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GUIDELINES FOR THE DESCRIPTION OF MINERAL ALTERATIONS IN SOIL MICROMORPHOLOGY

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A contribution of the *"Subgroup on Weathering Phenomena and Neoformations"* of the *"Working Group on Soil Micromorphology of the I.S.S.S."*

INTRODUCTION

This paper is based on discussions and reports of the meetings of the "Subgroup on Weathering Phenomena and Neoformations" of the "Working Group on Soil Micromorphology of the I.S.S.S.". The subgroup was set up in 1973 to investigate ways of describing and classifying weathering minerals and rocks.

Parts of the text are taken from a report on the activities of the subgroup, distributed to the participants of the "International Working Meeting on Soil Micromorphology" in Granada, 1977 (Stoops *et al.* 1977).

The purpose of this paper is to contribute to the micromorphological description of thin sections of soils, weathering products and superficial deposits, by proposing a simple classification and terminology for describing the morphological characteristics of weathered mineral grains. It deals with single, individual grains, in rock and in loose material. The description of the morphological changes taking place in single grains of a weathering rock may be considered as a first step

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towards the description of the latter.

According to Delvigne (1975), weathering is the partial transformation, isovolumetric or otherwise of rocks, soils or loose sediments, accompanied by changes in their colour, texture, hardness or shape. These changes occur by partial or complete disappearance of part or all of the original minerals and their possible replacement by a secondary, crystallized or amorphous, authigenic or partially allogenic material. The physico-chemical reactions responsible for the weathering occur between, on the one hand, percolating or underground waters, carbon dioxide, organic matter and various ions or colloids dissolved or transported by those waters, and, on the other hand, the crystal lattice of the transforming primary minerals and the ions released from it. These processes often tend towards an *in situ* accumulation of soft, porous and easily erodable material which is the main source of transported sediments. Although weathering may occur at greater depth due to important fracturing or high porosity of the rock, most commonly it occurs near the surface or at shallow depth under temperature and pressure conditions prevailing at the Earth's surface. There are thus important variations in the intensity of processes related to the type of climate or paleo-climate. The main factors controlling the intensity or rate of reactions are : temperature, rainfall, drainage, topographic locations and also the petrographic and mineralogical composition of the parent material.

Although our main interest is the weathering of minerals and rocks by meteorological agents, features resulting from other processes of alteration (e.g. hydrothermal) have to be included because of a lack of specific diagnostic criteria to separate such genetic groups. Moreover, many features resulting from mineral alteration (among others by hydrothermal solutions) are commonly observed in thin sections (e.g. iddingsitized olivine, chloritized biotite) and should be described, as they might have a big influence on further weathering of the mineral and the release of nutrients. Thus, the term alteration is used in its most general sense, covering mineralogical and chemical changes resulting from weathering and alteration *sensu stricto*, or even diagenesis.

THE DESCRIPTION OF ALTERATION PHENOMENA

The system proposed for description of alteration features is an open one without an established hierarchy. It must be noted that, although the proposed system is designed for individual grains in rock or soil, it may be applied also to the partial description of weathered rock fragments.

The most important morphological characteristics of weathering mineral grains are listed below, not necessarilly in order of importance.

1. The secondary porosity, including the arrangement of pores and secondary products, their shape and classification;
2. The pattern of mineral alteration or the location of the alteration within the mineral grain;
3. The degree of alteration;
4. The nature of the secondary products.

Some of these morphological aspects are discussed in more detail below.

THE SECONDARY POROSITY PATTERN

It should be noted that the term *pores,* as used here, includes not only the empty spaces present in a mineral or rock (voids sensu stricto) but also those filled by secondary products.

Chemical weathering generally proceeds along pores and fractures in rock and in minerals, and mostly creates new porosity. Therefore it is generally impossible to describe the chemical weathering in a rock or mineral without making reference to the porosity pattern.

In recognizable rock structures, the secondary porosity pattern of individual mineral grains has to be related to the surrounding grains.

In many instances it seems useful to differentiate pores according to Bisdom 1967 :

– *Transmineral pores* traverse the rock without following the grain boundaries (fig. 1a). They are very often several cm long and are frequently caused by mechanical forces, e.g. tectonics. The term will be used also for pores in amorphous or weakly crystalline materials.

– *Intermineral pores* traverse the rock following the grain boundaries (fig. 1b). If the intermineral pores are very close-spaced, the rock is crumbly and is made up of loosened, isolated mineral grains, as for instance in a granitic sand. They are frequently caused by physical weathering (e.g. insolation of marble) but may be also the result of chemical corrosion, as shown by S.E.M.-techniques.

– *Intramineral pores* occur within a mineral grain, and very often without connection with pores in adjacent mineral grains. The pore pattern is frequently related to specific crystallographic directions in the mineral grain (fig. 1c).

For the general description of the orientation and distribution patterns of pores at this stage we propose the terminology of Brewer 1964 (e.g. parallel, normal, oblique, etc.). Likewise, existing terminologies should be used for the shape of pores.

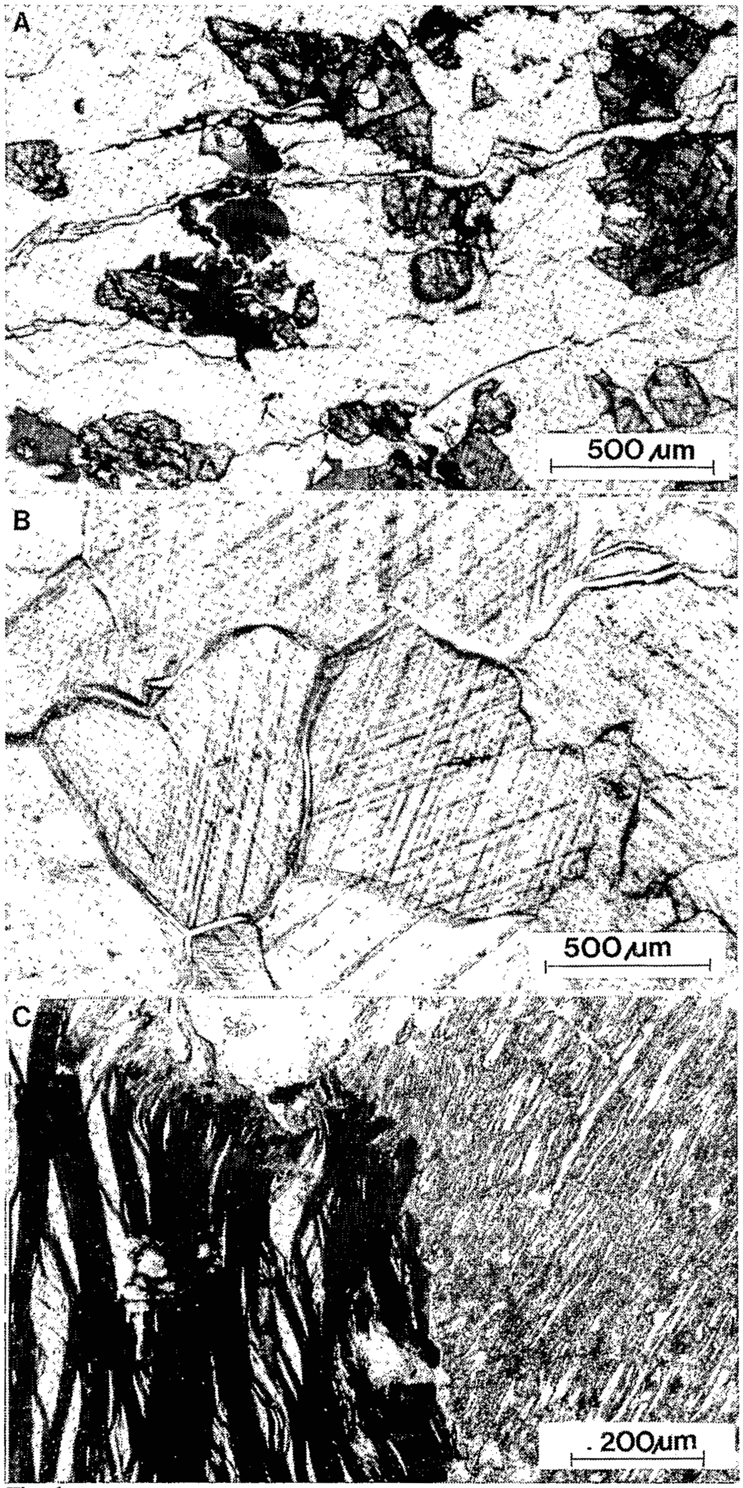


Fig. 1.

A Transmineral pores with accordant surfaces in a weathering plutonic rock (Zaire)

B Intermineral pores with accordant surfaces in a white marble (Turkey)

C Intramineral pores with non-accordant surfaces in weathering feldspar and biotite (Rwanda).

The distribution and orientation of the pores and secondary products commonly follow zones of weakness such as fractures or zones conducive to chemical weathering which in turn are controlled by internal and external factors.

The *internal factors* are related to the crystallographic properties of the mineral, such as cleavage (e.g. in pyroxene), twinning (e.g. in plagioclases), inclusions, chemical composition (e.g. zonation), crystallography (e.g. lattice defects). A mixture of two or more of the abovementioned types is common. These internal factors are especially important for the development of intramineral pores and associated weathering products.

The *external factors* include activities such as tectonics, pressure release,water circulation, fungal activities, biogenic activities (e.g. termites in saprolite), roots, etc. Mainly transmineral and intermineral pores are formed.

Such interpretations however are beyond the bounds of pure morphological description.

It may be usefull to distinguish between *accordant* and *non-accordant* surfaces of pores. Accordant surfaces are those that would fit exactly if they came together and closed the pore completely (cf. definition of Risse by Beckmann & Geyger 1967) (fig. 1a and b). Non-accordant surfaces are those that will not fit when brought together. Accordant surfaces occur mostly on chemically unattacked fissures and cracks, non-accordant pores include dissolution cavities, tubes (e.g. from fungal activity) and chemically widened fissures (fig. 1c)

PATTERNS OF MINERAL ALTERATION

Minerals may alter according to several, more or less complicated, patterns which are in many cases predetermined by internal or external factors. In the following paragraph we will give a schematic classification of the most common simple patterns. More complex situations can be described by combining a number of these patterns. The patterns can be used as long as the original outline of the mineral is recognizable and the pore spaces (empty or filled) created during weathering are conserved. This means that the scheme proposed is valid only for the cases where pseudomorphs are formed or the pores, left after partial or complete dissolution of the mineral are conserved. It must be emphasized that such weathering is not necessarily isovolumetric, e.g. pseudomorphs of kaolinte after biotite may be formed where an expansion in one direction is obvious. In order to distinguish

between situations of weathering where shape and/or size of the original mineral is wholy or partly conserved, the following definitions are proposed :
– *isomorphous (*) alteration :* the external shape and dimensions of the pseudomorph are similar to those of the original mineral. The word similar is used here, because in practice it is impossible to state whether size and shape are identical. An example is the iddingsitization of olivine.
– *mesomorphous alteration :* the external form of the original mineral is preserved or can easily be deduced, but the sizes have changed in one, two or three dimensions. The inequal change in size of one or two dimensions may introduce also a controlled change in shape, e.g. a square may become a rectangle when distinct kaolinite booklets are formed at the expense of biotite.
– *katamorphous alteration :* the external shape and dimensions of the original mineral may be changed in the pseudomorph; the external boundaries are no longer clear and continuous, but the position of the original mineral can still be recognized or deduced and the alteration products are not scattered in the surrounding materials. An example of this type of weathering is the occurrence of phantoms of totally weathered biotite or chlorite in the clay-matrix of a soil.

The alteration patterns, described below, are for isomorphous alteration, but can also be used for mesomorphous alteration. In all cases, the mineral grain has to be considered in its totality. This means for instance that, once fractured the whole original unit must be considered, and not the individual fragments. The gradual transformation of a mineral, taking place simultaneously throughout the whole grain, can not be described in terms of morphology, but only in terms of material (e.g. the gradual, uniform bleaching of biotite grains).

The alteration may be of a *pellicular* type (fig. 2a + b, fig. 3A, 1 and 2), i.e. starting from the border and gradually invading the mineral; a diminishing *core* of original material is left (fig. 3A, 2 and 3). Such an alteration is commonly observed in olivine (iddingsitization), sphene (to leucoxene) and other minerals without strongly expressed crystallographic directions such as cleavage, twinning, etc.. Another typical example of pellicular weathering is the congruent dissolution (Von Engelhardt 1976) of calcite, quartz, hypersthene, etc. in rocks and soils. The cores left behind after partial dissolution may have different shapes; they may be rounded, corroded, denticulate, or even

(*) The term isomorphous is used here in its general, literal meaning without any reference to specific meanings given in crystallography.

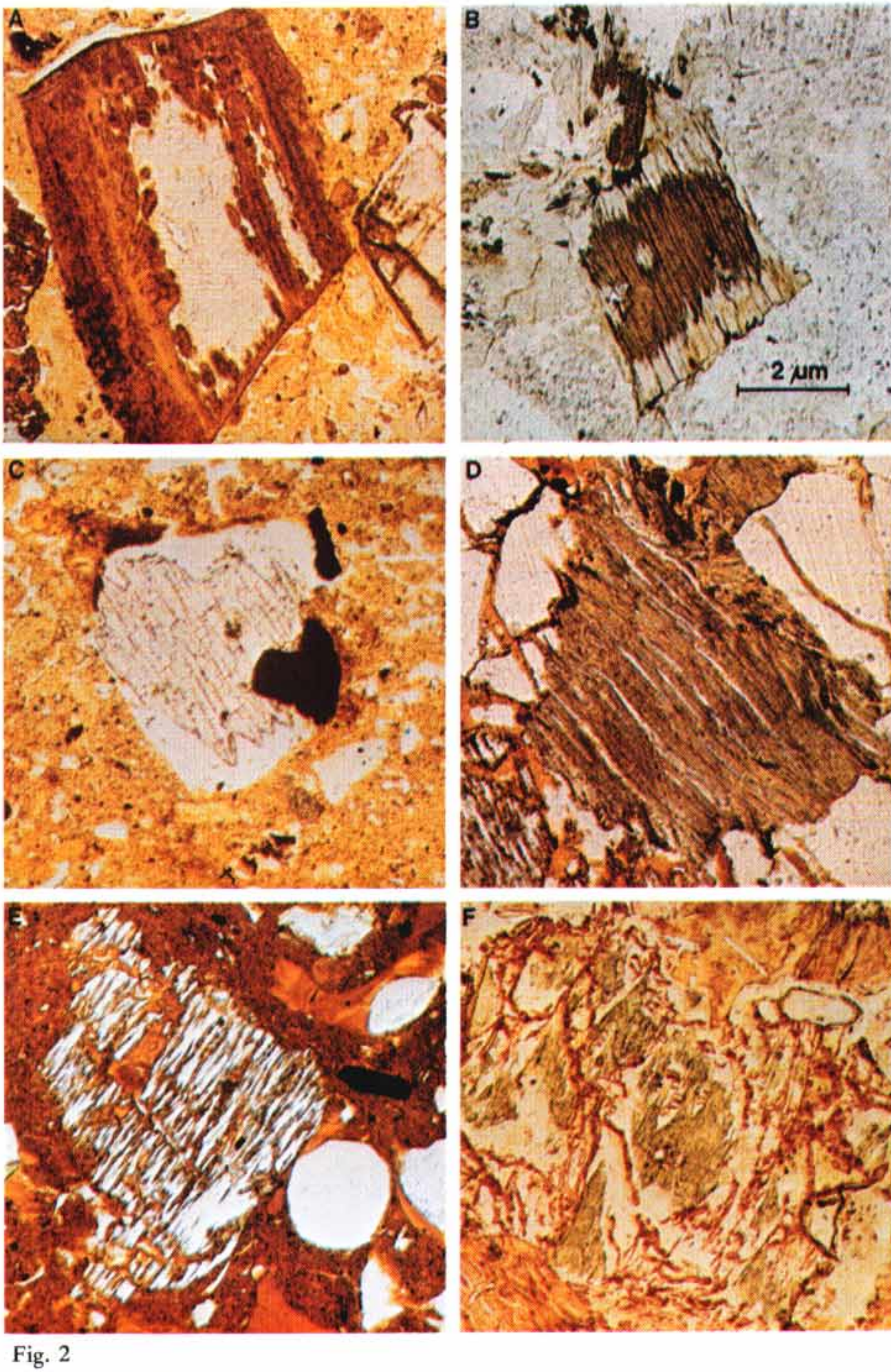


Fig. 2

Some alteration patterns

A Thick pellicular alteration of olivine to iddingsite; a large olivine core is left (soil on weathered basalt, Galapagos).

B Thick pellicular (and dotted) alteration of biotite into chlorite in a Kersantite (Brittany).

C Pellicular congruent dissolution of hypersthene in volcanic ash soil (Chili). A denticulate large core is left.

D Parallel linear alteration of biotite in a granite (Rwanda).

E Parallel banded alteration of perthitic feldspar in a soil on granite (Rwanda). The intramineral pores are filled with clay and iron oxihydrates.

F Irregular linear alteration of hornblende to smectite (stained red by safranine) and subsequent congruent dissolution of the random residues (Diorite, Ivory Coast).

euhedral (fig. 2c).

Commonly the alteration follows cracks, fissures, cleavage planes and other surfaces of weakness in the mineral. These surfaces may form a regular or irregular network. In the first case the alteration forms a *parallel or cross linear* and later a *parallel or cross banded* pattern (*organized (minute) residues*) fig. 3C, 1 and C2). The parallel patterns occur for instance in micas (fig. 2D), perthites (fig. 2E) and in sections parallel to the c-axis of inosilicates, the cross patterns in orthose and sections normal or oblique to the c-axis of ino-silicates. The cross linear and cross banded patterns correspond essentially to the "reticulate texture" as used in petrography.

These regular patterns are frequently observed in minerals with well expressed cleavage or twinning planes. When such crystallographic directions are only weakly developed, or missing, an *irregular linear* pattern (fig. 3B, 1) is formed, which is broadened to an *irregular banded* pattern (fig. 3B, 2) as alteration proceeds; as a result the residues are randomly distributed, and referred to as *random (minute) residues* (fig. 3B, 2 and 3) (fig. 2F). Examples can be seen in the weathering of garnet, olivine, etc. Since it is often difficult to recognize the organization of the minute residues, organized minute residues may often be classed as random minute residues.

A last simple type of alteration is that starting inside the mineral, apparently without reference to external or internal features. In early alteration stages the secondary products or pores appear as randomly distributed individual dots (*dotted*) (fig. 3D, 1), later as islands (*patchy*) (fig. 3D, 2). The residue initially has a *cavernous* appearance (fig. 3D, 2), changing gradually to a pattern of *dispersed (minute) residues* (fig. 3D, 3).

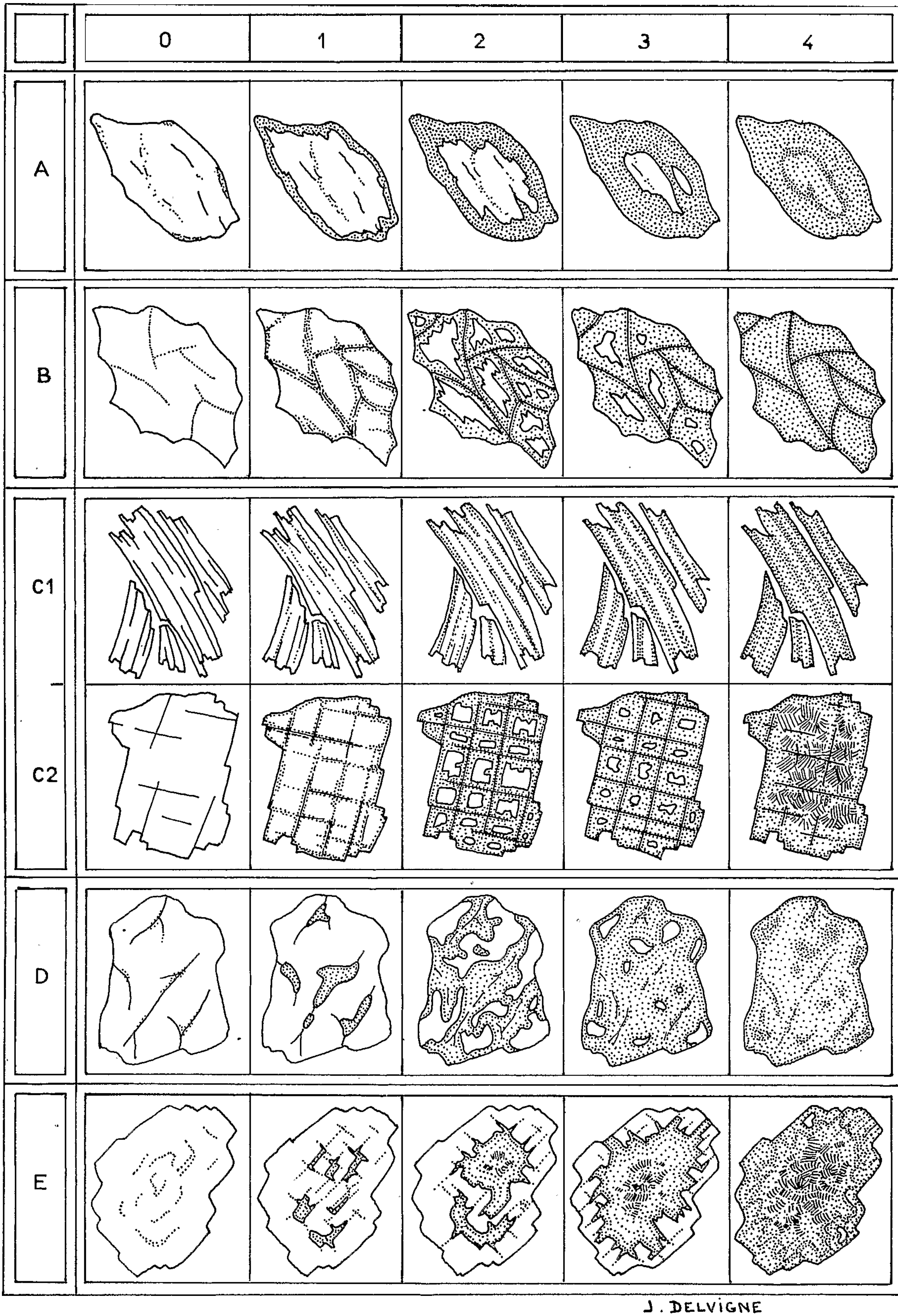
Combinations of the above-mentioned patterns are of course frequently observed, and should be described as such, as far as possible or desirable, otherwise the term *complex alteration pattern* should be used.

DEGREE OF ALTERATION

A scale of five classes has been set up to describe the degree of mineral alteration. Stage 0 is reserved for the unaltered (i.e. fresh) mineral. The higher the number (from 1 to 4) the greater the degree of alteration. Stage 4 represents the completely altered mineral :

Class 0 : *fresh or nearly fresh* : less than 2.5 % of the mineral has been altered;

Class 1 : *slightly altered* : 2.5-25 % of the mineral has been altered;


0
1
2
3
4
A
B
C1
C2
D
E
J. DELVIGNE

Class 2 : *moderately altered* : 25-75 % of the mineral has been altered;
Class 3 : *strongly altered* : 75-97,5 % of the mineral has been altered;
Class 4 : *completely altered* : more than 97,5 % of the original mineral has been altered.

The above limits are expressed in area percent. The degree of alteration expresses the relative amount of original mineral replaced by a secondary mineral or pore space (in the case of solution).

The combination of the pattern and the degree of mineral alteration as presented in table 1 and fig. 3, makes it possible to state with a single, simple but precise expression both characteristics. For class 1 the alteration pattern is expressed as a function of the secondary products or pores; for class 3 as a function of the residues of the original mineral, whereas for class 2 both characteristics might be used.

DISCUSSION OF SOME SPECIAL CASES

When considering mineral grains which are no longer in their original contexts, one should be aware of the fact that not all observed corrosion-like forms are due to weathering. Some of these features may have been present already in the non-weathered rock and became apparent after a certain degree of weathering, e.g. features associated with interlocking minerals (among others myrmekite), minerals which were originally subject to resorptive processes and mineral inclusions. A very common example is the quartz crystals from rhyolitic materials; their corroded aspect has nothing to do with weathering, but is the result of reactions in the lava (fig. 4).

A difficulty frequently encountered in the description of altered minerals is that the alteration can take place in several successive steps, related to different physico-chemical conditions (e.g. biotite to vermiculite and later to kaolinite), or may succeed a former alteration (e.g. olivine to serpentine, later to nontronite). In these cases the first alteration will be referred to the primary mineral, i.e. stage 0 is the fresh primary mineral. Stage 0 of the second sequence will be the end product of the first cycle of alteration.

Fig. 3

Alteration sequences, illustrating the different patterns and degrees of alteration (cf. table 1)

A Pellicular alteration of olivine to iddingsite
B Irregular linear alteration of olivine to nontronite
C_1 Parallel linear alteration of muscovite to kaolinite
C_2 Cross linear alteration of K-feldspar into amorphous material and feldspar
D Dotted alteration of olivine into nontronite
E Complex alteration of K-feldspar into amorphous material and kaolinte.

Table 1

Terminology for different patterns and degrees of alteration (cf. fig. 3)

<table>
<tr><td>1)</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td>3) 2)</td><td>0-2.5 %</td><td>2.5-25 %</td><td>25-75 %</td><td>75-97.5 %</td><td>97.5-100 %</td></tr>
<tr><td rowspan="2">A</td><td rowspan="11">ORIGINAL MINERAL</td><td rowspan="2">pellicular</td><td>thick pellicular</td><td></td><td rowspan="11">COMPLETELY ALTERED</td></tr>
<tr><td>large core</td><td>core</td></tr>
<tr><td rowspan="2">B</td><td rowspan="2">irregular linear</td><td>irregular banded</td><td></td></tr>
<tr><td>random residues</td><td>random minute residues</td></tr>
<tr><td rowspan="2">C.1</td><td rowspan="2">parallel linear</td><td>parallel banded</td><td></td></tr>
<tr><td>organized residues</td><td>organized minute residues</td></tr>
<tr><td rowspan="2">C.2</td><td rowspan="2">cross linear</td><td>cross banded</td><td></td></tr>
<tr><td>organized residues</td><td>organized minute residues</td></tr>
<tr><td rowspan="2">D</td><td rowspan="2">dotted</td><td>patchy</td><td></td></tr>
<tr><td>cavernous residue</td><td>dispersed minute residues</td></tr>
<tr><td>E</td><td colspan="3">COMPLEX</td></tr>
</table>

1. Degree of alteration (class)
2. Degree of alteration expressed in volume percent
3. Alteration pattern

A commonly observed polygenetic alteration is the formation of a rather stable secondary product in the cracks of the original mineral, as a first step, followed by the complete dissolution of the remaining primary mineral. It must be understood that in this case each individual fragment of the primary mineral, separated from the other fragments by a fringe of secondary products of the first cycle, undergoes in fact a pellicular alteration (in this case a congruent dissolution) during the second cycle, and can be described as such (fig. 2F). A well known example is the alteration of olivine, giving an irregular linear pattern of ironoxihydrates after the first alteration cycle. During the next

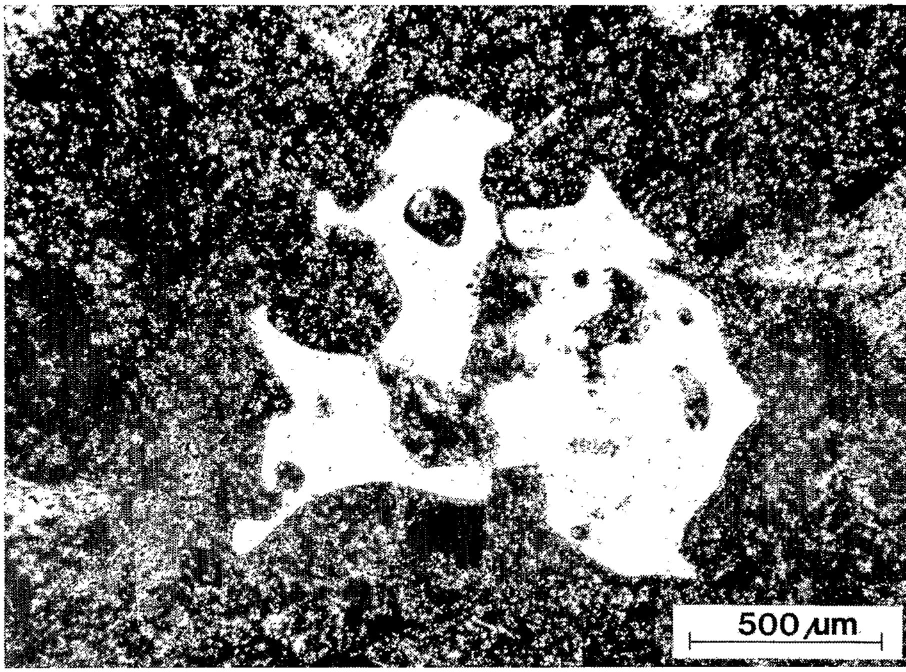


Fig. 4.

Crystal of quartz in a microdiorite corroded as a result of resorption (Belgium).

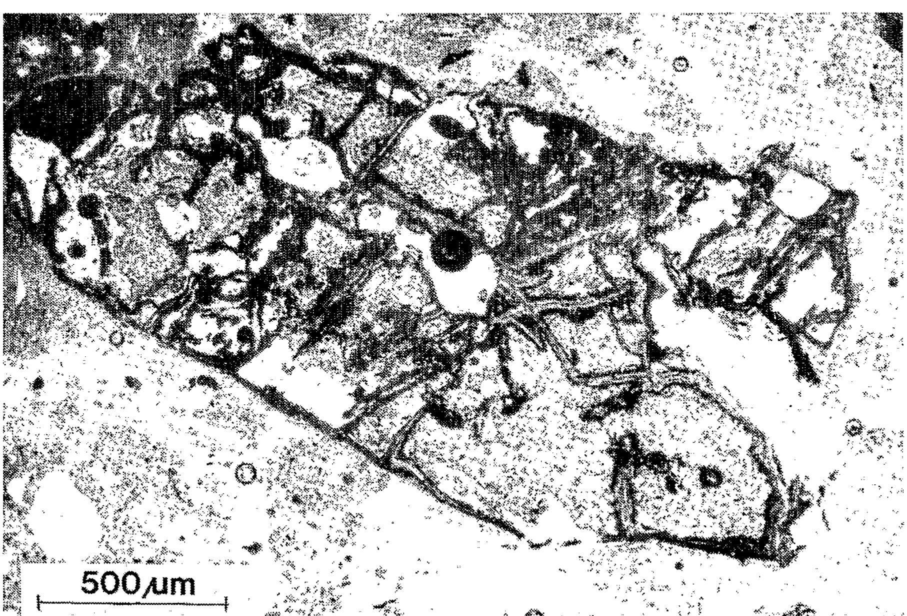


Fig. 5.

Irregular banded alteration of garnet with crystallization of goethite normal to the walls of the pores, and subsequent congruent dissolution of the random garnet residues (Cameroun).

cycle, characterized by other physico-chemical conditions, the olivine dissolves completely, and the so created pores are filled by allogenic gibbsite. This process is responsable for the formation of the so-called *boxwork structure* (fig. 5).

As mentioned previously, pores may be empty as well as filled to various degrees with authigenic and/or allogenic materials. It is often possible to describe the nature of the filling material (e.g. kaolinite, goethite, calcite), its colour, fabric, optical characteristics etc. A discussion of this however lies beyond the scope of this paper.

It is worthwhile to mention that isolated (volcanic) glass particles can be considered as individual mineral grains and that therefore their alteration can be described as above. This is valid for individual glass particles in tuffs, sediments or soils, but the scheme cannot be applied when the glass forms a continuous medium as for instance in a lava.

Although not conceived for that purpose, the alteration patterns proposed might be used as well for the description of weathering of rock fragments (treated as a single entity and thus considered as a homogeneous body) embedded in the soil material. The weathering patterns of a rock fragment however can be more complicated than those observed in a single mineral grain, because of its heterogeneity and the occurrence of different zones and gradations. The proposed terminology can therefore only be a first step towards their systematic description.

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ANNEX

Proposed translation of some terms
(For technical reasons the Russian translation is given on the last place).
F : French; G : German, S : Spanish, R : Russian.

$A_{1\&2}$ *(thick) pellicular,* F : pelliculaire (épaisse), G : (dick) rindenartig, S : pelicular (grueso), R : периферическая (толстая) корка

$A_{2\&3}$ *(large) core,* F : (grand) noyau, G : (grosser) Kern, S : nucleo (grande), R : (крупное) ядро

$B_1\&C_1$ *linear,* F : linéaire, G : linear, S : lineal, R : сетчатость

$B_2\&C_2$ *banded,* F : rubané, G : streifig, S : bandeado; R : полосчатость

B *irregular,* F : irrégulier, G : unregelmässig, S : irregular, R : неправильная

$B_{2\&3}$ *random (minute) residues,* F : (petits) résidus désordonnés, G : (winzige) Mineralreste unregelmässig verteilt, S : residuos (pequeños) al azar, R : беспорядочные (мелкие) остатки

$C_{2\&3}$ *organized (minute) residues,* F : (petits) résidus ordonnés ou arrangés, G : (winzige) Mineralreste regelmässig angeordnet, S : residuos (pequeños) organisados, R : упорядоченные (мелкие) остатки

C_1 *parallel,* F : parallèle, G : parallel, S : paralelo, R : паралельная

C_2 *cross,* F : croisé, G : gekreutzt, S : cruzado, R : крестообразная

D_1 *dotted,* F : en pointillé, G : punktiert, S : punteado, R : точечное преобразование

D_2 *patchy,* F : en taches, G : fleckenartig, S : parcheado, R : островное преобразование

D_2 *cavernous residue,* F : résidu caverneux, G : kavernöse Mineralreste, S : residuo cavernoso, R : островное преобразование

D_3 *dispersed minute residues,* F : particules résiduelles dispersées, G : verstreute winzige Mineralreste, S : particulas residuales dispersas, R : рассеянные (мелкие) остатки

Summary

A simple morphological classification and terminology is proposed to describe the pattern and degree of alteration of individual mineral grains in rocks and soils. The system is only intended for alterations wherein the original external outline

of the primary grain is preserved by the formation of pseudomorphs or the conservation of the porespaces created (*isomorphous* and partially *mesomorphous* alteration).

Five degrees (0 to 4) of alteration are distinguished on the basis of area percentages, and five different patterns, viz. pellicular alteration, linear alteration (parallel, cross and irregular) and dotted alteration patterns.

Three different types of pores are recognized in an altering rock : intramineral, intermineral and transmineral pores. They may either have accordant surfaces (when the opposite walls completely interlock) or non-accordant surfaces (when the opposite walls don't interlock).

This description of mineral weathering is a first step toward the description of rock weathering.

Directives pour la description de l'altération des minéraux en micromorphologie des sols

Résumé

On propose de décrire, à l'aide d'une classification et d'une terminologie simples, la morphologie et l'intensité de l'altération de grains minéraux individualisés au sein des roches et des sols. Le système est prévu uniquement pour les altérations dans lesquelles la configuration externe originelle du grain primaire est conservée par la formation de pseudomorphoses ou par la persistance des espaces poreux formés (altérations *isomorphes* et altérations partiellement *mésomorphes*).

On distingue cinq degrés (de 0 à 4) d'altération et de cinq types différents : l'altération pelliculaire, l'altération linéaire (parallèle, croisée ou irrégulière) et l'altération en taches.

On définit trois types différents de pores dans une roche en voie d'altération : pores intraminéraux, pores interminéraux et pores transminéraux. Ils peuvent être soit conformes (lorsque les bords opposés peuvent s'emboiter complètement) soit non-conformes (lorsque les bords opposés ne s'emboitent pas).

Cette description de l'altération des minéraux ne constitue qu'une première étape vers celle de l'altération des roches.

Richtlijnen voor het beschrijven van mineraalverweringen in de bodemmikromorfologie

Samenvatting

Een eenvoudige morfologische indeling en terminologie wordt voorgesteld om het patroon en de graad van verwering van individuele mineraalkorrels in gesteenten en bodems te beschrijven. Het systeem is alleen bedoeld voor die verweringen waarbij de oorspronkelijke uitwendige begrenzing van de primaire korrel bewaard blijft door de vorming van pseudomorfen of door het behoud van de gevormde holten (*isomorfe* en ten dele *mesomorfe* verwering).

Vijf graden van verwering (van 0 tot 4) en vijf verschillende patronen worden

onderscheiden : een schilvormige verwering, een lijnvormige verwering (evenwijdig, kruisend of onregelmatig) en een gestippelde verwering.

Drie verschillende typen van holten kunnen in een verwerend gesteente herkend worden : intraminerale, interminerale en transminerale holten. Ze kunnen aaneensluitend zijn (indien de tegenover elkaar liggende wanden volledig in elkaar grijpen) of niet aaneensluitend (als de wanden niet in elkaar grijpen). Deze beschrijving van de verwering van mineralen is een eerste stap naar de beschrijving van de verwering van gesteenten.