APPLICATION OF MICROMORPHOLOGICAL METHODS TO THE STUDY OF SOIL SEQUENCES IN THE TROPICS

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Summary: Soils in the tropics derive their characteristics mainly from their exceptional parent material: deeply weathered saprolite. Soil material is formed by pedoplasmation of the saprolite deleting the rock fabric and homogenising the material. As a result of environmental changes phases of erosion and deposition have alternated, resulting in a complex regolith comprising a stone-line and a cover. The overwhelming influence of the saprolitic parent material on the soil characteristics is demonstrated by a comparative study of two soil sequences, one on saprolite and one on uplifted coral reefs in Indonesia.

The characteristics of two profiles in contrasting positions of a toposequence on saprolite in Kalimantan are dominated by the influence of the preweathered parent material. The sequence on uplifted reefs in Ambon clearly shows that in fresh weathering products other soil forming factors, such as age, have a dominant impact.

An effort has been made to compare the presented data with the ideas of the late Kubiëna.

Key words: Indonesia, coral reef, micromorphology, pedoplasmation

1. INTRODUCTION

Although Oxisols represent only a small part of the soils found in the humid tropics, they are generally considered as the most typical expression of soil formation under warm humid conditions. This may be partially so, but in most cases their characteristics are the result of soil formation in an old preweathered material (Stoops 1989). Indeed, they are formed mainly on very old, relatively stable land surfaces (Buol *et al.* 1980) that have been subjected to at least two, generally more cycles of pedogenic weathering. In the, at present, temperate zones of the higher latitudes (e.g. northern and western Europe, Canada, most of the USA) such regoliths with old weathering products are practically absent as these materials have been removed during the glaciations, or were rejuvenated by eolian products. In general, but not exclusively, one can state that Oxisols (and associated Ultisols) are rather the result of a specific parent material (strongly weathered saprolite) than that of the influence of the present day climate. This hypothesis is supported by the study of soil sequences on young valleys cutting old geomorphologic surfaces (e.g. De Coninck *et al.* 1986). Interpretation of profiles on such slopes however is commonly complicated by the action of specific surface processes. Comparative study of soils on old plateau's and young parent materials (e.g.volcanic ashes, recently emerged surfaces) with soils from higher latitudes lead to a same conclusion.

2. THE TROPICAL REGOLITH PROFILE

2.1. General

In situ formed zonal soils in the humid tropics, apart from those on recent alluvial or volcanic deposits, develop in the upper part of a regolith or weathering profile, that can extend tens of meters in depth. The actual soil may be only a few meters deep and is developed in a pedoplasmated material. Below the front of pedoplasmation the rock structure becomes visible in the soft saprolite, which grades through a more coherent and harder saprock into the fresh rock (Aleva 1994, Ollier and Pain 1996).

This is the ideal complete regolith profile, which in theory can be found all over the world. In reality however, depending upon age, climate and parent rock, some of the zones can be strongly reduced, so that for instance the front of soil formation coincides with that of weathering, yielding a soil directly in contact with the parent rock. This is frequently the case in temperate soils, or in soils on active slopes.

In the humid tropics most regolith profiles are polygenetic, and have a typical feature: a "stone-line" or "stone-layer", corresponding to an old buried surface, beneath a so called "cover" (Fig. 1). The present day soil formation takes place in the "cover". The genesis of this stone-line and cover is not yet unambiguously explained, but it becomes more and more evident that there will not be one single explanation, but several, depending upon the situation. The two most popular theories are (i) the action of termites, and (ii) the process of micropedimentation. Most probably both processes are active, but depending upon the environment one will be dominant. In the case of the termite theory (de Heinzelin 1955, Stoops 1967, Soyer 1987, Stoops 1987) it is supposed that the cover results from the destruction of many generations of large termite mounds by micro-erosion. As the termites go up to 30 m depth to search for moist material to construct their mounds, new material is constantly added to the cover. This explains

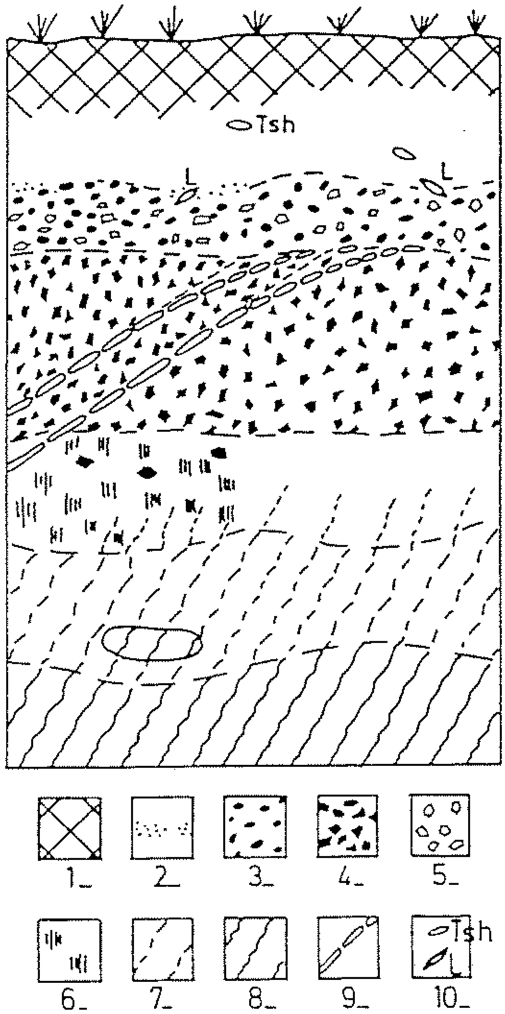

Fig. 1. Regolith with stone-line and cover. 1: epipedon; 2: cover, with coarser zones near the bottom; 3: rounded iron oxyhydrate nodules in transported part of stone-line; 4: angular iron nodules in *in situ* part of stone line; 5. detrital rock fragments; 6. mottled clay; 7. saprolite with boulder; 8. fresh rock; 9. chert band or quartz vein; 10. stone implements (L: Lupembian; Tsh: Tshitolian age). After Stoops 1967.

Table 1. Some data on two soils on mixed igneous rock from Pleihari (Indonesia) (extracted from Utami 1992).

Characteristic profile	Top	Footslope
Vegetation	conservation park	sugarcane plantation
Classification	Inceptic Hapludox	Inceptic Hapludox
pH H2O in A_1	4.69	5.02
B_{ox}	4.92	5.43
pH Kcl in A_1	4.21	4.90
B_{ox}	4.49	5.64
Fe_2O_3 $_{DCB}$ in % in B_{ox}, (soil)	9.86	12.63
(clay)	18.57	14.23
Sand in % in B_{ox}	7	8
Silt	38	25
Clay	57	67
CEC in $cmol/kg^{-1}$ in B_{ox}	6.60	8.55
Base saturation in % in B_{ox}	4.60	22.11

The heavy fraction of the fine sand is dominated by opaques (>94 %), the rest being ubiquists (zircon, tourmaline and rutile), the light fraction is dominated by quartz (94 - 99 %) with only a few grains of feldspar. The silt fraction of both profiles contain quartz, kaolinite and sesquioxides (goethite, hematite and gibbsite); the clay fraction contains kaolinite, goethite, hematite, gibbsite and quartz. In the hilltop profile traces of mixed layer minerals of the type mica/vermiculite were found, whereas in the footslope profile traces of mica/smectite mixed layers were noticed.

Although the profile on the top of the hill shows in the field clear signs of rejuvenation by surface erosion, as indicated by the presence of a large amount of saprolite gravel, the micromorphological characteristics reflect in the first place a strongly weathered and bioturbated material, typical for Oxic materials. In thin sections the presence of soft fragments of weathered rock is still more striking than in the field (Fig. 2), as they are much easier to recognise by their fabric than by their colour or consistency. The groundmass is characterised by a weakly to moderately developed granular and subangular blocky microstructure and a reddish brown cloudy micromass, composed of clay and iron oxides, with undifferentiated b-fabric.

The soil on the footslope shows a moderately developed subangular blocky microstructure, even in the Oxic horizon, and the micromass is a reddish brown cloudy clay with a weakly poro- to granostriated b-fabric superposed to a speckled one (Fig. 3). Coatings of fine reddish clay, although present, are restricted to less than 1 % by volume. The other profiles on the slope, not presented in this paper, have intermediate characteristics.

The differences noticed in physical and chemical characteristics are thus reflected in the micromorphology, for instance the denser microstructure in the profile on the footslope, and especially in the more developed b-fabric in the same profile. The characteristics of the strongly preweathered parent material are dominant over those provoked by rejuvenation and lateral transport of elements.

3.2. Soils on coral reefs

Very few information exists on soils formed on coral reefs, and the only micromorphological data found concern New Guinea (Brückner and Schnütgen 1995). For this reason a sequence of two profiles from Ambon (Indonesia) was studied in detail (Devnita, 1993). Their micromorphological characteristics will be compared with those of soils on chalk in a temperate region.

The two soils on uplifted coral reefs of Quaternary age are respectively a Dystric Cambisol (Hitu profile) and a Haplic Luvisol (FAO 1989) (Wailiku profile). The reefs of Quaternary age have been subject to an uplift. The most significant characteristics, of importance for the further discussion, are mentioned in table 2.

X-ray diffraction of the rock samples shows only calcite. The dissolution residue contains mica, quartz and minor amounts of kaolinite, feldspar and vermiculite. The clay fraction of the soils contains mainly kaolinite and and hydroxy-Al interlayered vermiculite and, in the Hitu profile, minor amounts of gibbsite, and chlorite. The silt fraction of both profiles is composed mainly of quartz, hydroxy-Al interlayered vermiculite and kaolinite, with in the Hitu profile also important amounts of gibbsite. The heavy mineral fraction consists mainly of opaques (92 - 98 %), with minor amounts of garnet, staurolite, kyanite and zircon as stable minerals, even as augite and diopsite, which are more concentrated in the top layers and probably of younger volcanic origin.

Thin section studies show that the reef consists of a porous micritic limestone with many remnants of recrystallised fossils (corraline algae, foraminiferans, molluscs, gastropods, echinoderms, bryozoans). Coatings and infillings of coarse calcite in pores point to later chemical precipitations. Few detrital grains (200 µm) of quartz are recognised. In both profile some thin coatings of weakly oriented clay are observed in the pores (Fig 4).

The microstructure of the Hitu profile ranges from angular blocky in the B/C to complex blocky and granular in the A_{11}. The micromass is reddish, finely speckled and cloudy in the subsoil but dotted in the A_{11}; its b-fabric is very weakly expressed or undifferentiated. A few small coatings of limpid reddish clay are observed throughout the profile (Fig. 5). Of special interest is the B/C horizon which is very heterogeneous, consisting of yellow en reddish clay zones, and dotted yellowish grey zones. The latter contain

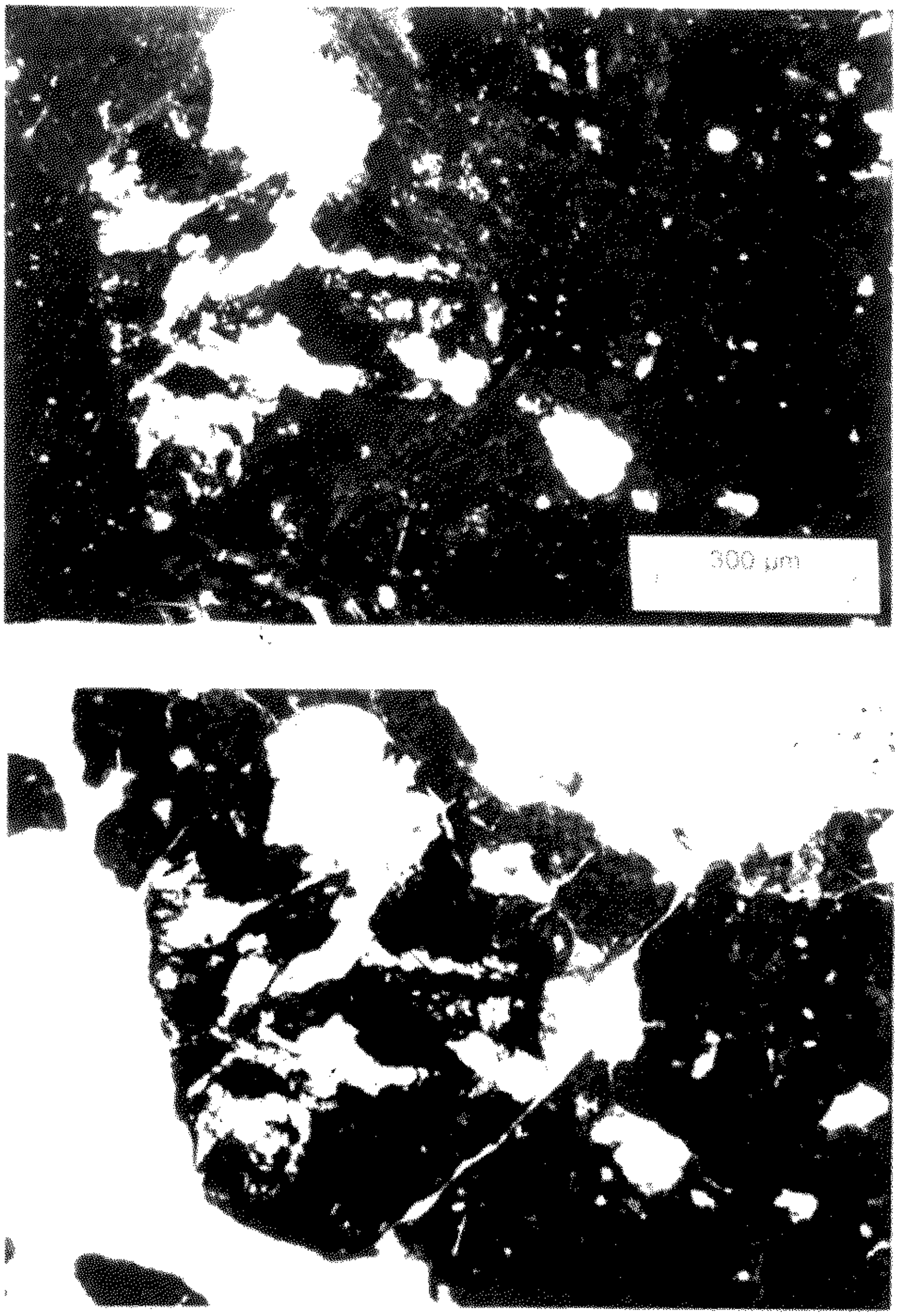

Fig. 2. Micrograph of rock fragment with gibbsite pseudomorphs in A horizon of profile on hilltop in Pleihari. PPL and XPL.

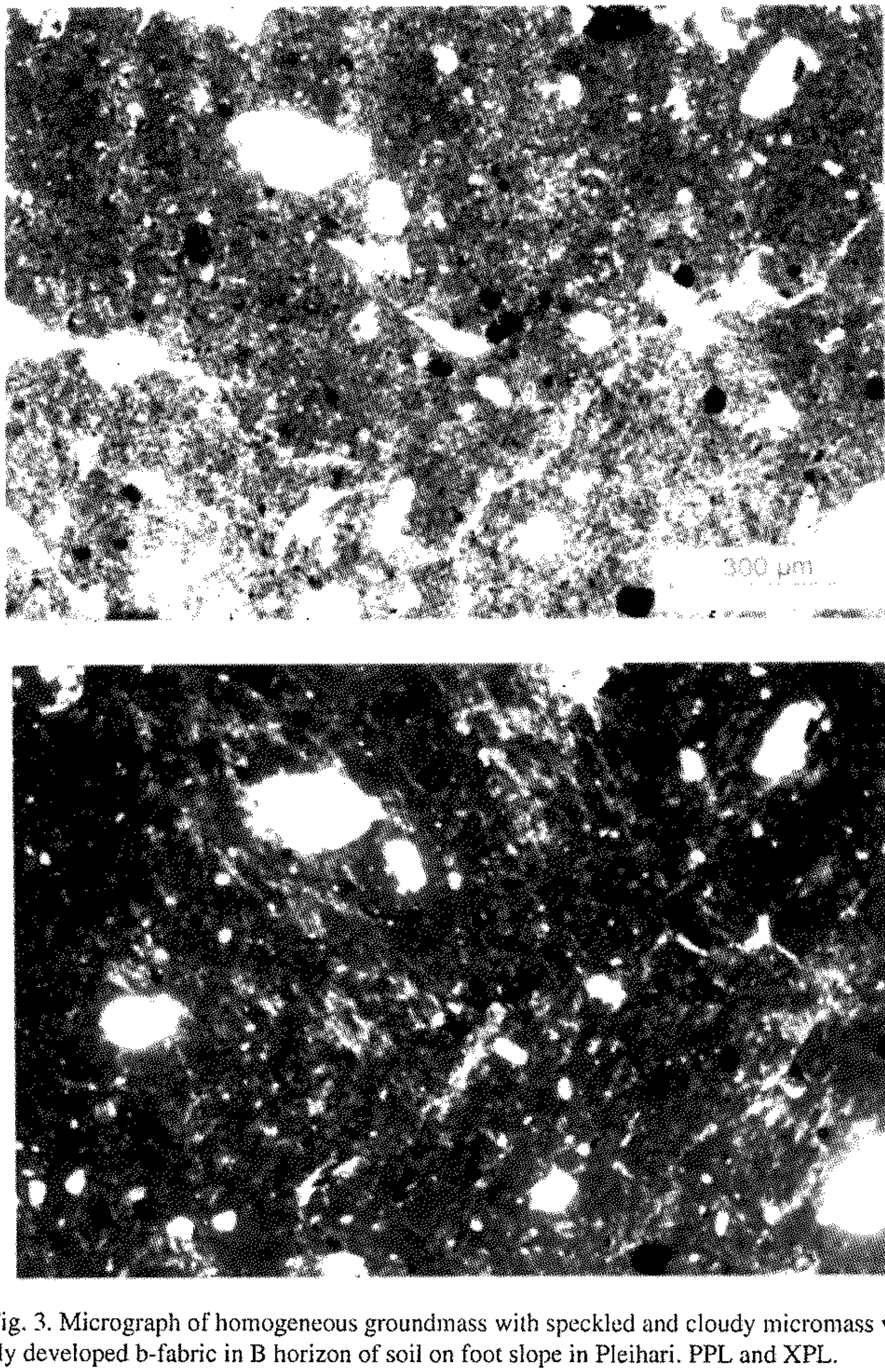

Fig. 3. Micrograph of homogeneous groundmass with speckled and cloudy micromass with weakly developed b-fabric in B horizon of soil on foot slope in Pleihari. PPL and XPL.

Table 2. Some data on two soils on uplifted coral reefs from Ambon (extracted from Devnita 1993)

Characteristic / Profile	Hitu	Wailiku
altitude a.s.l. in m	115	10
vegetation	clove plantation	mixed garden
slope in %	16	4
pH H_2O in A_{11}	5.7	7.5
in B/C	5.3	5.7
Fe_2O_3 DCB in soil in % (B/C)	25.36	9.38
Fe_2O_3 DCB in clay in % (B/C)	26.21	9.20
Fe_2O_3 ox. in clay in % (B/C)	7.78	4.84
Total sand in % (B/C)	0.40	4.20
% heavy minerals in sand (B/C)	6.62	0.75

many sericite flakes and are relatively rich in quartz; their micromass has a strong stipple speckled b-fabric. These zones can be compared with the inclusions of limestone dissolution products at the basis of clay with flint as described by Stoops and Mathieu (1970). Fe-Mn-hypocoatings point to weak hydromorphic conditions at the contact with the reef.

The microstructure of the Wailiku profile is mainly angular blocky, with intrapedal channels. The micromass consists of a finely speckled egg-yellow clay with well developed b-fabrics, mainly mosaic speckled, with some parallel striated zones in B/C and very strong crescent striated b-fabric in the B22 (Fig. 6). Clay coatings are relatively rare and thin. In the B/C irregular, diffuse nodules of reddish micromass are observed. The A_{11} is very heterogeneous, with material ranging from yellow over brown to dark brown; the latter is heavily dotted with organic particles and has an undifferentiated b-fabric.

The Wailiku profile clearly shows the characteristics of a Kalkstein Braunlehm *sensu* Kubiëna (1948), whereas the Hitu profile is a typical example of a Rotlehm. The difference can be explained by their age: the slightly tilted

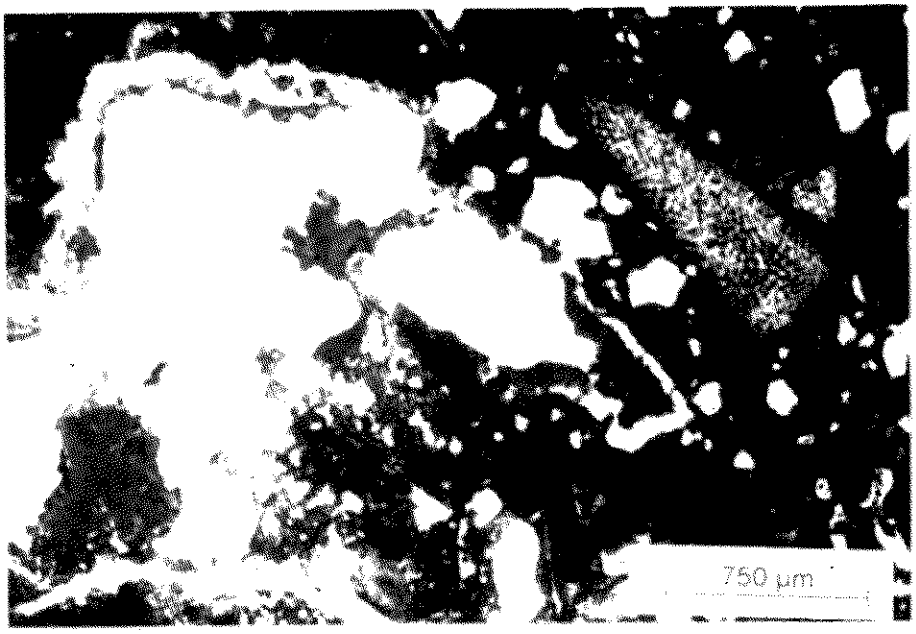

Fig. 4. Micrograph of coral limestone with disrupted coating of clay in macropore. PPL.

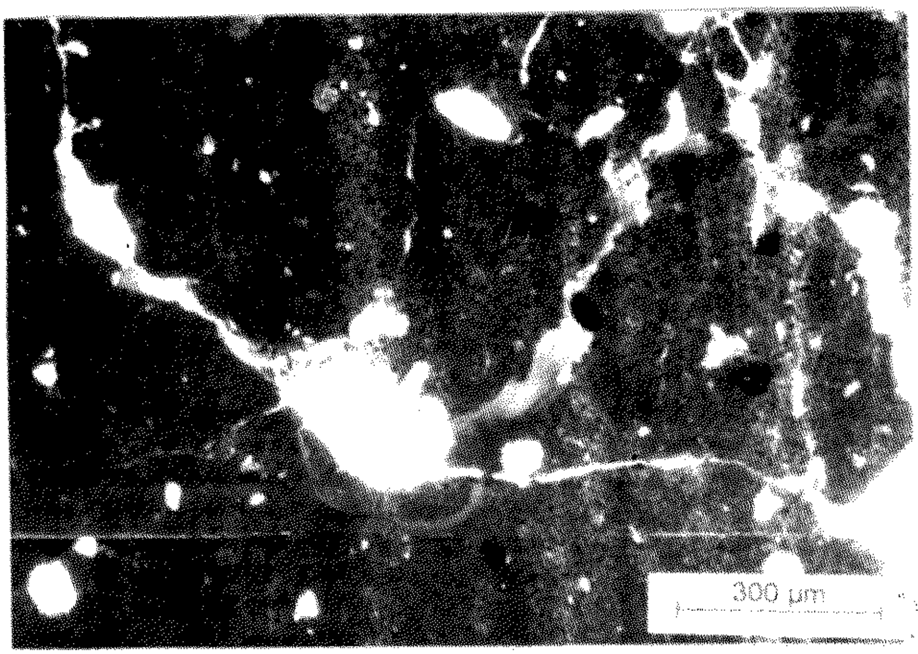

Fig. 5. Micrograph of homogeneous reddish groundmass in B-horizon of Hitu profile with fragment of clay coating. PPL.

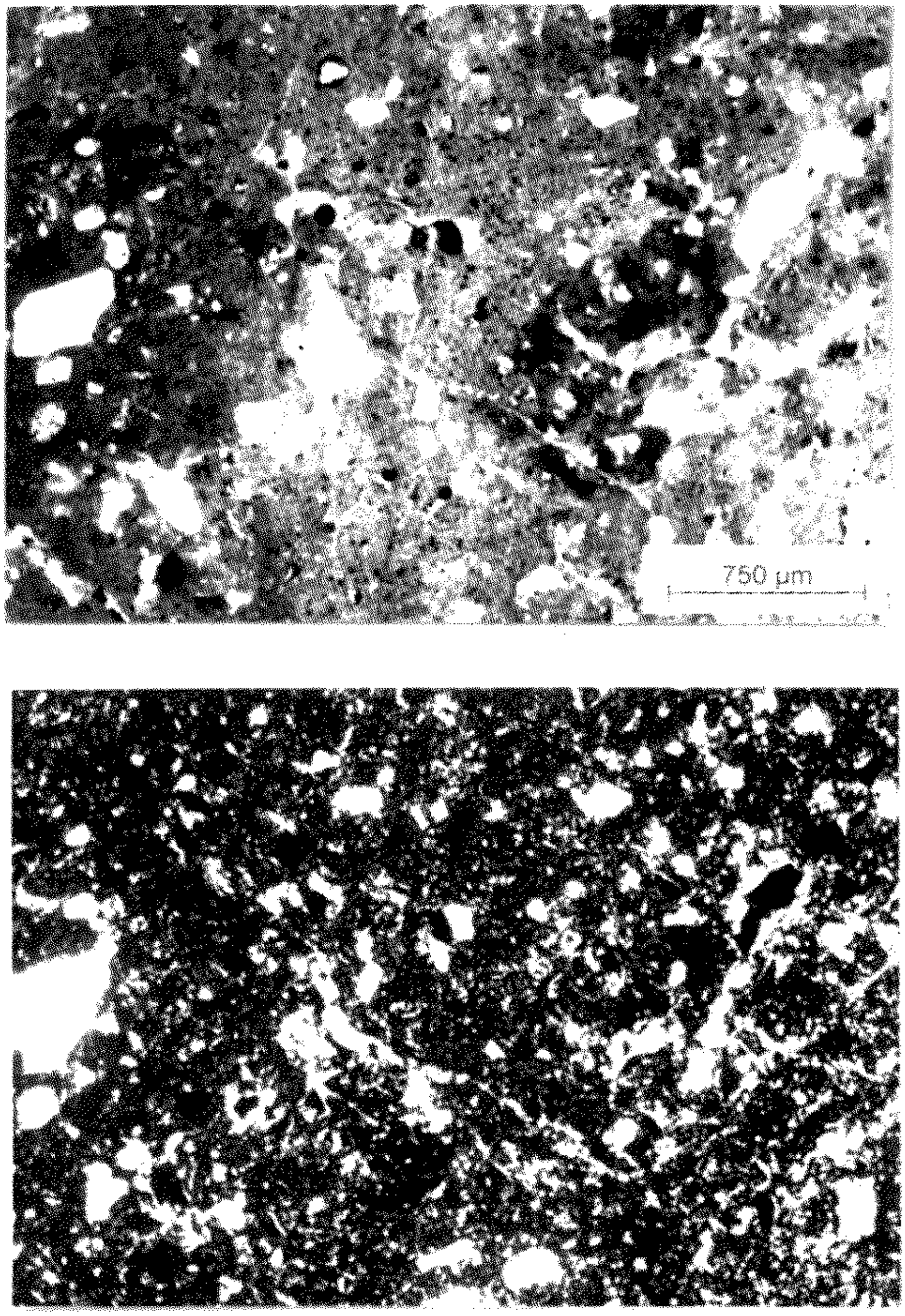

Fig. 7 Micrograph of diffuse reddish nodules in B/C-horizon of Wailiku profile, pointing to a starting rubefaction. Note also the presence of thin coatings of strongly oriented fine clay. PPL and XPL.

to Kubiëna's Rotlehm, whereas the younger is clearly a Braunlehm, indicating that the difference between both soil types can be also explained by a factor of age, and not only climate

As a conclusion one can state that in the sequence on limestone a differentiation between the profiles was possible because they formed on fresh material, whereas in the toposequence from Kalimantan soil characteristics are so much dominated by the preweathered status of the parent material that differences in other forming factors are practically oppressed..

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