Sci. Géol., Mém., 72, p. 37 - 46, Strasbourg, 1983

FERRALLITIC SOILS FROM BRAZIL: FORMATION AND EVOLUTION OF STRUCTURE.

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ABSTRACT

The study of three ferrallitic soil sequences from Brazil, developed upon basalt, granite-rhyolite and detrital sedimentary rocks respectively, under different types of climate, confirms the mainly "pedoplasmic" nature of the question of the formation of the structure of these soils. The study also points out the existence of possibly different lineages leading to different "facies" according to the nature of the parent material and pedobioclimatic conditions.

INTRODUCTION

The ferrallitic soils (French classification - CPCS, 1967) are usually characterized by the dominance of a clayey plasma. Generally, the permeability of these soils is sufficient to permit the complete infiltration of rain water which consequently favours deep lixiviation and impedes superficial erosion, thus leading to a very stable soil cover.

The high permeability of these soils results from their structure which includes an important network of interconnected voids. The formation of these structures occurs during a secondary evolution of kaolinitic, weathered rock to clayey B horizon through the process termed "pedoplasmation" by FLACH et al. (1968).

The structural evolution of these soils has been the object of a number of studies such as those of KUBIENA (1950), STOOPS (1968), BENNEMA et al. (1970), ESWARAN (1972), LEPSCHE and BUOL (1974), PEDRO et al. (1976), BEAUDOU et al. (1977), MULLER (1977, 1982), CHAUVEL (1977), BUOL and ESWARAN (1978), amongst others.

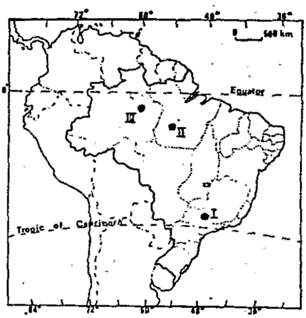

FIG.1 _ LOCATION OF STUDIED SOIL GROUPS

A number of authors have pointed out the existence of two types of very distinct structures and their intergradations in these soils. The first type corresponds to a centimetric blocky structure limited by cracks, and the second to a continuous granular structure with interconnected compound packing voids.

In order to study the influence of different factors on the genesis of these structures, we have chosen three groups of soils (I, II and III) located in different ferrallitic covers of Brazil (Fig. 1) and having different pedogenetic factors (table 1). The structural evolution of each of these groups is discussed below.

Table 1: Pedogenetic factors

Groups	Parent material	Climate	Vegetation
I	Basaltic rocks (Lower Cretaceous) very rich in iron.	Tropical, relatively high (= 800 m).	Semi deciduous tropical forest
II	Granites, microgranites and rhyolites (Precambrian), iron poor	Equatorial with a dry season.	Moist evergreen tropical forest
III	Detrital sedimentary rocks, (Tertiary), very poor in iron	Equatorial with a moderately dry season	Moist evergreen tropical forest

I. STRUCTURE FORMATION IN SOILS ON BASALTIC ROCKS (GROUP I).

The supergene evolution of basalt in the region of Ribeirão Preto (São Paulo) gives rise to two different soil types: "Terra roxa estruturada" or TRE (BRAMAO and SIMONSON, 1956; EMBRAPA, 1981) and "Terra roxa legitima" or TRL (BRAMAO and SIMONSON 1956) also known as "Latossolo roxo" (EMBRAPA, 1981). According to the american classification (SOIL SURVEY STAFF, 1975), the former is considered as "Alfisol" by OLIVEIRA and MONIZ (1975), while the later is a typical "Oxisol".

In a landscape dominated by remmants of ancient plateaus rising a few tens of meters above a gently undulating surface, the occurence of TRE and TRL is closely related to topography: TRE occupying somewhat steeper slopes and TRL the longer gentler slopes (Fig. 2).

TRE passes laterally to TRL as is indicated by the continuous "Stone-line" of blocks of weathered basalt associated with concretions (TRE), grading to concretions alone (TRL). TRE has a medium polyhedral strucure limited by smooth and bright plane surfaces. In the transitional zone the structure gradually becomes granular to medium polyhedral, while in TRL the structure is granular.

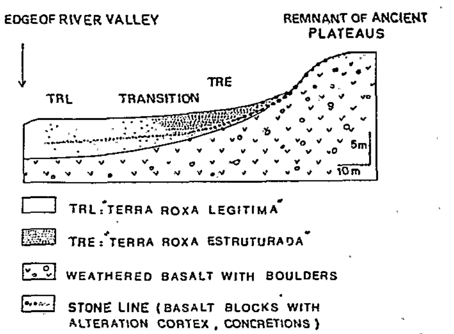

FIG.2 – PARTIAL TOPOSEQUENCE OF SOILS FORMED ON BASALT

Results

Microscopical analysis confirms the predominance of plasma, as well as the existence of lateral variation in the structure of the B_2 horizon.

At low magnification, one observes a network of predominantly vertical cracks in the TRE (photo 1), its partial obliteration by a microagregation in the transitional zone (photo 2), and its fading out in the TRL.

At high magnification, the following variations are observed:

1. In the TRE, the skeleton grains (magnetite, rare quartz and very weathered feldspars) are dispersed in an isotropic, relatively homogeneous plasma ("argillasepic" to "isotic" fabric of BREWER, 1964).

2. In the transitional zone, the feldspars disappear, while plasma separations develop, discontinuously at first, later becoming organized in a network of "stress-cutans" with a predominanctly vertical orientation, often marked by very fine cracks (photo 7). In this network roughly spherical volumes (about 100 μm in diameter) of an isotropic dark red plasma develop (photo 8) and eventually form an "agglutinic SRDP" according to ESWARAN and BAÑOS (1976). Interconnected compound packing voids develop between these volumes.

3. At lower topographic levels (TRL), the secondary action of the fauna randomly redistributes the small spheric volumes and the compound packing voids.

The other main characteristics of the B2 horizon in the TRE, the transitional soil and the TRL are shown in table 2.

Table 2: Main characteristics (extreme or means) of the studied materials.

Group	Sample	Clay %	Silt %	Sand %	CEC mEq/100g	pH	Fe2O3 %	Ki (1)	Hall.7A (2)	Sc (3) % of volume
I	B2 TRE	40-75	16-40	7-18	8-10	6.0	20-25	1.5-2.2	+ +	11.3
	B2 Trans									5.4
	B2 TRL	60-75	14-28	5-16	4-6	5.5	25-33	0.7-1.5	0	2.5
II	B2/rhyolite	46-66	25-46	6-8	2-5	4.5	2-5	1.6-1.9	+ +	C (4) 11-15 L (4) 1-2
	B2/granite	50-69	5-19	22-30	1-4	4.7	5-7	1.8-2.0	+	C (4) 10 L (4) 4
III	B1	85-96	1-2	6-11	3-5	4.5	2-3	1.6	0	0
	B2	85-90	1	6-9	1-3	5.3	2-3	1.7	0	2,6
	B3	64-70	9-10	20-25	1	5.4	2-3	1.7	0	10,3

(1): Ki = molecular ratio SiO_2/Al_2O_3 (2): Halloysite 7Å or metahalloysite
(3): Sc = swelling capacity. To evaluate Sc quantitatively we have determined the apparent specific volumes in dry (Vas) and humid conditions (Vah) of aggregates varying between 2 and 3 mm (MONNIER et al., 1973). The swelling capacity is defined as follows:

$$Sc = \frac{Vah - Vas}{Vas} \times 100.$$

(4): C = "compacted" and L = "looser".

Interpretation

The data as a whole show, in this case, a continuous, mainly geochemical evolution of the B2 horizon along the slope. According to PEDRO et al. (1976), it consists of a desaturation and a "Ferrization" of the kaolinite (fixation of ferric ions in the surface of clay particles, CHAUVEL et al., 1976), together with a crystallization of iron oxides which are responsible for a progressive deactivation of the clay, as indicated by the strong diminution of CEC and Sc between the TRE and TRL zones (table 2). The increase in gibbsite content, as shown by the low value of Ki in TRL, would result from a concommitant desilicification.

This progressive deactivation of the clay becomes visible in the microstructure as follows: in a first stage, both the swelling and the shrinkage phenomena induce the formation of cracks and slickensides in the TRE, followed by the development of a network of "stress-cutans", apparently as the result of internal stress. Simultaneously small isotropic cells of deactivated clay develop in this network. In a final stage, the transformation involves all the material and leads to a microgranular structure in which internal tensions disappear.

This lateral transformations seems to be a consequence of progressive slope retreat in which residual material slowly evolves toward a typical oxisol.

II. STRUCTURAL EVOLUTION IN SOILS ON ACID IGNEOUS ROCKS (GROUP II).

These soils, developed on granite, microgranite and rhyolite, are located in the State of Pará (eastern Amazonia, fig. 1). They are classified as "podzolico vermelho amarelo" by EMBRAPA (1981), which corresponds to "paleudults" of the american classification (Soil Survey Staff, 1975).

The toposequences observed are monotonous with structural differentiation occurring chiefly at the scale of the pedological profile.

In all cases, two surimposed structures of different sizes may be distinguished:

1. A medium to coarse structure, corresponding to groups of vertical or subvertical platelets and/or prisms, more clearly evident in dry periods than in humid ones. This structure is preferentially developed in the BC and B_2 horizons of soils formed on rhyolite (practically without a coarse skeleton; table 2). During very dry periods, the formation of oblique platelets with slickensides, in these soils, generates a vertic soil morphology.

2. A fine to very fine, mainly polyhedral structure, also including oriented aggregates (prisms and platelets), is always visible and, at times, dominant.

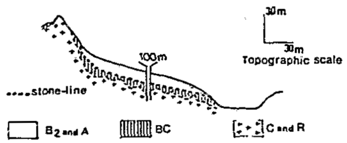

FIG.3 - TOPOSEQUENCE OF SOILS FORMED ON ACID IGNEOUS ROCKS IN THE STATE OF PARA

Such an ubiquitous organization is affected by two opposite evolutionary processes which act in different horizons of the pedological profile, as shown in Fig. 4.

1. A progressive decrease in compactness ("loosing") is often observed upwards from the BC horizon in the B_2 horizon (Fig. 4, profiles 1-4). It corresponds to an increase in the friability and fragmentation of the coarse aggregates resulting in a microgranular structure ("looser" B_2 horizon).

2. A local increase in compactness outlined by the reinforcement of the oriented structure which becomes dominant, and by the stretching of the fine structure (increasingly prismatic and bright surfaced). This evolution may occur at any of the following three levels of the profile:

- At the base of the B_2 horizon (Fig. 4, profiles 7 and 8). In this case, the stone-line constitutes its abrupt lower limit; the BC horizon is not affected.
- In the middle of the B_2 horizon (Fig. 4, profiles 4-6), which after compactation looks like an illuvial horizon, though this compacted B_2 horizon is not characterized by an increase in clay content. Such a differentiation has been observed only in materials with an important coarse skeleton (on granite).
- In the upper part of the profile (Fig.4, profile 1 and 3), as a remarkable superficial compact horizon, always associated with an accumulation of charcoal.

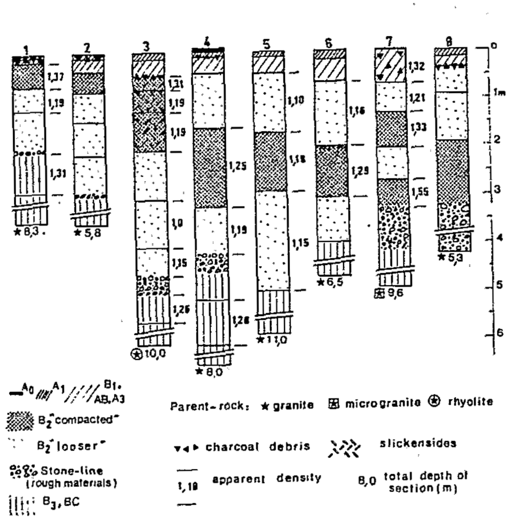

FIG.4 - SOIL PROFILES FORMED ON ACID IGNEOUS ROCKS

Results

Microscopical analysis shows the relations between the different coarse and very fine structures. At low magnification, these structures appear closely imbricated with a mode of spatial association differing according to the parent-rock:

- On granite, in material containing a coarse skeleton, conchoidal cracks intersect each other forming a network of scale-shaped cells (primary structure) subdivided into microaggregates (secondary structure).
- On rhyolite, in soils almost without a coarse skeleton, the spatial organization is different: roughly parallel planes separate the "pedal" (consisting of peds or aggregates) and "apedal" materials (in the sense of BREWER, 1964) (photos 3 and 4)

At high magnification, relationship between pedality and the plasmic fabric becomes clearer:

- The apedal material is characterized by the development of plasma separations (in-mo-vo-skel-masepic plasmic fabric according to BREWER, 1964). In soils with coarse skeletons, these plasma separations occur in two or three sets of roughly parallel zones ("bimasepic" or "trimasepic" fabric, photo 10). Fine cracks locally develop along these plasma separations (stress cutans). Illuviation cutans are absent.
- In the microaggregated "pedal" material, plasma separations are lacking in soil formed on rhyolite ("silasepic fabric"). In soil formed on granite (photo 9), the micropeds are confined by a network of plasma separations (network microped, according to MULLER, 1977). Where micro-aggregation develops, the original plasma separations gradually disappear.

The other main characteristics of the soils are summarized in Table 2. The CEC and pH are low, as is the Fe_2O_3 content also. Metahalloysite is always present and quite abundant in the soils on rhyolite. Swelling capacity differs strongly in "compacted" and "looser" materials.

Interpretation

In these soils, two opposite processes related to alternate wetting and drying, seem intervene.

- "Compaction", which dominates in the levels where the internal tensions are stronger and where the interaggregate porosity is inferior to the volume variations caused by swelling. A transmission of internal stress accompanies the development of plasma orientations and cracks.
- The "loosening" process, which acts where the interaggregate porosity is high enough to absorb the volume variation due to swelling. This occurs when swelling is moderate and/or when biological activity increases interaggregate porosity.

The predominance of one or the other process depends on the intrinsic characteristics of the material (skeleton grains size and distribution, metahalloysite content, clay activity) and on attendant ambiant conditions (pedoclimatic variations, pedostatical pressure, biological activity, etc.). Comparable variations of soil compactness have been studied in Cameroon and related to pedoclimatic conditions, notably seasonal dessication (HUMBEL, 1974). It particularly appears that extreme dessication may induce a radical modification of the microstructure and a complete reorganization of the ferrallitic plasma (CHAUVEL and PEDRO, 1978). It is possible that the superficial compacted horizons, associated with charcoal accumulation, may have formed during an arid period in the Brazilian Amazon (SOUBIES, 1979, 1980).

III. STRUCTURE FORMATION IN SOILS ON SEDIMENTARY ROCKS (GROUP III)

The soils developed on detrital sedimentary rocks cover low plateaus, approximately 70 km north of Manaus (State of Amazonas). They are classified as "latossolos amarelos distróficos" by EMBRAPA (1981) or "acrorthox" in the American classification (Soil Survey Staff, 1975).

Field descriptions show that all the soils, which occur under primary forests, have the following morphology:

O - Litter, 2 cm thick, of little decomposed plant fragments.
A and B1 : 0-30 cm, - Yellowish brown (10YR6/4), turning into yellow (10YR7/6) with depth; clay; weak blocky to granular structure.
B2 : 30-125 cm, - yellow (10YR7/6); clay; weak polyhedral and locally finely granular structure; porosity formed by cracks and, locally, **by intergranular voids.**
B3 : 125-250 cm, - Reddish yellow (7.5YR7/6); clay; weak blocky or prismatic structure, with numerous smooth surfaces.

Results

At low magnification, one observes the following:

- the continuous "S. Matrix" of the B1 horizon contains microscopic fragments of organic matter mixed with the clay by bioturbation;
- **the existence, in the B2 horizon, of larger aggregates, 2 to 5 mm in diameter,** limited by cracks, and of very fine aggregates (< 1 mm) enclosed inside biological voids (chambers and channels; photo 5);
- the continuous "S.matrix" of the B3 horizon with very fine cracks and rare biological voids (photo 6).

At high magnification, the plasmic fabric varies upwards:

- in the B3 horizon (photo 12) some striated orientations, associated with microfissures occur as patches within the "S.matrix", preferentially oriented vertically;
- in the B2 horizon (photo 11) the plasmic fabric becomes argillasepic and biological activity becomes evident along the cracks; microgranular structure locally develops. As mentioned previously, where microaggregation develops, the plasma separations tend to disappear.

The other main characteristics of these soils are indicated in table 2. The clay content is high; the CEC and the Fe_2O_3 contents are low; the swelling capacity is high in the B3 and very low in the B2 horizons.

Interpretation

Available data indicate that internal stress develops in the B3 horizon through alternate swelling and contraction. They are evidenced by the formation of discontinuous striated orientation, stress cutans and smooth surfaces.

At the level of the B2 horizon, the local biological activity redistributes the plasma into irregularly shaped microaggregates in which stress cutans are no longer observed.

Finally, in the B1 horizon, **in the presence of relatively high** concentrations of organic components, kaolinite becomes a material with a continuous structure that presents a low swelling capacity (table 2) and is heavily reworked by the fauna.

CONCLUSIONS

In the three groups of studied soils, both lateral (group I, soils on basalt) and vertical (group **II, soils on acid igneous rocks; group III, soils on detrital** sedimentary rocks) **variations in structure have been detected, and evidenced by an** increase in interconnected void space, by the progressive disappearance of plasma separations and stress cutans, and by a decrease in swelling capacity. This "normal" evolution of ferrallitic soil covers leads to an increase in permeability and therefore, to the stability of these covers with respect to superficial erosion.

The evidence shows that this evolution results from the interaction of three kinds of processes: the first, of a geochemical nature, consists of a continual deionization of the material, resulting in the crystallographic reorganization of iron compounds and a simultaneous deactivation (decreased CEC and swelling capacity) of the kaolinite through superficial "ferrization". Moreover, when the parent material is rich in amorphous ferric hydrates (group I), this "normal" ferrallitic evolution gives rise to a very stable porous framework.

The second process, a physical one, is driven by volumetric variations related to the alternate wetting and drying of the soil, an effect that is accentuated depending upon the dryness of the season and the aptness of the material to expand. In soils of group I, this process acts only in the initial phase of evolution (TRE), creating a network of fractures that facilitate the circulation of water and, consequently, deionization. Its role diminishes as a stable porous framework develops. This process may continue however, principally in the absence of amorphous ferric hydrates, and when metahalloysite is abundant, thus creating internal tensions, that are variable in both space (localized in the profile) and time (effect of dry periods, which are specially marked in soils of group II).

The third process has a biologic origin and contributes to the development of a microaggregated structure in certain horizons. Its effect is particularly evident in the very clayey soils of group III, which are very poor in ferric hydrates and develop beneath humid forest **where variations in humidity are limited.** With deforestation, this structure tends to disappear as porosity and permeability rapidely diminish and secondary hydromorphy develops.

AKNOWLEDGMENTS

The work was performed under the CNPq - CNRS/ORSTOM accord, with financial aid from IDESP and SUDAM, Belém, Pará. Part of this research was carried out in the Instituto Nacional de Pesquisas da Amazonia (INPA).

The authors are indebted to Drs. STOOPS (Laboratorium voor mineralogie, petrografie en micropedologie, Rijksuniversiteit, Gent, Belgium), FAIRCHILD and TROMPETTE (Instituto de Geociências, Universidade de São Paulo, Brazil), for their helpful criticisms and suggestions.

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RESUME

L'étude de trois ensembles de sols ferrallitiques du Brésil, développés respectivement sur basalte, sur granite-rhyolite et sur roche détritique, sous différents climats, montre que le développement de leur structure résulte d'une réorganisation des constituants de leur plasma. Cette "pédoplasmatique ferrallitique" accompagne l'évolution géochimique secondaire du complexe d'altération; elle peut être plus ou moins influencée par des processus physiques (gonflement et retrait lors des alternances d'humectation et de dessiccation) et par l'activité biologique.

Cette étude montre également que cette réorganisation peut conduire à des "faciès" différents selon la nature de la roche mère, selon de degré d'évolution géochimique des matériaux et selon les conditions pédobioclimatiques.

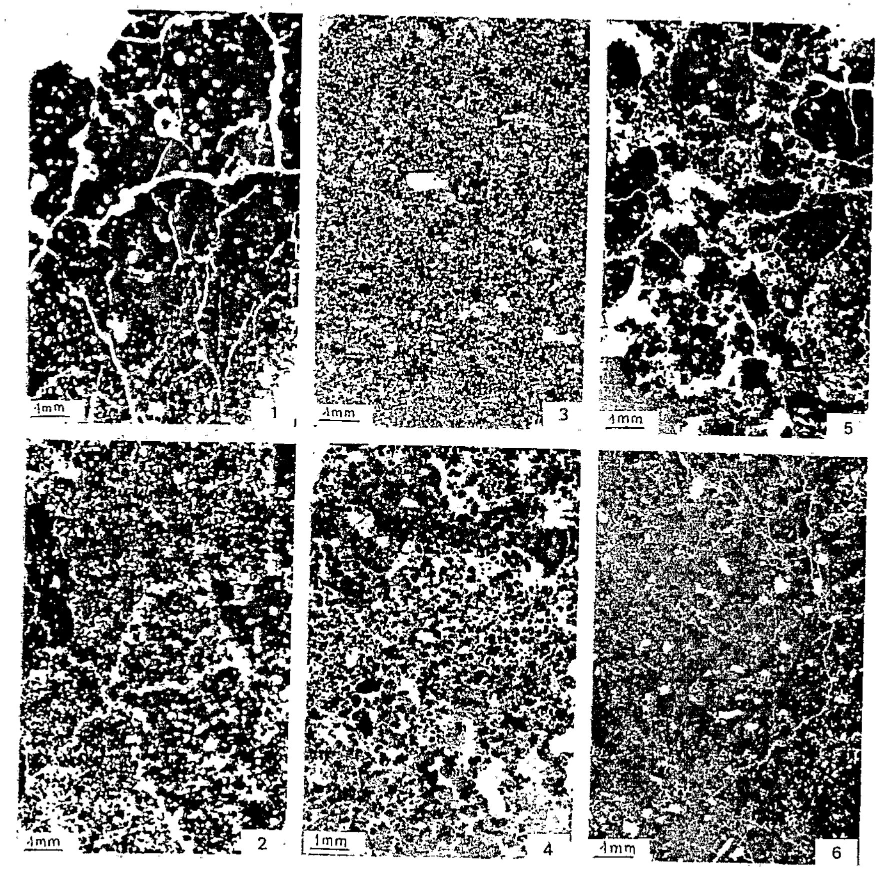

PLATE I. LOW MAGNIFICATION THIN SECTION MICROGRAPHS. (PLAIN LIGHT)

Photos 1-2 - B2 horizons of soils formed on basalt (group I).
Photo 1 - Crack network which is predominantly vertical in the TRE.
Photo 2 - Obliteration of the crack network in the transitional soil.

Photos 3-4 - B2 horizons of soils formed on rhyolite (group II).
Photo 3 - Continuous S. matrix in the "compacted" B2 horizon.
Photo 4 - Microaggregated volume in the "looser" B2 horizon.

Photos 5-6 - B2 and B3 horizons of soils formed on sedimentary rocks (group III).
Photo 5 - Larger and very fine aggregates in the B2 horizon.
Photo 6 - Very fine, predominantly vertical cracks in the B3 horizon.

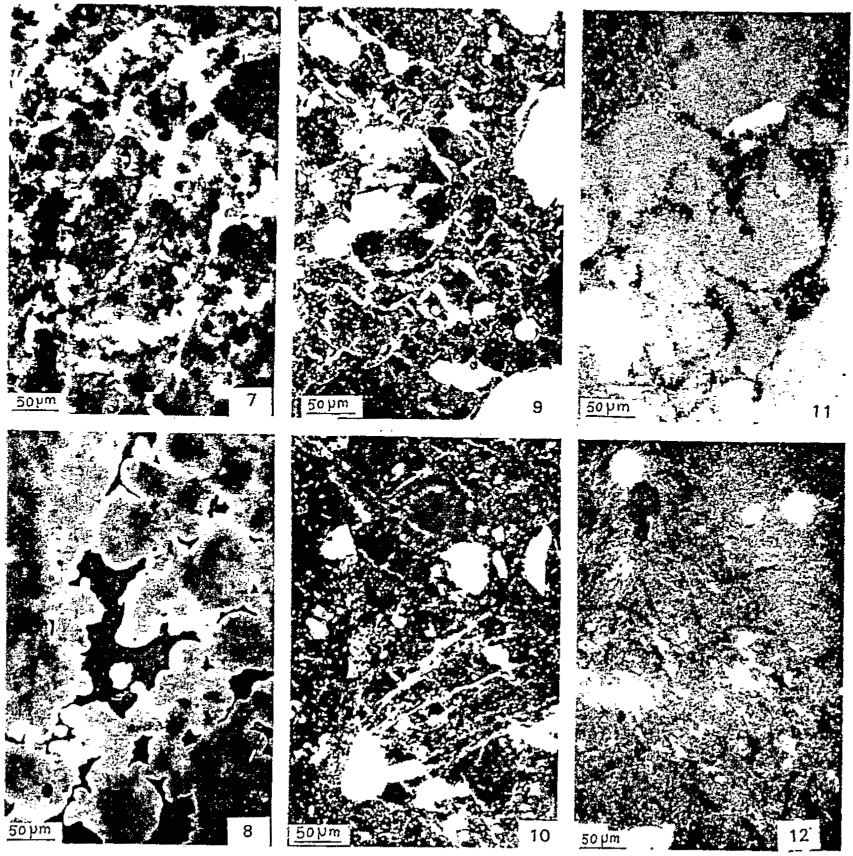

PLATE II. HIGH MAGNIFICATION THIN SECTION MICROGRAPHS. (CROSSED NICOLS)

Photos 7-8 - B2 horizons of soils formed on basalt (group I).
Photo 7 - Network of predominantly vertical stress cutans in the TRE (C.N. 859)
Photo 8 - Microaggregates formation in the transitional soil.

Photos 9-10 - B2 horizons of soils formed on granite (group II).
Photo 9 - "Network micropeds" in the "looser" B2 horizon.
Photo 10 - Network of plasma separations in the "compacted" B2 horizon.

Photos 11-12 - B2 and B3 horizons of soils formed on sedimentary rocks (group III).
Photo 11 - Rounded micropeds in the B2 horizon.
Photo 12 - Striated orientations and microvoids in the B2 horizons.