THIRD INTERNATIONAL WORKING-MEETING ON SOIL MICROMORPHOLOGY
WROCŁAW, 1969

ZESZYTY PROBLEMOWE POSTĘPÓW NAUK ROLNICZYCH 1972 z. 123

Some micromorphological aspects of soils developed in loess deposits of Northern France

M. JAMAGNE
C.N.R.A., Versailles, France

INTRODUCTION

GENERALITIES

All the observations that will be commented, result from the study of the most important loess formations from the north of the Paris basin, in connection with adjacent natural regions.

The purpose of this note is to emphasize the very important contribution of micromorphological studies to the characterization of the pedogenesis in loess materials.

With the help of micromorphological data, it is possible to select some peculiar phenomena, on a microscopical scale, which are related with well-defined, particular conditions. In this way, micromorphology allows both to estimate the type of pedogenesis undergone by a material, and the degree of evolution reached by any soil; on the other hand, ancient soils and paleosols can be characterized.

We will try to illustrate the contribution of this technique to defining a certain number of soil types presenting different degrees of evolution, and developed in loess materials. However, a brief preliminary description of the natural environment and a characterization of the materials involved is necessary.

THE REGION

Northern France, and especially the northern part of the Paris basin, has extensive areas covered with loess deposits, often showing considerable thickness.

The studied area includes different great natural regions: Picardie, Thierache, the Champagne border, Ile de France, with the Soissonnais, Tardenois and Haute-Brie (Fig. 1).

The underlying geological deposits present a great variety, from the primary basement to the tertiary deposits of the Oligocene. The climate

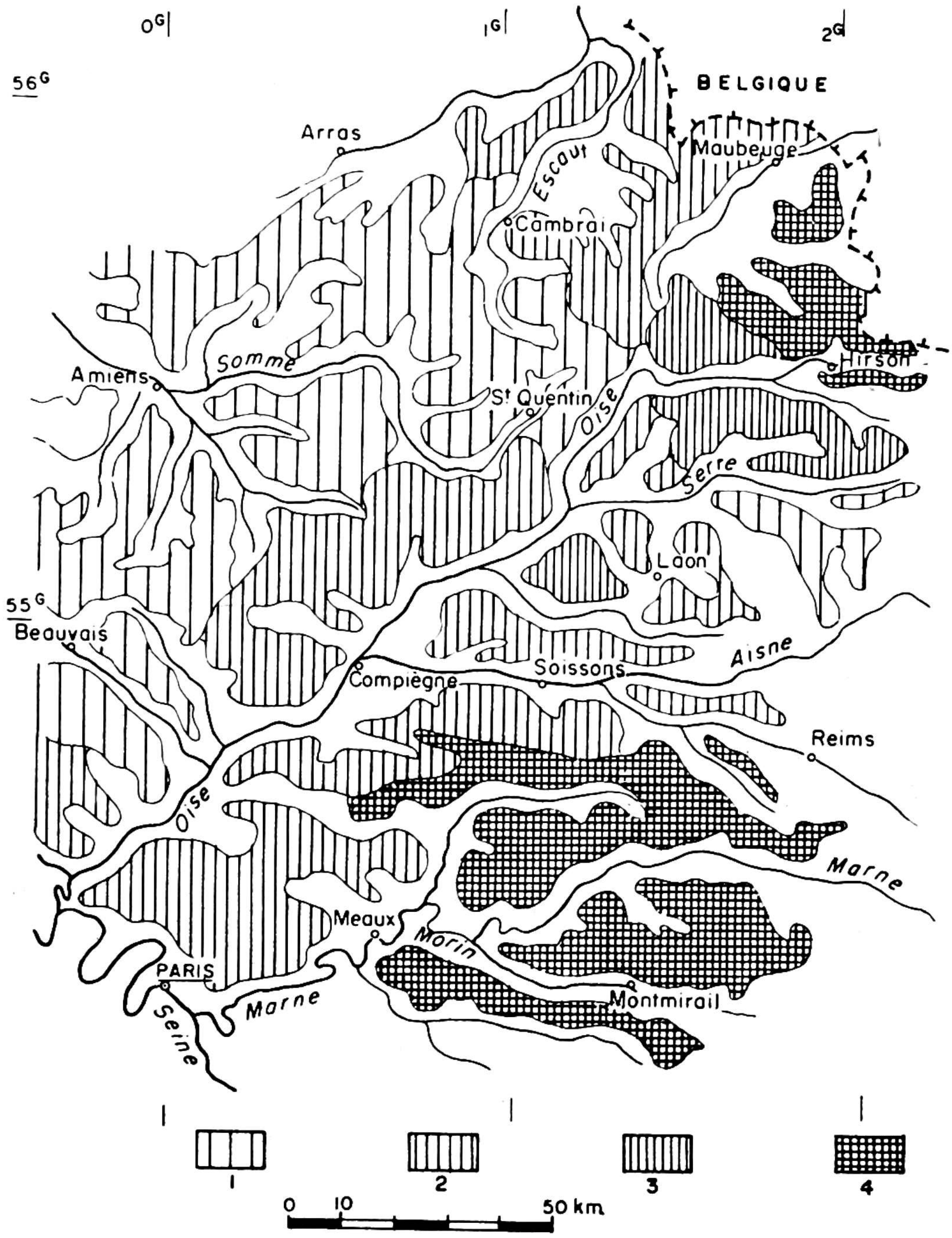

Fig. 1. Outline of distribution of the soils on loess formations in the studied area. *1* — "Sols bruns lessivés" associated with "sols bruns" and "sols calcimorphes", *2* — "Sols bruns lessivés" associated with "sols lessivés", *3* — "Sols lessivés" associated with "sols bruns lessivés", *4* — "Sols lessivés glossiques hydromorphes" associated with "sols lessivés".

of the region can be considered as rather fresh atlantic. The mean annual temperature varies between $9^{\circ}3$ and $10^{\circ}C$; the mean amount of precipitation ranges from 650 to 850 mm, with a rather regular distribution.

THE SILTY MATERIALS

The extensive loess cover involved is highly heterogeneous as for its nature, age and stage of evolution. Certain loess appear to be rather recent, dating from the youngest Pleistocene, or Würm III. Other layers show a much more heterogeneous composition, some of them being distinctly older. The clay content of the most recent loess deposits varies about 14/17% with around 14% $CaCO_3$; "lehms" have a content 20 to 22% clay.

The southern part of the studied region posesses more heterogeneous loess which can be considered as being of an older age: basis of the cycle of the recent loess or even the cycle of the ancient loess. Entirely decarbonated, these lehms are also more weathered, with a clay content ranging from 22 to 26%. The upper lehms may cover loamy deposits, where a different older evolution characterized by rather typical, more reddish tints, seems to have taken place. These materials would be dated as being of Riss or even Mindel age.

The north-north-east part is still more complex. Frequently, the presence of a very recent, homogeneous loess cover of only 0.60 to 1 m in thickness has been noted. The evolution of this layer seems very weak. This cover would be due to erosion phenomena and local reworking. Underneath this cover an older strongly developed loesslehm is found, frequently resting on loesslehm formations with traces of the influence of warmer climates.

At the contact between the cover and the underlying loess deposits, striking phenomena related to periglacial conditions are frequently observed: involution, cryoturbation, presence of small frozen blocks, picked up in a soliflucted lehm paste.

PEDOGENETIC EVOLUTION

The soils developed in these materials show a rather high variety and can be connected with the most important stages of development constituting the evolution sequence on loess described in Western Europe by different authors [6, 9, 16].

This sequence is as follows, every stage being represented by a soil type:

— *parental material* — *initial stage*: with localized development of *sols bruns calcaires ou calcimorphes* (Calcic or calcimorphic brown soils);

— *sol brun* — ("Braunerde" [1] — "Eutrochrept" [2] — "Eutric Cambisol" [3]);

— *sol brun lessivé* — ("Parabraunerde" — "Hapludalf" — "Brunic luvisol/Albic luvisol");

— *sol lessivé en voie de dégradation* — ("Parabraunerde/Fahlerde" — "Hapludalf/Glossudalf" — "Albic luvisol/Glossic luvisol");

— *sol lessivé glossique hydromorphe* — ("Parabraunerde — pseudogley/Fahlerde" — "Glossudalf/Fragiaqualf" — "Glossic luvisol").

Some of these, developed in loess deposits of the recent cycle have undergone an essentially post-glacial development, the most active period

[1] German classification.
[2] American classification (7° Approx.).
[3] Soil map of the world F.A.O.

of which seems to have been the Atlantic period; these soils would be 12 till 15,000 years old.

On older materials, "sols lessivés très dégradés", with a podzolic tendency and a distinct secondary hydromorphism have developed. They would have undergone the action of several successive pedogeneses and they can be considered as being several ten thousands years of age.

Numerous paleosols can be observed, characterizing contact levels between successive loess deposits. Some characteristics link them with some stage or another mentioned above. Others give evidence of genetic processes that are related with different environmental conditions.

Each of the main evolution stages, evidenced in loess materials, is defined by particular morphological, physical and chemical characteristics, and these data allow a rather accurate pedological definition.

The data studied here are of micromorphological nature.

METHODOLOGY

The samples, taken in boxes of the type recommended by Kubiëna [11], have been impregnated and prepared according to the method of Altemüller [2]. The technique of description, and the terms used, correspond to the terminology of Brewer [3], with some adaptations, proposed by Laruelle and utilized in the laboratory of the University of Ghent. References to Kubiëna's publications have been introduced. The data and description essentially refer to diagnostic horizons, with possible references to other characteristic levels.

EVOLUTION SEQUENCE

ORIGINAL MATERIAL — INITIAL STAGE

The loess materials, that can be considered as parent materials, are observed either at the surface in morphological position subjected to an accentuated erosion, or buried under more or less strongly developed soils.

The *skeleton* of the loess lehms of Northern France has a rather homogeneous composition. Essentially quartzitic, it yet contains a certain amount of weatherable minerals in the fine silt fraction. The skeleton is dominated by the 20-50 microns fraction, but a variable content of coarse sand grains is present. The calcareous loesses are characterized by the presence of very small fragments of detrital lime, regularly scattered in the matrix.

The *plasma*, showing essentially an argillaceous aspect, is homogeneous and regularly distributed; a few *plasma separations* can be observed with high magnifications, some of them being independent, others showing a skelsepic fabric; they all have moderate orientation.

Very numerous small packing *voids* are regularly distributed in the material and are related with a very high microporosity. The macroporosity, on the contrary, seems to be relatively low; a few orthovughs and vesicles can be observed.

At this stage, no particular pedological characteristic is perceptible.

As soon as the calcareous loess undergoes a pedogenetic influence, a mobilization and redistribution of the carbonates take place, with localized concentrations.

The soils developed are of the type "sol brun calcaire ou calcimorphe" (calcareous or calcimorphic brown soil): A_1 — A_3/(B) — C. Consequently the studied calcareous loesses nearly always contain a noticeable proportion of neoformed lime, present in the form of *calcitans*. These diffusion calcitans are built up starting from the voids: pores and fine root channels. They represent the most common form of this neogenesis lime (Fig. 2). They can also be observed in the form of much denser concentrations, or real concretions called "loess dolls".

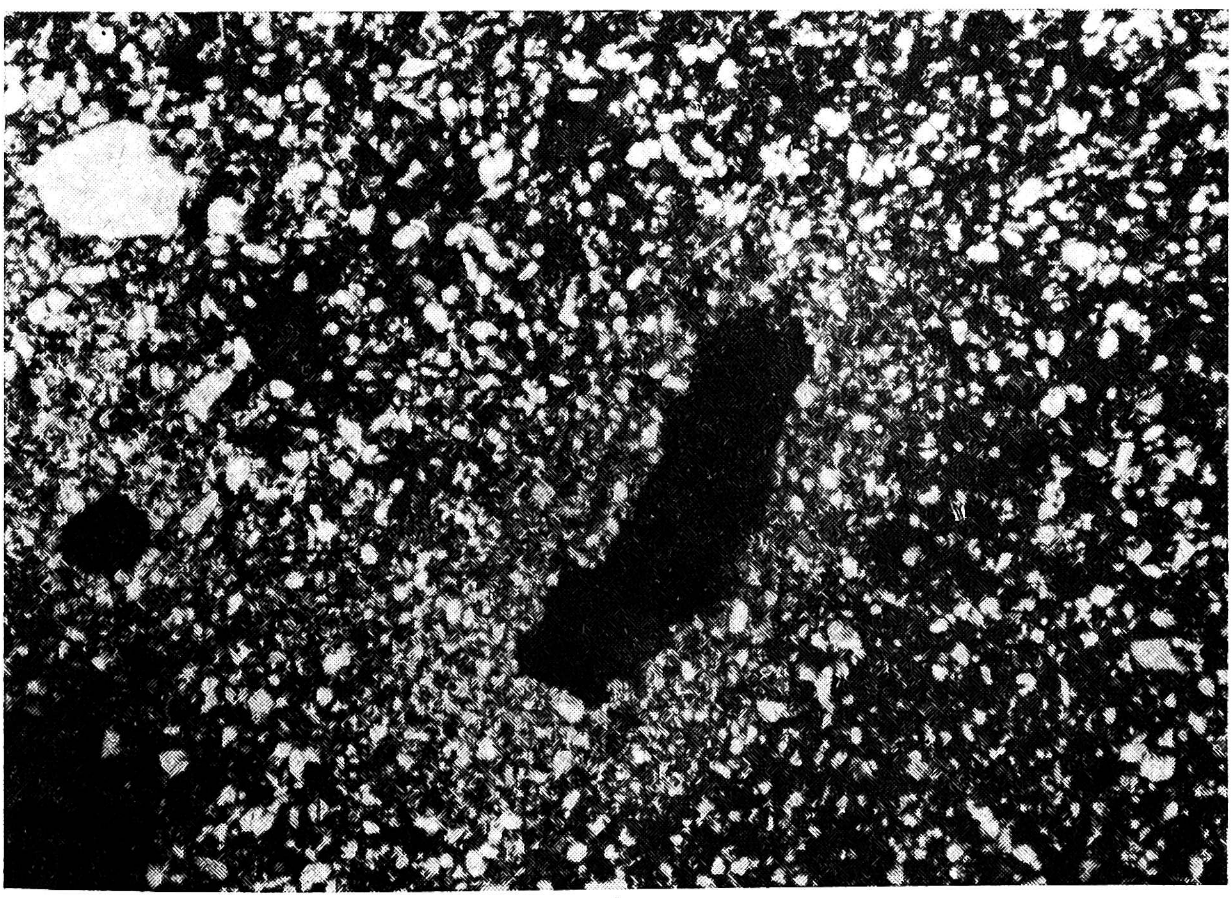

Fig. 2. Calcareous loess from Picardie. Homogeneous skeleton dominated by the 20-50 μ fraction with a few sand grains. The detrital lime is not very distinct, the calcitans form an aureole around the voids. Polarized light. ×70.

Plasma separations, clearly visible with normal magnifications, appear at that stage: localized alongside the skeleton, they are of skelsepic type. The *elementary fabric* can broadly be considered as being intertextic. No preferential repartition of plasma in the form of concentrations can yet be evidenced.

"SOL BRUN"

This is the stage of alteration and structuration of the material, with differentiation of a (B) horizon, showing a well-developed blocky structure and corresponding to a diagnostic "cambic" horizon of the american classification. The profile is of the type: A_1 — A_3 — (B) — C.

The *skeleton* does not present any particular variation, compared to the initial material, but for the elimination of detrital lime. Rather frequent presence of glauconite grains, showing variable weathering stages, can be noted.

The *plasma* presents a less great homogeneity and during this phase it is oriented more and more distinctly. Still having an essentially argillaceous constitution, it is distributed in a preferential way in the shape of clearly distinguishable separations. Well individualized *plasma separations* are present around the skeleton grains as well as in the form of isolated patches in the S-matrix.

Generally, the degree of orientation of these separations is moderate, just slightly more accentuated than in the original material.

The dominant *plasmic fabric* can be qualified as skel-insepic.

The *elementary fabric* or relative distribution in the basic structure essentially shows a dominance of the intertextic type.

The *voids* are principally represented by cavities with smoothed walls and numerous channels: "smoothed meta vughs" and "meta channels".

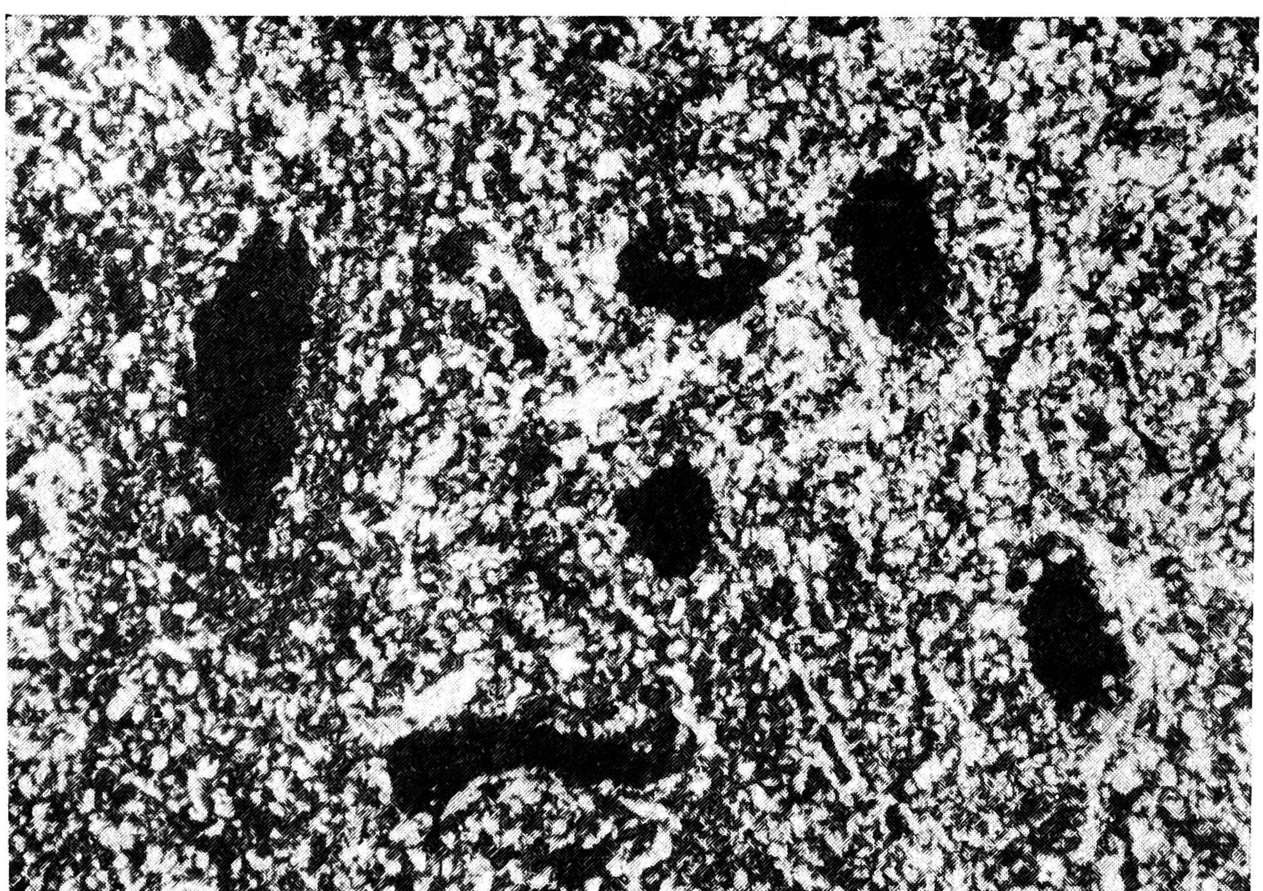

Fig. 3. (B) horizon — "Sol brun" — Soissonnais. Many voids are representative of the high porosity. Polarized light. ×70.

Owing to the well differentiated aggregation of the material, the macroporosity seems to be considerably more important here than in the preceding case (Fig. 3).

As for the *pedological features*, one can observe that a part of the clay fraction migrates locally and is deposited in the form of concentrations on the walls of the voids. The first voids to be affected by this deposition process are generally those having a mean diameter (50 to 200 microns).

These few argillans are rather strongly oriented.

Nevertheless, the faces of the structural aggregates are not likely to undergo an important coating at that stage of evolution, where the colloidal displacements in the matrix always appear to have a limited importance, and are probably related with very locally favorable conditions.

It seems probable that at this stage, processes of alteration and argilification occur, causing the apparition of a certain amount of clay enriching the original plasma [17].

"SOL BRUN LESSIVÉ"

The illuviation phenomena are particularly evident in this case, with a distinct differentiation of an "argillic" B_2t horizon. The profile is of the type A_1 — A_2 — B_1 — B_2t — B_3 — C.

This illuviation is very clearly characterized by the presence of numerous clay coatings in almost all the meso-and macropores, as well as on the faces of the structural aggregates [4, 6].

The *skeleton* always shows a rather homogeneous repartition.

The *plasma* is essentially argillaceous or argillo-ferruginous, and its distribution becomes less homogeneous, "without relation" with the mass, subcutanic to cutanic as for the separations.

The *plasma separations* surrounding the skeleton grains are very obvious in the mass of the S-matrix, while some plasma segregations with a stronger ferruginous character can be observed without an evident relation with the other constituants.

The *plasmic fabric* is therefore in-skelsepic.

Il all parts of the matrix, the *skeleton* is always very largely dominant compared with the plasma, the elementary fabric being essentially intertextic.

At the upper part of the B, we observe an agglomeroplasmic related distribution, and within the B, a fabric with porphyroskelic tendency, in relation with the few insepic plasma separations.

The *voids* are composed of numerous irregular vughs with smoothed walls, some of them being mammillated. At the B_2t level, simple or "dendroid" channels with smoothed walls can be observed, and seem to be in relation with the typical macromorphological blocky structure. In the C horizon a great number of regular vughs can be noted. At this stage, the macroporosity has become important, while the microporosity seems to have decreased considerably.

The *pedological features* are represented by the separations, as well as by important plasma concentrations.

Argillans and ferri-argillans, with yellow color and rather strongly oriented, appear in the voids: normal vughs cutans; in the channels: channel cutans; and at the border of the aggregates: ped cutans (Fig. 4).

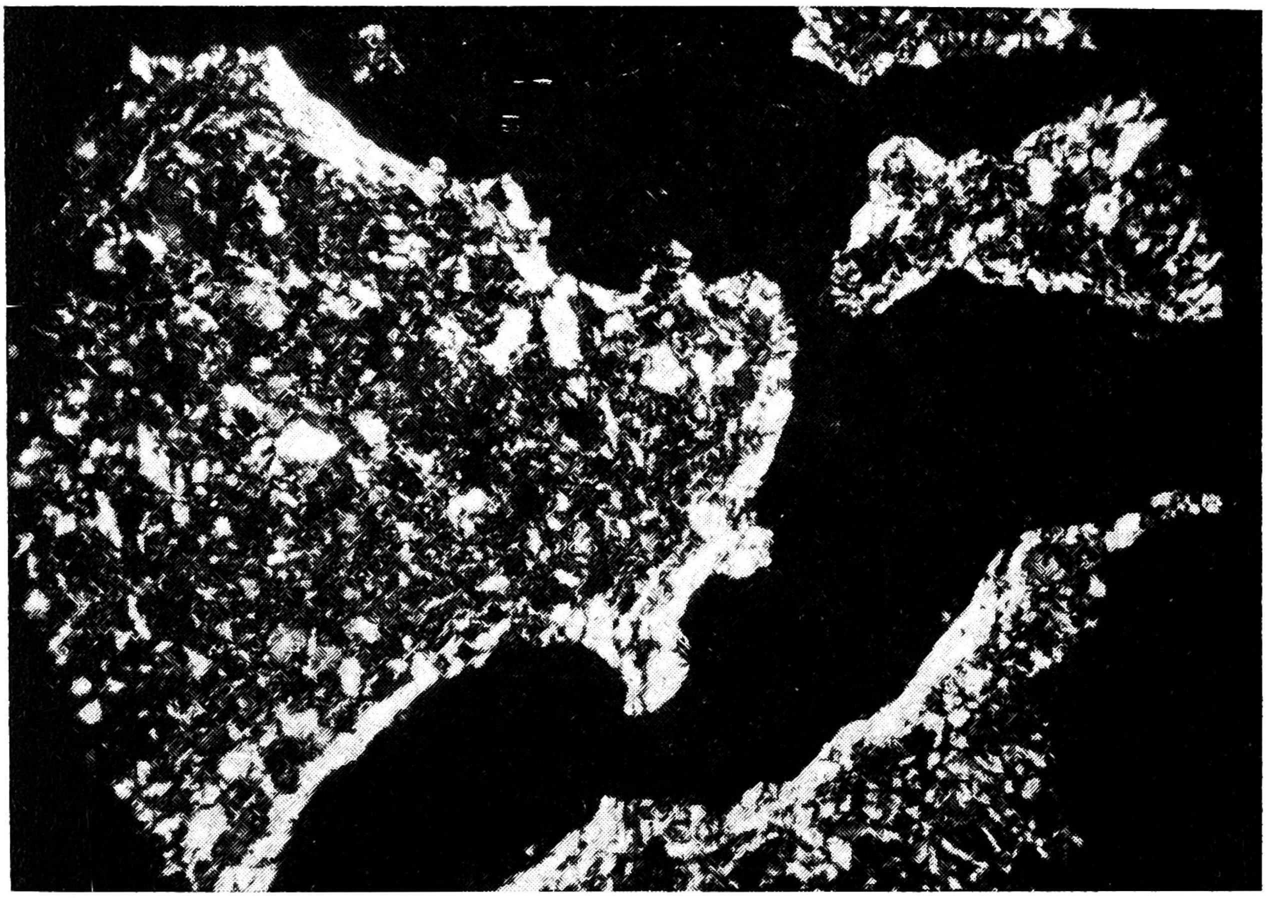

Fig. 4. $B_{22}t$ horizon — "Sol brun lessivé" — Picardie. Peds and voids are covered with thin yellow ferri-argillans. Polarized light. ×70.

Very numerous at the level of the B_2t, they only cover about 30% of the void faces in the B_3 horizon; in the C only a few traces can be observed. Some small *isotubules*, probably due to a rather recent filling up of voids, are normally found at the lower part of the B_2t.

These soils, showing well-oriented, pale yellow illuviation materials, seem to be characterized by a postatlantic evolution [6, 8]. This stage forms the most accentuated evolution, that can be observed on old loesslehm colluvial deposits.

"SOL LESSIVÉ"

The importance of the illuviation phenomena markedly increases and is related with a noticeable desaturation of the absorbing complex of the upper horizons. On the other hand, some traces of hydromorphism appear in the solum at the lower part of the Bt horizon. The composing horizons are: A_1 — A_2 — B_1 — B_2t — $B_3(g)$ — C.

The *skeleton*, still rather homogeneous, nevertheless presents locally a particular distribution. Indeed, the intensity of the leaching can have brought about the accumulation of fine silt fractions in some faunal burrows, as well as in some voids with sufficient dimensions, where they are included in the products of clay illuviation.

At that stage, the *plasma*, of argillo-ferruginous nature, is well oriented and has a yellow or reddish yellow color. Its distribution is here rather heterogeneous. The *plasma separations* are slightly more numerous and slightly stronger developed than at the stage of "sol brun lessivé". They always show a dominance of skelsepic fabric, with some scattered insepic segregations. Therefore, the *plasmic fabric* shows either agglomeroplasmic or porphyroskelic facies.

The *voids* are composed of numerous regular and irregular orthovughs, locally mammillated, as well as of single smoothed metachannels. It can be noted that the matrix of the aggregates of the Bt horizon presents a denser fabric, due to a porosity of little importance.

As for the *pedological features*, these more developed soils are characterized by a strong development of clay cutans with a reddish yellow color, composing *ferri-argillans*. These plasma concentrations are thicker than the yellow coatings of the typical "sols bruns lessivés"; rather strongly oriented, they present a clearly striated orientation pattern.

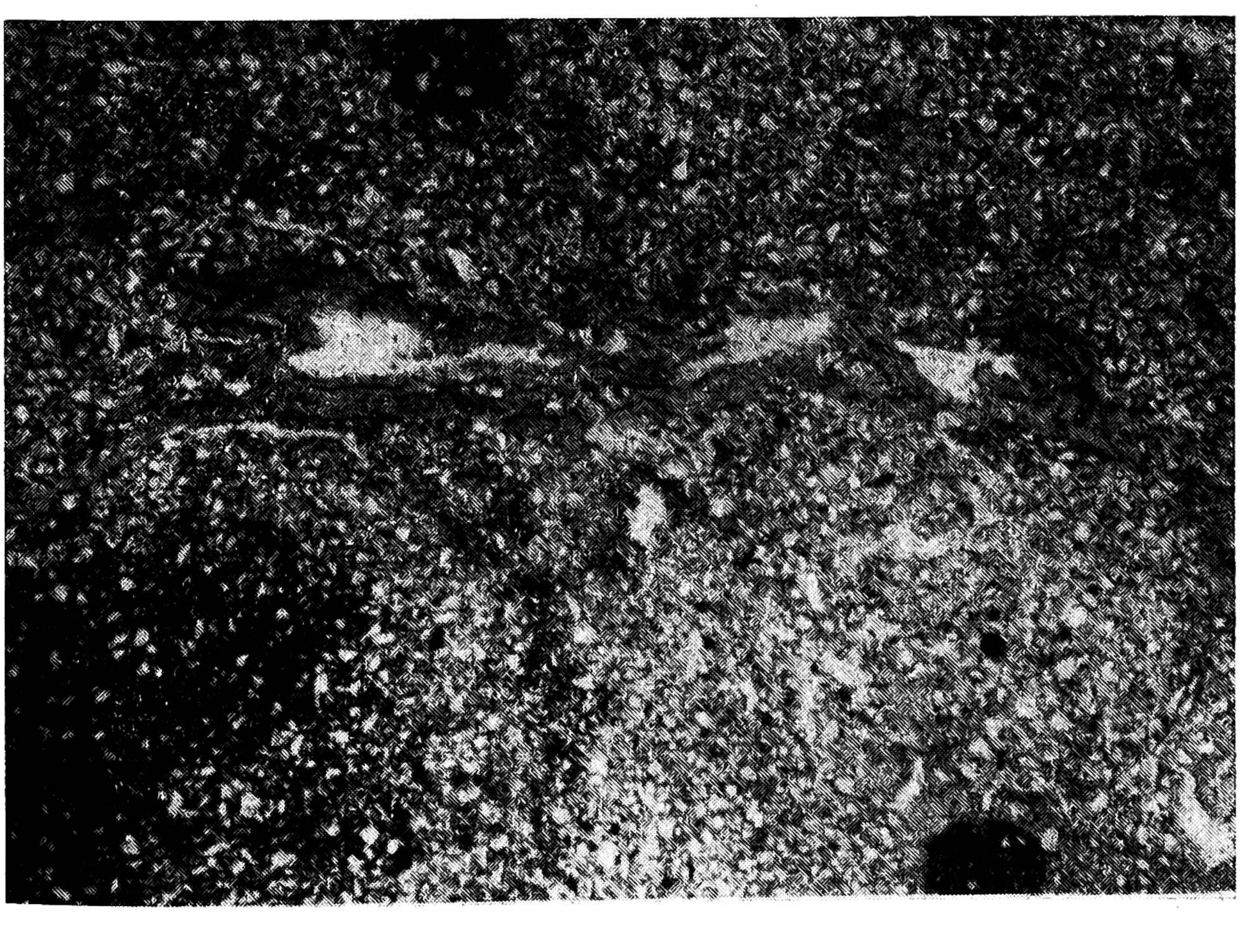

Fig. 5. $B_{22}t$ horizon — "Sol lessivé" — Thierache. In the middle of the photograph: ferri-argillans with decomplexation of iron oxides — Glaebules with diffuse or distinct boundaries. Plain light. ×70.

Almost all the soil faces in the argillic Bt horizon are affected by this process. Besides, diffusion cutans appear all over the solum, in connection with typical argillans. Some cutans present a certain amount of fine silt grains interstratified in the successive clay deposits, and probably mobilized in a mechanical or biological way.

Glaebules, ferruginous nodules, can be observed in the lower part of the Bt horizon, where they indicate a tendency to a temporary waterlogging and correspond to the oxydo-reduction mottles observed at this level in the profile in the field. The boundaries of these nodules are often diffuse and irregular (Fig. 5).

In this soil type, it is not uncommon to find pale yellow coatings, typical for a rather recent pedogenesis, fossilizing older and more ferruginous coatings [10]. In relation with the morphological and geomorphological data, a certain amount of evidences makes us think that the reddish yellow ferri-argillans would have been formed in a warmer and more humid climate than now, and corresponding to that of the atlantic period. Finally, in these "sols lessivés", fragments of coatings included in the matrix can be observed locally, and these could be interpreted essentially as a result of biological activity.

"SOL LESSIVÉ EN VOIE DE DÉGRADATION"

Although taxonomically not constituting a well-defined stage of development, this soil type presents some interest in the study of the evolution of loess deposits. Leached spots, rich in fine silt, appear on the aggregates of the upper part of the Bt, and correspond to a beginning degradation, that will be generalized in the next stage [4]. On the other hand, the characteristics of hydromorphism, of pseudogley, become very conspicuous. The profile is of the type: $A_1 — A_2 — B_1 — B_2t(g) — B_3g — C$.

The *skeleton*, homogeneous in general, presents again a somewhat particular distribution of some very fine fractions, which are carried down in the profile, due to a biological and mechanical action. The bleached degradation spots characterizing this evolution stage correspond to spots with progressing limits, that have lost most of their argillaceous plasma, liberating in this way a great part of the skeleton grains from their plasmic coating. In fact, these are "microerosion" spots.

The *plasma*, with an argillo-ferruginous aspect at the level of the B horizon, is rather heterogeneous, and irregularly distributed. Indeed, a formation of dark deposits of iron oxides can be observed, probably associated with some manganese oxides, showing irregular and diffuse boundaries, and impregnating the matrix.

The *plasma separations* are always distributed around skeleton grains and in the form of islands of little importance, but also, at the lower part of the Bt and B_3, in more or less parallel bands within the matrix. The *plasmic fabric* in the B horizon could be called ma-in-skelsepic. The appearance of the masepic character would express an increase of physical stress and strain, related to phenomena of compression and compaction. In a general way the Bt horizons of these soils appear slightly more compact than those of the preceding stage, with a relative increase of the plasma compared with the skeleton. So, according to the place of observation, the relative distribution of the constituents will be rather variable.

The *elementary fabric* can be called porphyroskelic. As in the preceding case, the *voids* are composed of regular and irregular vughs with smoothed walls, and of a rather important number of channels. The *pedological features* are numerous and diversified, related on the one hand, with the intensity of the evolution, on the other with the increase of the endohydromorphism.

The clay coatings are very numerous in the Bt. Some of them coat the walls of the voids and the faces of the peds, others are fragmented and included in the matrix. These coatings seem to be more ferruginous than those of the preceding stages. In strongly developed soils, where the degradation is already accentuated, one can observe, on the vertical faces of the structural elements, rather fine, very pale yellow coatings, that could correspond to phenomena of secondary illuviation, related to the degradation (De Coninck and Laruelle [5] — De Coninck, oral communication).

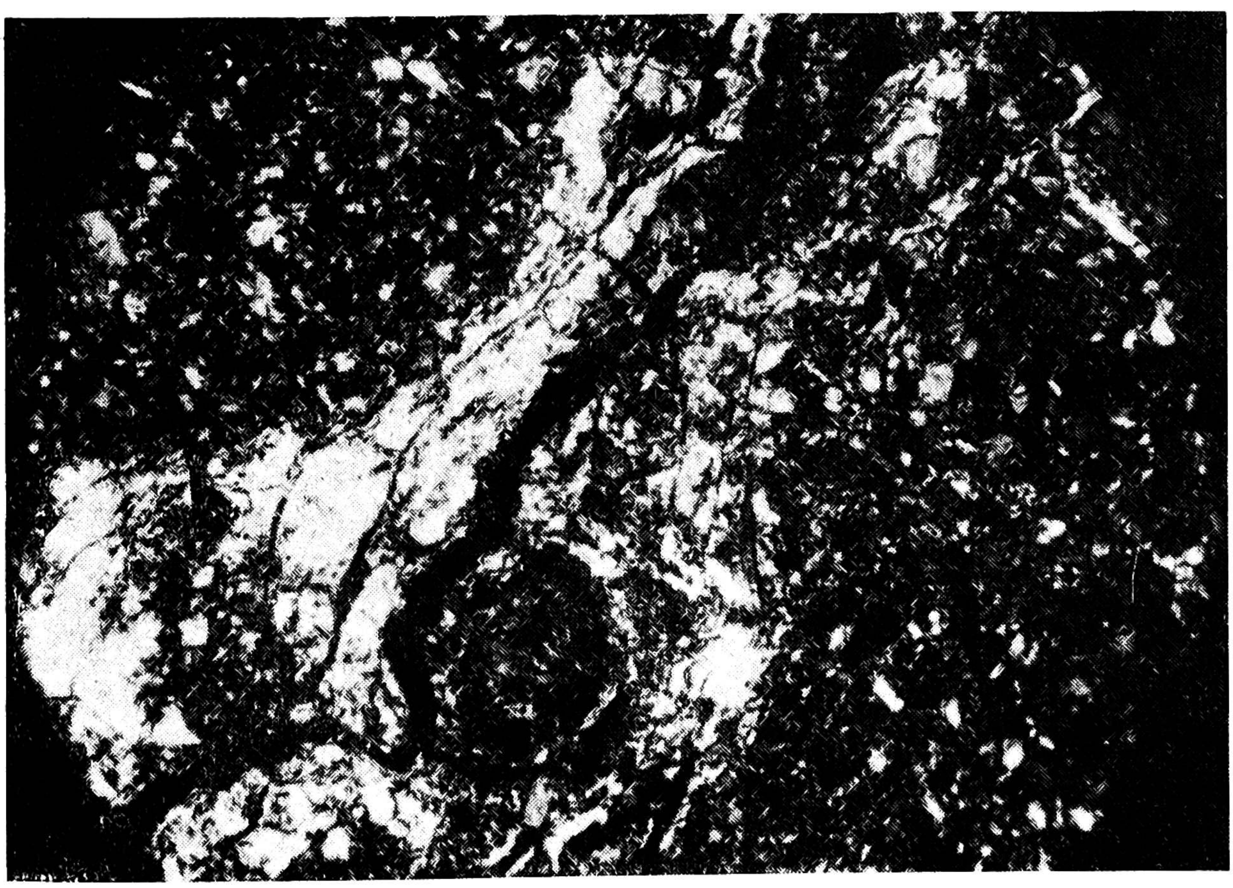

Fig. 6. B_{22}tg horizon — "Sol lessivé en voie de dégradation" — Haute-Brie. Thick compound ferri-argillans completely filling up a channel. Polarized light. ×120.

The presence of skeleton grains in some compound coatings is frequent at this stage of evolution. Consequently the characteristic *cutans* are simple illuviation ferri-argillans, and compound illuviation ferri-argillans and skeletans (Fig. 6). The rather frequent presence of black concretions and discontinuous films, probably mangans, can be noted. Other plasma concentrations appear in the form of *glaebules*: essentially ferruginous nodules with rather distinct or more diffuse boundaries: glaebular halos. Real, distinctly delimitated concretions can also be noted. The most common *pedotubules* are isotubules showing bulk filling up, and striotubules with progressive filling up. A few ferruginous crystallites are scattered in the B_2t and B_3 horizons.

"SOL LESSIVÉ GLOSSIQUE HYDROMORPHE"

This soil type probably contitutes the most accentuated evolution stage on loess materials. A real "dissolution" of the upper part of the Bt horizon and the formation of a tonguing can be established: pockets and tongues of degradation deeply penetrating in the accumulation horizon, and causing a progressive deepening of the A_2 horizon. This marked evolution is frequently related with the appearance in the depth of a compact horizon of a "fragipan" type in the B_3 and the lower part of the B_2t. Consequently, at this stage of evolution, a generalization of the degradation can be established. The profile type shows a succession of the following horizons: A_1 — A_2g — A & Bg — B_2tg — B_3gx — C_1gx — C_2g.

The *skeleton* presents an heterogeneity in some zones, the finest fractions being relatively more represented in these places. In the tongues of alteration, pockets are present, from which the argillic plasma has disappeared almost completely.

The *plasma* is very heterogeneous and is characterized by varied forms of ferruginous segregations. Iron oxide deposits acquire a considerable importance and are particularly numerous at the lower part of the A_2 and in the zone of alteration of the Bt horizon. They locally impregnate a matrix that can have preserved its plasmic fabric, and some pedological features (Fig. 7). Other zones show a plasma that seems to have lost most of its iron under the influence of the reducing conditions of the environment. The *plasma separations* of skelsepic type are only slightly represented in the upper horizons, but scattered regularly throughout the rest of the profile. Separations, elongated in bands or partially curved, of masepic type, appear in the S-matrix from the middle of the B_2t horizon down to the B_3gx. Some "subcutanic" separations are recognizable in the B_3gx.

Consequently, the *plasmic fabrics* vary from weak skelsepic in the upper horizons to in-ma-skelsepic in the B horizon, with associated vosepic. The masepic character seems to be distincly developed within the fragipan horizon, what would correspond to a maximum of mechanical stress, and

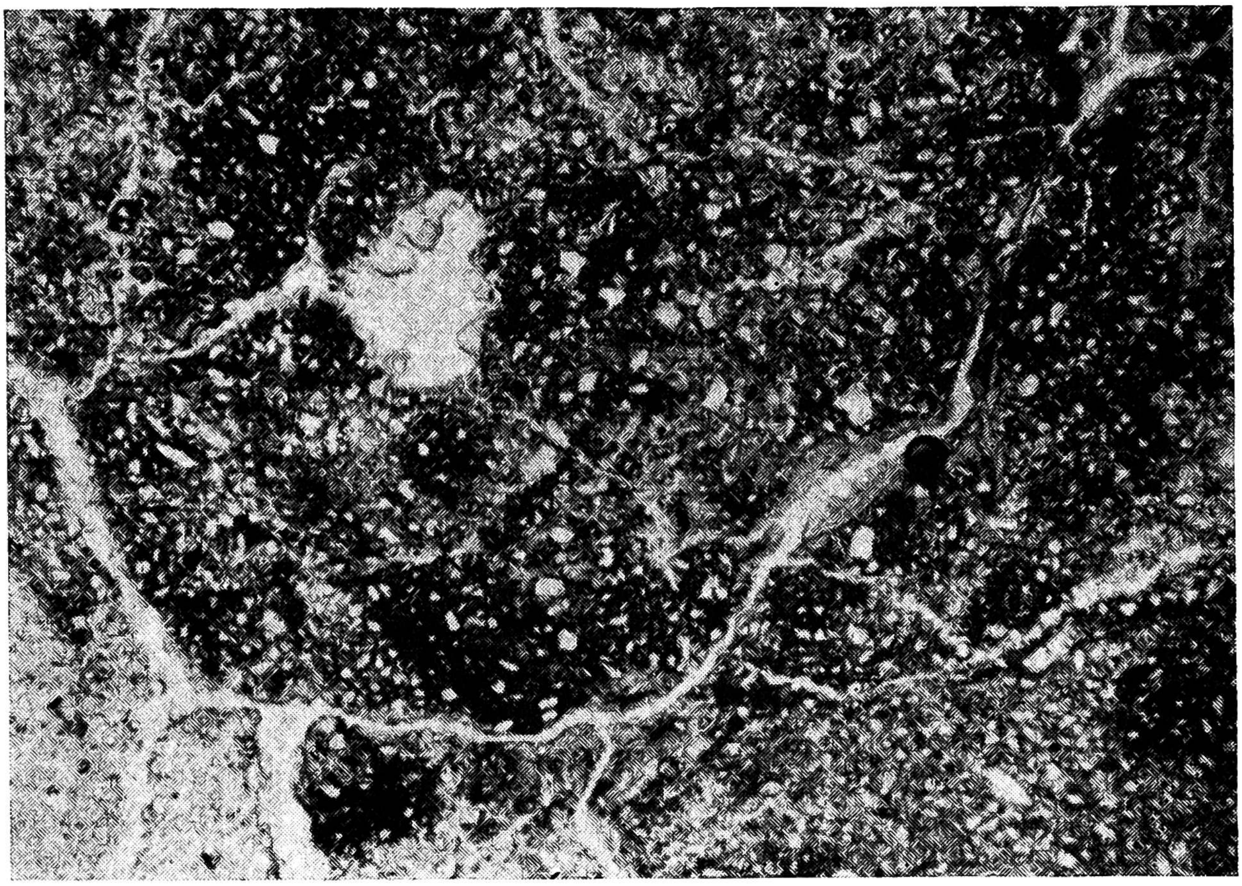

Fig. 7. A & Bg horizon — "Sol lessivé glossique hydromorphe" — Haute-Brie. Ferruginous nodule having fossilized locally the S-matrix with inskelsepic plasmic fabric, as well as yellow argillans. In the lower left hand corner, degradation spot. Plain light. ×70.

compaction. Very locally, skel-masepic or skel-bimasepic fabric can be dominant.

The *elementary fabric*, being granular or intertextic in the upper horizons, merges into distinctly more porphyroskelic in the rest of the solum. The *voids* show a high variation throughout the profile. At the surface, regular or irregular orthovughs are present, in association with small packing voids. Lower numerous channels appear, with smoothed walls, together with few irregularly distributed chambers. At the level of the B_3gx joint-planes are noted, probably corresponding with the important structural faces of the prismatic structure including a platy sub--structure of this compact horizon.

The *pedological features* are very numerous. The clay coatings are very important in the Btg horizon. Some of them, very thick, fill up entirely the voids in which they are formed. The *cutans*, at this stage, become particularly complex and present very different forms:

— some of them are moderately oriented simple ferri-argillans, with individualization of iron oxides.

— others are composed of an irregular succession of layers, some with an argillaceous texture, others essentially composed of fine silt grains: compound ferri-argillans-skeletans (Fig. 8 and 9).

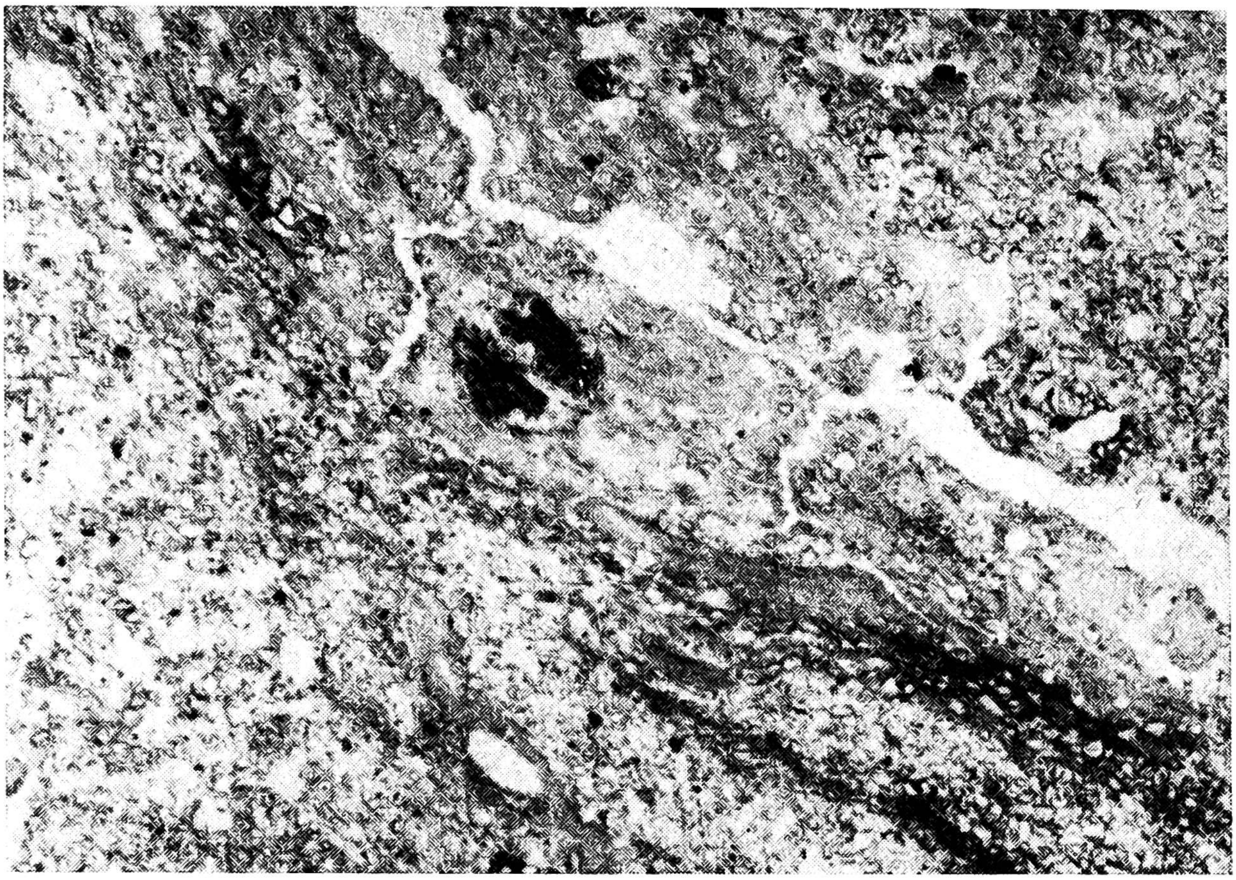

Fig. 8. $B_{22}tg$ horizon — "Sol lessivé glossique hydromorphe" — Haute-Brie. Complex argillo-ferruginous concentration with interstratified fine silt. Many ferruginous segregations. Plain light. ×70.

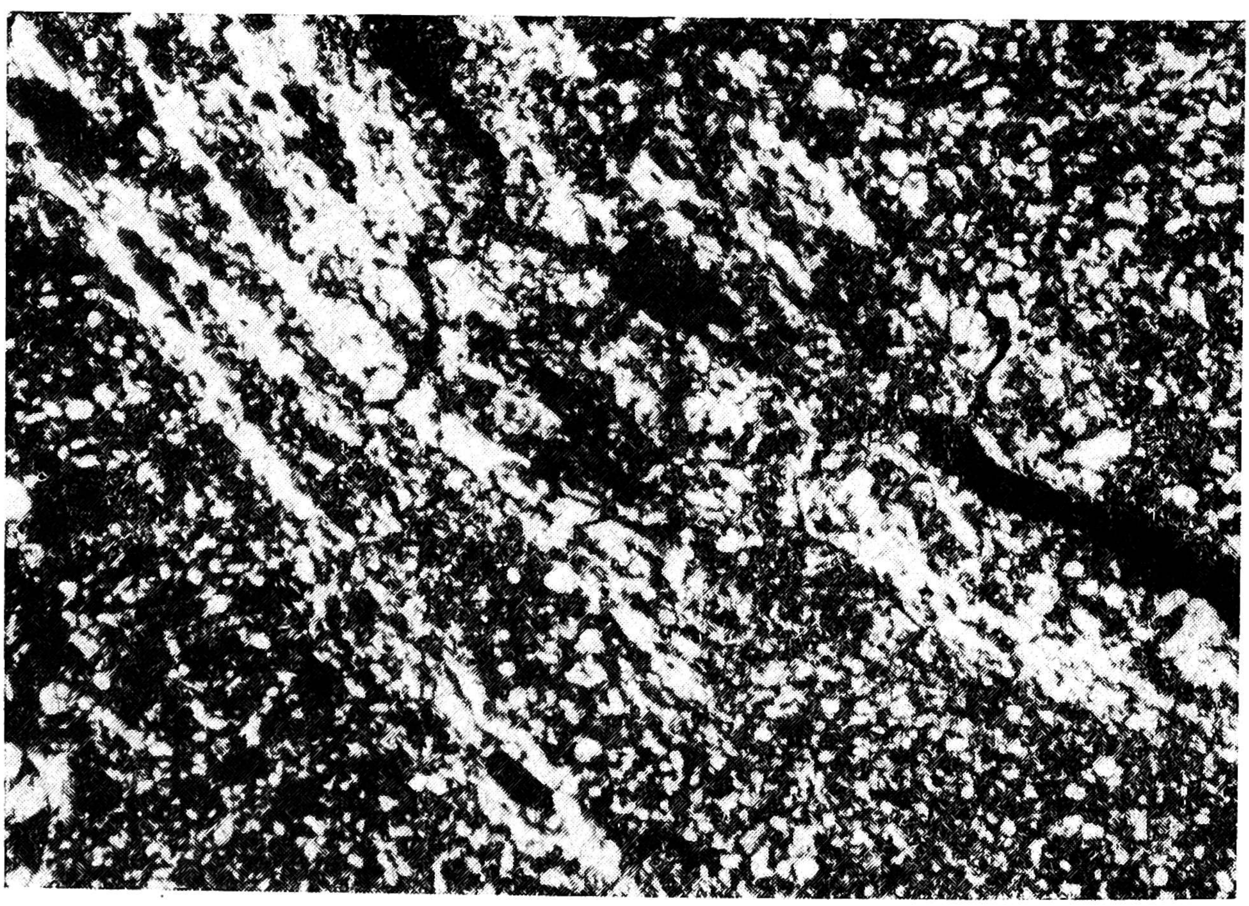

Fig. 9. Id. Polarized light. ×70.

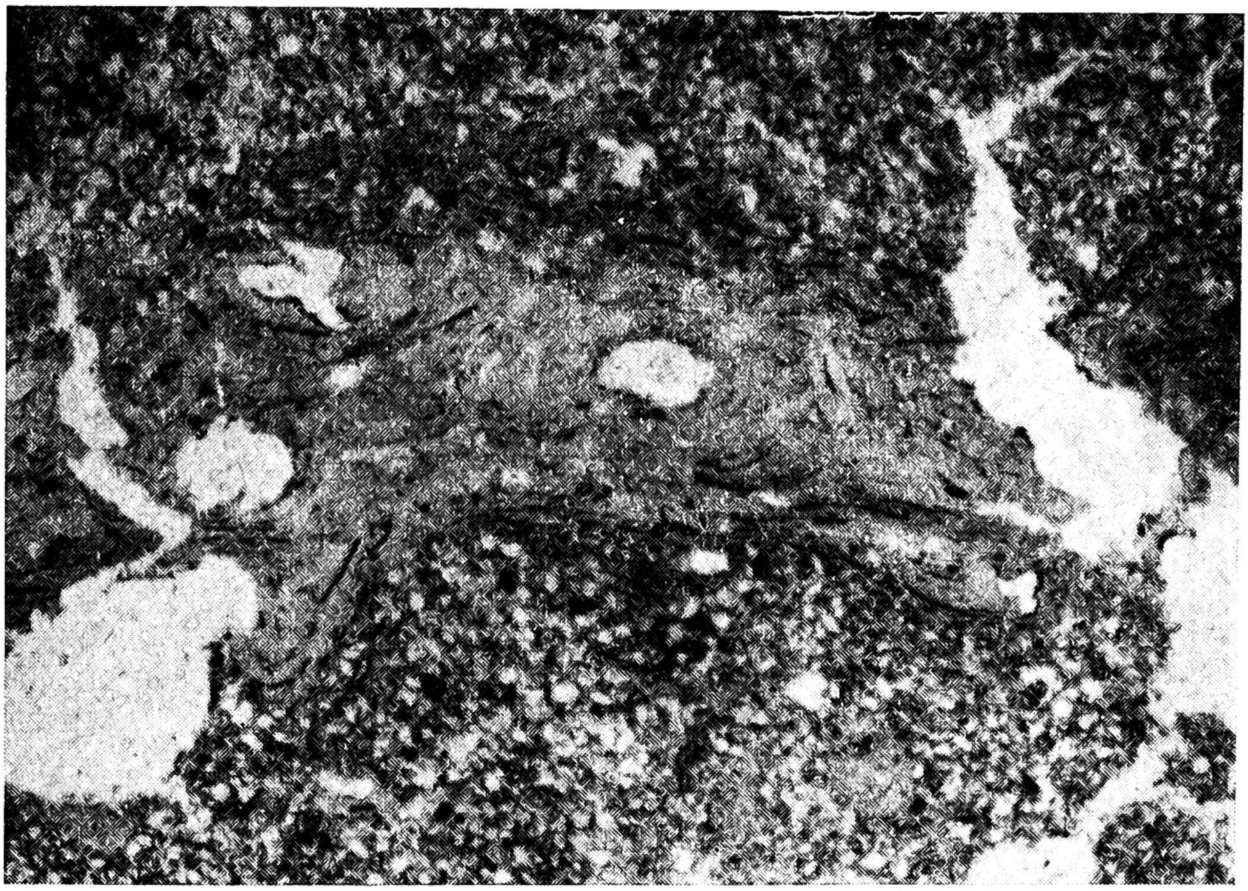

Fig. 10. B_{22}tg horizon — "Sol lessivé glossique hydromorphe" — Ardennes. Very thick ferri-argillan with very distinct plasmic organization. Plain light. ×70.

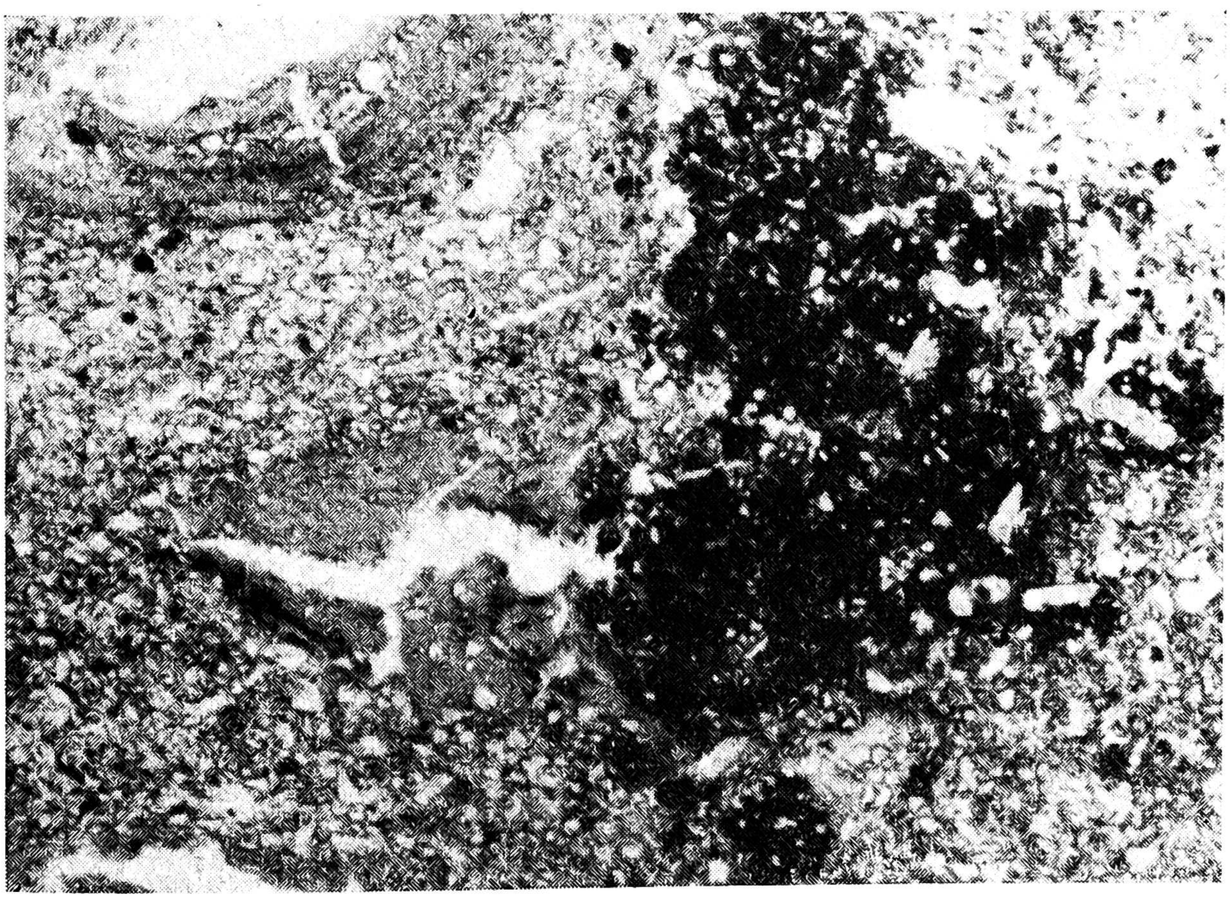

Fig. 11. B_3g horizon — "Sol lessivé glossique hydromorphe" — Haute-Brie. Complex plasma concentrations, with fine silt. Cutans of secondary illuviation. Well differentiated ferruginous nodule. Plain light. ×70.

— others finally show fine dark bands, interstratified in argillaceous layers, and probably composed of individualization forms of iron or manganese oxides (Fig. 10).

In relation with these normal void-channel-plane and ped cutans, a certain amount of diffusion cutans can be observed. In the lower part of the B_2tg horizon and within the B_3gx pale yellow *argillans* generally appear in these soils and would correspond to the greyish, often rather thick clay coatings observed in the field (Fig. 11). These can be considered as plasma concentrations due to a secondary illuvation, d.i. coatings composed of clay originating from the degradation in a hydromorphic environment. After reduction and removal of the iron oxides, which coated its surface, this clay seems to disperse and migrate easier (De Coninck, oral communication).

Fragments of ferri-argillans can be observed locally, reintegrated in the S-matrix, probably under the action of mechanical stress. On the other hand, in soils developed on old loesslehms or on loesses of the basis of the recent cycle, the frost action has caused the redistribution of numerous fragments of plasma concentrations in the bulk of the S-matrix. In the B horizons, the ferruginous segregations show variable degrees of individualization, some impregnating the matrix, others forming sesquans on the walls of the voids. The *glaebules* are largely represented by nodules and ferrigunous concretions.

The boundaries of the nodules in the A_2 and A and Bg are generally rather distinct. In the degradation horizon they locally fossilize the characteristics of the Bt horizon of the preceding stage (Fig. 7). Typical concretions with concentric organization can be noted in many places.

Striotubules are not uncommon at the contact between the B_2tg and B_3gx horizons, their clay and fine silt content would correspond to a filling up stage comparable with the processes of formation of compound cutans, discussed earlier. Here also, a few ferruginous crystallites are present in the lower part of the solum.

PALEOSOLS

The paleosols of the loess formations of Northern France are composed either of levels buried underneath more recent deposits, or of soils formerly buried, then brought to the surface under the influence of erosion agents. Therefore, these last soils show the surimposed imprints of sometimes very different pedogeneses.

The *skeleton*, always rather homogeneous and dominated by the 2-20 and 20-50 microns fractions can have untergone some important redistributions under the influence of cold climates: phenomena of cryoturbation or involution.

The *plasma*, often distinctly argillo-ferruginous, is generaly very heterogeneous and presents a mostly very strong degree of orientation. Many ferruginous segregations, which are sometimes very red, impregnate the brown to reddish brown matrix. Generally, the *plasma separations* are very numerous and have essentially skelsepic, masepic, bimasepic, even vosepic nature (Fig. 12). Therefore, the *plasmic fabric* is generally complex: (vo) — bima-ma-skelsepic.

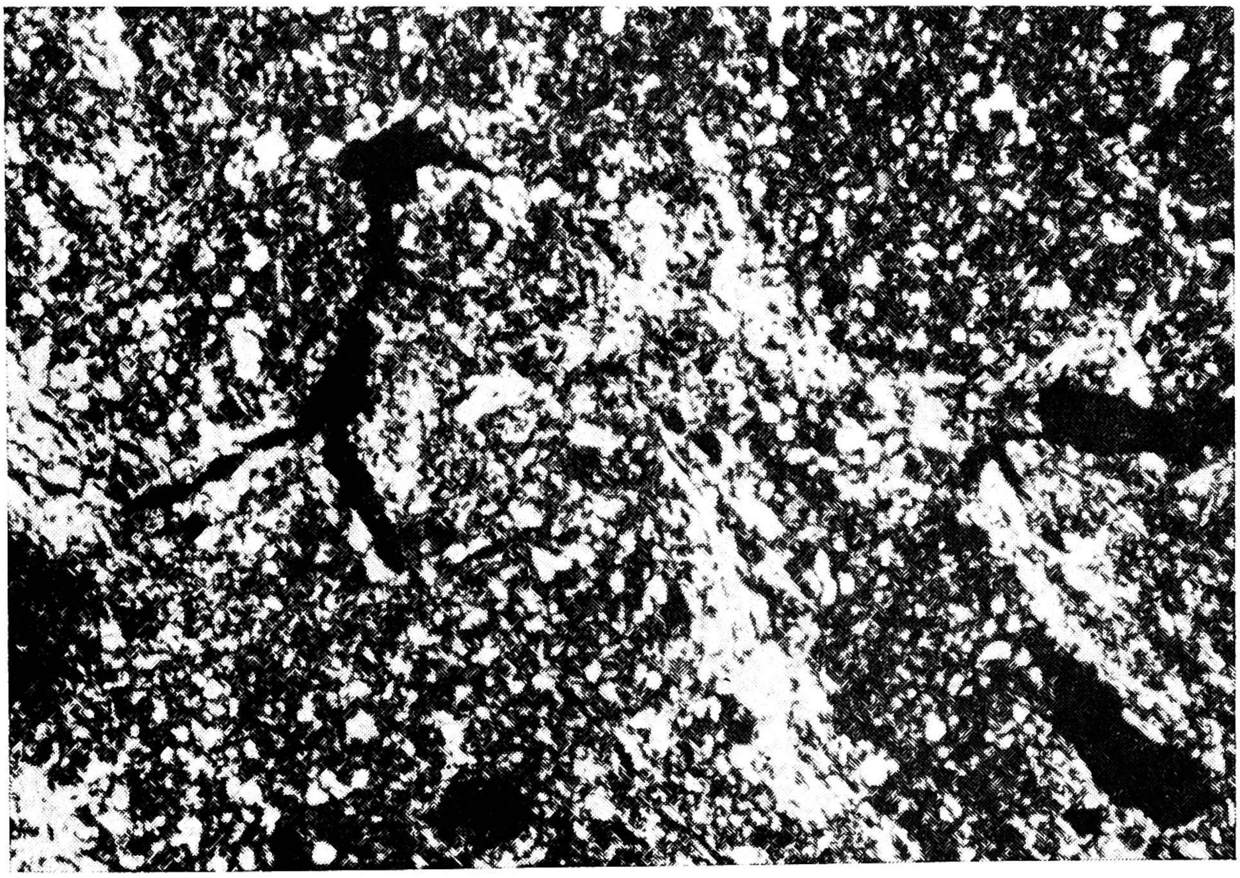

Fig. 12. II B_3b horizon — Paleosol on old loesslehm — Thierache. Note the numerous plasma separations, some of which masepic. Polarized light. ×70.

The basic structure of these materials, rather rich in clay and frequently having nearly the some amount of plasma as of skeleton, shows a relative distribution, or *elementary fabric* with a distinct prophyroskelic dominance. The *voids* are of variable nature and shape; for the most argillaceous profiles, many joint-planes and skew-planes seem rather characteristic. These facies are probably in relation with a certain internal dynamic of the horizons.

The *pedological features* can take very diversified aspects according to the nature and intensity of the processes involved, and considering the influence of a very recent or present-day pedogenesis if the paleosol is at the surface. One can observe cutans, in association or indepent, comparable with those described in the evolution sequence, and also very thick cutans up to several millimeters. Some are very pale yellow, others are more ferruginized, others finally almost entirely rubified (Fig. 13). The most pale ones could be interpreted locally as the result of an old degra-

Synoptic description table of different stages of evolution

Unities of description	Evolution stage					
	initial material calcareous loess	"sol brun"	"sol brun lessivé"	"sol lessivé"	"sol lessivé en voie de dégradation"	"sol lessivé glossique hydromorphe"
S-MATRIX						
Skeleton	Dominated by the 2-50 μ fraction, with grains of coarse sand-quartz, feldspars, zircon, tourmaline, epidote, hornblende, glauconite, biotite, ...					
	Homogeneous	Homogeneous	Homogeneous	Rather heterogeneous-	Rather homogeneous, particular distribution of fine silt	Rather homogeneous, redistributed fine silt
Plasma	Homogeneous — Argillaceous	Less homogeneous, more oriented — Argillaceous	Slightly homogeneous — Argillaceous to argillo-ferruginous	Rather heterogeneous — Argillo-ferruginous. Well oriented	Rather heterogeneous— Argillo-ferruginous — Ferruginous impregnations	Very heterogeneous — Argillo-ferruginous. Numeral deposits of iron oxides
Plasma separations	A few separations on the skeleton, or independent in the bulk of the matrix	As isolated patches and on the skeleton	Typically on the skeleton and as isolated patches	Numerous on the skeleton and in spots in the bulk of the matrix. Well oriented	On the skeleton, isolated and in bands	On the skeleton, in bands, isolated, subcutanic.
Plasmic fabrics		skel-insepic	in-skelsepic	in-skelsepic	ma-in-seklsepic	in-ma-skelsepic, locally skel-masepic
Basic structure	$SK \gg Pl \gg V$	$SK \gg Pl > V$	$SK > Pl > V$	$SK > Pl > V$	$SK > Pl \gg V$	$Sk > Pl \gg V$
Elementary fabric	Intertextic	Intertextic	Intertextic to agglomeroplasmic, locally porphyroskelic	Agglomeroplasmic to porphyroskelic — Denser fabric	Porphyroskelic — Dense in the B_3	Porphyroskelic in B, granular to intertextic in A_2

Voids	Packing voids; orthovughs, vésicles	Vughs and channels with smoothed walls	More vughs and channels	Narrower vughs and channels in B	Rather numerous vughs and channels	Packing voids and orthovughs in A_2; vughs, channels, chambers in B; joint planes in B_3
	High microporosity — Low macroporosity	Higher macroporosity	High macroporosity	Decrease of the porosity in B	Decrease of the porosity in B_3	Low porosity in B_3
Pedological features						
Orthic. *Separations* (see plasma)						
Concentrations						
Cutans	Diffusion calcitans	Few argillans in mesopores	Yellow strongly oriented ferri-argillans	Yellow and reddish — yellow ferri-argillans— Diffusion cutans — Fragmented cutans	Numerous ferri-argillans, some very ferruginous — Simple or compound — Skeletans and mangans — Fragments of cutans	Simple or compound ferri-argillans — Mangans — Sesquans — Secondary pale yellow argillans
Glaebules			Few isotubules	Ferruginous nodules in B_2t/B_3	Ferruginous nodules, glaebular nodules-Isotubules and striotubules	Nodules and concretions in A_2 — Segregations in B — Striotubules — Some papules
Diverse				Few crystallites	Few crystallites	Crystallites
Inherited-Pedorelicts						Few fragments of redistributed concentrations

dation. In these ancient soils, on the other hand, many ferruginous segregations can be observed. They are generally much denser than those existing in recent soils, with a brown, reddish brown or intense red color, the last ones being moderately birefringent.

Fig. 13. II B_{22}tb horizon — Paleosol on old loesslehm — Haute-Brie. Compound cutans with strong individualization of the iron oxides. Partial rubefaction. Plain light. ×70.

Many characteristic relicts are present: materials belonging to an old development and redistributed within the S-matrix, either by reworking in place due to frost action, or by more important displacements under the influence of solifluction phenomena. The frost action during cold periods is probably one of the most important agents of internal reworking observed. Indeed, many fragments of cutans are scattered around in the S-matrix. The degree of fragmentation is variable, from a few microns to several millimeters. In the same zone, a remarkable homogeneization of the fragments with the matrix can be frequently noted.

Very indurated ferruginous pisolithes, either regularly scattered, or concentrated in more important layers, are very characteristic from a micromorphological viewpoint. Originated out of an old pedogenesis and redistributed in the lanscape, their internal fabric is frequently very different from that of the surrounding material, their boundaries are very abrupt, and they are often surrounded by an envelop of very fine silt.

The micromorphological study of the buried paleosols and the determination of their own characteristics may allow, in rather numerous cases, to dissociate in uncovered soils the part related to old developments from the one related to recent genesis.

Finally, we can note that in relation with field observations, the rubefaction of some paleosols may affect either only the plasma concentrations enveloping the structural aggregates, or the bulk of the material.

DISCUSSION AND CONCLUSIONS

The study of thin sections of soils developed on silty materials, and particularly on loess allows to complete in a useful way the field observations and the analytical data.

Depending on the degree of the progressing evolution of the soils, the following items can established as being essential.

— The development of *plasma separations*. Firstly, separations appear around the skeleton grains and in the form of isolated patches within the bulk of the plasma. They individualize progressively, while their number increases. Then, more important separations are dissociated, elongated in more or less parallel bands.

— The modification of the *fabric* within the B horizons, coupled with a progressing compaction of the subsoil. The elementary fabric ranges from intertextic to agglomeroplasmic, then finally to porphyroskelic. This phenomenon seems in close relationship with the progressive increase of the bulk density going from 1,5 to almost 2 in the most compact horizons. As soon as the porphyroskelic fabric is reached, alternations of dessication and moistening would cause mechanical stress, which would be expressed by the appearance of masepic plasmic fabrics.

— The progressive development of *plasmic concentrations*. At first, the clay coatings are thin and are deposited, in a first stage, on the walls of the voids; after that, they gradually invade the surface of the structural peds, and thicken progressively, filling up the voids step by step. The rather thick, pale coatings of secondary illuviation show an advanced stage of evolution. Owing to a mechanical or faunal action, these cutans can be fragmented locally and integrated in the matrix.

— The appearance of *hydromorphic characters* in relationship with the evolution of the iron oxides. This element migrates and is deposited as individualized oxide; as soon as a temporary waterlogging occurs. At first, segregations with low content in oxides are formed, diffusing through the matrix and consolidating it. The glaebular halos are progressively replaced by more distinct nodules and concretions. Ferruginous coatings on the walls of the voids appear only in the most strongly developed soils. Diffuse segregations locally fossilize the invaded matrix.

According to Kubiëna's notions, it seems that we would have materials of "Braunerde" type, with presence of "Braunlehm — Teilplasma", and

"Braunlehm" in the form of "cutanic" concentrations. The old loess lehms would be characterized by an abundance of "Braunlehm-Teilplasma" that is partially residual, which proves that the conditions of formation were clearly different from those existing at the present day in the studied region.

On the basis of these micromorphological studies and of some morphological, geomorphological and analytical data, a number of hypotheses can be presented:

The "sols bruns lessivés" with simple coatings of yellow color would have developed essentially after the atlantic period, while the more reddish coatings, with local individualization or decomplexation of the iron oxides would be characteristic for a pedogenesis dating from that period.

The very complex coatings, with deposition of fine silt, related with a more or less strong degradation of the upper part of the soil, when present in the whole depth of the B horizons, would be characteristic of old soils, dating from the basis of the recent cycle.

In the soils developed on loess and dominated by the skeleton fraction, the micromorphological characteristics: — distribution of the plasma, — plasma separations and concentrations, — differentiation of the principal pedological features, take a very great importance in the study of the evolution processes.

The differentiation and the proper dynamic of the different pedogenetic horizons can be evidenced in this way.

The micromorphological data reflect very well the influence of the fundamental processes of the pedogenesis at the different stages of evolution:

— primary alteration phase and plasma reorganization.

— illuviation phase with appearance of important plasma concentrations.

— secondary phases of degradation, illuviation and hydromorphism.

On the other hand, the micromorphological characterization of the paleosols may allow to dissociate the influence of different types of pedogenetic conditions on polygenetic soils.

In this way the micromorphological data take a considerable importance in the definition of the different types of soils developed on loess materials.

SUMMARY

The most important soils developed in the loess formations of Northern France have been studied with the held of thin sections. They characterize the different stages of a theoretical sequence of pedogenetic evolution, or form paleosols.

The parent material starts its evolution with a progressive decarbonatation, the lime accumulating locally in the shape of calcitans. In the stage

of "sol brun", a progressively stronger orientation of the plasma occurs, with individualization of many plasma separations. The "sols bruns lessivés" and "sols lessivés" are characterized by the presence of plasma concentrations of steadily growing size: argillans and ferri-argillans, as well as by the change from an intertextic to an agglomeraplasmic and than porphyroskelic elementary fabric.

In the more developed soils, areas of micro-degradation appear in the first place, as well as many concentrations of iron oxides. The appearance of masepic plasmic is observed. After that, the degradation generalizes, with appearance of compound cutans enriched in fine silt, numerous ferruginous glaebules, ans characteristics of secondary illuviation.

The observed paleosols are generally characterized by very pronounced phenomena of migration, accompanied with more or less intense ferruginization and considerable reworking due to frost action. The data brought together by these observations express rather well the influence of the fundamental processes of the pedogenesis on loess at the different evolution stages, and allow a rather accurate characterization of the paleosols.

REFERENCES

1. Altemüller H.-J., 1957. Bodentypen aus Löss im Raume Braunschweig und ihre Veränderungen unter dem Einfluss der Ackerbaues. Thèse de Doctorat. Institut für Bodenkunde, Université de Bonn, 250 p.
2. Altemüller H.-J., 1962. Verbesserungen der Einbettungs- und Schleiftechnik bei der Herstellung von Bodendünnschliffen mit Vestopal. Z. Pflanzern., Düng. Bodenk. 99, 164-177.
3. Brewer R., 1964. Fabric and mineral analysis of soils. John Wiley and Sons, Inc. New York-London-Sidney.
4. Cline M., 1949. Profile studies of normal soils of New York. I. Soil Science 68 (3).
5. de Coninck F., Laruelle J., 1964. Soil development in sandy materials of the Belgian Campine. In: Soil Micromorphology, 169-188, Elsevier Publ. Comp. Amsterdam.
6. Dudal R., 1953. Etude morphologique et génétique d'une séquence de sols sur limon loessique. Agricultura I. 2è sér., 2, 119-163, Louvain.
7. Fedoroff N., 1967. Un exemple d'application de la micromorphologie à l'étude des paléosols. Bull. A.F.E.Q. 12, 1967-3, 193-209.
8. Jamagne M., 1966. Contribution à la connaissance de quelques sols sur limon loessique du Nord de la France — Etude micromorphologique. Mém. Lic. Université de Gand, 149 p., Gand.
9. Jamagne M., 1967. Données sur l'évolution pédogénétique des formations limoneuses en Europe occidentale. Colloque sur les limons du Bassin de Paris. Mém. Soc. Géol. de France.
10. Jamagne M., Fedoroff N., 1967. Comparaison micromorphologique de quelques sols sur limons du bassin parisien — Colloque sur les limons du Bassin de Paris. Mém. Soc. Géol. de France.
11. Kubiëna W. L., 1938. Micropedology. Collegiate Press, Ames, Iowa.

12. Kubiëna W. L., 1953. Soils of Europe. Thomas Murby and Comp. London.
13. Kubiëna W. L., 1964. Zur Mikromorphologie und Mikrogenese der Löszböden Neuseelands. In: Soil Micromorphology, 219-235, Elsevier Pub. Comp. Amsterdam.
14. Laruelle J., 1958. Micromorphologie des sols de la Belgique. Pédologie VIII, pp. 79-102, Gand.
15. Laruelle J., 1965. Notes on Soil Micromorphology. International Training Center for Post-Graduate Soil Scientists. University of Ghent.
16. Lieberoth I., 1963. Lössendimentation und Bodenbildung während des Pleistozäns in Sachsen. Géologie 12 (2) p. 149-187.
17. Rode A. A., 1965. Podzolisation and lessivage. Pochvedenie 1964. Trad: Soviet Soil Science, avr. 1965, p. 660-671.