

MORPHOLOGY OF MINERAL WEATHERING AND NEOFORMATION.
II NEOFORMATIONS*

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ABSTRACT

Micromorphology is a unique technique for the study of mineral newformations and transformations in soils, as it allows the identification of the spacial relations between newformations and other soil features, including porosity.

A systematic review is given of the pedogenetic minerals recognizable in thin sections with optical methods. Their habits are frequently related to specific environmental conditions.

1 INTRODUCTION

Soil mineralogy is becoming more and more restricted to the study of the colloidal fraction of the soil, its identification, genesis and behaviour. Not sufficient attention is given, in our opinion, to the study of larger newformed minerals, such as the more soluble species in saline soils and the different iron compounds in wet soils.

Relatively large pedogenic minerals are found essentially in three different environments: (i) in arid and semi-arid areas, where precipitation is not sufficient to leach the soil; (ii) in more or less closed systems of wet soils, where leaching of constituents is hindered, and (iii) in strongly leached soils, where essentially residual elements, mainly sesquioxides, tend to individualize. The occurrence of some pedogenic minerals such as pyrite and thenardite, is restricted to one of these environments, whereas some others such as calcite and goethite, can be found in quite contrasting situations. Minerals formed under different conditions can usually be distinguished by their habit and their paragenesis.

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Few information is available on the habit of the different pedogenic minerals in relation to their environment, as it is the case for most rock forming minerals in relation to their geological environments (e.g. Kostov, 1977). A better understanding of the habits of pedogenetic minerals might be very useful to detect subtle changes in pedogenetic processes and environments. Very little is known also about the formation of pseudomorphs. Furthermore, the concept of mineral paragenesis (i.e. the genetic association of a group of minerals) is practically not developed in soil science.

It is the aim of the authors to discuss some of these mineral newformations in relation to their pedogenetic environment. The discussion will be mainly restricted to features observed with the petrographic microscope.

Thin section studies on the more soluble salts in arid soils are lacking, although their submicroscopic aspect has been treated in several papers (Eswaran et al. 1980, Vergouwen, 1981) Some of the most soluble components tend to disappear during impregnation, especially when they are present in relative small amounts. The type of polyester and diluant used is expected to play an important role. Also with regard to unstable wet soils our knowledge is restricted as far as micromorphology is concerned.

2 MINERALS

2.1 Native elements

The only native element that occurs as pedogenic mineral is sulphur, but it has never been reported in thin sections.

2.2 Sulphides

The only sulphide mineral that has been reported in thin sections as a newformation in soil materials is **pyrite**. The opaque framboids, which have a brass-like luster in incident light, are mostly associated with decaying organic matter (e.g. roots), although single crystals can occur in the groundmass (Pons, 1964, Miedema et al. 1974). Pyrite framboids are not restricted to soils on marine sediments, but were also observed in marshy soils, in association with siderite and vivianite, although their stability fields are different (Stoops, 1983)

2.3 Halides

Only a restricted number of chloride minerals has been observed in the soil, the most common of which is **halite**. It is easily over-

looked in thin sections because of its low relief and isotropic nature. Only larger, natural crystals with an orthogonal cleavage pattern (Fig. 1) are noticed in thin sections, as the acicular or threadlike efflorescences tend to disappear during impregnation (Hanna and Stoops 1976). Halite has been observed together with gypsum, thenardite, burkeite etc. (Tursina et al. 1980, Vergouwen, 1981); this does not mean however that these associations are in equilibrium.

2.4 Oxides and hydroxides

Pedogenic oxide minerals are practically always microcrystalline, and therefore not recognizable as individual crystals in thin sections. This is the case for hematite, maghemite, anatase and the Mn-oxides. Also many hydroxides, such as the Mn-hydroxides, boehmite, diaspore, lepidocrocite etc. are known as microcrystalline features in the soil. Goethite and gibbsite however can form relatively large crystals.

Gibbsite forms coatings of silt to fine sand sized, short prismatic crystals (pseudohexagonal, according to SEM-observations, Eswaran et al. 1977), or pure xenotopic nodules. These features are most probably the result of a crystallization from the soil solution, contrary to the microcrystalline (fine silt to clay sized) gibbsite, forming nodules or impregnating the groundmass, which is frequently the result of in situ residual weathering. Gibbsite coatings are best developed in tropical saprolites (e.g. early stages of pseudomorphic weathering of Al-silicates) and in some Andisols. In bauxites both the coarse and the very fine crystalline gibbsite occur.

Goethite occurs essentially as (fine)clay sized crystallites disseminated in the groundmass and pedofeatures. Only under specific conditions larger crystals are formed. In very wet soil horizons (i.e. saturated during long periods) goethite crystallizes as multilayered coatings (Fig. 2) composed of fanlike aggregates of fine needles, consisting of a parallel stacking of very fine crystallites (Stoops, 1983). These coatings have in general low interference colours, locally grading even to optical isotropism. In tropical saprolites and laterites, goethite forms relatively thick, regular multilayered dense coatings, the crystals of which are oriented perpendicular to the surface affected. When evolving from gel-like material, bodies with a microcrystalline xenotopic fabric are observed. Goethite commonly occurs as pseudomorphs after other

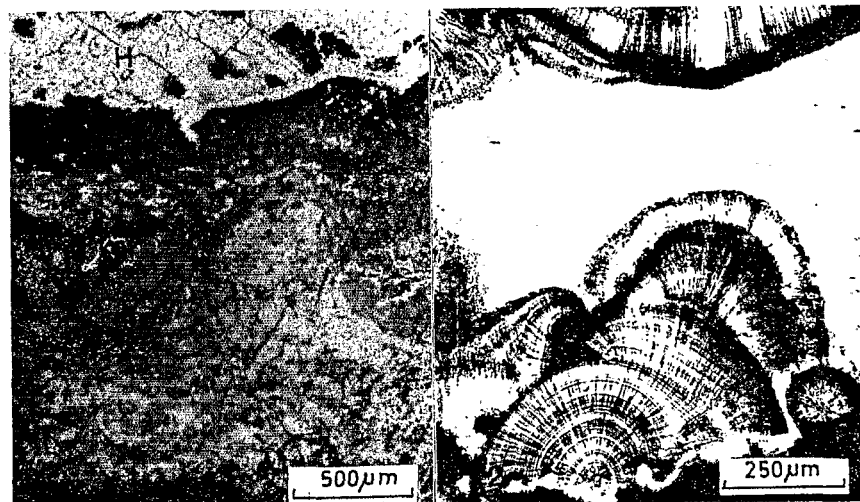


Fig. 1 : Halite (H) with orthogonal cleavage pattern overlying a surface crust with lenticular crystals of thenardite (T) in a salt crust from Peru. PPL.

Fig. 2 : Compound coating of needle-shaped goethite crystallites in a bog ore from Belgium. PPL.

minerals (Embrechts and Stoops 1982) or plants.

2.5 Carbonates

The most common pedogenetic carbonate is undoubtedly calcite. Calcite is one of the best studied, but also one of the most variable pedogenic minerals. It shows a wide variety of shapes and habits, and occurs as well in arid soils as in temperate and tropical soils with restrained drainage. In most micromorphological descriptions a distinction is made only between microcrystalline (sometimes called micritic), crystalline (sparitic) and acicular (lublinite) calcite. Few attention was given to transformations from one type into another.

Ducloux et al. (1984) studying pendants on a pebble, observed following sequence of habits: amorphous carbonate > monocrystalline needles > polycrystalline needles and rods > compound needles and scalenohedral crystallites > rhombohedral crystals. From a mineralogical point of view the same authors concluded that the amorphous carbonate can be transformed first to disorganized calcite, later

to calcite (in winter) or to monhydrocalcite first and then over aragonite to calcite (in summer) (Dupuis et al., 1984). Very quick crystallization gives rise to microcrystalline (micritic) calcite. Most probably the Mg content of both the calcite and the soil solution will play also a role (Watts, 1980).

Although since long reference was made to a relation between soil fauna, flora and calcite precipitation, only recently detailed studies were made. The occurrence of polyconcave calcite crystals (fine sand size) with a fan like extinction pattern in root residues or root channels, surrounded by a decalcified hypocotyledon was described in detail by Herrero (1987) and Jaillard (1987). The oligoblastic grains are systematically filling in the lumen of the plant cells. As a result of pedoturbation these cytomorphic grains can become incorporated in the groundmass where they can accumulate and constitute up to 25% of the soil material. Wright (1984) emphasized the relation between micro-organisms and needle shaped calcite. The senior author observed in several soils of the Pampa a deposition of equant calcite crystallites around mycelium threads.

In dry soils, calcite mainly occurs as microcrystalline inter-florescences (impregnations) which tend to become purer and coarser (xenotopic) through recrystallization, casually combined with epigenetic replacement of the silicate minerals. In well drained steppe soils acicular calcite filling in the biopores seems the most abundant form, even as in some semi arid soils. In the relatively moist zones of these soils, as well as in depression soils of the tropics, calcite forms relatively large, coarse grained aggregates, sometimes with a tendency to featherlike crystals, as a result of splitting.

The polymorph of calcite, aragonite, has been reported only few times in soils, and no thin section descriptions exist with respect to its habit.

Siderite (FeCO_3) has been reported as a pedogenic mineral especially in thin sections of wet alluvial soils (e.g. bog ore). It occurs as xenotopic coatings (Fig. 6) on pore walls when present in high amounts, as small crystallites or small spheroidal aggregates in the groundmass or as pore infilling (Stoops, 1983). It can easily be mistaken for calcite, except for its weathering to brown goethitic substances. In bog ore it is often associated with vivianite.

More soluble carbonates and bicarbonates are found associated with sulphates (e.g. thenardite) and halite in some salt crusts.

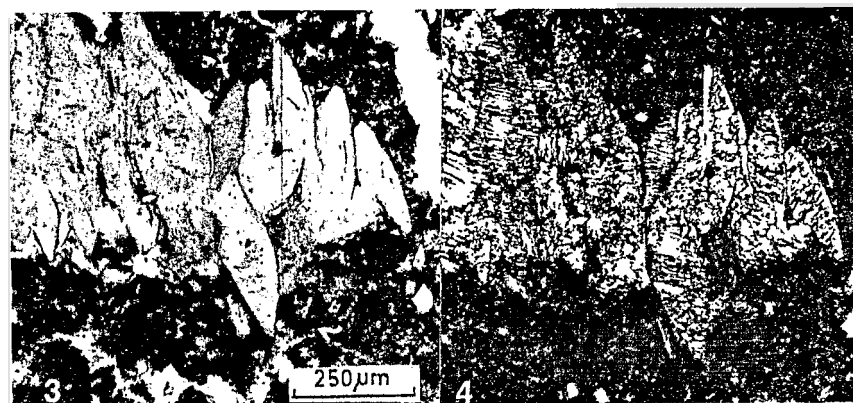


Fig. 3 : Bassanite pseudomorph after lenticular gypsum in an alluvial soil from Egypt. PPL.

Fig. 4 : Idem, XPL. Note the internal fabric of the pseudomorphs.

Trona ($\text{NaHCO}_3 \text{ Na}_2\text{CO}_3 \cdot 2\text{H}_2\text{O}$) forms radiating, tree-like aggregates of slender prismatic crystals with high interference colours. **Burkeite** ($\text{Na}_6\text{CO}_3(\text{SO}_4)_2$) was observed in salt crusts, associated with trona and thenardite, as short prismatic crystals forming coatings on pores, or as loose long prismatic crystals in the salty groundmass.

2.6 Sulphates

The most common sulphate mineral in soil is **gypsum**. In arid soils gypsum practically only occurs as lenticular crystals, as well in a calcic as in a non-calcic groundmass. The only exception, apart from some splitted crystals, seems to be the fibrous gypsum described in some Vertisols of Sudan and southern Egypt (Stoops and Ilaiwi, 1980). The length/ width ratios of the lenticular crystals are variable, but their relation to other conditions is not yet understood. Twin crystals, very common in geological materials, were only seldom observed in some rather saline soils. Pseudomorphic transformations to the hemihydrate (**bassanite**) (Fig. 3 and 4) have been described several times (Simon and Aguilar, 1980), but they can also be the result of heating during thin section preparation. The transformation to calcite is less common, although pedogenetically important. Whereas the pseudomorphic transformation to bassanite seems to follow the crystallographic orientation of

the gypsum, mainly parallel to the cleavage, this is not the case for the replacement by calcite. Pedogenic anhydrite with a dendritic habit has been observed only in one Egyptian desert soil. Nests of slender prismatic crystallites of **celestite** (SrSO_4) (Fig. 5) associated to large gypsum concentrations, were described by Barzanji and Stoops (1974).

In semi arid conditions, gypsum mostly occurs as coarse xenotopic pore infillings. In acid conditions (e.g. in acid sulphate soils, peat) gypsum is found mainly as pseudohexagonal crystals (in the matrix), or as spheroidal aggregates of acicular crystals in voids.

Thenardite (NaSO_4), when formed as a result of rapid evaporation in the pore system (e.g. efflorescences), invariably has an acicular habit; the needles are grouped in semi-spheroidal aggregates. In the groundmass, where crystallization is slower, lenticular crystals are formed, similar to gypsum crystals, except for the absence of cleavages (Fig. 1). Very fragile chrysanthemum-like thenardite aggregates result from the dehydration of mirabilite (Tursina et al. 1980). Mirabilite has never been observed in thin sections as it dehydrates during preparation. Thenardite is associated with gypsum, halite, trona and mirabilite

Other sulphate minerals (e.g. bloedite, hexahydrate, leonardite) have been observed in salt crusts (Vergouwen 1981), but no thin section data are available.

All the above mentioned sulphate minerals are essentially found in dry to very dry areas, however, **barite** (BaSO_4) was mainly observed in relatively wet environments. It occurs in the groundmass as nests of small, short prismatic, sometimes slightly lathshaped crystals, in a range of soils (e.g. Ultisol, Alfisol, Vertisol) that have slightly saline groundwaters (Stoops and Zavaleta, 1978).

Jarosite, formed in acid sulphate soils, occurs as masses of crystallites, not individually recognizable with the optical microscope (Miedema et al, 1974), and therefore not further discussed here.

2.7 Phosphates

Only one pedogenetic phosphate mineral has been described in thin sections, namely **vivianite** ($\text{Fe}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$). In fact, not the colourless vivianite, but the deep blue oxivivianite is observed in thin sections, as a quick oxidation of part of the divalent iron takes place during sampling and preparation. It occurs essentially

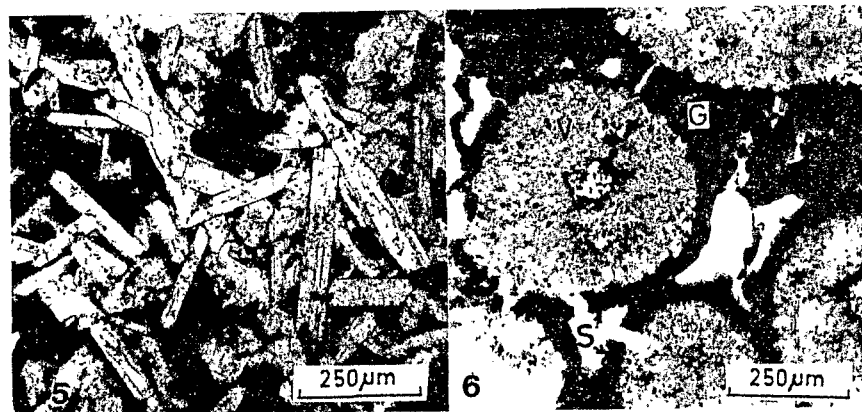


Fig. 5 : Accumulation of prismatic crystals of celestite in a gypsiferous soil from Morocco. PPL.

Fig. 6 : Rootchannels filled with granular vivianite (V) and surrounded by siderite (S) coating, with some interstitial goethite (G) in a bog ore from Belgium. PPL.

as relatively large lath-shaped minerals, both as single crystals or radial aggregates, or as granular, microcrystalline aggregates (Fig. 6) or coatings. It is characterized by its blue colour and strong pleochroism (Stoops 1983). Transformation of vivianite to an isotropic, yellowish substance through complete oxidation has been observed in several cases.

2.8 Silicates

Most pedogenetic silicate minerals are phyllosilicates and seldom have a sufficient large size to be visible, as individuals, in thin sections. Newformed kaolinite can form small, worm-like crystals (elongated normal to the cleavage direction) in the groundmass of clayey saprolites. It is still under discussion in how far some clay coatings can be formed in situ as a result of mineral newformation (cfr. the Russian "polynite" concept, Parfenova and Yarilova 1957)

3 DISCUSSION

Considering the distribution and habit of the newformed minerals in soil, a few general remarks can be formulated:

- acicular habits are exceptionally abundant amongst the pedogenic minerals. This is especially the case when minerals crystallize

rapidly in pore spaces (e.g. calcite, thenardite, halite, gypsum). Spheroidal aggregates of acicular crystals are more common in moist environments (e.g. goethite, siderite, vivianite).

- many crystals do not form in the groundmass, but preferentially crystallize in pore spaces (e.g. thenardite, halite); their crystallizing force is probably not sufficiently large to remove mechanically the groundmass; others (e.g. celestite, barite, siderite) are formed essentially in the groundmass. When formation takes place both in the groundmass and in the pore space, a different habit is to be expected.

- minerals crystallizing in different environments display generally also different habits (e.g. calcite, gypsum, goethite).

- physicochemical conditions in soils are changing frequently and relatively quickly (compared to geology) so that equilibrium situations are seldomly reached. Therefore only mineral associations are easy to identify while real mineral paragenesis seldom occur.

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AMPHIBOLE ALTERATION TO VERMICULITE IN A WEATHERING PROFILE OF GABBRO-DIORITE

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ABSTRACT

Amphibole weathering to vermiculite in ferromagnesian sandy grains of saprolite and C horizon of a Typic Rhodoxeralf from southern Portugal is studied. Minerals identification and alteration studies were accomplished by X-ray diffraction, optical and electron (scanning and transmission) microscopy and electron microprobe analysis. Vermiculite replaces amphibole along planes which are parallel to the cleavage planes (110) of the primary silicate. In this process the contents of Si, Ca and Mg decrease whereas Fe content remains approximately constant during the initial stage of weathering. On the basis of lattice coherence between a chain silicate and a 2:1 layer silicate, a solid state transformation of amphibole into vermiculite with no intervening non-crystalline phase is proposed.

1 INTRODUCTION

Vermiculite, an interstratified vermiculite-smectite, goethite and hematite were reported as weathering products of a gabbro-diorite consisting mostly of amphiboles and plagioclase feldspars in different stages of alteration to scapolite (Abreu, 1986).

Preliminary studies using optical microscopy and X-ray diffraction analysis indicate a progressive replacement of amphibole by a yellow-brown 2:1 layer silicate during the rock weathering. These preliminary results appear to be similar to those firstly reported by Barshad and Fawzy (1969) and, more recently, by Eggleton (1975, 1984, 1986), Eggleton and Boland (1982), Eggleton and Smith (1983) and Cole and Lancucki (1976) to explain the weathering mechanisms of some ferromagnesian silicates.

This paper examines the alteration of amphibole during weathering of a gabbro-diorite in the south of Tagus river, Portugal, by thin sections studies, electron microprobe analysis, X-ray diffraction and scanning electron microscopy (SEM). The alteration mechanism is evidenced by means of transmission electron microscopy (TEM).