ELSEVIER

Catena 21 (1994) 243–256

CATENA

The weathering of basaltic rocks in Burundi and Vietnam

L. Schirrmeister[a], M. Störr[b]

[a]Humboldt-University, Department of Geography, Universitätsstrasse 3b, 10099 Berlin, Germany

[b]Usedom Haus 11, 17406 Ostklüne, Germany

Abstract

Various stages of tropical weathering are described using a number of examples of red soil formation derived from rift basalts in Burundi and laterite bauxites from plateau basalts of South Vietnam. The phenomena of decomposition of primary minerals are comparable in the two regions. Fine-grained montmorillonites, kaolinites, halloysites and hematite were formed during an initial stage of weathering. The two generations of kaolinites, goethites and gibbsites are the main products of a more intense stage of weathering. The gradients of chemical activities in the micro-environment (surfaces of grains, pores, microfissures) seem to be the controlling factors of weathering.

1. Introduction

The weathering of basalts in the tropics is one of the exogenic alteration processes of rocks of the highest intensity. The study of the weathering of rift basalts in Burundi and laterite bauxites from plateau basalts in South Vietnam helps explain the processes of disintegration of the parent minerals and the formation of new minerals. There are no genetic relationships between the two areas. However both basalts are products of a younger volcanism and lie in regions with a recent tectonic uplift. In both these cases of tropical weathering the profiles have been described as well zoned groundwater laterites (according to Valeton, 1967).

The examples presented give evidence of various stages of this process of weathering. We have tried to illustrate the progress of tropical weathering from the initial disintegration of basalts to the final formation of laterite bauxite by comparing the data of these two examples.

Four profiles with altogether 22 samples from Burundi taken by one of the authors and three profiles with altogether 23 samples received from colleagues from Vietnam

SSDI 0341-8162(93)E0042-X

have been investigated by X-ray analysis, polarising microscopy, and scanning and transmission electron microscopy.

2. Geological situation

The Tertiary rift basalts of the Rusizi Plain in Northern Burundi (Fig. 1) are rocks formed by the volcanism of the western part of the East African Rift System (Miocene–Pliocene). The youngest rift-tectonics are characterized by a strong uplift of the rift shoulders. The effusion of volcanic rocks in the western rift was connected with a raising of the bottom of the graben (Lange, 1986).

These basalts belong to the South Kivu Volcanic Area. The basalt sheets with thicknesses of about 60 m, consist of six flows of a chemical and mineralogical

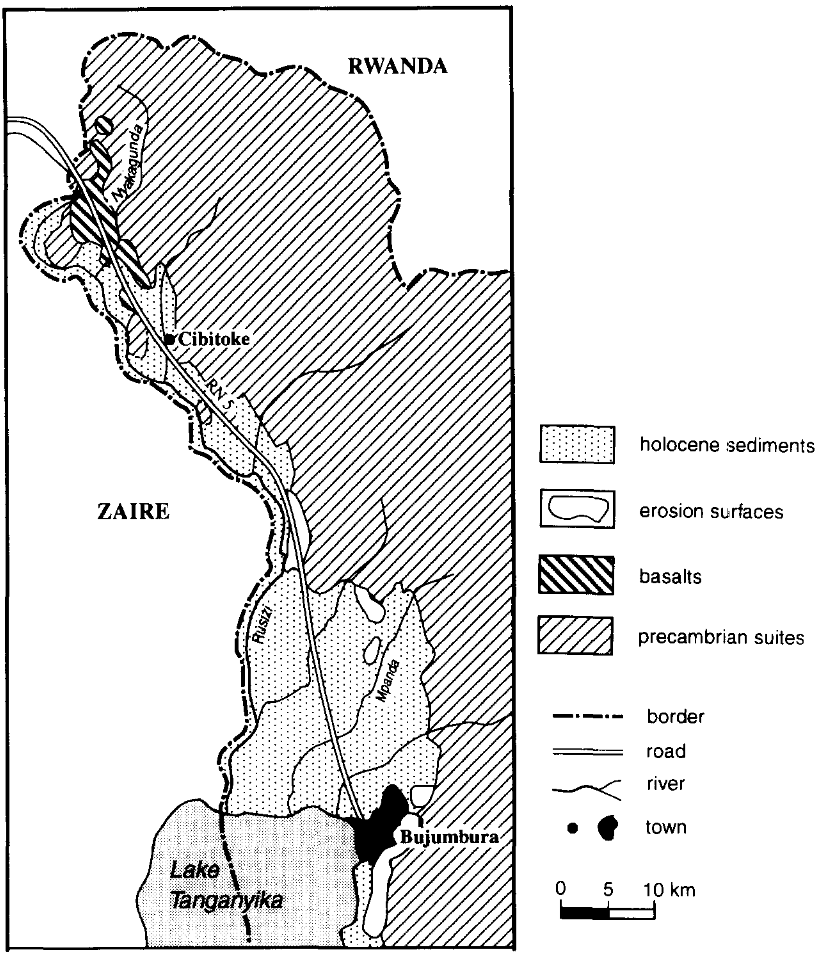

Fig. 1. Sketch map of the North-Burundi geology (simplified according to Radelescu, 1981).

composition varying from alkali olivin basalt to tholeiite (Tack and Paepe, 1983). There are tuffitic horizons between the basalt sheets. The weathering products of the basaltic rocks in Burundi are montmorillonitic–kaolinitic red soils and red–black soils with thicknesses of one to three meters.

The laterite bauxites from South Vietnam investigated are weathering products of plateau basalts (Pliocene–Pleistocene) (Tran Quang Tinh and Nguyen Thi Mui, 1986) of the M'Nong Plateau situated at the borderline to Cambodia. The profiles are exposed along the National Road No 14 from Ho Chi Minh City to Buong Me Thuót across the M'Nong Plateau (Fig. 2). The flood basalts consist of tholeiites,

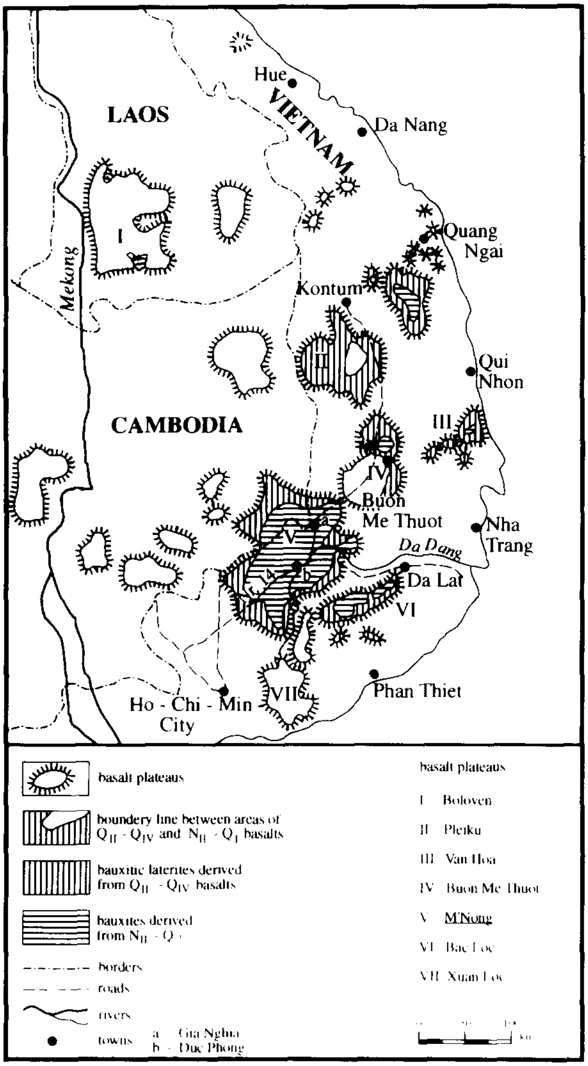

Fig. 2. Basalt plateaus and bauxitic weathering crust in South Vietnam (according to Do Tuyet, 1986).

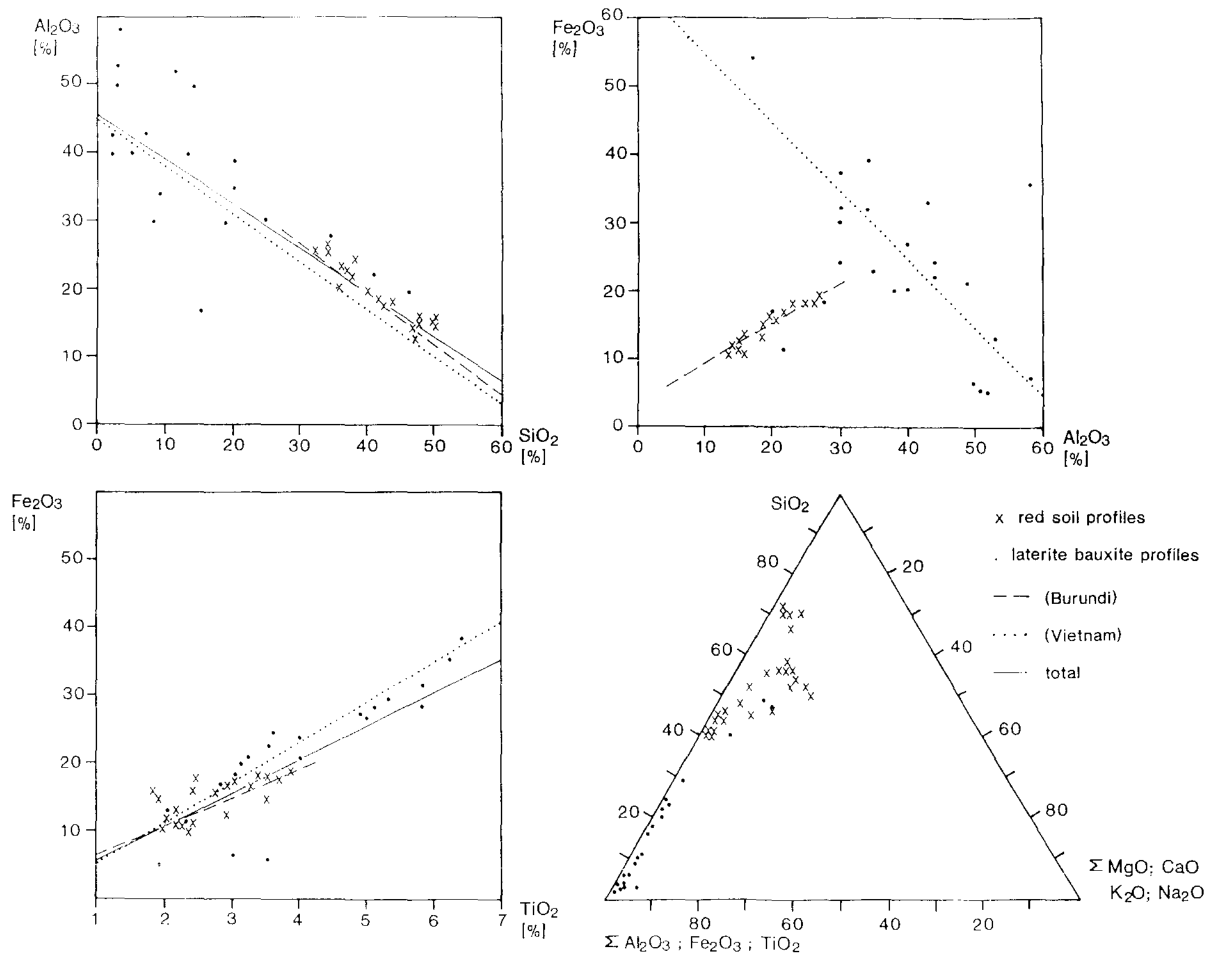

Fig. 3. Chemical alterations in the profiles of red soil in Burundi (×) and laterite bauxites in Vietnam (●) as examples of the whole process of the tropical weathering of basalts.

andesite basalts and pyroxene basalts. The basalts of this area are dark gray to black and massive with an ophitic or amygdaloidal texture. There are great differences in composition and texture between the basalt effusions (Mikhailov et al., 1981). Since Lacroix (1933) it has been known that two types of basalt occur in Vietnam — a younger basalt (Q_2–H) and an older basalt (N_2–Q_1). The bauxites were formed only on the older basalt. The basalt plateaus have risen due to a neotectonic activity (uplift) since the Miocene (Do Tuyet, 1986). The M'Nong Plateau is characterized by a higher central bauxitic level and a lower marginal lateritic level (Luzin et al., 1985; Do Tuyet, 1986). The formation of bauxite is influenced by the tectonic uplift of the basalt plateaus (Bárdossy and Aleva, 1990, p. 420).

3. Phenomena of weathering

3.1. Chemical conditions

The comparison of the chemical circumstances of the weathering profiles investigated reveals the following (Fig. 3):

– a strong decrease of alkalies and alkaline earths, as a first stage of disintegration of feldspars (Holdren and Speyer, 1985)
– desilification and accumulation of aluminium oxide
– enrichment of iron and aluminium oxide in the red soil profiles of Burundi and the differentiation of the aluminium oxides from the iron oxides by the formation of bauxites in Vietnam
– a mutual accumulation of iron oxide and titanium oxide

We correlated the results of the X-ray fluorescent analysis of the red soil profiles in Burundi and those of the laterite bauxites of Vietnam, and finally correlated all the data (see curves in Fig. 3). The intensity of mobilization of elements is different in these two cases. The red soil profiles show a weaker accumulation of aluminium, iron and titanium oxide and also a weaker decrease of silica, alkalies and alkaline earths.

3.2. Decomposition

The microscopic phenomena of disintegration of parent minerals in both of the investigated areas are comparable to one another. The weathering of several mineral grains started at the surfaces of the crystals. Streaked solution pits and grooves can be recognized. Relic minerals decomposed into several layers parallel to the crystallographic orientations. Exfoliation of twinning lamellae of plagioclases (Fig. 4) can be clearly seen. The preservation of cleavage systems of crystals by newly formed minerals filling the cleavage is observable, too (Fig. 5).

During the weathering of the rift basalts in Burundi the primary structures were dissolved in the zone of decomposition, whereas the relictic basaltic fabric has been preserved, especially in the laterite bauxites of Vietnam. The primary plagioclase laths

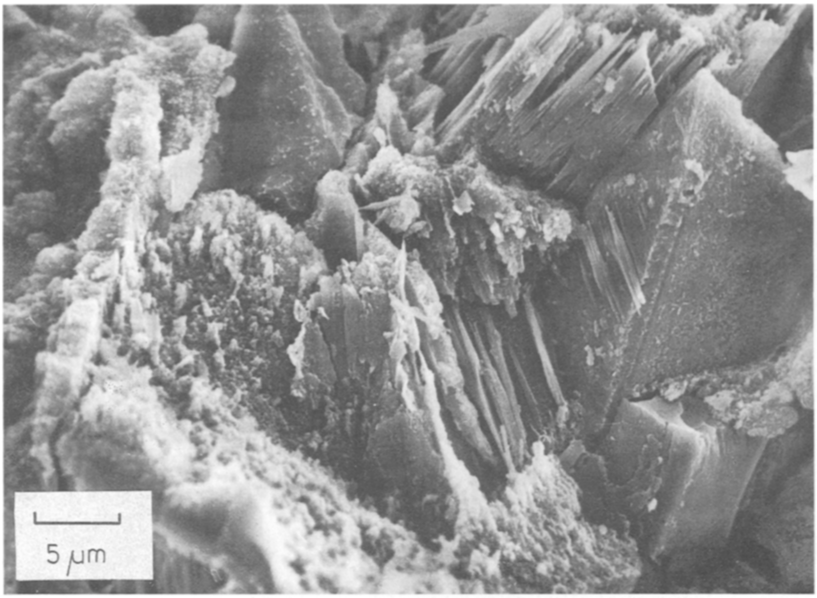

Fig. 4. SEM: Exfoliation of twinning lamellae of plagioclases.

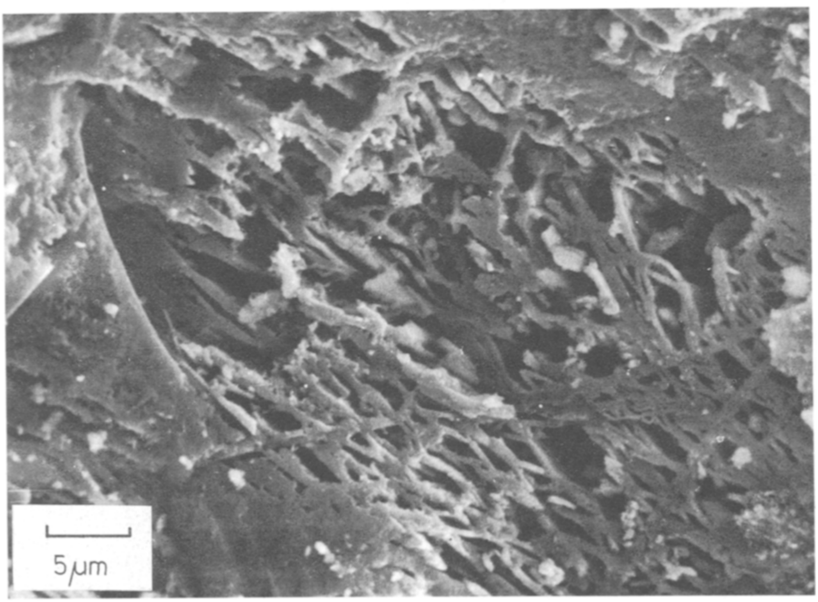

Fig. 5. SEM: Conservation of relictic cleavage system by newly formed phases.

Fig. 6. Microsection: Gibbsites/kaolinites pseudomorphic to plagioclases.

are filled with a mosaic of kaolinites and gibbsites (Fig. 6). A distinction between the two minerals could be made by their differing birefringence.

3.3. Neoformation

The main weathering products in the red soils of rift basalts in Burundi are kaolinite, halloysite (Fig. 7), montmorillonite, hematite and goethite. The other minerals like quartz, plagioclase and titaneous minerals seem to be relictic. The mafites of the rift basalts have been transformed into montmorillonite. The montmorillonites occur as rosette aggregates. The montmorillonite crystals have various sizes depending on the structure of the parent rocks. Small-sized montmorillonite crystals (0.1–0.5 μm) formed on massive basalts, and larger crystals (1–2 μm) on amygdaloidal basalts and tuffites (Figs. 8 and 9).

Kaolinite appears as a newly formed phase already in solution pits on surfaces of primary plagioclases (Fig. 10). Kaolinites and halloysites are very fine-grained (<0.1 μm). Figures and interpretations are comparable with those given by Gilkes et al. (1980).

The laterite bauxites on plateau basalts in Vietnam consist predominantly of gibbsite. According to the kaolinite–gibbsite-relations proposed by Gardner (1970) they were formed proceeding through a kaolinite stage. Montmorillonite is not contained in these profiles.

At the bottom of the laterite bauxite profiles in the weakly decomposed basalt the newly formed iron phases build up fine-grained globular goethite crusts. The goethite

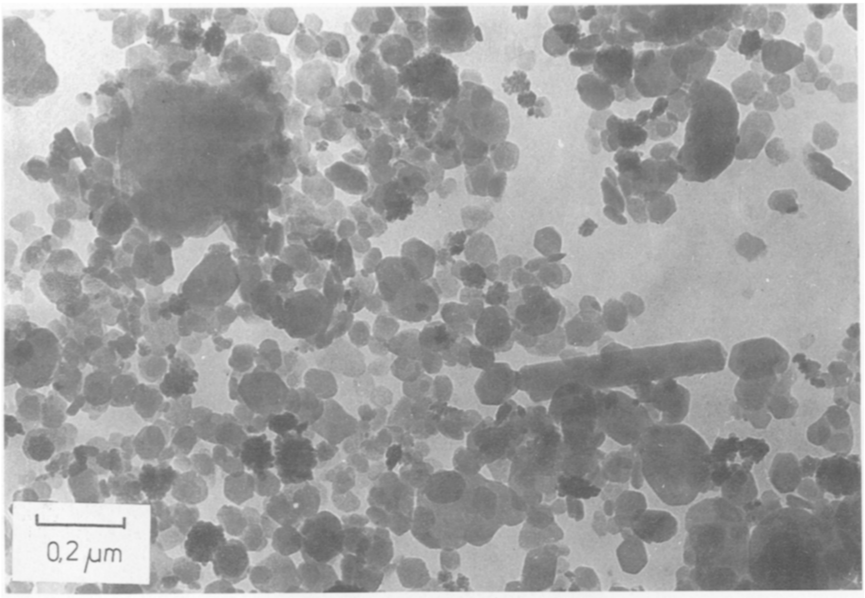

Fig. 7. TEM: Kaolinite and halloysite in red soil horizon.

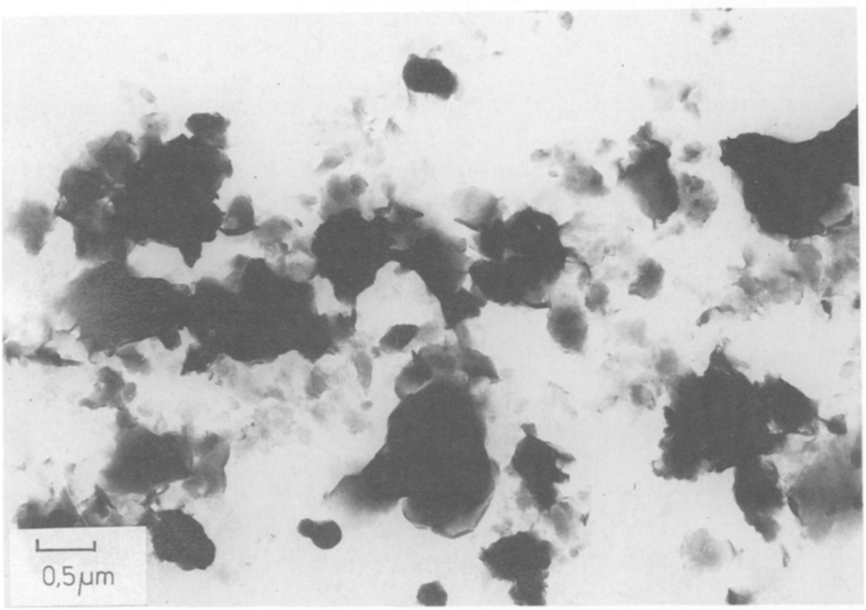

Fig. 8. TEM: Montmorillonite from a weathered tuffitic horizon.

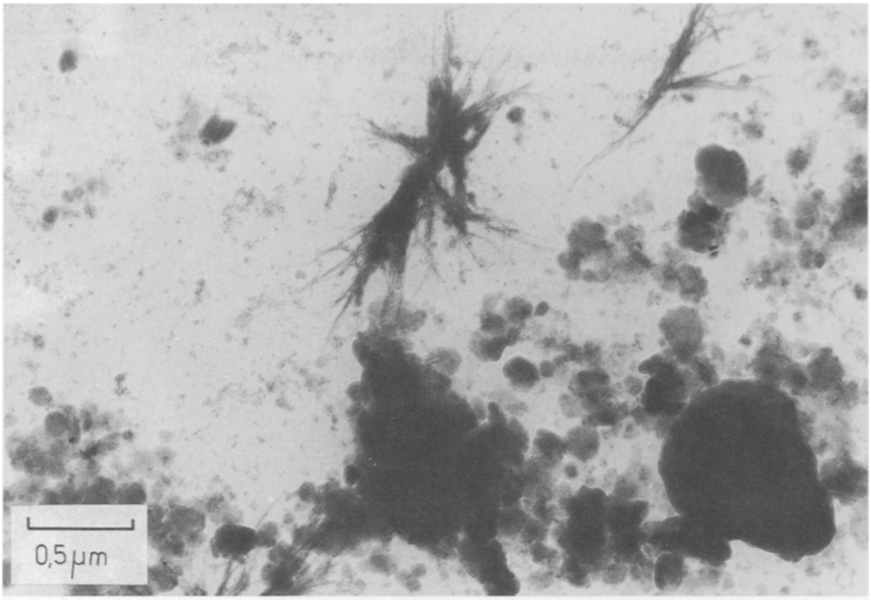

Fig. 9. TEM: Nontronite and kaolinite from weathered amygdaloidal basalt.

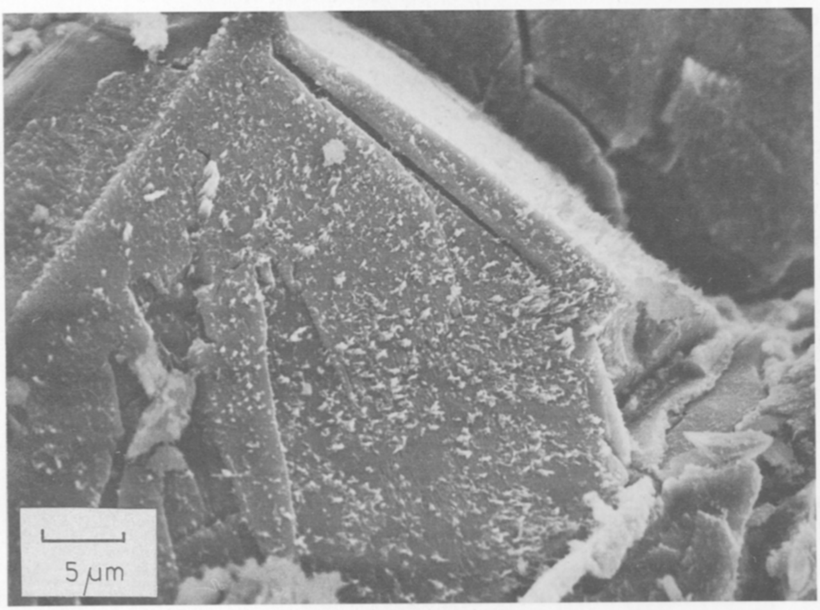

Fig. 10. SEM: Surfaces of a feldspar grain with newly formed clay minerals in solution pits.

Fig. 11. Microsection: Goethite coats between and across the plagioclases in decomposed plateau basalt.

coats the undecomposed plagioclases and lines the walls of cavities (Fig. 11). Several plagioclase laths were preserved causing the transformation of the goethite coated plagioclase into kaolinite and gibbsite to take place in a special microenvironment.

The cavities of the laterite bauxite are filled with gibbsite druses (Fig. 12). The prismatic aggregates are composed of gibbsite plates (Fig. 13). We have observed colloform texture of aggregates of clay minerals and iron phases in the red soil from Burundi as well as in laterite bauxite from Vietnam (Fig. 14). Furthermore, it was possible to determine two generations of new phases in the laterite bauxite of Vietnam. Fine-grained and disordered kaolinite, goethite and gibbsite originated from the weathering of a dense rock matrix. Coarse-grained, well ordered phases (Fig. 15) were formed in pores, fissures and other cavities. A description of such a differentiation in grain size and degree of order was given by Eswaran et al. (1977) for gibbsite, Amouric et al. (1986) for goethite and hematite and Tardy and Nahon (1985) for kaolinite.

4. Conclusions — some remarks on the weathering process

In the colloform texture of mineral aggregates, part of the formation of new minerals may have started from amorphous phases (Keller, 1979). But the close connection between surfaces of parent minerals and weathering minerals (growth, pseudomorphism) can be interpreted as a direct transformation without intermediate stage.

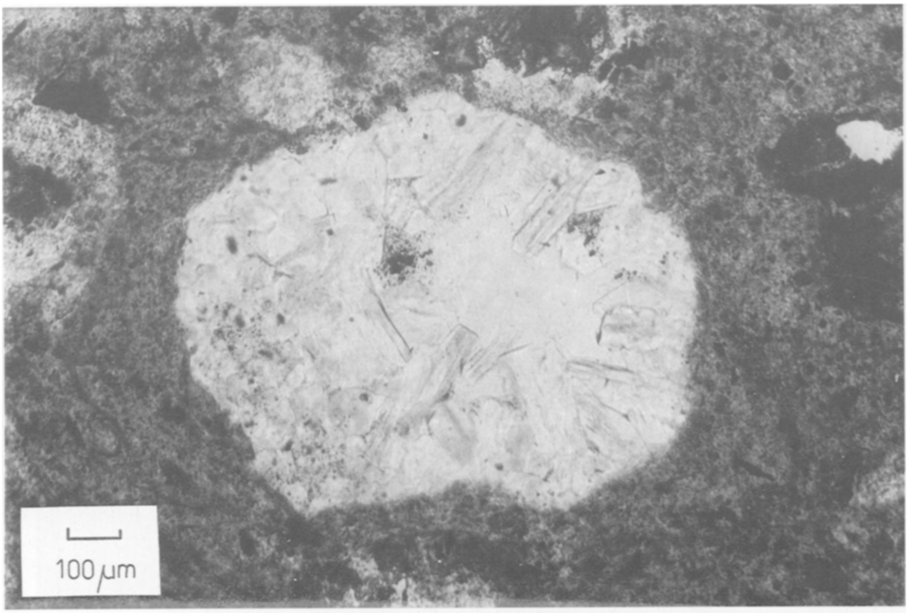

Fig. 12. Microsection: Gibbsite filled druse in the bauxite horizon.

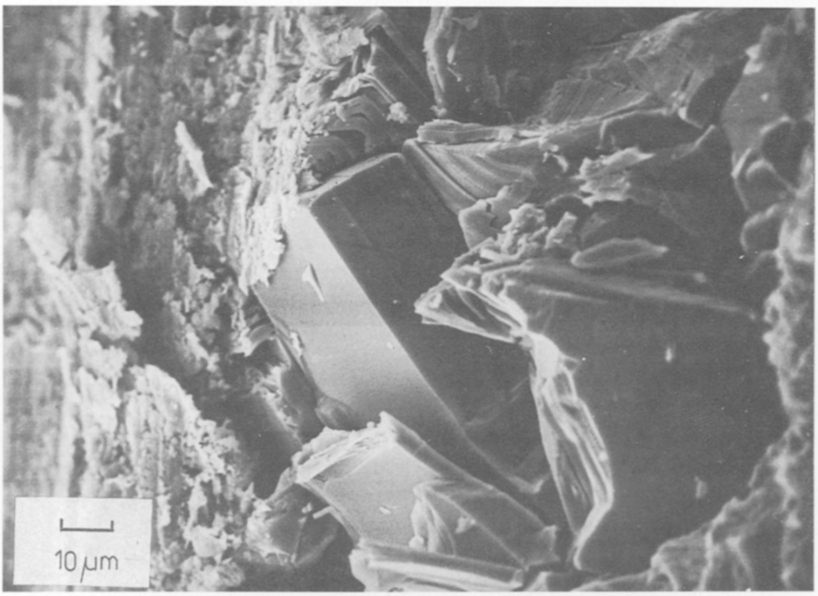

Fig. 13. SEM: Gibbsite in a druse in laterite bauxite.

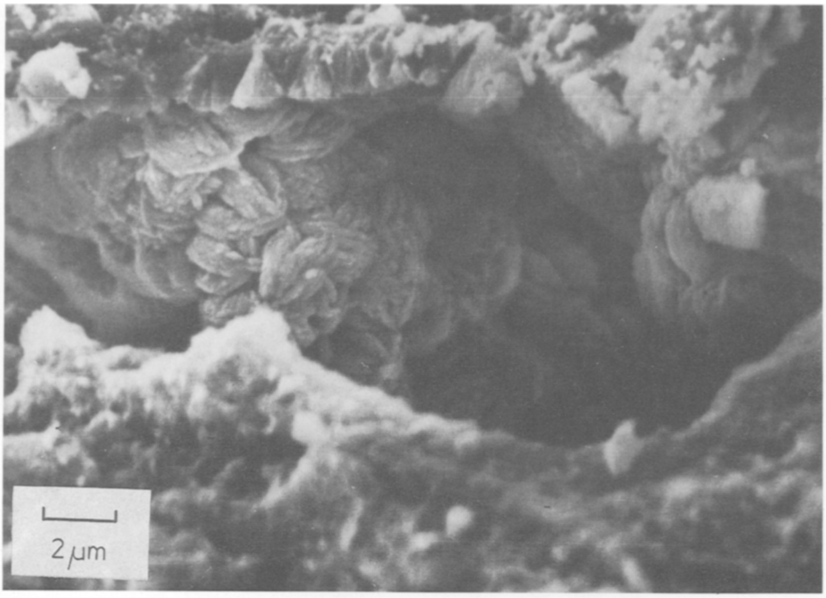

Fig. 14. SEM: Collomorphic aggregates in pores of laterite bauxite.

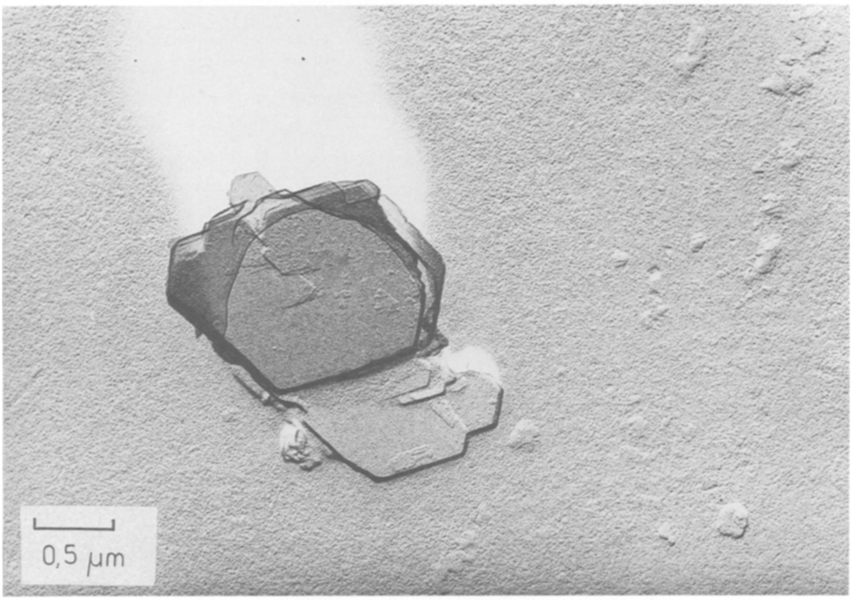

Fig. 15. TEM: Kaolinite crystal from laterite bauxite.

The decomposition of primary minerals starts at weak points in the crystal lattice (Schott and Berner, 1983). The Neoformations occur only in very small cavities such as pits and grooves in which the chemical conditions are different from those of the rest of the profile (Meunier and Velde, 1979).

The relation of mineral stabilities in the microenvironment and the influence of water activity depending on pore spaces are assumed to be important controlling factors of the tropical transformation of minerals (Tardy and Novikoff, 1988; Didier et al., 1985). Decomposition and neoformation occur simultaneously. The compounds released by decomposition are fixed by neoformation provided they are not removed with the solutions. For this reason, the gradients of chemical activities remain nearly stable and the weathering process continues (Chou and Wollast, 1984). The chemical activities in the microenvironment differ very widely from the macrochemism in the whole profile so that various mineral phases can form on the grain surfaces, although they are exposed to similar macroconditions (Anand et al., 1985).

The mineral transformation in tropical weathering of basalts includes a broad spectrum of reactions — from solid state reactions such as the biotite–kaolinite tranformation (Ahn and Peacop, 1987) and the olivine–smectite transformation (Eggleton, 1984) to ionic reactions including the disintegration of feldspar (Holdren and Berner, 1979). The formation of mixed-layer minerals (Herbillon et al., 1981; Tardy, 1985) and of amorphous phases (allophane, imogolite; Wada, 1987) is also part of this spectrum. According to Kronberg et al. (1987) the weathering of rift basalts in Burundi to montmorillonitic–kaolinitic red soils can be regarded as an example of the initial stage of tropical weathering, whereas the formation of laterite bauxites of Vietnam represents an example of the continuation of the weathering process to an extreme stage (Schirrmeister et al., 1990, 1991).

References

Ahn, J.H. and Peacop, A.R., 1987. Kaolinisation of biotite: TEM data and implications for an alterations mechanism. Am. Mineral., 72: 353–356.

Amouric, M., Baronnet, A., Nahon, D. and Didier, P., 1986. Electron microscopic investigation of iron oxyhydroxides and accompanying phases in lateritic iron-crusts pisolithes. Clays Clay Miner., 34: 45–52.

Anand, M., Gilkes, R.J. and Armitage, T.M., 1985. Feldspar weathering in lateritic saprolite. Clays Clay Miner., 33: 31–43.

Bárdossy, G. and Aleva, G.J.J., 1990. Laterite Bauxite. Dev. in Economic Geol. 27. Elsevier, Amsterdam, 624 pp.

Chou, L. and Wollast, R., 1984. Study of weathering of albite at room temperature and pressure with a fluidized bed reactor. Geochim. Cosmochim. Acta, 48: 2205–2217.

Didier, Ph., Perret, D., Tardy, Y. and Nahon, D., 1985. Equilibres entre kaolinite ferriféres, goethites alumineuses et hématites alumineuses dans les systême cuirassés — rôle de l'activité de l'eau et des taille des pores. Sci. Géol. Bull., 38: 383–397.

Do Tuyet, 1986. Neotectonic and geomorphological indicators in estimating prospect of lateritic bauxite on bauxite plateaus of South Vietnam. In: Proc. I. Conf. Geol. Indochina, Ho-Chi-Minh-City. General Dep. of Geol. of Vietnam, Hanoi, Vol. 1, pp. 339–351.

Eggleton, R.A., 1984. Formation of iddingsite rims on olivine: a transmission electron microscope study. Clays Clay Miner., 32: 1–11.

Eswaran, H., Stoops, G. and Sys, G., 1977. The micromorphology of gibbsite formation in soils. J. Soil Sci., 28: 136–143.

Gardner, R.L., 1970. A chemical model for the origin of gibbsite from kaolinite. Am. Mineral., 55: 1380–1389.

Gilkes, R.J., Anchalee Suddhiprakarn and Armitage, T.M., 1980. Scanning electron microscope morphology of deeply weathered granite. Clays Clay Miner., 42: 2–34.

Herbillon, A.J., Frankart, R. and Vielvolve, L., 1981. An occurrence of interstratified kaolinite–smectite minerals in a red black soil toposequence. Clay Miner., 16: 195–201.

Holdren, G.R. and Berner, R.A., 1979. Mechanism of feldspar weathering. I. Experimental studies. Geochim. Cosmochim. Acta, 43: 1161–1171.

Holdren, G.R., Jr. and Speyer, P.M., 1985. pH-dependent changes in the rates an stoichiometry of dissolution of an alkali-feldspar at low temperature. Am. J. Sci., 285: 994–1026.

Keller, W.D., 1979. Bauxitization of syenite and diabase — illustrated in scanning electron micrographs. Econ. Geol., 74: 116–124.

Kronberg, B.J., Nesbitt, H.W. and Fyfe, W.S., 1987. Mobilities of alkalis, alkaline earths and halogens during weathering. Chem. Geol., 60: 41–49.

Lacroix, A., 1933. Contribution á la recherche de composé chimique et minéralogique des roches eruptives de l'Indochine. Bull. Serv. Géol. Indochine, Hanoi, XX, 122 pp.

Lange, U., 1986. Eine geomorphologisch–pedochemische Fallstudie aus Ost-Burundi: Morphodynamik und Morphogenese in den wechselfeuchten Tropen. Karlruher Geographische Hefte 17, 222 pp.

Luzin, G.P., Jakushev, V.M. and Guzowski, L.A., 1985. Lateritic bauxites on basalts of Neogene–Quartenary age in Southern Vietnam. Izv. Akad. Nauk U.S.S.R., Ser. Geol, 3: 116–133 (in Russian).

Meunier, A. and Velde, B., 1979. Weathering mineral facies in althered granites: The importance of local small-scale equilibria. Min. Mag., 43: 261–268.

Mikhailov, B.M., Bronewoi, B.A. and Odoky, B.N., 1981. The laterite crusts of modern tropical zones of the world. Litol. Polezn. Iskop., 6: 65–100 (in Russian).

Radulescu, I., 1981. Burundi — carte géologique. Ministère de l'Energie et des Mines, Projet de Recherches Miniéres, Bujumbura.

Schirrmeister, L., Störr, M. and Ngyuen Thanh Ha., 1991. Lateritbauxite auf Basalten Vietnams. Z. Geol. Wiss., 5: 491–500.

Schirrmeister, L., Störr, M., Nkurunziza, P. and Stösser, R., 1990. Zur Verwitterung von Riftbasalten der Rusizi-Ebene (Nordwestburundi) unter besonderer Berücksichtigung des Kaolinites. Z. Geol. Wiss., 5: 557–568.

Schott, J. and Berner, R.A., 1983. X-ray photoelectron studies of the mechanism of iron silicate dissolution during weathering. Geochim. Cosmochim. Acta, 47: 2233–2240.

Tack, L. and Paepe, P., 1983. Le volcanisme du Sud-Kivu dans la plaine de la Rusizi au Burundi et ses relations avec les formations géologique avoisinantes. Museé Royal Afrique Central, Département Mineralogique, Tervuren (Belg.), Rapport Annuel, pp. 137–145.

Tardy, Y., 1985. Equilibres physicochimiques entre l'eau et les minéraux des argiles — I. Domaines des stabilité. In: J. Cases (Editor), Interaction Solide–liquide dans les Milieux Poreux. Editions Techniques, Paris, pp. 3–18.

Tardy, Y. and Nahon, D., 1985. Geochemistry of laterites, stability of Al-goethite, Al-hematite and Fe^{3+}-kaolinite in bauxites and ferricretes — an approach to the mechanism of concretions formation. Am. J. Sci., 285: 865–903.

Tardy, Y. and Novikoff, A., 1988. Activité de l'eau et déplacement des équilibres gibbsite–kaolinite dans les profiles làteritiques. C.R. Acad. Sci. II, 308: 39–44.

Tran Quang Thinh and Nguyen Thi Mui, 1986. Caractéristiques de la coupe d'altération làteritique sur les épanchements basaltiques du Sud-Vietnam. In: Proc. I. Conf Geol. Indochina, Ho-Chi-Minh-City, Vol. 2, pp. 609–638.

Valeton, I., 1967. Laterite und ihre Lagerstätten. Fortschr. Mineral., 44: 67–130.

Wada, A.K., 1987. Minerals formed in a mineral formation from volcanic ash by weathering. Chem. Geol., 60: 17–28.