Micromorphological and Mineralogical Reconstruction of Tertiary Saprolite and Soil Formation in the "Vogelsberg" Basaltic Region (Site Lich/Oberhessen, Germany)

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ABSTRACT: Noticeable red and brown soils are developed on the western periphery of the Vogelsberg Mountains. They came early to be considered as relics of Tertiary weathering processes of basaltic rock. In their colour and composition they resemble certain tropical soils. In the "Eiserne Hose" ("iron pants") bauxite pit, an accumulation of redeposited red soil material up to 7 m thick is visible in the northern wall. This accumulation is interspersed with "Bauxite Bulbs". Drilling uncovered 30 m of an isomorphic decomposed basalt, the so-called "Saprolite". In the western part of the pit, this pale grey saprolite almost reaches the surface and passes upwards into red loamy soil. The transition from the saprolite downward to fresh basalt has not been observed.
The original parent rock can be reconstructed by means of micromorphological study applied to undisturbed saprolite samples. In addition, these methods are suitable to uncover the mineralogical, petrographic and pedogenetic links and relations hidden in the entire sequence "Basalt–Saprolite–Soil".
The saprolite contains no remaining primary silicates. Its groundmass consists mainly of clay minerals, predominantly kaolinite. Phase and interference-contrast microscopy, however, shows that the silhouettes of former feldspars as well as pyroxenes are preserved. The transition zone from the grey saprolite upward to the red "Loam" was obviously formed in situ. Fine reddish clay material forming coatings and pore fillings is the most prominent feature.

KEY WORDS: Basalt, saprolite, mineral weathering, soil formation, optical microscopy, phase contrast.

Introduction

The tertiary "Red Soils" on the western periphery of the Vogelsberg Mountains were subjected to intensive relocation processes during the long time since their formation. Their original structure, therefore, is only rudimentarily preserved, if at all. Younger pedogenic processes and admixing of alien materials must be also taken into account. All this makes the comprehension of their development very difficult.

Due to their local occurrence and mineral composition, these red soils were early considered to have formed from basaltic rock or decomposed basalt ("Saprolite") and to be similar to tropical soil formations, especially to laterites (Schottler 1918, Harrassowitz 1921 and also Schönhals 1954). Later, these soils were intensively studied by Schellmann (1966) and Wirtz (1972). Today, most striking are the different names these soils received over the years (Latosols, Red Lateritic Soils, Red Plastosols, Red Loams etc.). This doubtlessly is partly due to the different and lately revised pedological nomenclatures, but probably to an even greater extent is due to the uncertainties concerning their origin.

Studies of their microscopic fabric are still mostly lacking although they would be well suited to uncover the mineralogical, petrographic and pedogenic links and relations hidden in the sequence "Basalt–Saprolite–Soil". Based on the site "Eiserne Hose", Altemüller and Poetsch (1984), to be followed by Schwarz (1987, 1988), demonstrated the importance of thin section microscopy. The present paper is based on these works and on our own micromorphological studies.

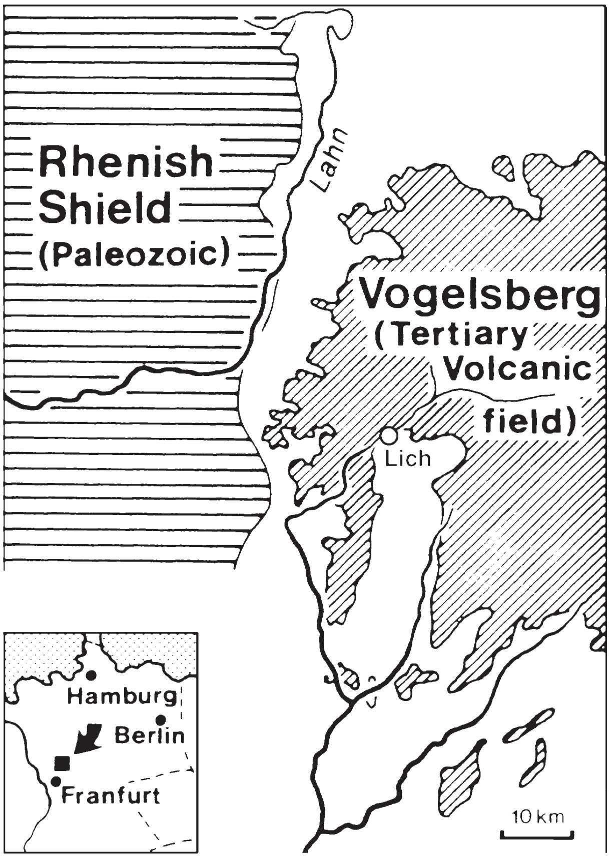

Fig. 1. Location Map.

The site "Eiserne Hose"

In this former bauxite pit, about 2 km east of the village of Lich (see Fig. 1), "Red Lateritic Soil" is exposed as a 7 m thick accumulation of debris, mined till 1975 (Photo 2). The soil is interspersed with the so-called "Bauxite Bulbs", and, deeper down, with fragments of brown iron crusts. The transition from this soil to the underlying saprolite is not visible. The saprolite, generally pale to whitish-grey, partly changed in colour due to infiltrations, can be still found in the western part of the pit, reaching almost to the surface (Photo 1).

If not disturbed by mining, which is still active to some degree, this material passes upward into red loamy soil (Fig. 1). Due to its micromorphological properties, Altemüller and Poetsch (1984) considered this soil to be autochthonous.

Saprolite and the reconstructed parent material

The light, whitish-grey groundmass, already recognizable with a magnifier (10x) on fresh fragments, becomes totally translucent in thin sections with plain transmitted light. Due to the very similar refraction of the matrix and the impregnating medium (1.55–1.56), the matrix becomes mostly invisible (Photo 3). Its birefringence is very small (0.003–0.006, Photo 4). The internal structure of the matrix becomes visible only with phase contrast and with interference contrast (see the general papers of Altemüller 1974 and 1997). Then, a cellular, porous composition of layered networked material is visible, which can be considered kaolinite clay due to its optical properties, together with optically amorphous components. These properties predominantly stem from the alteration of plagioclase, as becomes obvious by comparing various basalts from the surrounding area. The outer shape of plagioclase is still partly retained as a kind of pseudomorphism (Photo 5). Nevertheless, association of certain forms of plagioclase with the still existing features is not possible. Our observations indicate that andesine with marginally increased Na content is the most prominent among them, as it also dominates the compared rocks.

Former pyroxenes, displaying their typical aggregated arrangement, show a clear pseudomorphism as well. They have Fe/Mn-infiltrated edges with higher birefringence. Besides this, no traces on the former minerals are left (Photo 6).

Very striking are the marked pseudomorphoses of olivine (see Delvigne 1998), here in the form of "Iddingsite" (mineralogically mostly goethite). The transition from olivine to iddingsite in basalt takes place before plagioclase and pyroxenes start to change. The shape and arrangement of iddingsite grains in the saprolite (Photos 3, 4) totally correspond to the shape and arrangement of olivine minerals in the former basalt. Due to its high stability against later pedogenic processes, iddingsite is of high diagnostic value.

These changes in the mineral composition (dissolution of minerals combined with partial or complete retention of the resulting pores, or intensive clay formation) contribute substantially to the considerable porosity of the saprolite (Photo 5). The physical measurements of pore volumes in soil yielded values of 60 % at a depth of 3.20 m, and 50 % at a depth of 1 m (Saprolite, western wall of the pit). The measurements of Häfele (1995) fall into the same order of magnitude with 59 % and 61 %, respectively.

The only mineral remaining unchanged is ilmenite (Photos 3, 4, 6). It is found in the form of small opaque plates, appearing as ledges in thin sections. Gibbsite was not found in the saprolite at first (before 1984). It was found later, after additional mining at the site when hardened, banked areas could be examined in the upper part of the saprolite stratum. They were filled with finely crystalline gibbsite. Schwarz (1987) points to a thin, exceptionally hard bauxite bank within the saprolite.

In the "Eiserne Hose" pit, the transition from the saprolite to the fresh or only partly weathered basalt was not found. The parent material, therefore, has to be reconstructed from the saprolite. Our first association with an alkaline basalt was not representative. We now agree with Schwarz, proposing a tholeiitic basalt. If the feldspars do not allow for an estimation, as is the case here, it is the content of olivine/iddingsite (max. 15 %) and ilmenite that speak for a tholeiitic basalt (using the data of Schricke 1975 as a basis).

Red loam remainders at the upper edge of the saprolite

Red loamy soil horizons – probably a Nitisol according to WRB (1998) – could be clearly seen in the past (Fig. 2) and are still preserved in very limited areas within the pit, although the majority

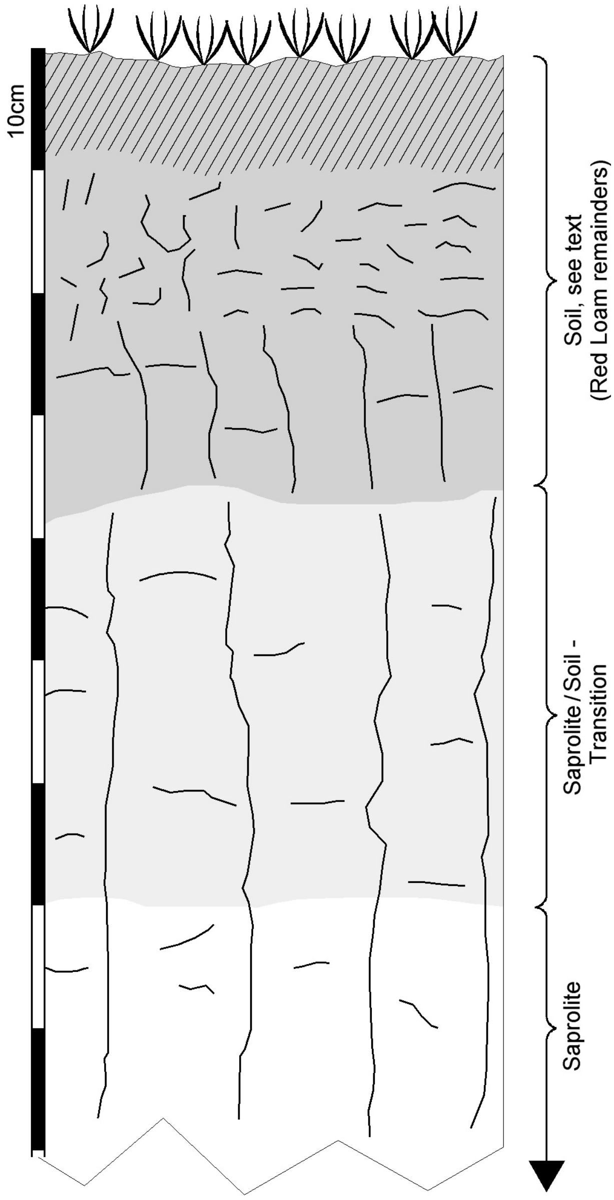

Fig.2. Saprolite / Soil-Transition (see Photos 7–9)

has been removed by mining. They fade effortlessly to the underlying saprolite. A very marked structuring can be observed into angular, smooth, clayey polyhedrons, homogeneously red to violet-red in their interior. Larger and more prismatically shaped cleavage blocks are found further downwards. They already show saprolite features in their interior, visible even with a magnifier, but are nevertheless more reddishly coloured. In thin sections, the interrelation with the saprolite can be proved well into the homogenous red zones. If observation starts from the saprolite, the colourless, porous, kaolinitic matrix with its pseudomorphoses of plagioclase and pyroxene disappears. The matrix is dissipated, probably more or less diluted as well, and infiltrated with reddish fine clay (Photos 7, 8, 9). The fragments of iddingsites drift apart but are preserved. Ilmenite is totally transformed. Its ledges, formerly opaque and black in transmitted light, disintegrate into small reddish, translucent flakes which are partially surrounded by highly refractive, achromatic, extremely fine-grained secondary minerals. By means of an Atterberg-cylinder, the fraction particularly rich in reddish iron oxides was extracted from the clay and silt fractions under a microscope. It consisted of iron-oxide aggregates 1–4 µm in size. In collaboration with the Institute of Geology of the University of Hamburg, this fraction and a pure hematite sample were compared by X-ray diffraction analysis. This revealed that the red fraction of 1–4 µm is relatively rich in hematite.

The achromatic formations are the so-called "Leucoxenes", i.e., titanium oxides, predominantly rutile. The relocated fine clay consists mainly of Fe-oxides rich in hematite, supplemented by poorly crystallized kaolinite and a minor amount of gibbsite.

These finds correspond very well with the results of microprobe analysis taken from three thin sections as shown in Table 1.

	spot number	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	TiO_2	∑
Red loam, sample EH-4198								
Clay matrix+leucoxene	16	26.34	22.17	3.26	0.03	0.02	**27.61**	79.82
Iddingsite	03	2.28	9.04	**68.28**	0.23	0.22	1.89	82.17
Clay matrix reddish	09	**35.95**	**27.84**	9.84	0.09	0.02	1.62	75.76
Clay coating	05	**32.45**	**32.31**	9.98	0.20	0.04	1.58	77.18
Saprolite, pale grey, sample EH-4204 + 4010								
Ilmenite	08	0.04	0.10	**53.11**	3.09	0.91	**46.95**	104.24
Ilmenite, corroded	05	0.09	0.08	**43.24**	2.67	0.27	**49.18**	102.11
Clay matrix+leucoxene	12	32.45	32.36	3.81	0.28	0.04	**5.70**	84.97
Iddingsite	07	2.56	9.00	**70.85**	0.25	0.43	1.20	84.41
Clay matrix, whitish	06	**46.22**	**36.20**	1.63	0.32	0.00	0.12	84.88
Clay coating	01	**36.09**	**31.30**	8.35	0.23	0.01	1.04	77.59

Table 1. Some representative data of X-ray microprobe analyses of thin sections. All data given in wt.%. X-ray microprobe analysis courtesy of Institute of Mineralogy and Petrology, University of Hamburg.

As already described in 1984, it is most likely that the red loamy clay which forms noticeable fillings in the upper and in the deeper part of the saprolite originates from a former horizon considerably thicker than the recent one. However, it certainly does not stem from an extraneous covering stratum, which would result in a different composition.

We are inclined to consider the "disintegration" of the saprolite structure as a weathering process, from which this mobile clay fraction emerges partially by dispersion. In addition, such a weathering process could explain the formation of gibbsite which is quite frequently found in clay coatings, but appears also as a separate horizon within the saprolite, as indicated above. Continued weathering could finally allow for a shift towards the "Red Earth" which is significantly poorer in silica and richer in Fe-oxides compared to the "Red Loams".

The weathering of ilmenite is of importance insofar as it allows the red hematite component to emerge. The studies of ilmenite weathering conducted by Anand and Gilkes (1975) in the pallid zone of Australian laterites showed that only the (Leukox)-components rutile and anatase were preserved, whereas the newly formed hematite fell subject to disintegration and eluviation. In our case hematite is stable.

The "Red Lateritic Soil"

The direct contact between the "Red Loam" as described here and the overlying "Red Lateritic Soil" is not visible. At the "Eiserne Hose" site, considerable differences were observed between the autochthonous "Red Loam" and the detrital red soil masses. The latter consist of more or less rounded, brownish-vermilion, earthy aggregates of different size in a quite loose composition.

Apart from the earthy, crumbly aggregates (Photo 10), some areas in the profile always break down into polyhedrons. These show externally a certain similarity to the red loams. Thin sections, however, show variable and irregular morphologies, which underlines the debris character of the material. Traces of the relocation processes can be found down to the 10µm size level. Of all the saprolite components, only iddingsite traces are easy to discern. The dominating matrix is strongly enriched in Fe-oxides, both irregular and detritus-like. In thin sections which are sufficiently thin, colour variations from reddish to yellowish can be observed, suggesting goethite and hematite. Both minerals were verified in this material by Shi (1989) by means of a very exact analysis of corrected X-ray diffraction diagrams. Clay coatings were found locally, almost identical to those described in the former paragraph dealing with the "Red Loams". It is, nevertheless, uncertain whether the areas with clay enrichment are to be considered as showing a relic structure.

Cleavage blocks macroscopically considered as "red loam-like" frequently show a dense, Fe-rich internal matrix under a microscope, without the typical features of illuviated fine clay. Nevertheless, such material can be considered a clay-deprived relic overlying a horizon of clay illuviation, because its basic similarity in material is out of question.

Photo 1. In the western part of the pit, the saprolite is exposed in a thickness of up to 3.5 m. To the right, in the lower part of the profile, indurated, gibbsitized strata are found. Years ago, the transition to a red-loam-like soil, rich in clay, used to be exposed in the upper part of the profile (see Fig. 2).

Photo 2. Relocated red soil material in the northern wall of the pit. This material is characterized by an admixture of irregularly distributed gibbsite bulbs, mm- to dm-sized.

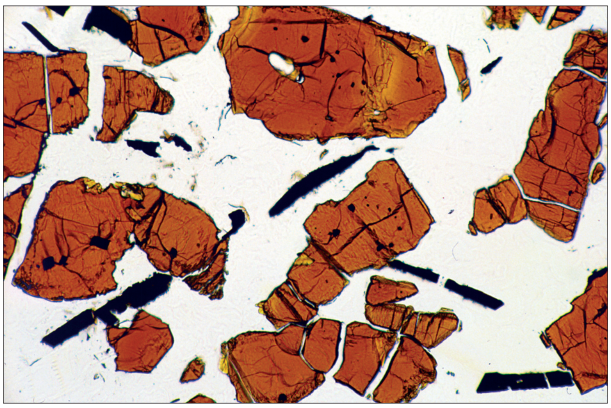

Photo 3. Saprolite, western wall of the pit, depth 3.30 m, thin section, plain polarized light (PPL). Reddish-brown iddingsite crystals, partially retaining the crystal shape of the former olivine, can be seen in the upper centre, opaque ilmenites with their characteristic thin tabular cross-sections are found within the bright matrix, 440×660 μm in original size.

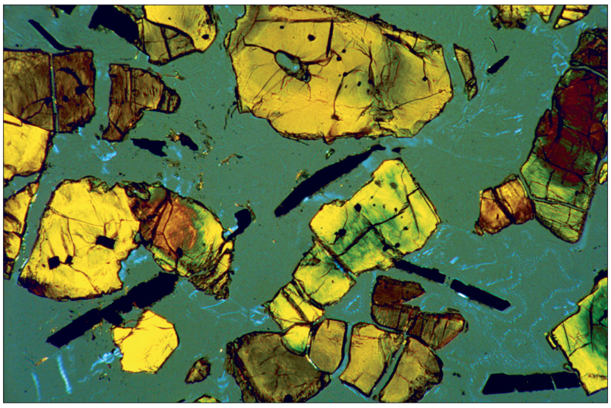

Photo 4. Same spot as on Photo 3, diagonally crossed polars. The matrix is characterized by its very low birefringence, 440×660 μm in original size.

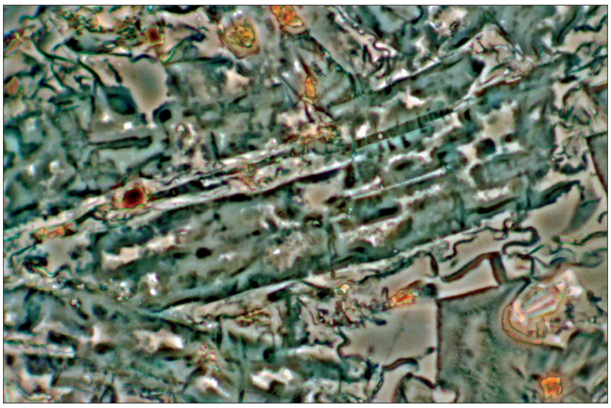

Photo 5. Saprolite matrix, western wall of the pit, depth approx. 1 m, phase contrast. The newly formed clay minerals (predominantly kaolinite) can be recognized by their bluish colour against a background of bright pores, which mostly represent dissolution caverns. Plagioclase is totally transformed into kaolinite, the original crystalline shape of the plagioclase, including the polysynthetic twinning is retained (see central part), 240×360 μm in original size.

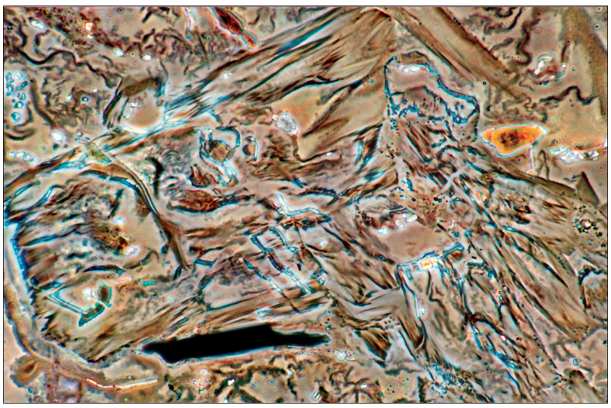

Photo 6. Saprolite, western wall of the pit, depth 3.30 m, phase contrast. The former pyroxenes are totally dissolved. The "cockscomb" shapes, proving a certain stage of pyroxene dissolution, are characterized by attached secondary iron oxides and some kaolinitic clay. Dissolution cavities dominate, 140×210 μm in original size.

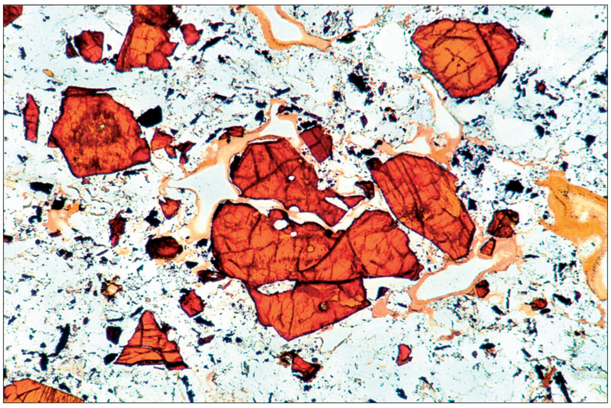

Photo 7. Transitional zone from saprolite to the overlying soil (see Fig. 2), western wall of the pit, **depth 55 cm**, PPL. The original saprolite fabric is only marginally disturbed. Coarse pores are clad with micro-laminated kaolinitic clay containing iron oxides, 700×1050 µm in original size.

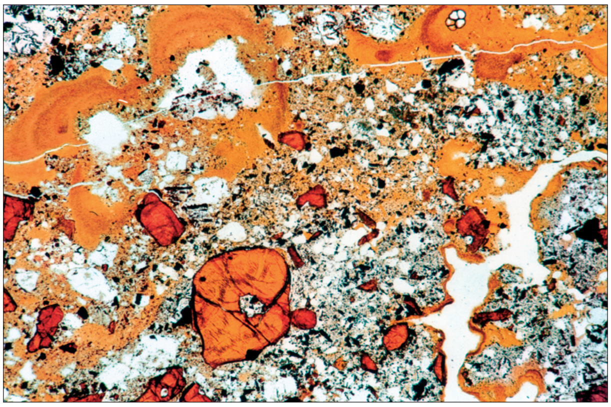

Photo 8. Same transitional zone, **depth 30 cm**, PPL. Iddingsite is broken up, mostly mechanically. Ilmenite is predominantly transformed into red iron oxides. The content of yellow-brown clay material increases. Clay cutans are mostly incorporated within the matrix, 700×1050 µm in original size.

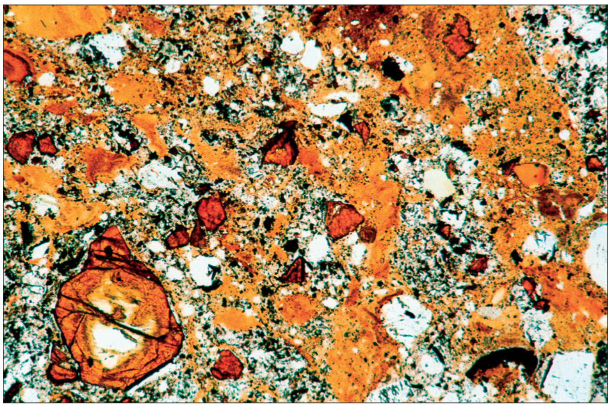

Photo 9. Same transitional zone, **depth 15 cm**, PPL. The formation of brown clay and the homogenisation of the material is more advanced here, 600×900 µm in original size.

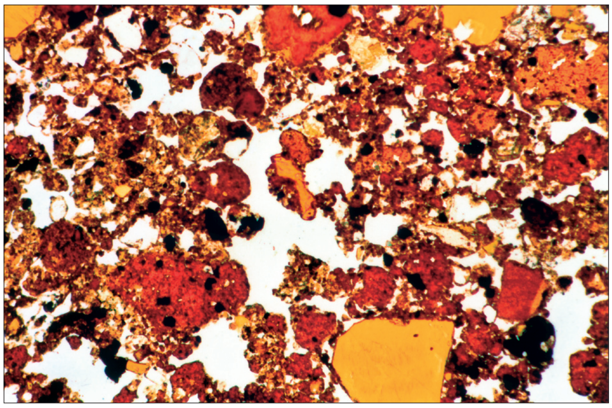

Photo 10. Characteristic red-earth-like material with very marked aggregation, northern wall of the pit, depth 5.50 m, 530×800 µm in original size.

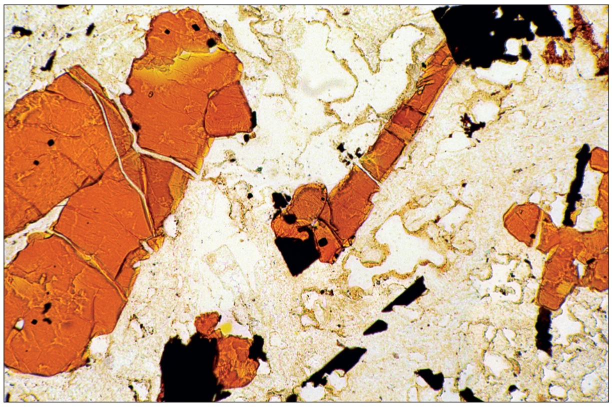

Photo 11. Red earth with bauxite bulbs, western wall of the pit, depth 30 cm, PPL. The fabric of the bauxite bulb, especially the spatial distribution of iddingsites and ilmenites, largely corresponds to the saprolite from the western wall (see Photo 3), 300×450 µm in original size.

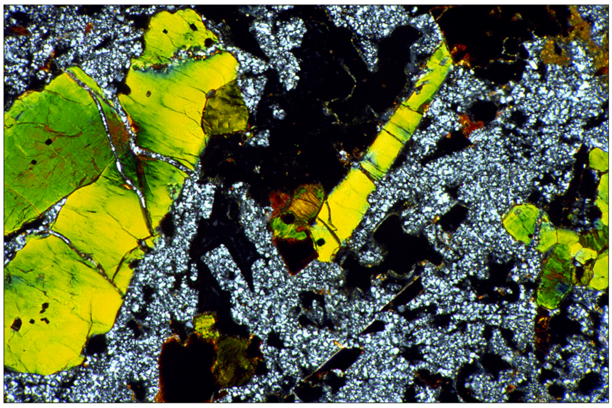

Photo 12. Same spot as Photo 11, crossed polars. The matrix of the bauxite bulb consists of gibbsite (fine crystalline, birefringent masses), 300×450 µm in original size.

Bauxite Bulbs

The internal fabric of the bauxite bulbs mostly resembles that of the saprolite as mentioned here, thus being close to the fabric of the original basalt as well (Photos 11, 12). Schricke (1975) already pointed to the basalt-like fabric of bauxite bulbs from the area of sheet "Londorf" of the geological map. Schwarz (1987, 1988) described several variants of them, which point not only to tholeiitic basalt, but also to basanite. Consequently, it must be assumed that they have been transported laterally over some distance. At any rate, the bulbs have definitely not been formed in the red soil. There is no doubt that the precipitation of gibbsite within the saprolite protected the ore component from weathering. Magnetite prevailing over ilmenite – or even magnetite alone – is frequently found in the bulbs, which is a hint to basanite-saprolite.

Conclusions

Considering the enormous variability of rock, saprolite and soil formations, considering also the long time involved, all research on that subject can only be seen as an effort to a stepwise approach. Here, methods of micromorphological study are indispensable.

- Concerning the reconstruction of the parent material from the saprolite, reliable statements can be made. Because of the frequent lateral variation of the material, this reconstruction is even more reliable than the deduction from the neighbouring rock forms.
- A close micromorphological relation exists between the saprolite and the studied "red loam"-like soil relics, which therefore can be considered autochthonous.
- A direct transition from saprolite to the "Red Lateritic Soil" cannot be presented yet.
- A link between the autochthonous "Red Loam" relic and the detrital "Red earth" (Red Lateritic Soil) is obvious as far as the material is concerned, but cannot be proposed particularly regarding the fabric because the "Red Earth" has been found in only relocated form yet.
- The bauxite bulbs are almost completely based on saprolite fabric. They originated, therefore, in the saprolite. In their larger cavities, more or less "protected" clay coatings are found. It is advisable to examine the fabric preserved in the bulbs more closely.
- The terms "Red Earth" and "Red Loams" etc. as they are used here, may be understood merely as descriptive terms. At this stage, they are not intended to express any form of typological classification. Neither is here anything decisive said on the "Laterite" subject.

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