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MICROMORPHOLOGY OF THE ALTERATION AND WEATHERING OF PYROXENES IN THE KOUA BOCCA ULTRAMAFIC INTRUSION, IVORY COAST, WESTERN AFRICA.

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ABSTRACT

At the contact with younger surrounding granites, the clinopyroxenites of the Koua Bocca ultramafic intrusion have been partly transformed by hydrothermal alteration: orthopyroxenes are altered to talc, tremolite or cummingtonite whereas clinopyroxenes are altered to hornblende or actinolite. Within the superficial environment, under the influence of weathering processes, the pyroxenes are weathered to ferriferous smectites under vertic conditions, whereas with fersiallitic processes, the unstable smectites were gradually replaced by kaolinite and haematite. In the oldest indurated crusts, pyroxenes have been replaced by iron hydroxides to form porous boxwork pseudomorphs whose pores, in some cases, have been filled by later goethite or gibbsite.

I. INTRODUCTION

The ultramafic intrusion of the Koua Bocca, located about 200 km NNW of Abidjan, dates from the Abronian period (2.000 M.Y.), an intra-Birrimian gap located between the "Supergroupe Volcano-sédimentaire" and the later "Supergroupe de Comblement" (TAGINI, 1971). The intrusion is composed, in the lower levels, of clinopyroxenites containing orthopyroxene, olivine, opaque minerals and hornblende and, in the upper part of melagabbronorites containing basic plagioclase, hornblende and clinopyroxene.

The Abronian ultrabasites are earlier than the orogenic period which emplaced the surrounding "baoulés" granites (1.800 M.Y.). In the inner part of the intrusion, the rock are practically unmetamorphosed, but near the contact with the later granites, several concentric aureoles have developed, characterized by progressively more important metamorphism. In the inner aureole, only the olivine is transformed, within the middle aureole, the orthopyroxene is transformed as well and within the outer aureole, the clinopyroxene and plagioclase are also transformed.

The geomorphic history of the region began in the early Tertiary. The formation of several erosional surfaces is closely related to sucessive periods of weathering and distinct lateritic crusts formation. The oldest surfaces reduced to isolated remnants, are ferrallitic (kaolinite + gibbsite + ferruginous components) with some trace of bauxitic materials. The middle surfaces are fersiallitic (smectite + kaolinite) with ferruginous indurated crusts. The most recent lower level is vertic (smectite + vermiculite) with calcareous and manganesiferous concretions.

Only the alteration of pyroxenes is discussed here. Two different types of alteration occur: a deep alteration by late- or post-magmatic processes, and a shallow and superficial weathering. About 2.500 samples were studied in thin sections, analyzed by means of X-ray diffraction. The most characteristic samples were analyzed with the electron microprobe.

II. PETROGRAPHIC STUDY OF THE PYROXENES

The clinopyroxene is the most abundant and presents typical granoblastic structures with a mosaic of polygonal grains several tenths of a millimeter long. Some sub automorphic porphyroblastic crystals are observed in the re-crystallized rocks. Clinopyroxene is also found as inclusions within the poikiloblastic crystals of orthopyroxene, magnetite and hornblende. The clinopyroxene is a diopsidic augite (Wo = 0.45; En = 0.44; Fs = 0.11) and does not present any significant chemical variation from base to top of the sequence.

The orthopyroxene, much less abundant than clinopyroxene, is generally associated with olivine. It occurs in several different forms:

- in the usual clinopyroxenic rocks, it is present as polygonal grains associated with the clinopyroxene in the granoblastic structure;
- near or within the olivine-bearing levels we find orthopyroxene as porphyroblastic subhedral crystals, as large poikiloblastic "amoeboid" crystals, or as irregular symplectic assemblage with magnetite (HAGGERTY and BAKER, 1967) around a central core of incompletely assimilated olivine;
- in the middle metamorphic aureoles, it occurs as large porphyroblastic subhedral crystals. 3 to 5 mm long, surrounded by a poikiloblastic ring of green hornblende.

No matter what the crystal form, the orthopyroxene exhibits the constant chemical composition (Wo = 0.02; En = 0.72; Fs = 0.26) of a bronzite close to hypersthene.

III. HYDROTHERMAL ALTERATIONS

Along the fractures formed by the post-magmatic processes as well as along the leucocratic veins injected during the mobilization of the granites and within the metamorphosed rings, the pyroxenes suffered varied fates in accordance with the importance of and the proximity to these features. The orthopyroxene reacts much more rapidly and sooner than the clinopyroxene: near the contact with hydrothermal veins the orthopyroxene is completely transformed, whereas clinopyroxene persists intact.

A. First stage: OPx → Talc + Mgt and CPx = CPx

Near the thinnest hydrothermal veins, the transformation of the OPx leads to more or less complete pseudomorphs of talc with small opaque grains representing the iron originally contained in the OPx but excluded from the talc. Ferriferous talc is sometimes observed within the outer aureoles: the microstructures are similar but the opaque inclusions are in much smaller abundance or even absent.

The alteration is peripheral and centripetal, or accompanies the transmineral hydrothermal veins. The OPx remnants are irregularly shaped with gently denticulated limits along the c-axis of the mineral. The neoformed talc is rarely oriented but rather occurs as aggregates of small particles randomly distributed (see plate A1). The magnetite is either disseminated within the talc or concentrated near the outer margin of the pseudomorph. The transformation is generally isovolumetric; a small volume increase is sometimes observed: a radiating network of fractures is formed around the pseudomorph and is filled by talc or eventually by excess magnetite. The symplectic structures are always well preserved during the transformation into talc.

The CPx is very little disturbed during this first step; actinolite without magnetite and sometimes accompanied by calcite, can develop along the important veins. Other minerals are not transformed except the olivines which are completely replaced by serpentine + magnetite, by ferromagnesian amphiboles or by iddingsite.

B. Second stage: OPx → Talc + Mgt → Tremolite + Mgt

With increased influence of the metamorphic and hydrothermal processes, the talc which was formerly the only mineral replacing the OPx, is now associated with colourless amphiboles; these can dominate or even be the sole mineral in the pseudomorph. Normally the neoformed amphibole would belong to the cummingtonite-grunerite series; however since natural cummingtonite with composition similar to the magnesian orthopyroxenes of the Koua Bocca do not exist (DEER, HOWIE and ZUSSMANN, 1972, v.2,p.235), the neoformed amphibole belongs to the tremolite-actinolite series, the necessary calcium coming from the concomitant CPx transformation. The excess iron crystallizes into magnetite with, eventually, a small quantity of cummingtonite associated with tremolite. If the three silicates are present together, the talc always appears between the pyroxene remnant and the neoformed amphibole.

These colourless amphiboles are often arranged in bundles of fibrous or acicular prisms parallel to the c-axis of the original pyroxene (see plate A3). The transformation is isovolumetric. Nevertheless, in contact with soft minerals like vermiculite or biotite, radiating sheafs of tremolite prisms can form in which the crystals traverse the envelope of the pseudomorph and penetrate into the neighbouring phyllosilicate, forming non isovolumetric urchin-like pseudomorphs (see plate A6).

The symplectites are also transformed into tremolite, but the fine structures of magnetite lamellae are partly destroyed during amphibole crystallization: opaque lamellae become rounded and form inclusions or fill interstices between prisms or they recrystallize into small automorphic opaque grains (see plate A5).

The CPx is only partly transformed into fibrous or lamellar green actinolite arranged into sheaves or irregular mosaics which progressively mask the original granoblastic structure (see plate A2).

C. Third stage: CPx → Act + Pist and CPx → Hnb

The pseudomorphs after OPx experience no further development. They have been totally transformed into tremolite-cummingtonite-magnetite. No more talc or unaltered orthopyroxene residues are observed. The clinopyroxene, until now partly undisturbed, is deeply transformed as follows:

- One type of transformation, near the hydrothermal veins, is a continuation of stage two: the pyroxene is ultimately transformed into actinolite, and the original structures are progressively effaced and ultimately disappear. A new complex unoriented structure develops in which chlorite and titanite form simultaneously from opaque minerals, zoisite and paragonite form from plagioclase (if present) and pistachite or penninite form from the more altered clinopyroxenes.
- A second type of transformation occurs within the contact aureoles near the surrounding granites. The rocks are partly recrystallized and irregular micropatches of hornblende are formed within the CPx crystals (see plate A4). In a more advanced stage, a neosoma consisting of Na-Ca-plagioclase, orthoclase and sometimes of quartz, appears first as small isolated crystals and later as large poikiloblastic ones. The paleosoma recystallizes into large idiomorphic green hornblende in the inner part of which corroded remnants of CPx or actinolite inclusions may yet be observed. The zonation is distinct and sinuous within the hornblende around the CPx inclusions and regular and rectilinear in the external automorphic fringes developed at the contact with the neosoma. This zonation corresponds to significant variations in the chemical composition of the hornblende.

IV. SUPERFICIAL WEATHERING

The profiles associated with the oldest geomorphological surfaces gave rise to ferrallitic, occasionally bauxitic, profiles. In the old uneroded fersiallitic profiles, smectites are formed in the lower levels (below 12 m depth) and kaolinite + iron compounds are formed in the upper autochthonous horizons (between 5 and 12 m depth) by progressive degradation of the early formed smectite. In the most recent surfaces, the vertic weathered profiles are, from base to top, more or less similar to the deep smectitic horizons of the fersiallitic profiles.

A. Weathering of the clinopyroxene

This pyroxene is the most abundant mineral of the Koua Bocca rocks, and its weathering will strongly influence the mineralogy and the petrology of the weathered levels and soils. Having very little alumina (3%) and little ferrous iron (8%), this pyroxene is an augite with a composition near that of diopside.

1. First stage: CPx → microdivision (amorphous material)

This first step is observed only in the very weakly weathered rocks at the bottom of some profiles. It rapidly desappears in the weathered horizons where secondary smectites are formed. The peripheral fringe of the pyroxene crystal, and the walls of the intramineral and transmineral fractures, lose their transparency, becoming grey and weakly opaque in thin section and plane light because of the comminution of the crystal along cleavage planes, principally the (010) plane (see plate B1). These grey fringes may correspond to the amorphous areas observed in the pyroxenite of the western Ivory Coast (NAHON and COLIN, 1982). Nevertheless, the amorphous pellicular shell is too thin to be clearly identified with the optical microscope. The microdivided grey fringes extend irregularly toward the crystal fractures and defects prior to the appearence of the first smectite crystallites.

2. Second stage: CPx → CPx + Smectite

The smectite appears quickly along the cleavage planes. Its orientation is not irregular: in a perpendicularly cut prism section, the extinction of the smectite and of the pyroxene is simultaneous. The smectite is dark yellowish beige and not pleochroic. In section cut parallel to the c-axis, its extinction takes place when the c-axis of the CPx is parallel to the cross-hairs, yet the pyroxene remains lighted: the primary and secondary minerals do not become extinct simultaneously. The smectite colour, distinctly pleochroic, varies from bright yellow to creamy beige. Extinction of all the smectite particles takes place simultaneously. It demonstrates the influence of the pyroxene crystalline network on the secondary mineral orientation. The primary remnants are finely denticulated (plate B3). Interplasmamineral voids do not appear.

3. Third stage: CPx + Smectite → Smectite

The denticulated residues, reduced to some small diamond-shaped particles isolated within the smectite, quickly disappear with continued weathering. The smectite is distinctly oriented and arranged into parallel layers: it occupies the whole pseudomorph with each of the original grains exhibiting its particular orientation (see plates C1 and C2). The original granoblastic structure is well preserved.

The porphyroblastic CPx are more slowly weathered, and incomplete pseudomorphs are often observed in the upper horizons. In this event, the residues, until now surrounded by smectite, are diretly weathered into iron hydroxide. The result is a mixed, porous pseudomorph, composed of early formed smectite, at the center of which one or several empty pores, corresponding to the later pyroxene weathering, are located: a peripheral fringe of iron hydroxide coats the inner fringe of the smectite and diffuses between the smectite layers (see plate B5).

4.Fourth stage: Smectite → Amorphous material

In the transition horizons of the fersiallitic profiles, the homogeneous smectite pseudomorphs become coloured with irregular brownish patches and exhibit small pores corresponding to dissolution forms (see plate D5), principally along the intermineral fissural network. The granoblastic structure is disjointed. The final network becomes broader by peripheral dissolution of the pseudomorphs with precipitation of iron, in part liberated from the smectite and, in part, introduced by the fissures.

The pseudomorphs stained brown by iron exsolution are later progressively discoloured at the same time that small red regularly distributed grains of haematite particles form. These particles are later laterally concentrated along the sides of the pseudomorphs. As this transformation is controlled by the fissural network, a complex layered or banded structure develops in which alternating dark nearly opaque zones, red zones formed by joined haematite particles, banded yellow zones with dispersed red granulation, and completely discoloured zones without granulation, are observed (see plate D1). The colourless areas are amorphous and are the result of the latest stage of the smectite degradation (see plate D2).

5. Fifth stage: Amorphous material → Kaolinite

It is within the largest and most discoloured amorphous areas that the first kaolinite crystals appear. The crystals, several microns long,rapidly grow and drive back the small haematite grains, concentrating them at the crystal borders.The amorphous fringe is not always observed, which corroborates its transitory and ephemeral character. Finally, a granular microstructure is developed in which the small colourless kaolinite areas are nearly joined and arranged within a thin cellular network of haematite (see plates D3 and D4). The grain size in such weathered rock is finer than that of the smectitic weathered rocks, each clinopyroxene grain having given rise to several tens of kaolinite crystals.

6. Sixth stage: Recrystallization of the Kaolinite

In the transition upper horizons, the structures are completely reorganized and the dimensions and proportions of kaolinite are greatly increased. Crystals grow and form large booklets with displacement and progressive concentration of the haematitic material. A coarse granoblastic structure results,but the grain size of the weathered rock is now appreciably larger than that of the original rock, several pyroxene grains giving rise to only one polycrystalline kaolinitic area fringed by dark red haematite walls. At this step of the transformation, the structure and even the nature of the parent-rock are no longer recognizable. Without careful study of all the successive transformations, there is nothing that would suggest the "in situ" wheathering of a specially aluminum-poor pyroxenite.

B. Weathering of the orthopyroxene

Orthopyroxene is an accessory mineral in the majority of the Koua Bocca rocks. Very susceptible to hydrothermal processes, it is often transformed, even at the base of the weathered profiles, into talc or amphiboles much more resistant to weathering than the original pyroxene. The pyroxene is a bronzite close to hypersthene.

1. First stage: OPx → Smectite

The weathering generally begins along the transmineral fractures, more or less transverse to the c-axis of the prism or along the intermineral planes; weathering then progresses peripherally. The microdivision stage with an amorphous material has not been observed. If fractures are open, the weathering progresses rapidly, but very often, thin cutans of nontronite form within these fractures. The cutans show varied colours and orientations and are easily distinguished from the neoformed smectites developed between these cutans and the pyroxene cores (see plate B4). The smectites are slightly pleochroic (yellowish green to yellowish brown) and arranged parallel to the c-axis of the pyroxene. The fringe of the smectite bands is thinly denticulated and penetrates like sawteeths along the pyroxene cleavage planes. The central core has rectilinear limits where it parallels the c-axis and denticulated limits in other directions (see plate B2). All the residual cores within a single original crystal are tightly encased within the smectite and preserve their original straight extinction parallel to the extinction direction of the smectite. As the weathering progresses, the residual cores disappear and the pseudomorph will become well oriented and regular on the whole. The transformation is isovolumetric.

In the event of the weathering of a symplectic mixture of OPx + Mgt, the delicate structures of the magnetite lamellae are not perturbed (see plate B6).

2. Second stage: OPx → Smectite + Fe-oxihydroxides

The largest and/or the least fractured OPx crystals may be only partially weathered in the deep horizons. Residual cores may persist as high as the upper levels. Weathering processes, until now favourable for smectite formation, become, in the upper levels, favourable for the formation of iron hydroxide through more complete solubilization of the mineral. The result is a lace-like network consisting of a framework of smectite formed in the lower horizons, and empty pores corresponding to the later-weathered residual cores. These pores are coated with more recently formed iron hydroxides which impregnate the margins of the smectite (see plate C5).

The above described sequence is often also observed in the case of incomplete talc pseudomorph: pyroxenic residues are dissolved and the talc is partly degraded, becoming porous and fringed by brown hydroxide deposits (see plate C6). In the case of the degradation of a symplectic pseudomorph, the smectite is transformed into a lace-like network of residual iron hydroxide whereas the inner delicate structure of original magnetite lamellae is perfectly preserved (see plates C3 and C4).

V. FERRALLITIC WEATHERING

In the oldest weathered levels and in the cortex which surround boulders on rock outcrops, pyroxenes are directly weathered into iron hydroxide without going through a prior smectite phase. Weathering penetrates the crystal along cracks, or from the mineral margins. The most open cracks are coated, on both sides, by an iron hydroxide deposit, the mid-plane of the fracture remaining empty (see plate D6). Later, hydroxides penetrate into the pyroxene along the cleavage planes, forming a denticulated pattern outward from the fracture. In the beginning, the hydroxides and the pyroxenic cores are joined. However, as denticulated residues decrease, an empty interplasmamineral pore appears: the residues become loose within the ferruginous cells so that they do not maintain a simultaneous extinction pattern. At the end, a porous pseudomorph is formed with a boxwork structure.The wall thickness depends upon the original pyroxene type:diopside gives thin walls and important empty volume, hypersthene gives thicker walls and reduced empty volume (DELVIGNE, 1969).

The iron hydroxide is very poorly crystallized, dark-brown-coloured and more or less isotropic. The aluminum never crystallizes into individual gibbsite crystals. Later, the early formed hydroxides recrystallize with a little loss of material, since a distinct reduction of wall thickness is always observed. But the most remarkable fact is the distinctive orientation of all the goethite particles throughout the whole pseudomorph. The extinction is simultaneous and parallel to the c-axis of the original CPx or OPx crystal. This conservation of the original orientation was masked during the first phase and only appears as poorly crystallized and amorphous material disappeared (DELVIGNE, 1965).

In the very old bauxitic crusts, the pseudomorphs after pyroxene, initially porous and only ferruginous are filled by late and secondary goethite and gibbsite. The largest crystals may fill the entire cavity or even the whole pseudomorph with or without destroying the intercellular network of early hydroxides. The porous, essentially ferruginous pseudomorphs after olivine are also filled by gibbsite. This demonstrates that the gibbsite is allochthonous, the original aluminum content of the pyroxene being only 3% and that of olivine being near zero (DELVIGNE et al., 1979).

VI. CONCLUSIONS

In spite of the two thousand million years which separate the deep metamorphic alteration from the superficial weathering, the geochemical processes involved in both show a continuum.

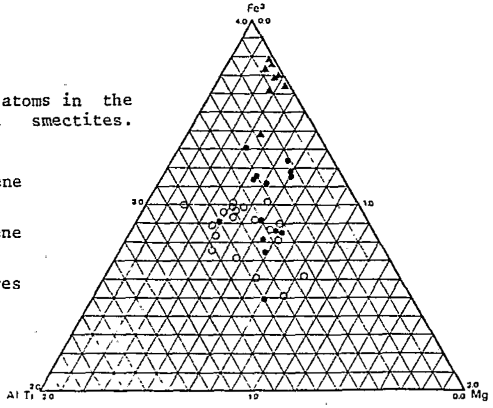

FIGURE 1

Distribution of Al + Ti, Mg and Fe atoms in the octahedral layer of the neoformed smectites.

Open circles:
pseudomorphs after clinopyroxene

Solid circles:
pseudomorphs after orthopyroxene

Triangles:
illuviated smectite in fractures

At depth, under the severest metamorphic conditions, the OPx is transformed into magnesium-rich and iron-poor amphiboles with an external contribution of calcium. The excess iron is fixed as magnetite. Under conditions a little bit less severe, talc is formed: original magnesium is conserved, iron goes to form magnetite and calcium is no longer required. Under conditions still less severe, a ferriferous talc is formed: magnesium and iron are conserved, and secondary magnetite does not appear.

Near the surface, in the lower weathered horizons, the tendency for the incorporation of iron in the secondary products, continues with increased importance: a significant part of the iron is incorporated in the smectites, whereas a part of the magnesium begins to be eliminated. At the surface, magnesium is completely eliminated and only the iron is maintained as hydroxide. The kaolinite is not observed during the weathering of the aluminum-poor orthopyroxene.

The clinopyroxene transformations are a little bit more complex because this mineral reacts much later, under more drastic conditions. Amphiboles are formed into which pyroxenic iron and calcium may enter.

Near the surface, clinopyroxene also reacts later, when the other minerals are already weathered. Calcium is not maintained in secondary minerals and eliminated.It will reappear as calcareous concretions in the down-slope vertic profiles. Normally the secondary smectite should be a saponite. However the smectite that forms is a ferriferous smectite: the pyroxene only reacts in higher horizons where the iron influence is more important. The compositions of the smectites formed from ortho- and clinopyroxenes are very similar: the octahedral Fe-atom ratios are respectively 2.98 and 2.89/4 on the average. The smectite illuviated or neoformed within the rock fractures, is still more ferruginous (3.71/4) and is true nontronite (see fig. 1).

In the upper horizons, magnesium until now retained in the smectites disappears together with a part of the silica. Kaolinite is formed by degradation of smectite and probably with an external contribution of aluminium. The iron not admissible into the kaolinite structure (fe-atom ratio = 0.17/4) therefore crystallizes as haematite.

At the surface, where leaching is complete, the fate of the two pyroxenes is the same as that of olivine and hornblende: only iron hydroxide is formed. During the later stage of accumulation, aluminum and iron liberated from kaolinite through a bauxitic process provisionally fill the previously ferruginous porous pseudomorphs as cutans or cristallarias of goethite and gibbsite, while silica is leached and wholly eliminated from the landscape.

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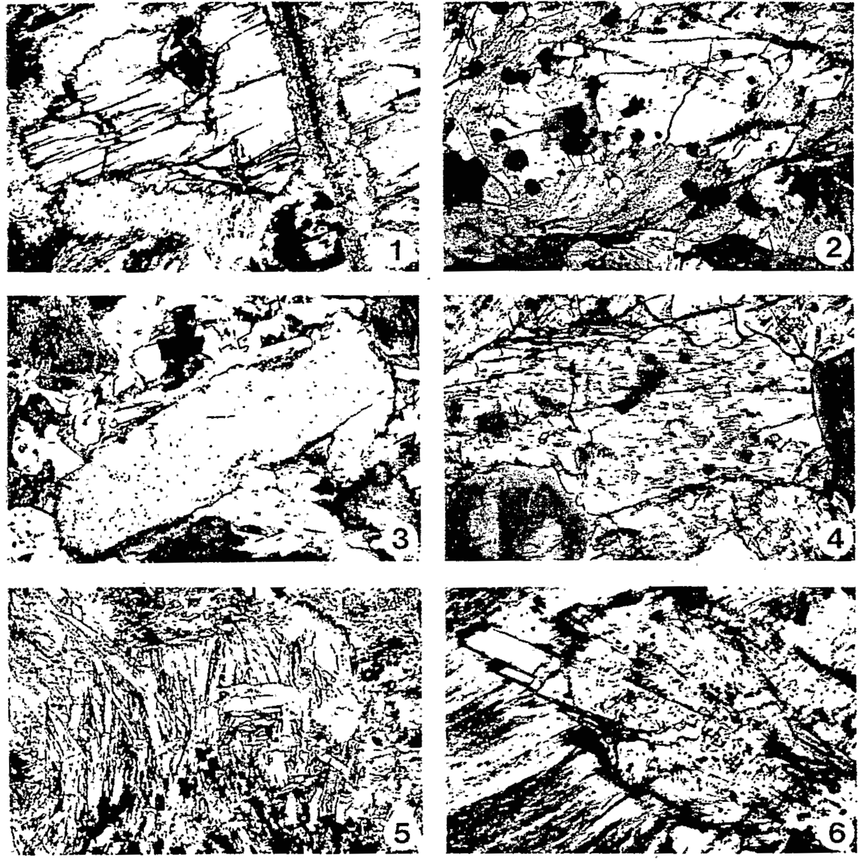

PLATE A

1: CS 936 - Obj 6.3, Oc 10, C.P.: Partly transformed OPx into Talc + Mgt. Peripheral alteration and along transmineral fractures.

2: CK 230 - Obj 6.3, Oc 10, P.L.: Partly transformed CPx porphyroblast into fibrous sheaves of green actinolite. Magnetite inclusions are rounded.

3: CK 325 - Obj 6.3, Oc 10, P.L.: Completely transformed euhedral OPx prism into regularly oriented fibres of tremolite and into small magnetite grains.

4: CK 277 - Obj 6.3, Oc 10, P.L.: Partly transformed CPx porphyroblast into internal irregular patches of hornblende and external multicoloured zoned hornblende.

5: KB 627 - Obj 6.3, Oc 10, P.L.: Acicular prisms of tremolite and euhedral grains of magnetite in a completely transformed orthopyroxene.

6: KA 905 - Obj 6.3, Oc 10, P.L.: Urchin-shaped pseudomorph with acicular tremolite penetrating into soft vermiculite outside of the original boundaries.

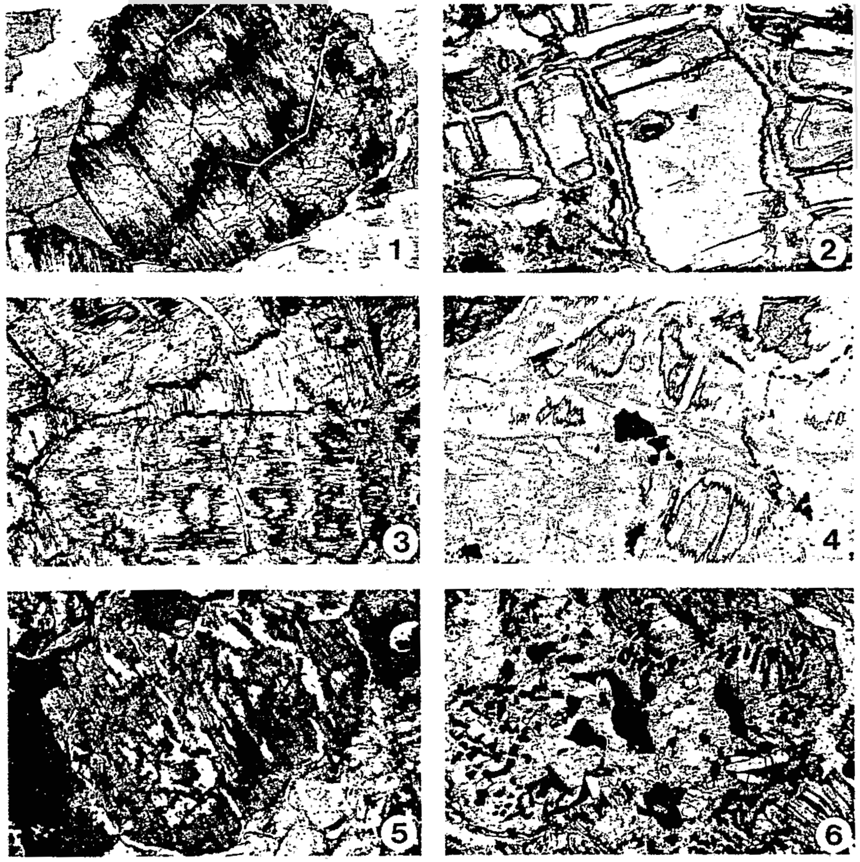

PLATE B

1: KB 613 - Obj 6.3, Oc 10, P.L.; Grey fringes related to the comminution along the cleavages appearing in a weakly weathered CPx crystal.

2: KB 313 - Obj 6.3, Oc 10, P.L.: Partly weathered OPx into smectite along transmineral fractures. Denticulated remmants are clearly seen.

3: KD 257 - Obj 6.3, Oc 10, P.L.: Partly weathered CPx crystals into oriented smectite around denticulated cores. Note fractures across the prisms.

4: KB 603 - Obj 6.3, Oc 10, P.L.: Advanced stage of OPx weathering into smectite. Note particular orientation of early formed smectite along internal cracks.

5: KA 819 - Obj 6.3, Oc 10, P.L.: Partly degraded smectite into iron oxi-hydroxides around pores in a completely weathered CPx crystal.

6: KB 613 - Obj 6.3, Oc 10, P.L.: Complete pseudomorph of a symplectic mixture of OPx and Mgt: non oriented smectite and undisturbed magnetite lamellae.

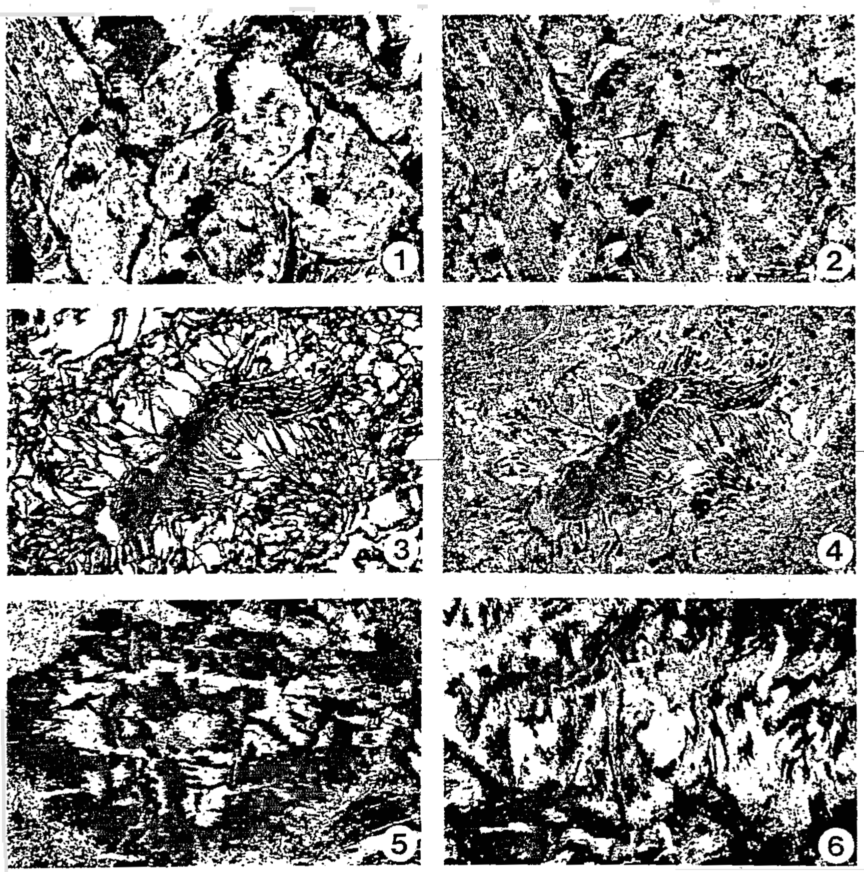

PLATE C

1: KD 240 - Obj 6.3, Oc 10, C.P.: **Completely weathered CPx crystals** into smectite; **the original granoblastic rock structure is well preserved.**

2: KD 240 - **Obj 6.3, Oc 10, P.L.: Note the particular orientation** of the smectite **layers within each of oseudomorphs.**

3: KD 469 - Obj 6.3, Oc 10, P.L., green filter: Pseudomorph after symplectic mixture of OPx+Mgt. OPx, early weathered into smectite, was degraded into haematite....

4: KD 469 - Obj 6.3, Oc 10, C.P.85°, red filter: ....whereas the magnetite lamellae are not disturbed during both successive transformations.

5: KD 471 - Obj 6.3, Oc 10, P.L.: Mixed pseudomorph after CPx composed of early formed smectite and later formed iron hydroxide.

6: KA 263 - Obj 6.3, Oc 10, P.L.: Partly degraded talc: formation of irregular dissolution pores fringed by iron hydroxides.

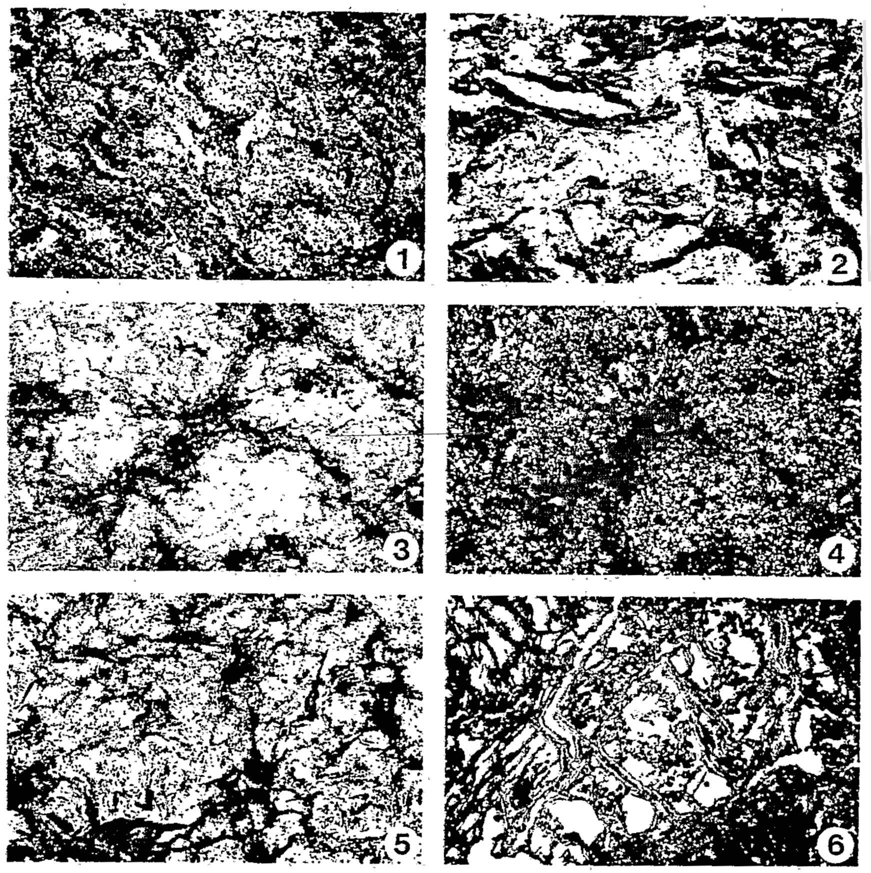

PLATE D

1: KD 439 - Obj 6.3, Oc 10, P.L.: Intermediate stage of smectite degradation with formation of small randomy distributed or partly concentrated haematite grains

2: KD 468 - **Obj 6.3, Oc 10, P.L.: Degradation of the smectite into amorphous areas and into kaolinite within an iron irregular banded structure.**

3: KD 450 - Obj 6.3, Oc 10, P.L.: First small kaolinite crystals within discoloured **areas between irregular, wholly and diffused red haematitic network.**

4: **KD 450 - Obj 6.3, Oc 10, C.P.: The fine grained kaolinite is not oriented and oc**curs as smaller crystals than in the recrystallized sample below (see D5).

5: KD 466 - **Obj 2.5, Oc 10, P.L.: Coarse kaolinite booklets and irregular red haematitic network as seen in the last stage of the CPx weathering.**

6: KA 207 - Obj 6.3, Oc 10, P.L.: Ferruginous boxwork after OPx in an old indurated crust. Note open fractures coated by iron hydroxides.

RÉSUMÉ

Au contact des granites encaissants plus jeunes, les clinopyroxénites de l'intrusion ultrabasique du Koua Bocca sont partiellement transformées par altération profonde: les orthopyroxènes sont altérés en talc, trémolite et magnétite avec un peu de cummingtonite, les clinopyroxènes en hornblende ou en actinote. Dans les conditions superficielles d'altération du type vertique, les pyroxènes sont altérés en smectites ferrifères tandis que dans les altérites fersiallitiques, les smectites instables sont progressivement remplacées par la kaolinite et l'hématite. Dans les formations cuirassées anciennes, les pyroxènes sont transformés en hydroxydes de fer organisés en structure cloisonnée dont les pores peuvent être colmatés par des cristallisations tardives de goethite et/ou de gibbsite allochtones.