The petrocalcic and petrogypsic horizons are formed by growth and interlocking of authigenic crystals that have little affinity for the surface reactive groups on the s-matrix surfaces. The O^{2-} portion of the CO_3^{2-} and SO_4^{2-} is more reactive with a strong electron acceptor like Ca^{2+} than the relative weak electron acceptor -OH and -COOH groups on the s-matrix surfaces. Cementation occurs as crystals cohere to each other through chemical intergrowth and physical interlocking. The s-matrix is not held in place by adhesion and is displaced by the increasing volume of crystic plasma.

5.   REFERENCES

Allen, B.L. 1985. Micromorphology of Aridisols. In: L.A. Douglas and M.L. Thompson (Editors), Soil Micromorphology and Soil Classification. Soil Sci. Soc. Am. Spec. Pub. No. 15, Madison, WI, pp. 197-216.

Brewer, R., Sleeman, J.R., and Foster, R.C. 1983. The fabric of Australian soils. In: Soils an Australian Viewpoint, Division of Soils, CSIRO, CSIRO: Melborne/Academic Press: London, pp. 439-476.

Bullock, P., Federoff, N., Jongerius, A., Stoops, G., Tursina, T., and Babel, U. 1985. Handbook For Soil Thin Section Description. Wain Research, Mount Pleasant, Wolverhampton, WV, England, 47 pp.

Chadwick, O.A., Hendricks, D.M., and Nettleton, W.D. 1987. Silica in duriq soils: I. A depositional model. Soil Sci. Soc. Am. J., 51: 975-982.

De Coninck, F. 1983. Genesis of Podzols. Acad. Analecta (R. Acad. Belg.), 45:2-65.

De Coninck, F. and McKeague, J.A. 1985. Micromorphology of Spodosols. In: L.A. Douglas and M.L. Thompson (Editors). Soil Micromorphology and Classification. Soil Sci. Soc. of Am. Spec. Pub. 15, Madison, WI, pp. 121-144.

Innes, R.P. and Pluth, D.J. 1970. Thin section preparation using an epoxy impregnation for petrographic and electron microprobe analysis. Soil Sci. Soc. Am. Proc., 34:483-485.

McKeague, J.A. and Guertin, R.K. 1985. Fabrics of some Canadian soils in relation to particle size and other factors. Soil Sci., 133:87-102.

Nettleton, W.D., Nelson, R.E., Brasher, B.R., and Derr, P.S. 1982. Gypsiferous soils in the Western United States. In: J.A. Kittrick, D.S. Fanning, and L.R. Hossner, (Editors). Acid Sulfate Weathering, Soil Sci. Soc. of Am. Spec. Pub. No. 10, Madison, WI, pp. 147-168.

Soil Conservation Service. 1972. Soil Survey Investigation Report No. 1. Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples. USDA, Lincoln, NE, 63 pp.

Soil Survey Staff. 1975. Soil Taxonomy: A basic system for making and interpreting soil surveys. USDA-SCS Agric. Handb. 436. U.S. Government Printing Office, Washington, D.C., 754 pp.

Sposito, G. 1984. The Surface Chemistry of Soils. Oxford University Press, New York, 234 pp.

Torrent, J. and Nettleton, W.D. 1978. Feedback processes in soil genesis. Geoderma, 20:281-287.

Torrent, J., Nettleton, W.D., and Borst, G. 1980. Genesis of a Typic Durixeralf of Southern California. Soil Sci. Soc. Am. J., 44:575-582.

FORMS AND ORIGIN OF ALUMINA IN THE A2 HORIZON OF THE TROPICAL PODZOLS OF TAHITI (FRENCH POLYNESIA).

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ABSTRACT

Above 1100 m, on the moderate slopes of basaltic planezes in Tahiti, the rather cold climate and the abundant rainfall (3200 mm) allow the organic matter to accumulate. The soils are podzols developed on a substratum desilicated and rich in aluminium. They are characterized by a thin humo-ferruginous spodic horizon and a thin gibbsitic albic horizon (A2). Forms and origin of alumina in this horizon are studied here. Microphormic observations of soil thin-sections, analysis through the scanning electron microscope allow to distinguish three forms of alumina : 1 - inherited gibbsitic microgeodes; they are formed in the natural microsites of the weathering horizon whose alveolar structure is preserved. They have been subjected, without any visible modification, to the pedogenic evolution, before podzolisation appears. 2 - orange-coloured "plaquettes" likely to reach 1 mm including alumina, titanium, and iron. They are often juxtaposed to organic accumulations. These "plaquettes" are most often perforated and altered by numerous mycelial hyphae. Their presence raises the problem of their origin (probably "phlobophenes") that remains to be defined and of their evolution affected by the fungial lysis. 3 - secondary alumina in the form of a thin edge round the patterned or non patterned organic matter. Its observation through the U.V. fluorescence can account for the stability of the organic matter in the A2 horizon rich in aluminium. Its suggests an evolution in the podzolisation process.

1 INTRODUCTION

The podzolised soils, whether present of fossil, studied by many authors in tropical or temperate zones, all come from predominantly quartzy formations. Podzolization leads us here to differentiate between three horizons : 1 - a thick organic horizon of the "mor" or "moder" type, 2 - a quartzy, bleached eluvial horizon (A2 or albic), 3 - a humo-ferruginous illuvial horizon (spodic).

However, acid crystalline rocks and sandstonelike or sandy rocks do not have the monopoly of podzolization. In the tropics, it can also affect completely quartz-free materials. ZEBROWSKI (1975) has given a description of podzols at a high altitude on Reunion Island, that come from volcanic ash, whose A2 horizon is still siliceous but is composed of opal particles of vegetable origin (phytoliths"). Even more original are the podzols recently discovered, again at a high altitude, in Tahiti (JAMET, 1987a, 1987b). They develop on gibbsite-containing "ferralites" deriving from basalt. Not only are these soils quartz-free, they are also almost completely desilificied. A concentration of the gibbsite

gives its light tint to the A2 horizon. The extent of this horizon is very small and it rests on a very thin indurated spodic horizon (placic hozizon). This paper is devoted to the forms, the origin and the stability of the alumina of the A2 horizon of these podzols.

2 SOILS STUDIED AND THEIR ENVIRONMENT

The climate of Tahiti is of the wet tropical type, considerably tempered by the surrounding ocean and the sharp relief. The podzols occur under special stational conditions : at the summits of moderately sloping basaltic planezes, at an altitude of more than 1,100 m, at a mean temperature of 15° C and at least 3,200 mm rainfall; they are currently overlaid by an acidophilic shrubby heath covered with "Gleichenia linearis" (fern) which is very dense and allows large quantities of organic matter to accumulate.

The soils under study are located on a 20 % slope, at an altitude of 1,300 m They have an albic horizon (A2) of 2 to 6 cm that is gibbsitic, grey-whitish (5YR4/1) unctuous when fresh, but darkening and hardening as it dries. It lies without any transition on a spodic horizon a few millimetres thick, considerably indurated and fossilized by a humo-ferruginous cement, which impedes the penetration of fine roots.

3 METHODS

After observation using an optical microscope, microanalyses were carried out with a microprobe on thin carbon-metallized soil thin-sections. Sandy fractions, extracted from the soil after treatment with H2O2 and dispersion of the clays, as well as natural aggregates were analyzed in the same way. After gold-metallization, identical samples were observed using the SEM. These studies were completed by thermogravimetric analysis, mineralogical studies (X-rays) applied to the whole of the soil, several of its granulometric fractions, chemical analysis including free iron by DEB method and selective semi-kinetic extraction of amorphous and paracrystalline minerals (dissolution by HCl 4N, 10 minutes, 10 successive extractions) by QUANTIN and LAMOUROUX method (1974).

4 RESULTS

4.1 Overall chemical composition of the A2 horizon

The A2 horizon has an unusually high carbon content, approximately 22 %, only part of which is in the form of humus (reactive organic matter); the rest probably corresponds to "phlobophenes" (root concentrations of phenolic products). The mineral fraction, representing a little under 2/3 of the soil (in weight) comprises 45 % "clay". This is composed in particular of Al_2O_3 (30 %), Fe_2O_3 (24 %) and TiO_2 (22%), but it contains little SiO_2 (2 %). The iron, 4/5 of which are in "free" form, is divided into two practically equal phases : an

"amorphous" phase, which is quickly dissolved using the QUANTIN and LAMOUROUX method and a finely cristallized phase (goethite, magnetite). The commonest form of the titanium is anatase, which is abundant, particularly in the < 2 µm fraction.

4.2 Mineralogy of the aluminium

The thermal and X-ray diagrams indicate that the A2 horizon contains large amounts of gibbsite, which have been evaluated by thermogravimetry at 60 % in the < 2 µm fraction, and 50 and 55 % in the 2-20 µm and 20-250 µm fractions. The overall gibbsite content, obtained by means of chemical analysis, is equal to 46 % of the total mineral fraction. The differential solubilization obtained using the QUANTIN and LAMOUROUX method gives a proportion of amorphous alumina equal to approximately 1 %, which is confirmed by extraction with the reagent oxalic acid-oxalate NH4 at a pH of 3.

4.3 Forms of the aluminium

The observation of thin sections using the optical microscope reveals several types of plasma/skeleton assemblages : assemblage of the "intertextic" type in which the elements of the skeleton are linked by plasma bridges, assemblage of the granular type without plasma, or "agglomero-plasmic" with fairly loose plasma filling. Aluminium is to be found everywhere, both in the "grains" of the skeleton and in the plasma.

(i) The "grains" of the skeleton fall into four types, namely :

1° - elements which, as wiewed in cross-section, have the form of white rings of crystallites with high birefringence, ranging from 60 to 600 µm in diameter (Fig. I1). This is gibbsite. These rings can be concentrated in small zones or scattered throughout the mass. Added to these are numerous small grains of the same kind, fifteen or so micrometres in diameter, presumably resulting from fragmentation of the others (Fig. I1). All of these are gibbsitic elements that give the horizon its light tint.

When they are observed with the SEM on microaggregates (Fig. I2) or in the sandy fractions, we can see tiny microgeodes like "eggshells" with frequent excrescences, marked by numerous corrosion features (Fig. I3). The microanalysis carried out on the soil thin sections and on isolated elements indicates the presence of almost pure alumina (with only 1.25 % iron and 1 to 2 % Si+P+Ti). These microgeodes, which are often broken, reveal a partial plasma filling or one of secondary gibbsitic crystallizations (Fig. I4)

2° - isotropic "plaquettes" of an uniformly orange colour on thin sections, with lengths of 0,1 to 1 and even 2 mm. They seem to belong to two generations, one formed by highly coloured elements, only slightly weathered, and the other formed of lighter coloured, smaller elements, perforated by an often very dense

network of dissolution channels with diameters of 4 to 5 μm, by mycelial hyphae whose abundance has led at times to almost total lysis.

On observing these "plaquettes" using the SEM, after they have been separated from the sandy fraction, we note oblong, cylindrical or tapering shapes, some hard and brittle, others flexible and granular in texture. They can be up to a hundred or so micrometres in diameter (Fig. I 5-6). Less frequently, we encounter hard "plaquettes", from 2 to 3 mm long and 150 μm thick. These might be "phlobophenes" accumulations of phenolic products occuring inside the roots of certain plants and enriched with mineral elements. Microanalysis shows a mineral content of 5 to 28 %, including titanium and iron, as well as 2 to 5 % of alumina.

3° - minerals inherited of the basaltic parent rock, composed of picotite (aluminous chromite) and augite.

4° - fragments of old roots, partially petrified by gibbsite.

(ii) The plasma : This forms a fairly loose filling between the "grains" of the skeleton; it is brown, isotropic, essentially organic or "organo-mineral" dotted with ochre particles. In UV light, some microaggregated areas possess a fluorescence that is generalized or localized on the border of micro-aggregates, underlining the presence of fine "neocutanes". Microanalysis of these areas reveals mineral substance contents ranging from 20 to 65 %, including iron, titanium and 9 % aluminium (on average).

5 DISCUSSION AND CONCLUSIONS

By contrast with classical podzols, whose A2 horizon contains only residual forms of Fe and Al oxihydroxides in free state (SOUCHIER 1984), the podzols of Tahiti have, and this is extremely rare, a large accumulation of alumina in the very core of this horizon. These are chiefly gibbsite microgeodes, inherited of a first concentration of the alumina in the weathered alveolar basalt. In the soil, they initially resisted to weathering. Gibbsite, in fact, is usually difficult to dissolve (CHESWORTH and MACIAS-VASQUEZ, 1985). However, under the influence of podzolization, close to the surface, it is destabilized (WILKE and SCHWERTMANN, 1977) and solubilized by the fulvic acids (RIGHI et al., 1982). Using the SEM, we can observe numerous features of dissolution and weathering on the surfaces of the gibbsite microgeodes which mark the release of the aluminium.

The "phlobophenes", which are also inherited, are impregnated with aluminium. When they are "digested" by microscopic fungi, they also release aluminium.

The A2 horizon is also enriched by a part of the aluminium realised by horizon A1. The latter in fact contains 5 % aluminium (biogeochemical recycling) and the gravity waters collected at its base contain a high proportion of water-soluble Al (300 μ g/1). At the bottom of the A2 horizon, the Al content of these
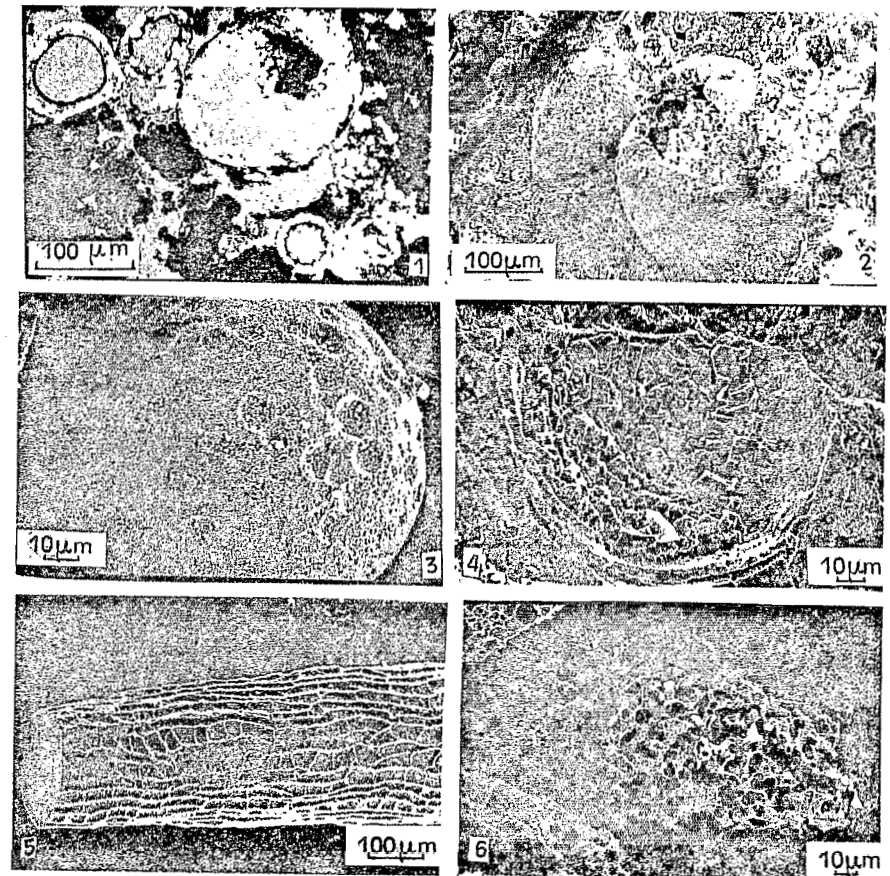
Fig. I-1 Thin-section of the A2 horizon : cross-section of gibbsitic microgeodes of different sizes and microaggregates of organic matter.
2 to 6. SEM micrographs.
2 - Gibbsitic microgeodes in undisturbed fabric.
3 - A gibbsitic microgeode marked by corrosion "features"
4 - A broken microgeode with a partial secundary gibbsitic crystals filling.
5 - An unweathered "phlobophène".
6 - "Phlobophène" perforated by a very dense network of channels, by mycelial hyphae.

same waters has now dropped to just 160 µ g/1, which gives us reasonable grounds for thinking that a part of the aluminium from these different sources is fixed there immediately. Observations in U.V. light tend to confirm this hypothesis. The fluorescence of certain plasmic areas and numerous coatings, which is linked with aluminium hydroxides, highlights the presence of alumina deposits in relation with the organic material.

To sum up, it seems that a large portion of the aluminium re-solubilized in the very core of the A2 horizon, or migrating to it, is immobilized there in the form of complexes or associations with the organic material. As aluminium has a particularly marked stabilizing effect on this material (DUCHAUFOUR, 1986), and as this stability is even further increased by the precipitation of hydroxides forming fine coatings on the surface (SEQUI, 1981), the organo-aluminous complexes are swiftly immobilized and, as they resist to weathering (RIGHI et al,. 1982), accumulate in the A2 horizon. It would appear then that, under present conditions, under the strong ionic aluminic pressure, the organic acids that migrate to A2 are quickly blocked there, thus slowing down the podzolization process. This, in turn, suggests an evolution in the process that still remains to be studied.

6 REFERENCES

Chesworth, W. and Macias-Vasquez, F., 1985. pe, pH and podzolisation. AM.J.of Sci. vol. 285 : 128-146
Duchaufour, P., 1986. La notion de processus élémentaire de pédogénèse définie par Gerassimov, ses différentes possibilités d'utilisation. Sci. du sol, 196/2 : 163-170
Jamet, R., 1987a. Tahiti : les sols et leurs aptitudes culturales et forestières Notice explicative n° 107, édit. de l'ORSTOM, Paris, 124 pp.
Jamet, R., 1987b. Sur l'existence de podzols à gibbsite et anatase. Analyse des podzols tropicaux de Tahiti (Polynésie Française). C.R. Acad Sci. Paris, t. 305, série II : 875-880
Quantin, P. et Lamouroux, M., 1974. Adaptation de la méthode cinétique de Ségalen à la détermination des constituants minéraux de sols variés. Cah. ORSTOM, Sér. Pédol., vol. XII, n° 1, Paris, pp. 13-46.
Righi, D., Dupuis, T., Girault, P., 1982. Altération expérimentale de gibbsite par des acides fulviques. Sci. du sol n° 2 : 145-151.
Séqui, P., 1981. Organo-minéral interactions with respect to the possibility of migrations in soils. In : Migrations organo-minérales dans les sols tempérés, coll. int. du C.N.R.S., n° 303, Nancy (1979) : 235-239
Souchier, B., 1984. Les podzols et la podzolisation en climats tempéré et montagnard. A.F.E.S., Livre jubilaire, Paris : 77-96.
Wilke, B.M., Schwertmann, U., 1977. Gibbsite and halloysite decomposition in strongly acid podzolic soils developped from granitic saprolite of the Bayerichen Wald. Geoderma, 19 : 51-61.
Zebrowski, Cl., 1975. In atlas des D.O.M. : La Réunion, les sols podzolisés, pl. 10 C.E.G.T. - I.G.N., Paris

MICROMORPHOLOGY OF SOILS DEVELOPED IN MAFIC SAPROLITES AND ASSOCIATED TILLS.

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ABSTRACT
Pre-Wisconsinan mafic saprolites have become the parent materials for post-Wisconsinan soil formation in northerly latitudes. Pedogenesis has not produced significant micromorphological changes in saprolitic parent material but soils formed on associated basalt-derived tills display characteristic pedofeatures.

In areas of previously glaciated terrain, it was presumed that all the pre-Wisconsinan soil cover had been removed and swept southwards to the terminal advances of the glacial ice. However, saprolites or decomposing rock structures usually the result of an intense weathering environment and a long period of landscape stability prior to the last glaciation, were identified in glaciated areas of New England in the 1930's (Goldthwaite and Kruger, 1938). In the following decades saprolites were discovered in Canada in Quebec (Blais, 1959; Cimon, 1969; Clement and DeKimpe, 1977) and Ontario (Rutherford and Churchward, 1975). Dejou and associates (1982) and DeKimpe and coworkers (1984) report the presence of saprolites apparently formed from basalt in Quebec. Rutherford and Thacker (1988) have shown some of the characteristics of soils formed on mafic saprolites in areas as far apart as Nova Scotia and British Columbia.

The A and B and most of the C horizons have been removed from the pre-Wisconsinan soil leaving only the saprolite parent material for post-Wisconsinan soil development. The object of this paper is to present some of the micromorphological features observed in soils formed from mafic saprolites in northern latitudes and to compare them with associated soils formed in till from mafic rocks.

MATERIALS AND METHODS

Undisturbed and oriented soil samples were collected and impregnated with styrene/polyester/acetone resin by vacuum suction and after maturing, thin sections were prepared. The thin