the biospores (Pl. I, 3 & 4), they postdate the bioturbations. Gibbsite tends to replace quartz grains when the latter occur as clusters.

In the saprolite (L2), the phyllite is completely kaolinitized, but the foliations still remain visible due to the arragement of very small opaque constitutents (ore grains, graphite) (Pl. I, 1). Gibbsite occurs as rosettes (250 µm in diameter), formed by in situ replacement of the kaolinitic groundmass, with inclusion of impurities. They are composed of interlocking poikilotopic crystals with irregular outlines and similar to the "gibbsite glomérulaire" described by Delvigne and Boulangé (1974) in schists. A large area of the section consists of bioturbated material containing more sericite and some gibbsite nodules ; crescent-like fabrics are common. Limpid yellowish kaolinitic channel coatings and infillings are observed. In the L2-2 dark red impregnations (3.44 % Fe(d) occur in both types of material, whereby the gibbsite rosettes remain intact (Pl. II, 1 & 2).

In the lower plinthite (L3), a homogenized grayish groundmass (L3-2, 0.53 % Fe(d) with kaolinite and sericite is found, still containing sharp delimited fragments of kaolinitic saprolite, showing relicts of foliation and sometimes gibbsite (L3-1, 6.1 % Fe(d) , 15 % Al-substitution in the goethite). In the grayish groundmass, vertical reddish streaks (L3-3, 2.01 % Fe(d) with a yellowish halo occur. In the central reddish zone crescent-like bioturbations are clearly visible (Pl. II, 3), impregnated with fine granular hematite, similar to that described by Schmidt-Lorenz (1964).

In the upper plinthite zone (L4) the grayish groundmass disappears and a mosaic of yellowish gray (L4-2, 1.47 % Fe(d) , 0.020 % Fe(o) and reddish (L4-1, 6.74 % Fe(d) , 0.02 % Fe(o) flecks with gradual transition remains. Except for the color, the groundmass is homogeneous, but contains more sericite than below. Several subangular saprolite fragments (500 µm - 10 mm in diameter) with clear relicts of foliation, are observed (Pl. II, 4). Some are completely kaolinitized, others still contain sericite. In some cases, they are completely impregnated with fine granular hematite (L4-3, 14.57 % Fe(d) , 0.01 % Fe(d). Few yellowish clay coatings cover the voids, in the lighter zones, some brownish hypocoatings are noticed. Few, strongly corroded quartz grains are also present. In the reddish zones, traces of bioturbation are better expressed, indicating a less complete homogenization.

The lower petroplinthite zone (L5) consists of a yellowish brown groundmass (about 30 % by surface) with reddish, goethite rich (about 40 %) flecks (L5-L) (7.95 % Fe(d) , 0.005 % Fe(o) , 33 % Al-substitution in the goethite) and dark red hematitic nodules (L5-H, 17.65 % Fe(d) , 0.003 Fe(o). The yellowish brown groundmass is heterogeneous, with some more grayish flecks (fragments of infillings) and has a crystallitic b-fabric due to the presence of sericite flakes. It is strongly bioturbated and has locally granular channel infillings. The nodules are mainly saprolitic schist fragments, practically without sericite, commonly containing clusters of gibbsite and corroded quartz grains (Pl. III, 3), and strongly impregnated with relatively coarse hematite aggregates.

The upper petroplinthite zone (L6) differs from the lower petroplinthite zone by the absence of mottles, and an increasing quantity of hard nodules. The interstitial groundmass consist of a rather homogeneous speckled yellowish clay with a crystallitic b-fabric, due to the presence of sericite flakes (L6 - L 4.48 % Fe(d) , 0.05 % Fe(o) , 18 % Al-substitution in the goethite). A few thin clay coatings and phytolithes are present. Its granular and compacted crumb microstructure points to a biological reworking. The nodules are mainly hematitic (L6- H. 22.11 Fe(d) , 0.07 % Fe(o) , 18 % Al-substitution in the goethite), some of them containing coarse grains of quartz or their gibbsite pseudomorphs. Some display the cellular fabric described by Schmidt-Lorenz (1964), others are practically opaque with inclusions of quartz grains or gibbsite pseudomorphs. The laterite nodules no longer show exclusively fabric relicts related to the underlying phyllite.

The overlying massive laterite layer (L 7) consists mainly of subangular laterite nodules of different fabric, composition and size, with an interstitial groundmass. The most recent groundmass, occurring in the center of the interstices, is a yellowish brown, very homogeneous speckled clay with undifferentiated b-fabric (L7-1 and - 2, 4.28 and 4.33 % Fe(d) , 0.04 and 0.05 % Fe(o) , 28 % Al-substitution in the goethite). The older phase, occurring in protected spots, is less homogeneous, with brownish streaks and flecks, some thin clay illuviations and hypocoatings of brownish iron oxides (partly hematitic) on fissures. The latter sometimes contain gibbsite infillings. The nodules are largely hematitic, but with coatings of goethite. Many of them are clearly polygenetic. Their Fe(d) content ranges between 6.25 and 20.96 %. The massive laterite block (L8) has a similar fabric and composition. Here, cementing of nodules by iron oxides and clay (older matrix phase) is well expressed.

5. DISCUSSION

Taking into account that the grain size distribution was determined on untreated samples, the strong increase of the coarse sand fraction in L4 and L5 must be explained by the appearance of iron-oxide nodules. The trend of an increasing clay content from the saprock to the upper saprolite corresponds to the normal weathering pattern. These data are corroborated by the micromorphological observations.

The soil material has a low pH, a negative ΔpH ($pH_{KCl} - pH_{H2O}$), decreasing towards the lower saprolite, and a very low base saturation (Table 1). The very low C.E.C. is in agreement with the mineralogical composition of the clay and silt fraction (kaolinite and sericite, absence of 2:1 clays). The C.E.C. shows a general decreasing trend with depth. All these characteristics point a highly weathered (Oxic) material.

Within the same zone, the contents of DCB-extractable Fe and Al increase in following order : loose material, mottles, slightly hard nodules, hard nodules. Within the profile, an increase is observed from the saprock to the massive laterite. The Fe(o) /Fe (d) -ratio is always very low, indicating that most of the iron is present in a crystalline form. According to the Mössbauer data, hematite is dominant in the nodules and goethite strongly dominant in the yellowish groundmass.

As no traces of 2:1-clays were found, a direct kaolinitization of the sericite schist may be considered as the main weathering process. The random orientation of the kaolinite domains, and the absence of pseudomorphs, suggests a recombination of Al and Si from the soil solution. The parallel arrangement of the opaque inclusions in the groundmass, a relic fabric, points to a gradual replacement of sericite by kaolinite. Formation of granular hematite probably dates from the same period.

Gibbisitization in the lower layers (L1 and L2) took place under two different forms : in the L2, the kaolinitic groundmass is locally replaced by rosette-like gibbsite aggregates, with preservation of the relicts fabric mentioned above (Pl. II, 1 and 2). This is clearly a case of in situ desilicification. This process took place before bioturbation and formation of ferruginous mottles. In the L1 bioturbation gave rise to sericite-rich channel infillings with crescent-like fabric. Fissures in these infillings, sometimes continuing in the groundmass, have pure gibbsite coatings and infillings, pointing to a later, probably absolute accumulation of gibbsite (Pl. III, 1 and 2). This means that calculation of weathering intensities based on the non-mobility of the Al-ion in the profile would not be possible for this saprolite, unless one supposes that the aluminum is derived from the same layer, as gibbsite is the stable phase in the larger pores, whereas kaolinite is stable in the microporous environment of the matrix, as proposed by Tardy & Novikoff (1988). A small amount of undisturbed limpid yellowish clay coatings in both layers indicates that the last visible process is clay illuviation. The L2 is the only layer containing a considerable amount of sillimanite, suggesting a slight difference in parent material.

The homogenization is almost complete in the lower plinthite zone (L3), although isolated saprolite fragments are still recognizable. This zone is the most intensively weathered of the whole profile : it contains the highest amount of kaolinite (82 %) and only a small amount of sericite, the kaolinite has the highest Hinckley index (1.29), the clay fraction is devoid of quartz, the light sand fraction contains the highest amount of gibbsite grains and the goethite of the mottles has a relative high Al-substitution (15 %). The latter figure will be even much higher for the central part of the mottles which is older than the diffuse halo, as deduced from the preserved crescent-like internal

1	2	3	4
L7	72	0.46	6
L5	71	1.06	32
L4	76	0.95	27
L3	82	1.29	48
L2	67	0.91	25
L1	27	0.98	29

Table 4 : Kaolinite content (based on TG) and Hinckley Index.

1. Sample
2. Kaolinite (%)
3. Hinckley Index
4. B.C. (low defect kaolinite) (%)

fabric, and therefore formed before the hydromorphic conditions. All these characteristics point to a strong weathering in a free leaching environment. A slight difference in composition of the original rock however cannot be excluded, as this zone contains considerably more andalusite grains in the sand fraction than the others.

The upper plithinte zone (L4) is less weathered. Some of the saprolite fragments contain sericite, others are completely kaolinitized and impregnated with fine granular hematite. This might point to a mixed origin of the materials. In that case this layer is not in situ, which could explain the difference in the degree of weathering of the L3 and L4. Anyway, the materials are derived from the same type of rock. The hydromorphic characteristics here are the most recent features, apart from a weak clay illuviation.

In the overlying petroplinthite layer, the number of iron-rich mottles and hard hematitic nodules increases towards the top. Al-substitution (33 -18 %) in the goethite of the mottles indicates a relative free leaching environment (FitzPatrick and Schwertmann, 1982), although temporarily water-logged. The groundmass remains rich in sericite, and relatively heterogeneous. In the upper part of the petroplinthite layer, part of the nodules are clearly of foreign origin. This is still more evident in the overlying massive laterite band. Here two phases of interstitial groundmass are present : the most recent has all characteristics of an oxic material (very homogeneous, finely speckled to cloudy reddish or yellowish clay with a weakly speckled or undifferentiated b-fabric (Stoops, 1983, Stoops and Buol, 1985), the older egg-yellow and more hyaline, showing in situ iron segregations (hypocoatings) and coatings and infillings with microcrystalline gibbsite, proving a subrecent leaching.

One of the most striking processes in this profile is pedoplasmation. It is visible in the deepest layer as channel infillings perturbating the relic rock structure. The infillings are characterized by a crescent-like internal fabric, composed of alternating layers with a rather contrasting composition and color ; in many cases, they are richer in sericite than the surrounding matrix. The lowest pedoplasmation layer therefore has still a heterogeneous aspect, characterized by a crescent-like distribution of different materials. If impregnated by iron oxyhydrates, this fabric is "frozen" and remains preserved in mottles and nodules higher in the profile. Gradually, this fabric is destroyed by new generations of passage features, which become more and more homogeneous, so that only the crescent-like orientations of sericite flakes are visible, no longer their crescent-like distributions. The so formed matrix gradually changes from grayish to yellowish.

The first iron segregations in the saprolite occur as a concentration of small (about 25 µm) hematite granules (called "plinthitic hematite" by Schmidt-Lorenz, 1978). In the plinthite the mottles are formed by a concentration of fine dispersed hematite embedded in a halo of goethite. Once a yellowish groundmass appears, no plinthitic hematite seems to form anymore. The hydromorphic conditions responsible for the formation of these mottles are to be considered as fossil, since thin, yellowish illuviation clay coatings penetrate the soil material till the deepest layer, without being affected by the hydromorphism.

6. CONCLUSIONS

The micromorphological study of the profile shows that the lowest part is formed by weathering in situ of a relatively homogeneous parent material derived from phyllites. Beginning from the upper plinthite layer, an addition of similar material, transported over a short distance, most probably by colluvionation, has to be taken into consideration, whereas the petroplinthite clearly contains elements of foreign origin. Mineralogical analyses alone will not allow the derivation of these conclusions, because of the high degree of weathering and the similarity between the parent material and the allochtonous material. Micromorphology has proven to be a very usefull tool in this study.

The apparently simple profile proves to be rather complicated and polygenetic. Weathering has alternated with hydromorphism, pedoplasmation, Al-translocation and clay-translocation, in addition to the above mentioned colluvionation.

From a micromorphological point of view, the different steps of pedoplasmation, and the formation of gibbsite rosettes by in situ desilicification of the kaolinite matrix are most instructive, as they are helpful in disentangling the chronological sequence of events.

ACKNOWLEDGMENTS

The authors want to thank Mr. C. Landuyt for his valuable help during the study of iron minerals and to Dr. R. Vandenberghe (Laboratorium voor Magnetisme - R.U.G.) for providing the Mössbauer data. This research was carried out in the frame of grant n° 2.9010.88 of the National Fund for Scientific Research (Belgium).

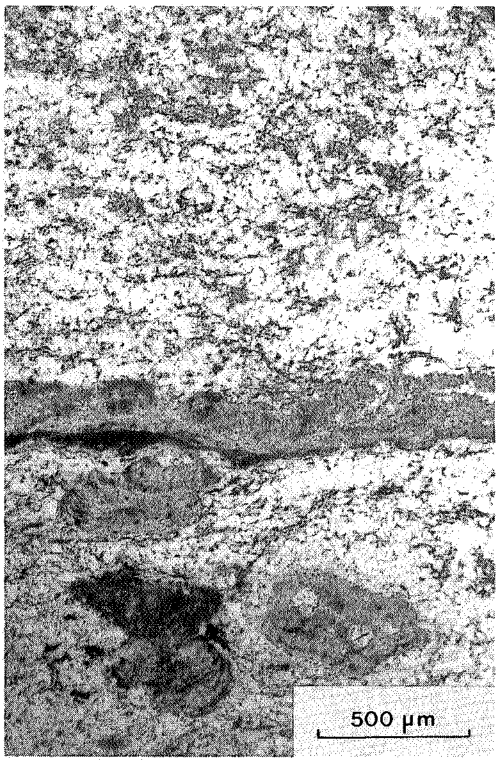
PLATE I

1. L2 : Vague relic microfoliation and bioturbations (grayish) with crescent-like internal fabric. Diffuse rounded spots are gibbsite rosette. PPL.

2. L1 : Kaolinitic saprolite with relicts of foliation and sericite rich bioturbations. PPL.

3. id., detail of bioturbations with crescent-like fabric ; the white spots and lines are infillings of coarse gibbsite. PPL.

4. id., XPL. Gibbsite crystals are visible as white linings.



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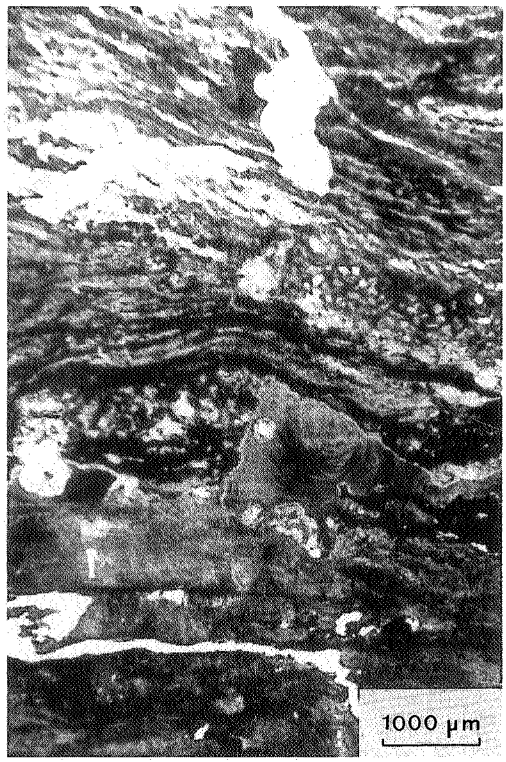

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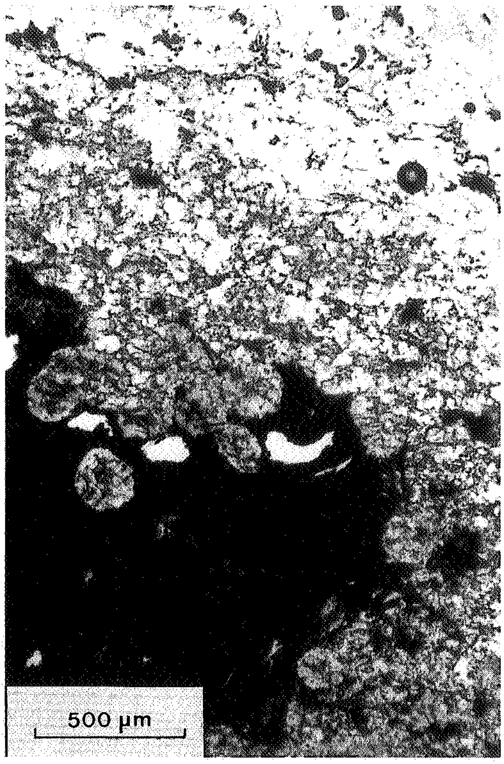
PLATE II

1. L2 : Undisturbed saprolitic material with gibbsite rosettes, invaded by iron oxides (black on micrograph). PPL.

2. id., XPL. The radial fabric of the gibbsite rosettes is clearly shown by the extinction figures.

3. L3 : Plinthitic rock fragment with saprolite fabric (center and left) and crescent-like bioturbations (left upper part) in homogenized groundmass. PPL.

4. L4 : Relic fragment of kaolinitized saprolite with foliation, and hematite impregnated bioturbations (right upper corner). PPL.



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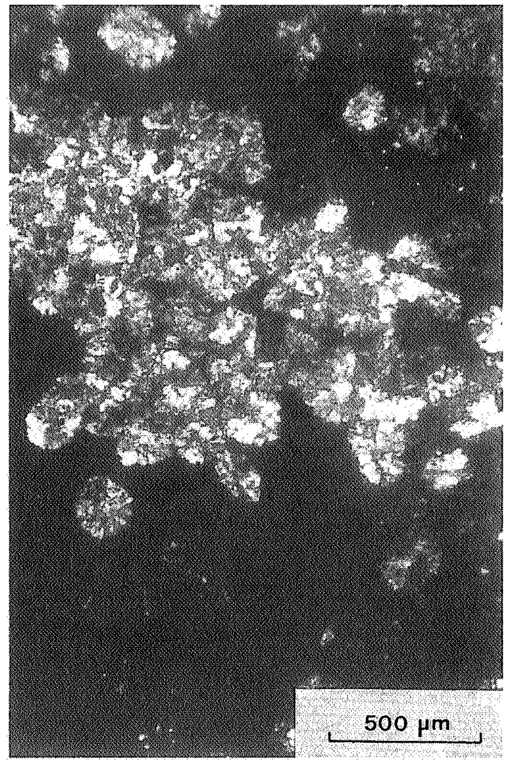

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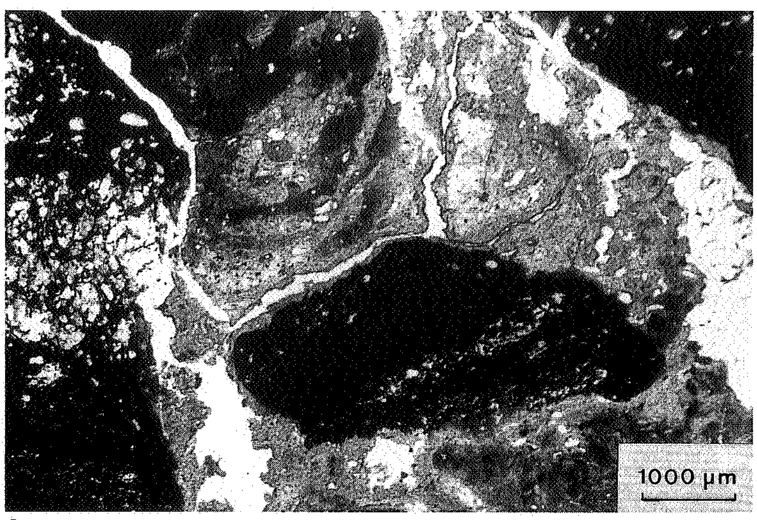

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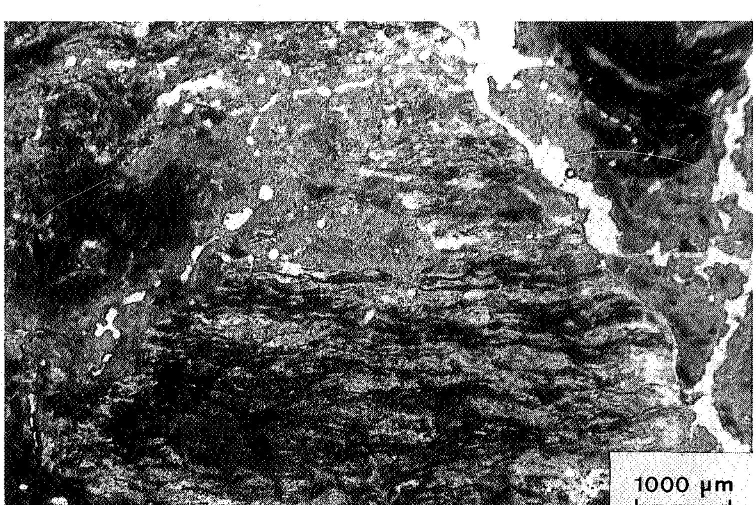


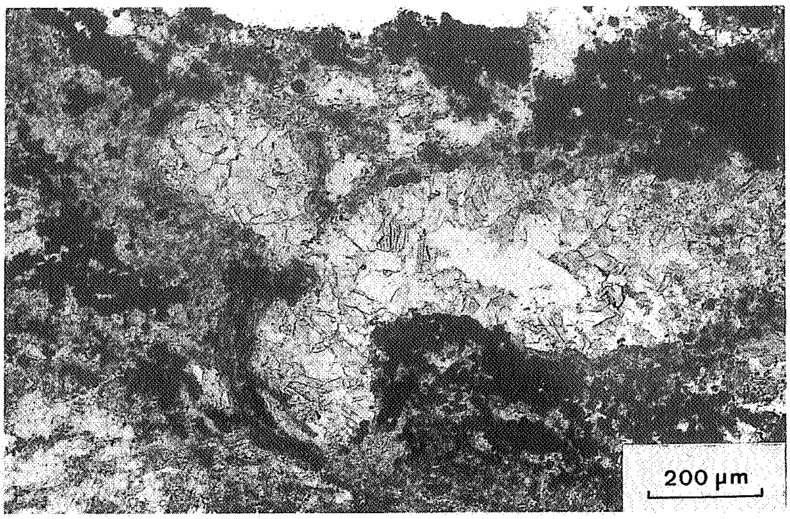
4

PLATE III

1. L1 : Biopore with neoformed gibbsite infilling (PPL).

2. id., detail of gibbsite crystals. SEM.

3. L5 : Corroded quartz grain. Note void between grain and matrix at the right side of the micrograph. SEM.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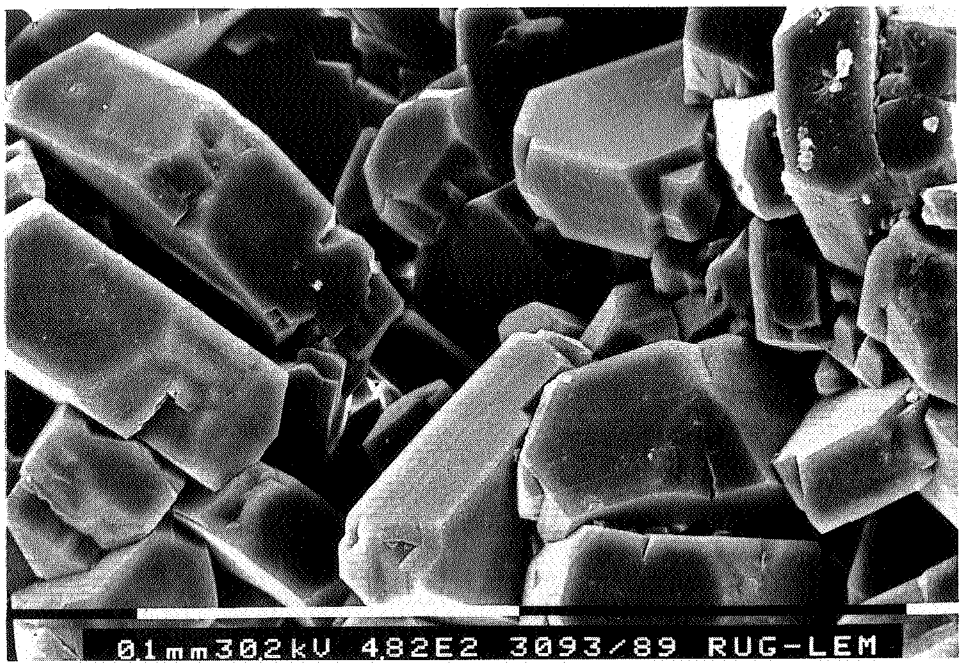
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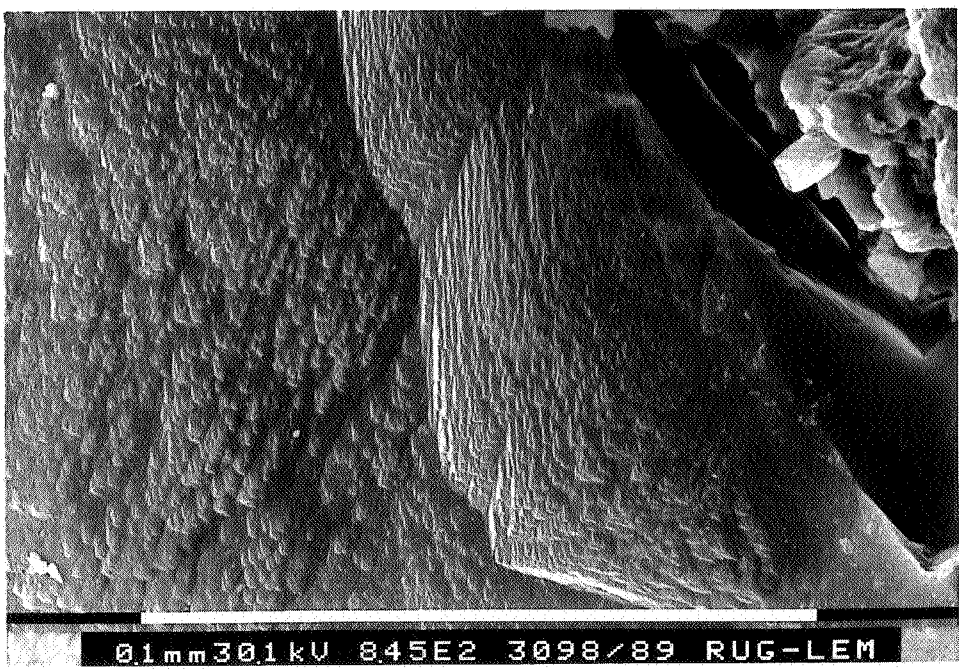
2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3

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Manuscript received on 17th May 1990 and accepted for publication on 15 June 1990.