ALTERATION OF BASALT AND FORMATION OF KAOLINITIC AND GIBBSITIC MATERIAL IN THE REGION OF RIBEIRÃO PRETO (SP), BRAZIL

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ABSTRACT

Mineralogical and chemical analysis were carried out on samples of soil profiles and underlying materials, occurring on a topographic sequence.

The underlying material consists of a weathering product of a basic rock of basaltic type, with no weatherable primary minerals present but with the original structure preserved. Minerals of the kaolinitic group are the only secondary minerals present in these materials.

A typic latosol (Latossolo Roxo) occurs in the footslope and it is a essencially gibbsitic (gibbsite/kaolinite ratio > 1) and its contact with the parent material is very sharp. On the backslope occurs a blocky structured soil (Terra Roxa Estruturada) constituted mainly of minerals of the kaolinitic group (gibbsite/kaolinite ratio < 0,2). The contact with the parent material is more gradual. The Terra Roxa Estruturada changes progressively downslope into the Latossolo Roxo.

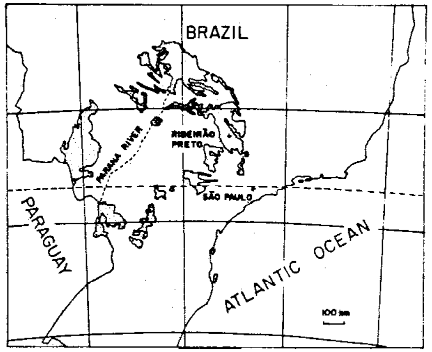
A "stone line" was observed in the Terra Roxa Estruturada profile formed by blocks of partially weathered basalt and lithorelictual concretions of small size (< 3 cm). Towards the latosol the blocks decrease in size and quantity and in the Latossolo Roxo profile only the concretions subsist.

Considering the morphological aspects and the results of mineralogical and chemical analysis one can suppose that the normal evolution in this area is towards the formation of a gibbsitic material (LR). The kaolinitic material (TRE) corresponds to a rather particular situation due to the proximity of the rock, either in the upper part of slope or in the stone line. The presence of this weatherable material, a continuous source of silica and bases, would produce a saturated medium, inhibiting gibbsite formation.

The presence of silans in the base of the TRE profile, which disappears gradually toward the LR seems to confirm the proposed evolution of the materials.

INTRODUCTION

The supergene evolution of basalt in the region of Ribeirão Preto (SP) (Fig. 1) gives origin to two different soils materials: Terra Roxa Estruturada and Lotossolo Roxo. As concerns the mineralogy of secondary minerals, it has been pointed out by many authors (Moniz and Lackson, 1967, Carvalho, 1970 and Gonçalves, 1978) that the Terra



Terra Roxa Estruturada and Latossolo Roxo formed on basalt.

FIG. 1. Distribution of Terra Roxa Estruturada and Latossolo Roxo.

Roxa Estruturada is predominantly kaolinitic, while the Latossolo Roxo is gibbsitic (30-40% gibbsite). The most apparent difference between them lies in the morphology of the B horizon: the Terra Roxa Estruturada having a blocky structure with fissure and plasma separation (Brewer, 1964) and the Latossolo Roxo a crumb granular or massive structure with fluffy and loose consistence. Pedro et al. (1976) concluded that the difference is mainly a question of pedoplasmatic nature, the evolution from the first to the second resulting from the continuous deionization of the material. This induces, at the same time, the superficial iron adsorption of the secondary constituents and the gradual inactivation of clay minerals.

The relationship of Terra Roxa Estruturada and Latossolo Roxo with the topography is well known at São Paulo State: Terra Roxa Estruturada is related to strongly undulated slopes, while Latossolo Roxo is related to gentle undulating topography.

In some areas, as for example Ribeirão Preto, these soils occur together on a topographic sequence and the same relationship is found (Carvalho, 1970, Gonçalves, 1978).

The main objective of this work was to study the formation of these kaolinitic and gibbsitic material occurring on a topographic sequence and the methods of study were mainly micromorphological.

For this purpose, it has being selected an area in Ribeirão Preto, State of São Paulo, located approximately 340 km north of São Paulo City.

GENERAL CHARACTERISTICS OF THE AREA

Geology

The materials under examination were formed on basaltic rock of lower cretaceous age,

and included in the Serra Geral Formation. This Formation (Almeida, 1964) consists of several lava flows, each one ranging in thickness from 15 to 50 meters. This rock is described as a tholeitic basalt (thin section micrograph - photo 3) having mainly calciplagioclase (andesite and labradorite), clinopyroxenes (augite and pigeonite) and magnetite, ilmenite, titanomagnetite. The accessory minerals are mainly volcanic glass, apathite, hornblende and pyrite. Near the contacts of the lava-flows amygdales filled with zeolites, calcite, quartz and chlorite are found.

Topography

The topography of the area is dominated by ancient remnants rising above a gentle undulating surface. These remnants can occur as isolated hills and as continuous high flat interfluves. In the study area (photo 1) we find an isolated hill with a gentle round top, giving way to a more extensive steep slope (above 50%) that breaks sharply into a very long slope (2 to 10%).

The Soil Sequence

In the remnant previously described, Terra Roxa Estruturada and Latossolo Roxo occur in a close relationship with the topography (photo 2). Terra Roxa Estruturada is related to the more extensive steep slope while Latossolo Roxo is related to the long gentle slope. The Terra Roxa Estruturada (profile I) changes downslope, through intergrades, into Latossolo Roxo (profile II).

The underlying material is a rather weathered basalt with no weatherable primary minerals present but with the structure preserved. Minerals of the kaolinitic group are the main secondary mineral present.

A stone line is observed within the soil material in the entire sequence (photo 2). At the upper part of the slope (photo 4) the stone line is formed by large blocks of basalt having only a thin cortex of alteration, with no lithorelictual nodules. In the middle part (photo 5 - plate I) the basalt blocks are smaller, rather weathered and mixed with a large amount of lithorelictual nodules. In the lower part (photo 6) the blocks are completely weathered and only the external forms subsist. The stone line in this case, is formed essentially by concretions (lithorelicts with ferruginous outerband).

Figure 2 presents a schematic diagram showing the distribution of the weathered materials and soils on the topographic sequence.

It can be observed that the Terra Roxa Estruturada on the steep slope, is in contact with basaltic blocks containing weatherable minerals. These blocks are both the boulders in the stone line and rock fragments mixed with soil. On the contrary, the Latossolo Roxo contains only lithorelictual nodules completely altered. It can also be observed the presence of concentrations of secondary silica at the base of Terra Roxa Estruturada profile, which disappears progressively towards the Latossolo Roxo profile. Finally one can see that the destruction of the inherited structure of the

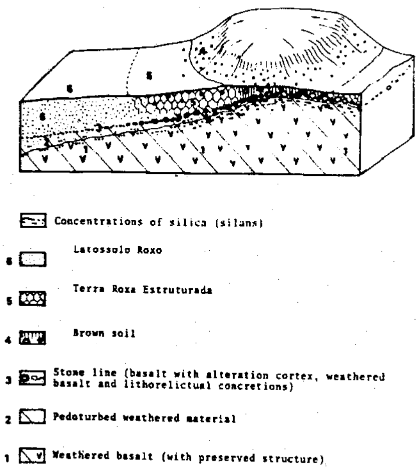


FIGURE 2

Schematic diagram of the topographic sequence studied.

basalt (or pedoturbation) follows a front marking the transition between the alterite and the IIB horizons. Downslope, towards the Latossolo Roxo this front becomes more and more deep, relative to the stone line level. In the typic and well developed Latosol the front is situated several meters below the stone line.

The main mineralogical and chemical characteristics of the different minerals occurring in the sequence are showed in Table 1.

TABLE 1. MINERALOGICAL AND CHEMICAL CHARACTERISTICS OF PROFILES I AND II AND OF BASALT.

Profile	Material	Chemical Composition						Mineralogical Composition		
		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SiO_2/Al_2O_3			
II	B Horizon (1)	15.9	25.7	29.0	≤0.02	0.05	1.0	Kaolinite ++	Gibbsite ++	Hematite Magnetite
	IIB Horizon (1)	20.6	24.3	31.0	≤0.02	0.05	1.4	Kaolinite +++	Gibbsite ++	Hematite Magnetite
	IIB Horizon (2)	24.1	16.4	33.1	≤0.02	0.05	2.5	Kaolinitic Minerals	(Silica)	Hematite Magnetite
	Alterite	27.6	18.8	26.8	0.02	0.05	2.5	Kaolinitic Minerals	(Silica)	Hematite Magnetite
I	B Horizon (1)	25.5	25.3	25.0	0.02	0.40	1.7	Kaolinite ++++	Gibbsite +	Hematite Magnetite
	B Horizon (3)	25.2	24.0	24.1	0.02	0.45	1.8	Kaolinite ++++	Gibbsite +	Hematite Magnetite
	IIB Horizon	31.7	15.7	23.5	0.21	1.02	3.4	Kaolinitic Minerals	Silica	Iron Oxide Magnetite
	Alterite	33.0	14.9	24.7	0.23	1.26	3.8	Kaolinitic Minerals	Silica Weathered Prim. Miner	Iron Oxide Magnetite
Basalt		50.2	13.3	16.1	5.8	4.5		Primary Minerals		

(1) Powdery material forming micropeds; (2) Weathered rock - lithorelicts; (3) Large structural material.

CHARACTERIZATION OF THE WEATHERED AND PEDOLOGICAL MATERIAL

The microscopic characterization of the studied materials will be presented for each one of the two profiles, from the bottom to the top, i.e., starting from the parent rock.

Profile I - Terra Roxa Estruturada (Plate II)

- The basaltic structure is preserved in the kaolinitic alteration material (photo 7). The opaque minerals (magnetite, ilminite, ...) are pulverized (compare with photo 3). Iron concentrations of red colour seem to develop in the S-matrix around the voids. Concentrations of secondary silica (silans) are observed on the pore walls. Some large fissures are filled in with ferri-argilans.
- From this alterite, a pedoturbed material is formed in the IIB horizon (photo 8) and the inherited structure of the basalt disappears almost completely. One recognizes secondary silica concentrations and iron oxydes with diffuse limits.
- In the stone line (photo 9) the boulders are formed of nearly fresh basalt, with only a cortex of alteration.
- Above the stone line, the B horizon, is macroscopically characterized by a continuous structure, breaking down into blocks separated by fissures. Under the microscope (photo 10) this material seems to be constituted by few skeletons (opaque minerals) and in particular by a plasma having two different aspects:
  - deep red with argillasepic fabric, rather spheric volumes (100 - 200 μ diameter) presented as micro-nodules or micro-peds (MP);
  - yellowish red with plasmic separation, forming the S-matrix.

Locally, one observes at thin sections, the transition between the continuous structure and a material having a micro-aggregated structure. When this transition is clear (photo 11) one can see the continuation of the fissures thoughout both materials. This means that the micro-peds as well as the interstitial porosity which split them, are developed "in situ" (maybe as an effect of elluviation of the yellow-red plasma which is no more present in the micro-aggregated material). The chemical analysis (Table 1) show that a relative Al enrichment follows the micro-aggregation (5- 10% gibbsite). The microscopic observation of the samples of the B horizon shows that the volumes occupied by the micro-aggregated material increases downwards in the sequence, marking the progressive transition to Latossolo Roxo.

Profile II - Latossolo Roxo (Plate III)

- In the weathered rock (photo 12) the basalt inherited structure is well preserved. One can see that the secondary silica concentrations (silans) are no more continuous: they appear as isolated islands, oriented according the lines of old fissures, now filled in with kaolinite. This seems to indicate that the existing silans are inherited from an old evolution phase (silica illuviation) followed by a desilicification and neoformation of kaolinite. The analytic results (Table 1) show that the molecular ratio SiO_2/Al_2O_3 of the weathered rock decreases from 3.8 for profile I, to 2.5 for profile II, indicating a progressive elimination of excedent silica (not combined silica).

The pedoturbed material formed from this alterite in the IIB horizon, is shown in photo 13, and one can see the volumes with structure inherited from basalt (W). One can recognize here concentrations of dark, red isotropic plasma placed between the plagioclases relicts and including sometimes opaque minerals. Out of the pedoturbation front (F) these volumes are separated by voids (V) while the opaque minerals are pulverized and the plagioclases firstly break down and then disappear progressively. Thus, it changes very rapidly (over 1 mm) into a material formed essentially of micro-peds (Mp) of dark red plasma. The continuity of this transformation and the shape and the arrangement of the micro-peds (like in a jig-saw puzzle) indicate that they are developed in situ from the alterites. The chemical analysis (Table 1) shows that this micro-aggregates corresponds to an important relative accumulation of aluminum together with a removal of silica and iron (molecular ratio SiO_2/Al_2O_3 changes from 2.5 in the alterite to 1.4 in the micro-ped). The neoformed gibbsite (20%) identidied by X-ray is not visible under the microscope.

In the stone line, the nodules and concretions (photo 14) preserve the structure inherited from basalt. But the plagioclases are completely transformed into finely crystallized gibbsite. The opaque minerals are not very abundant and the iron is present, between the plagioclases and in the cortex, in the form of dark red hematite.

Above the stone line the B horizon is formed essentially by micro-peds of approximately 100 μ of diameter (photo 15) stuck to each other. It is clearly recognized the agglutinic-related distribution pattern considered by Buol & Eswaran (1978) as characteristic of latosols.

The SEM observation shows that the micro-peds are assembled as a very porous organization, locally interlocked. This material, easily penetrated by the roots and by the soil fauna, presents in many places, evidences of bioturbation (Jongerius, 1970).

In Table 1 it can be seen that this material has a molecular ratio SiO_2/Al_2O_3 of approximately 1 and near 30% of iron content. It is essentially formed by a plasma composed of oxy-hydrates of iron and aluminum (hematite and gibbsite) and kaolinite, which are not identified in the optical microscope or SEM.

DISCUSSION

Considering the field observation, and the results obtained it is possible to present some considerations about the mineralogical and structural transformation occurring in the different materials from the upper to the lower part of the sequence and from the base to the top of the profiles:

The weathered rock observed at the footslope (Profile I) presents continuous silans, as a result of recent silica illuviation coming from the alteration of basalt. The

progressive disappearance of the silans downwards can be considered as a result of the steep slope backwards (and consequently a receding of the silica source).

. The destruction of the basalt preserved structure seem to be different according to its situation in the topographic sequence. In the backslope, down to Profile I (Terra Roxa Estruturada) the abundance of silica and bases seems to inhibit both the micro-aggregation and the formation of gibbsite. Downwards, in Profile II (Latossolo Roxo) the lower content in the medium, allows the transformation "in situ" of the alteration material (kaolinitic) into an assemblage of micro-peds having 10 to 20% gibbsite. Downwards the front corresponding to this micro-aggregation deepens more and more in the alterite.

. The stone line is formed at the base of the talus in the steep slope, by accumulation of basalt blocks coming from the alteration material where they were included. These boulders change gradually into smaller blocks which are progressively more weathered and mixtured to increasing amounts of lithorelictuals gibbsitic nodules. This progressive changing can be also explained as a result of a slope backwards, leaving behind, on the surface of the material with preserved basaltic structure, boulders that would be gradually weathered in situ. Finally, in the typic well developed latosol, a stone line formed by some lithorelictual concretions will rest, separating the micro-aggregated material developed in situ, from the transported and porous one, situated below.

. The B horizons, below the stone line, in the backslope of the sequence, and down to Profile I, are affected by the proximity of the alterating rock, which liberates a considerable quantity of silica and bases. In this case also, the saturation of the medium inhibits the micro-aggregation and the formation of gibbsite. The materials formed essentially of kaolinite and ferric hydrates, present continuous structure, which breaks down into blocks limited by fissures. The micro-structure is characterized by the abundance of plasmic separation, resulting from tension and pressures originated by swelling and contraction. Getting away from the silica and base sources there is a progressive desaturation of the medium. Thus, there occurs a development of volumes of more colored plasma (hematitic) which is isotropic and rather spheric: they consist of nodules (Brewer, 1964) or micro-nodules (Pedro et al., 1976 and Chauvel, 1977) and also, micro-peds. When they become dominant a continuous and stable structure, where an interstitial porosity is developed, is formed. It can be also observed a relative aluminum accumulation together with the micro-aggregation. The final product is a latosolic material (oxic horizon) which is very porous and easily penetrated by the roots and the soils fauna, originating the observed bioturbations. These transformations, both mineralogical and micro-structural occur successively from the top to the bottom of the sequence. It can also be admitted that the transformation occurs likewise as a function of time (leaching duration) together with the slope regression. This continuous evolution from a ferri-kaolinitic pedoplasma under the influence of leaching duration gives origin to an oxic-"lateritic" horizon (Pedro et al., 1976).

CONCLUSIONS

The formation of the latosolic cover in the region of Ribeirão Preto can be considered as resulting from the mineralogical and structural transformations following two axes:

. in the vertical sense, at the base of the latosol, the weathered and kaolinized basalts, with preserved structure, change directly into micro-peds, i.e., into a pedologic structure. This transformation is followed by a silica loss and a relative aluminum accumulation. The process only goes on if the medium has already been leached, assuring the deepening of the latosol downwards;

. in the lateral sense, from the talus with steep slope, where basalt blocks are liberated by erosion, a progressive transformation affecting different profile layers is observed:

  . the weathered rocks are initially enriched in silica and basic cations and further progressively desaturated of these elements but keeping relicts of the initial silicification;

  . the stone line which presents all the transformations stages from the fresh basalt to lithorelictual concretions (gibbsitic and hematitic);

  . the B horizon, initially kaolinitic, well saturated with basic cations and well structured, become more and more desaturated, gibbsitic and micro-aggregated downwards.

This progressive, lateral transformation seems to be an evidence of the slope back-erosion, leaving behind materials that become gradually latosolic.

Finally, it seems that the slope back-erosion and the latosolic evolution contribute to topography peneplanation and to generalized extension of the micro-aggregated lateritic cover.

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PLATE I

Photo 1. Landscape view showing one of the ancient remnants.

Photo 2. Road cut showing the topographic sequence:
WB - Weathered Basalt
SL - Stone Line (with indication of Photos 4, 5 and 6)
I - Blocky structured soil profile (Terra Roxa Estruturada)
II - Latosol profile (Latossolo Roxo)

Photo 3. Thin section micrograph of the basalt
Pl - Plagioclase; Py - Pyroxene; O - Opaque minerals;
Vg - Volcanic glass; V - Voids

Photo 4. Stone line on the upper part of the s'ope, showing large blocks of basalt with an alteration cortex and some lithorelictual nodules.

Photo 5. Stone line at the middle part of the slope, containing boulders of basalt rather weathered and lithorelictual nodules.

Photo 6. Stone line at the lower part of the slope, having heavy few blocks of completely weathered basalt and a large amount of lithorelictual ferruginous and aluminous concretions.

PLATE I

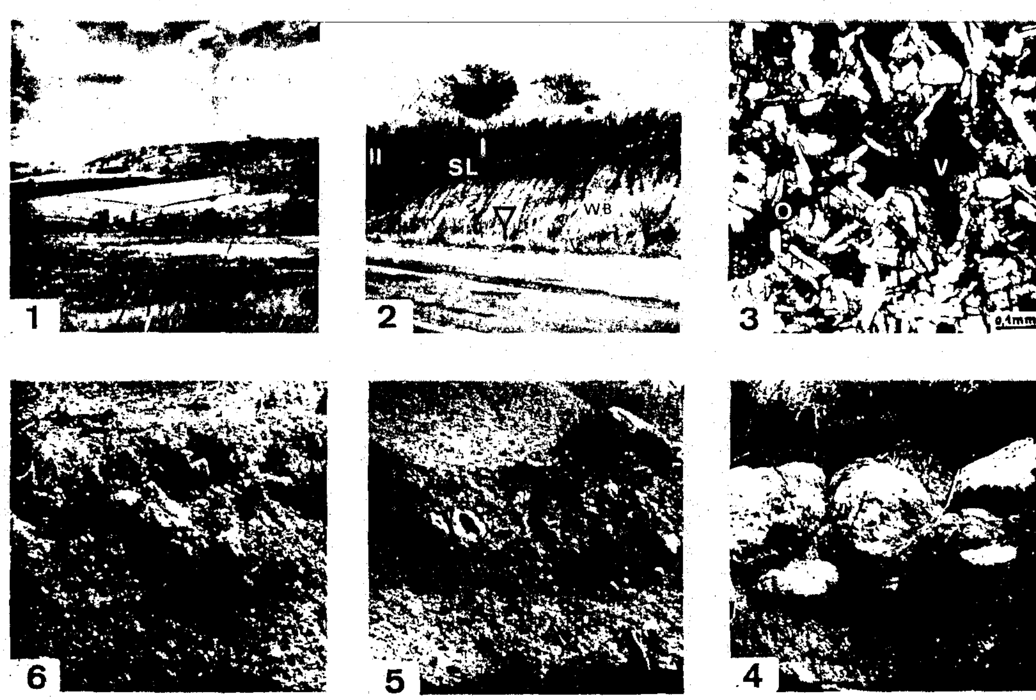

PLATE II - THIN SECTION MICROGRAPHS OF PROFILE I - BLOCKY STRUCTURED SOIL (TERRA ROXA ESTRUTURADA).

Photo 7. Weathered basalt in the middle part of the slope (cross polarized light):
K - Kaolinitic material with preserved structure of basalt; Si - Secondary silica concentrations (silans); O - Opaque minerals; H - Hematite; V - Voids.

Photo 8. Soil material below the stone line showing the contact soil and weathered rock (crossed polarized light):
K - Kaolinitic material; Si - Secondary silic- concentrations (silans); H - Hematite; O - Opaque minerals.

Photo 9. Block of basalt with a cortex of alteration (W) from the stone line (crossed polarized light):
Pl - Plagioclase; Py - Pyroxene; O - Opaque minerals.

Photo 10. Soil material above the stone line, with continuous structure (crossed polarized light):
Mp - Round micropeds, made up mainly of red argillasepic plasma; Sm - Yellow anisotropic; S - Matrix.

Photo 11. Soil material above the stone line showing the transition from a continuous structure (on the left) to a microaggregated structure (on the right). Observe the continuation of the fissures in both materials.

PLATE III - MICROGRAPHS OF PROFILE II - LATOSOL (LATOSSOLO ROXO).

Photo 12. Thin section of weathered basalt at the lower part of the slope (crossed polarized light):
K - Kaolinitic material with preserved structure of basalt; Si - Inherites secondary silica concentrations (silans). Remark the smaller amount and discontinuity as compared to Photo 7:
O - Opaque minerals.

Photo 13. Thin section of the soil material below the stone line showing the contact soil and weathered rock (plain light):
W - Weathered rock; F - Petoturbation front; Mp - Micro-ped (remark the matching as in a jigsaw puzzle); V - Voids; H - Hematite.

Photo 14. Thin section of the lithorelictual concretion of the stone line (crossed polarized light):
G - Gibbsite; V - Voids; H - Hematite; F - Ferruginous outer band.

Photo 15. Thin section of the soil material above the stone line, with micro.aggregated structure (crossed polarized light):
MP - Micro-ped with agglutinic SRDP (Eswaran et al., 1975); V - Interpedal voids; O - Opaque minerals.

Photo 16. SEM of the same material as shown in Photo 15:
Mp - Interlocked micropeds, indicating in situ formation; V - Voids.

PLATE II

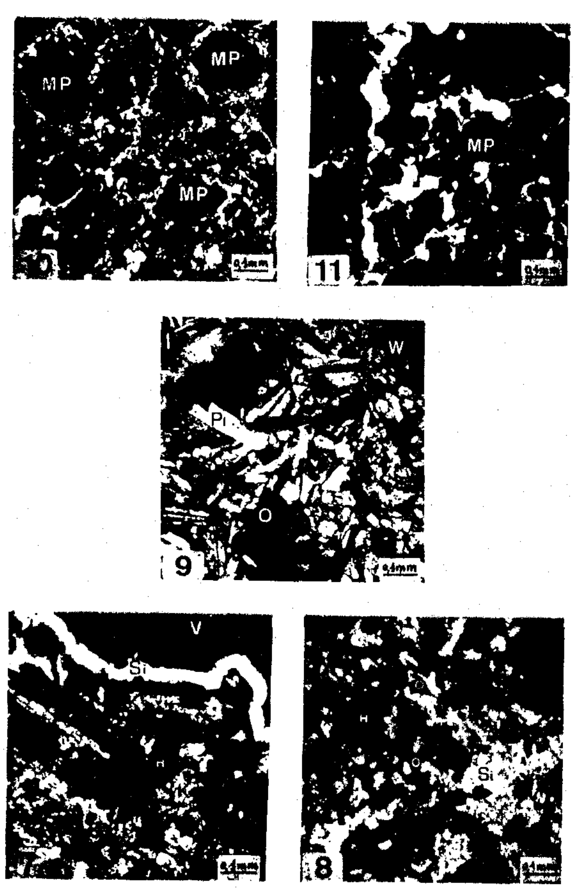

PLATE III