PEDOLOGIE, XXXIX-2, p. 119-151, 10 tables, 5 figs., Ghent, 1989

PLANOSOLS IN THE "CHAMPAGNE HUMIDE" REGION, FRANCE A MULTI-APPROACH STUDY

D. BAIZE

Abstract

This article is devoted to acid soils with strong differentiation that have developed in sedimentary clay material of the early Cretaceous period (Champagne Humide, France).

Macro and micromorphological, granulometric, physico-chemical and mineralogical studies were conducted on seven profiles selected from an initial 60 pits. Also, the soil water regime was investigated in situ over a 5-year period by simple procedures using piezometers, tensiometers and neutron measuring devices; 200 to 420 mm of rainfall are removed annually by lateral flow as a temporary shallow water-table.

Four isoquartz balances were established, indicating that these soils became differentiated as a result of the lateral translocation of clay minerals from the upper horizons without significant accumulation in the deeper layers. Initial homogeneity of the parent material was determined by various methods, so that these soils can be defined as "pedomorphic planosols" whose formation is not related to a particular climate, but to two combined site factors : a slowly permeable clay parent material and a subhorizontal topography. Unlike sandy or silty materials, the clay materials studied here showed an essentially lateral natural drainage.

Key-words

Planosols, pedogenesis, clay materials, France.

D. Baize - Service d'Etude des Sols et de la Carte Pédologique de France, INRA - Départ. Science du Sol, Centre de Recherches d'Orléans, Ardon, F-45160 Olivet, France.

1. INTRODUCTION

1.1. Purpose and approach

This paper presents the main approaches and major results of an extensive overall study of the highly acid planosols of Champagne Humide (southern Paris Basin) which have developed from cretaceous clay deposits (Baize, 1983). Details on the methods employed and on general results are given in the three following articles : study of particle size distribution (Baize, 1980a), isoquartz balances (Baize, 1980b) or soil water regime (Baize, 1984).

The research was conducted by following a "multi-approach" procedure. First, the greatest possible number of independant methods have been used. In preference, the more comprehensive methods (such as soil survey) and those for investigating the soil mantle in situ have been employed. Each independant approach yielded basic data. After critical examination, the latter served to elaborate partial syntheses. The relevant combination of these syntheses (i.e. taking into account any apparent contradiction between existing phenomena and results of earlier processes) led to reliable final conclusions.

Table 1 shows in part the approaches followed and the methods and material used. The various study methods have been applied to a relatively large number of selected representative profiles. A sizeable amount of data has therefore been collected. It is also evident to which point these methods differ in terms of site (field or laboratory) and scale of observations (from micrometre to kilometre). For such an article, it was also necessary to condense the obtained results to a great extent. This is why each chapter contains only an indication of these methods used and an outline of the major results and partial conclusions.

1.2. Planosols - Previous works

The name planosol was introduced in the 1938 USDA Soil Classification. This designation is now widespread, especially after its use at the highest taxonomic level in the legend of the FAO-UNESCO Soil Map of the World (1974).

Dudal (1973) summarized all the studies carried out in the world until 1971 concerning planosols or related soils. Since that time, several surveys can be mentioned. Most of them have taken place in Africa or in South America, a few in Europe (Carvalho Cardoso and Teixeira Bessa, 1973; Conea et al., 1973; Trashliev et al., 1975; Feijtel et al., 1988).

Morras (1979), after a book-review, states that the only consistent feature of all planosols appears to be their seasonal waterlogging; this may be related to climatic conditions, topographic posi-

Table 1.
The "multi-approach" proceeding applied to planosols of Champagne Humide : questions, methods and material.

QUESTION TO BE SOLVED	METHODS USED	STUDY MATERIAL
1. What is the morphology of these soils, their constituents, their wawater regime?	. medium-scale mapping . soil descriptions; particle-size and chemical analysis . X-ray diffraction	. about 40,000 ha . 60 pits both described and sampled . 7 profiles
2. Are there pedomorphic or lithomorphic planosols?	. arguments relating to mapping . particle-size distribution study . test area study . heavy minerals study	. >1500 auger borings . 282 sampled horizons . 12 ha, 8 profiles . 2 profiles
3. Are there evidences of illuviation?	. microscopic examination of thin sections	. 21 horizons from 5 profiles
4. What are the factors and conditions of the soil water regime?	IN SITU : . piezometer and tensiometer readings; neutron scattering	. 2 sites for five years
	. bulk density and weight soil moisture measurings	. samples from the two sites
	LABORATORY MEASUREMENTS ; . solid density . relationship moisture/pF	
5. Do material losses from the E horizons accumulate within the S horizons, in invisible form?	. isoquartz balances	. 4 profiles
6. What is the composition of waters in the subsurface runoff?	. chemical analysis of waters and suspended particles	. 11 water samplings from one site (brook)

tion or slow permeability of the parent material. Thus, the morphology of planosols appears to result from convergence, different soil-forming processes and mechanisms occurring according the case.

In France, the term planosol was first applied by Favrot and Legros in 1972. In this particular case, these were "lithomorphic" planosols in which a heterogeneous double layer material existed, previous to soil formation. At the same time, Begon and Jamagne (1973) described planosols and planosolic soils corresponding to the ultimate stage of "sols lessivés dégradés", in which the slowly permeable horizons result from considerable clay illuviation. Planosols formed directly from homogeneous clay material have been reported, for the first time, in the Paris Basin (Baize, 1976; Begon et al., 1976; Isambert, 1984).

2. THE ENVIRONMENT : THE "CHAMPAGNE HUMIDE" REGION

The "Champagne Humide" is located in the southeastern Paris Basin, France. It is clearly differentiated from the wine growing Champagne because it is strictly confined to the outcropping of sedimentary strata of the early Cretaceous period. The present study is only concerned with a part of this region (areas near Chaource, St. Florentin and Auxerre).

The stratigraphic sequence (Barremian to Cenomanian) displays abrupt vertical and lateral lithological variations, but clay deposits remain dominant. Many parent materials result directly from clay sedimentation. In addition, several materials that did not initially consist of clays were converted into clay materials due to moderate weathering processes; for instance, the "green sands" of the Albian period were transformed by disintegration of glauconitic pseudo-sands and the Cenomanian marls by simple decarbonatation.

Several lithological facies can be distinguished among parent materials : marls, glauconitic or non-glauconitic calcareous clays, non calcareous glauconitic clays and continental variegated clays. From a granulometric point of view, four categories can be recognized in the field : heavy clays, clays with a silty skeleton, clays with a fine sand-sized skeleton and sandy clays. Thus, there is a great diversity of materials exposed to pedogenetic processes, and this diversity is increased by the variety in mineralogical compositions (see below).

The "Champagne Humide" is a gently plain at low altitudes (120-130 m). Most soils are temporarily waterlogged and show strong acidity. For this reason, the vegetation consists chiefly of forest stands and permanent pastures.

Local climate is characterized by moderate annual rainfall (630-770 mm), well distributed throughout the year. Mean annual temperature is close to 10.5° C. This predominantly oceanic climate, affected by western and southwestern winds, has rather mild winters and temperate summers. Temperature in Auxerre averages 2.5° C in January (coldest month) and 18.6° C in July (warmest month).

3. SOILS

The initial basic knowledge was derived from medium-scale mapping (Baize, 1976). Material is described in table 1.

3.1. Morphology of the profiles

The studied soils always show horizons poor in clay (silty of sandy) that overlie clay or sandy-clay horizons. In addition, they exhibit a strong textural differentiation and an abrupt nearly-horizontal transition between the two types of horizons.

During field mapping, the upper clayey horizons had been presumed to be structural horizons rather than the result of illuviation. This hypothesis was to be tested. Thus, the sequence of horizons can be designated as : A, E, Eg, S, SC, C (new French nomenclature, Référentiel Pédologique, 1988; E = previously A_2 and S = previously (B)).

Some variations exist nevertheless, depending on type of humus, podzolic evolution in the A horizon, thickness of coarse-textured E horizons (widest range of 20 to 90 cm; usual range of 35 to 45 cm), waterlogging intensity and hydromorphic properties of the Eg horizons, aspect and importance of "morphological degradation" phenomena (Jamagne, 1978; Pedro et al. 1978) at the textural contact, and presence or absence of a clay "bulge" (highest clay content in the S horizon);

Hydromorphic features of the Eg horizons vary with each profile. In dry periods (June through November), the following features can be observed : streaks combining light colours and rust-brown colours, bleached spots or mottling and ferro-manganic nodules of variable size. In humid periods (January through April), waterlogging occurs due to temporary subsurface watertables, giving the coarse-textured upper horizons a nearly sludge state and ephemeral greyish or greenish colours (gleying is weakly expressed due to the lack of iron).

"Morphological degradation" at the top of the S horizons is evidenced by both discoloration and local alteration of the texture. Volumes of soil material of varying size become differentiated at the top of the clay horizons. These volumes contain much less clay (hence their greater porosity and looser structure) and much less iron (hence their whitish colours) than the remainder of the S horizons. Morphological degradation only occurs in one solum out of two : it is not a general phenomenon. When clearly visible, such degradation fluctuates between two extremes. At last, there are thin skeletans coating the ped surfaces over the upper 5 to 8 cm of the S horizon (designated as Sd sub-horizon). As a maximum, degradation affects 20 to 60 % of the volume of the Sd horizon, which may be from 10 to 30 cm thick. These degraded volumes are, however, preferentially oriented : they extend more deeply along the vertical faces of the prismatic peds. This type of glossic-like degradation is encountered mainly in the soils richest in silt-sized skeletal grains. This last facies is very similar to that observed in the "sols lessivés dégradés" (CPCS, 1967) on medium-textured materials.

The S horizons are characterized by : heavy clay or sandy-clay textures; cubic and/or prismatic structures, which are finer in the upper part of the horizon; presence of many ochre or rust-coloured spots that are clearly visible on the beige, grey of green matrix; moderate and constant humidity contrasting with the winter waterlogging of the E horizons. Other features can also be observed in some exceptional profiles : slanted slickensides, few thin reddish or brownish clay coatings, and grey coatings.

The C horizons consist of slightly weathered cretaceous sediments that have been little affected by soil-forming processes. There are four criteria of field identification. If the parent-rock contains $CaCO_3$, the C horizons are not fully decarbonated and show fequently a calcic Cca sub-horizon in their upper part. The passage from S to C horizons is sometimes gradual and is characterized by loss of structure. The C horizons have only a coarse and weakly developed prismatic structure. Whatever the season, these deep horizons appear to be dry. Lastly, the clayey geological sediments become clearly recognizable on the base of their colour (blackish, brownish or slate-coloured) and of their "soapy" of "rubbery" touch. It is only at this depth that the glauconitic green sands maintain their sandy texture, the glauconite grains being intact and well individualized.

3.2. Mineralogical data of the clay fraction

The parent rock shows a diverse mineralogical composition. Within each profile, few qualitative differences are noted between E, S and C horizons. A more thorough study (separating clay fraction into granulometric sub-fractions) points to three main statements :

- the E horizons exhibit a relative accumulation of the coarsest clays (0,2 - 2 µm) and of quartz, kaolinite and titaniferous minerals;

- from the bottom to the top of the glauconiferous profiles, the finest glauconites show a geochemical evolution : progressive opening of the layers with acquisition of swelling properties ("transformation smectites", Robert and Barshad, 1973) and along with a loss of potassium, magnesium and iron;
- concerning the Flogny profile, vermiculitization of the illites has been established, a significant loss of potassium affecting the finest particles. The genesis of "transformation smectites" seems to have been inhibited in the Eg horizon by the fixation of probably aluminous ions.

The clay minerals currently found in planosols of the Champagne Humide are mainly inherited from cretaceous sedimentation. Only those clay minerals that result from the transformation or neoformation are of pedogenetic significance, but it is difficult to point them out as they remain a minority "drowned" in the original heritage.

Planosolization is not related to one type of phyllite mineral in particular, although it affects 2:1 minerals much more than kaolinite. The 2:1 minerals seem nevertheless to be more weatherable and/or smaller and/or more mobile.

3.3. Major analytical data

The forested planosols of the Champagne Humide show an acid or strongly acid pH in water. All A and E horizons as well as most deeper horizons are below pH 5.5. The highest acidity level is found in the "podzol-like" humus-rich A horizons (pH in water < 4.0). Base saturation values remain lower than 65 % in the A and E horizons (usually < 30 %), and range from 8 to 100 % in the S horizons, depending on the parent material (table 2).

CEC values obtained for the clay fractions show a systematic decrease in the E horizons. This might be due to the interlayer position of aluminous compounds blocking a number of exchange sites.

Ratios of total iron to clay content suggest a relative accumulation of iron in the Eg horizons. Furthermore, the highest total iron levels are usually encountered in Sd or S horizons. Consequently, there is some absolute accumulation of iron in the uppermost S_1 horizon.

Ratios of free to total iron clearly indicate that weathering increases from the bottom to the top of the profiles. The same applies to ratios of Al extracted with Tamm's reagent to total Al levels. The horizons closest to the abrupt textural change (Eg, Sd or S_1) contain the highest amount of exchangeable aluminium. Finally, Al^{3+} plays a dominant part in the E horizons where its level exceeds that of basic cations.

A major gradient therefore exists between (i) slightly acid (sometimes calcareous), saturated or weakly desaturated, slightly weathered C horizons devoid of free aluminium; (ii) clayey, acid, more or less desaturated, increasingly weathered S horizons containing considerable amounts of exchangeable and "free" aluminium; (iii) coarse-textured, highly acid (organic protons and Al^{3+}), strongly desaturated and highly weathered A and E horizons.

Table 2.
Some physico-chemical data of planosols in the Champagne Humide. (Note : nothing is mentioned concerning the C horizons because of their large variability).

Horizons	Clay content (%)	CEC of the horizon* (me/100g)	Base saturation (%) (forest)	CEC of the clay fraction (me/100g)
A, E & Eg	5 to 26 mostly 10 to 18	1 to 8	10 to 65 mostly 10 to 30	5 to 39 mean = 14
Sd, S & SC	32 to 60	8 to 24	8 to 100	16 to 56 mean = 36

* at pH 7, saturation with NH_4Ac

3.4. Additional field data

During soil survey and profile pit examination, several major facts have been registered. First, an everyday field observation from December to May showed temporary shallow watertables circulating above slowly permeable clay layers. Not only is waterlogging visible in any pit or hole, but also water circulation does (rather fast in spite of the slight slopes). For instance, the deeply rutted forest tracks become small active brooks.

Secondly, during summertime, the clayey S horizons, although located at small depth, are never dry and show no obvious shrinkage. In fact, these horizons are sheltered from evaporation because they are under tree cover, thick litter and silty or sandy surface layers.

3.5. Conclusions

It is obvious that the above-described soils correspond exactly to the concept of planosol (Dudal, 1973; FAO-UNESCO, 1974) because of their morphology and of their peculiar type of temporary subsurface waterlogging.

4. LITHOMORPHIC OR PEDOMORPHIC PLANOSOLS?

A prerequisite to a pedogenetic interpretation was to find out whether the strong textural differentiation was due to some initial abrupt lithological discontinuity (cretaceous sedimentation or recent deposit), or to a particular soil-forming process in situ. In the first case, it would be possible to speak of "lithomorphic" planosols (Favrot and Legros, 1972); in the second case, these soils could be referred to as "pedomorphic" planosols. To elucidate this point, arguments relating to mapping or particle size distribution have been used.

4.1. Arguments relating to mapping

A first qualitative argument was provided by medium-scale mapping. During the survey, the textural variations of the E horizons were shown to be well correlated with the lithological facies of the geological layers appearing in successive outcrops (fig. 1).

In fact, field surveys on E horizons show rapid textural variations, on a decametric scale. The observed textures range continuously from pure medium sand to sandy silt loam. This excludes the hy-

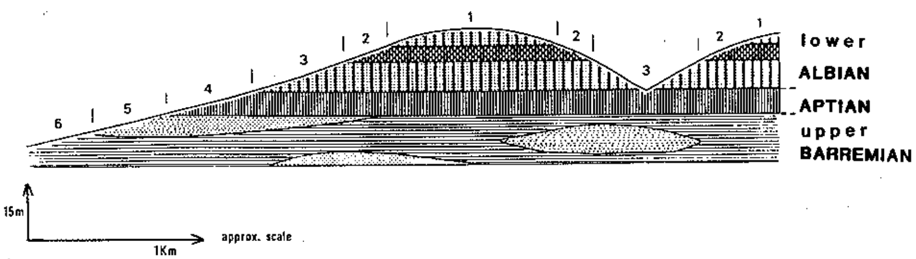


Fig. 1.
Textural variations of the Eg horizons are well correlated with the lithological facies appearing in successive outcrops (schematic presentation) :

- 1 and 3 = medium sand over glauconitic "green sands"
- 2 = silty sand over grey clays with a fine-silty skeleton;
- 4 = sandy silt loam over slightly calcareous yellow clays;
- 5 = fine sand over variegated sandy clays;
- 6 = sandy silt over variegated clays with a fine-silty skeleton.

pothesis of a shallow deposit of remote origin. Furthermore, the details of these variations can only be understood in relation to the detailed facies variations of the geological sequence. For example, sandy-textured surface horizons (n° 1 and 3, fig. 1) always overlay deep green sandy-clay horizons, whereas silty loamy textures overlay the aptian yellow clays (n° 4).

Rapid variations within the cretaceous sedimentation are the only cause of granulometric variability in surface horizons. This is a major argument in favour of the rather strict autochtony of the A and E horizons. Consequently, the latter seem to have had the same parent material as the deeper clay horizons.

4.2. Study of "granulometric skeletons"

This study (Baize, 1980a) was conducted on a large number of samples (282 horizons), with the interest exclusively been oriented towards the sand and silt fractions. The clay fraction was excluded by calculation because the < 2 µm fractions are more mobile (vertical or lateral translocation), more sensitive to geochemical degradation, and because they may occur within the horizons as a result of the in situ weathering of coarser particles (disintegration of glauconitic pseudo-sands or micro-division of the fine silt-sized illites). Six granulometric fractions could be used (table 3). These values, expressed as a percentage of their sum, served as a basis for comparing horizons of the same profile ("vertical" comparisons, fig. 2) or horizons of different sites ("horizontal" comparisons).

Table 3.
Calculation of the "écart brut" (Eb) between two horizons, i.e. the sum of differences of the six granulometric fractions (absolute values in per cent). Example : Héry profile.

Horizon	LF (2-20 µm)	LG (20-50 µm)	SF1 (50-100 µm)	SF2 (100-200 µm)	SG1 (200-500 µm)	SG2 (500-2000 µm)	
Eg	14.1	13.0	37.1	28.1	6.8	0.9	
Sd	17.5	12.3	42.0	24.1	3.4	0.8	
=/=	3.4	0.7	4.9	4.0	3.4	0.1	Eb=16.5

As a first qualitative approach, diagrams were constructed, For the purpose of simplification, they only compared the Eg and Sd or S_1 horizons of each profile (two samples vertically close, but

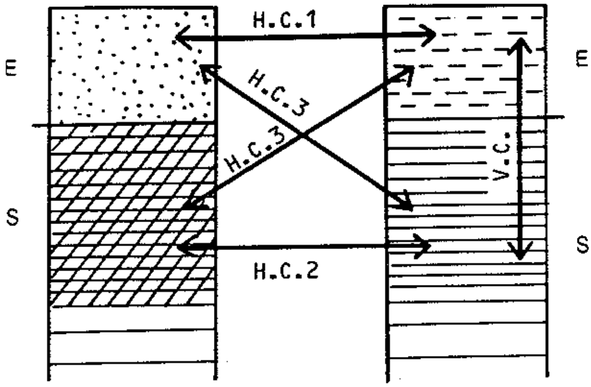


Fig. 2.
Comparisons between "granulometric skeletons" (V.C. = vertical comparisons; H.C. 1, 2, 3 = horizontal comparisons).

placed on either side of the abrupt textural change). Among the 55 studied pairs, similar material was found in 53 cases besides 1 doubtful case, and 1 certain case of heterogeneity.

Afterwards, a quantitative index termed "écart brut" (Eb) was calculated (table 3). Many treatments were applied to this index, but only one result will be mentioned, namely the distribution of the "écart brut" obtained by vertical comparison within the 55 profiles. Some forty sites showed Eb indices lower than 20. It was felt that this result indicated a good homogeneity in particle size distribution. For the other profiles, however, there are no clear answers due to the lack of references for this kind of index.

4.3. Study of a small test area

This study was made in three steps : mapping over 95 ha, sampling of 17 E horizons, and then sampling of 8 profiles located within a 12-ha polygon. In order to examine the 8 E and S pairs, the 120 "écarts bruts" that distinguish the "granulometric skeletons" of the 16 horizons have been calculated. The E and S horizons of a same profile generally showed rather low Eb indices, lower than those calculated between two horizons of two distinct profiles. This, however, is not an absolute rule : the two horizons most similar in terms of particle size distribution are derived from eluviated horizons of two remote sites. Then, the profiles were geographically relocated in relation to each other in order to compare spatial proximity with mathematical proximity. Of the 15 relations examined in this way, 14 show that the E and S horizons of the same profile are more similar than the E and S horizons in closely spaced profiles.

In conclusion, there is a variability from one site to another over very small distances but a relatively strong genetic link within each profile.

4.4. Heavy minerals

A study of the heavy minerals in four profiles pointed to the cretaceous nature of all E and S horizons. This fact, once again, excludes the hypothesis of an allochtonous deposit of remote origin.

4.5. Conclusion - New question

The cretaceous sedimentation appears to be quite heterogeneous with abrupt field variations, especially in particle size distribution. All qualitative and quantitative arguments converge to one and the same conclusion : the rapid and substantial changes from one site to the next contrast with the close similarities between horizons of a same profile located on either side of the abrupt textural change ("planic contact"). A number of technical and pedologic difficulties were encountered. A good initial uniformity in particle size distribution could however be demonstrated in over fifty profiles, hence in the majority of the soils considered. Differentiation of the surface horizons poor in clay is therefore not related to some original sedimentary discontinuity or recent deposit, but results from soil formation in situ. This had to be elucidated before pursuing any research on the evolution of this type of planosol. We are dealing with pedomorphic planosols.

The above considerations lead to a further question : does the strong textural differentiation result from relative clay accumulation in a S horizon, or does it result from absolute clay accumulation in a BT horizon due to argilluviation?

5. MICROMORPHOLOGY

Regarding the distribution of clay, observations of thin sections in five profiles revealed a nearly total lack of argillans and ferri-argillans (usually indicating clay illuviation) in the clayey S horizons. The few cutan-like features seem rather to be diffusion or stress cutans, but they are of little importance considering the textural differentiation of the soils. The very few typical illuviation cutans were found in the Eg and Sd horizons rather in the clay-rich S horizons.

In addition, thin section examination allowed recognition, at the microscopic level, of some features already observed in the field, e.g. conversion of glauconite grains into yellow-greenish poorly limpid plasma, stress cutans and vo-sepic plasmic fabric along fissures corresponding to slickensides, iron impregnation and nodulation representing the rust-coloured spots typical of waterlogging or weathering, and "morphological degradation" at the top of the S horizons associated with the disappearance of the clayey plasma.

Consequently, the planosols of Champagne Humide do not appear to have undergone significant clay illuviation. Additional evidences must, however, be provided in support of this statement (see chapter 7).

6. WATER REGIME

Two forested sites have been selected in order to understand the water dynamics under the best possible natural conditions. Several independant in situ methods were used from May 1977 to January 1982, as well as laboratory tests (table 1). The results obtained on both the HERY and PONTIGNY sites were in good agreement, except for a few slight differences. For lack of room, only the main results will be presented here. Any reader interested by more detailed results can refer to Baize (1983; 1984).

Climatic water balances were calculated. They indicate a considerable soil water deficit in 1978 (July to November), a smaller one in 1979 (July to September), a slight shortage in September 1980 and 1981, and no deficit in 1977. Winter water surplusses were determined as being 178 mm, 306 mm, 217 mm, 282 mm and > 162 mm respectively for each winter period. In summer, natural drainage may have occurred in August 1977. In June 1981, a considerable water surplus is pointed out by calculation : 45 mm during the first 10-day period, 11 mm during the third.

The presence of water in short piezometers pointed to the existence of a subsurface watertable, hence to waterlogging of the coarse-textured E horizons. This shallow watertable appears every year in January, February and March. It was observed once in late December 1980, in May 1979, on 10 June and 10 August 1981, but was not detected in April nor during the other months. It could not be determined whether the watertable is continuously present in winter. Three long periods of watertable existence have nevertheless been identified : 20 days from 24 January to 14 February 1979; 63 days from 9 January to 14 March 1980 and 22 days in January 1981. The shallow watertable was present for less than 8 days in May 1979, March 1980 and December 1980.

The absence of a subsurface watertable may be as ephemeral as its presence, e.g. it could be observed on 27 December 1980 and 1 January 1981 but not on 30 December 1980.

81 neutron moisture measurements have been carried out between May 1977 and January 1982, i.e. an average of one every 21 days for nearly 5 years. To study variations in the course of time, the raw readings have been expressed in a standard form as a percentage of the total variation throughout the 81 measurements for each horizon (0 % = min. reading; 100 % = max. reading). In such a way, the horizons can exhibit four different states :

- dry (raw readings < 30 %);
- wet (raw readings > 65 %); : very close to field capacity;
- transitional : rewetting or drying;
- waterlogged (raw readings exceeding 80 %) : excess of water saturating all the voids, especially packing voids, channels and macropores.

There was a good correlation between these raw values and the presence of a subsurface watertable detected with the short piezometers.

Temporary waterlogging was only encountered at depths of 15, 25 and 35 cm in the two sites (A and E horizons). At these depths, the wet state corresponds to raw data ranging from 65 to 80 %, whereas the waterlogged state would be evidenced by higher percentages. None of the horizons occurring under the "planic contact" exhibits a waterlogged state which differs from the wet state.

After calibrating the raw data and converting them into volumetric moisture amounts, the soil moisture contents could be calculated for each measuring date (expressed in mm). Table 4 shows which is possibly a favourable period. Between 10 November 1978 and 24 January 1979, 142 mm of rainfall were recorded. It may be assumed that 103 mm of water rewetted the soil and that 39 mm were removed laterally (or evapotranspired) because they did not reach the C horizons. From 24 January 1979 till May 1979, 335 mm of rainfall were recorded. Of these 335 mm, 15 mm are assumed to have contributed to the soil rewetting, whereas 320 mm were laterally drained, evapotranspiration being probably negligible at this period, under deciduous trees.

Various field and laboratory measurements were used in establishing some kind of volumetric balance at extreme moisture contents (assuming that the total porosity remained constant). Such balances demonstrate :

- the large water capacity available in the E horizons (> 24 %);
- the small water capacity available in the S horizons (7 to 8 %) and their high content of strongly retained water;
- the very small volumes occupied by air during periods of maximum moisture content (1.5 and 4 % in the S horizons; 3 to 7 % in the E horizons). At these times, aeration is there-

Table 4.
Water balance during a rewetting period. Example : Héry profile (under deciduous forest).

Horizon	10.11.1978 (date of max. drying) water amount in mm.	24.01.1979 increasing of the water amount since 10.11.78	21.05.1979 increasing of the water amount since 24.01.79
0			
A + E	70 mm	+ 68 mm	+ 3 mm
40 cm			
S + SC	313 mm	+ 33 mm	+ 12 mm
130 cm			
C_1	107 mm	+ 2 mm	- 4 mm
170 cm			
$C_2 + C_3$	140 mm	- 2 mm	- 5 mm
230 cm			
RAINFALL :		142 mm	335 mm

$\boxed{142\ mm}$ ↗ 103 mm in the soil profile to a depth of about 170 cm	$\boxed{335\ mm}$ ↗ 15 mm in the soil profile to a depth of about 130 cm
$\boxed{142\ mm}$ ↘ 39 mm are laterally removed or evapo-transpired	$\boxed{335\ mm}$ ↘ 320 mm are laterally removed or evapo-transpired
SOIL WATER STORAGE RECONSTITUTION	LATERAL RUNOFF

fore very weak and the medium becomes reducing. In the driest periods, maximum air volume in the S horizons remains low (9 and 11 %).

The relationship between matric potential (pF) and moisture weight has been studied. Measurements were made on undisturbed and undried soil samples (collected in the field, using 1000 cm^3 cylinders), and peds of about 5 cm^3. Between pF 2.0 and 3.5, for the E horizons, moisture values obtained on cylinders disagree with those found on peds. It may be inferred that there is a rather coarse porosity (between 0.5 and 15 µm) corresponding probably to inter-aggregate and/or biological voids.

This discrepancy does not occur in the S horizons, because such voids do not exist at this pF range of common occurrence in the field. In the clayey horizons, only slight moisture variations are noted between pF 1.0 and 2.5. These horizons have few voids > 5µm; in other words, they are slowly permeable in all seasons.

In conclusion, all the horizons exhibit their lowest moisture level in autumn, as a result of evapotranspiration and prolonged water deficit. Early in winter, the rain rewets and saturates the E horizons, and rewets the upper part of the S horizons. If small cracks exist in autumn within these layers, they rapidly close due to rewetting and swelling. By late winter and early spring, the rain still saturates the E horizons, but penetrates no longer or very slowly, into the S horizons. Most of the water excesses are quickly carried away laterally by temporary subsurface watertables. The C horizons do not seem to be reached by precipitation water. The constant moisture content of these weakly structured horizons indicates a slow water transit.

Those detailed studies have only confirmed and quantified the facts which have been observed during mapping. The abrupt textural change is the main cause of the essentially lateral water movements. Conversely, this lateral soil water dynamics is involved in the existence of the planosolic morphology (see chapter 9.4.).

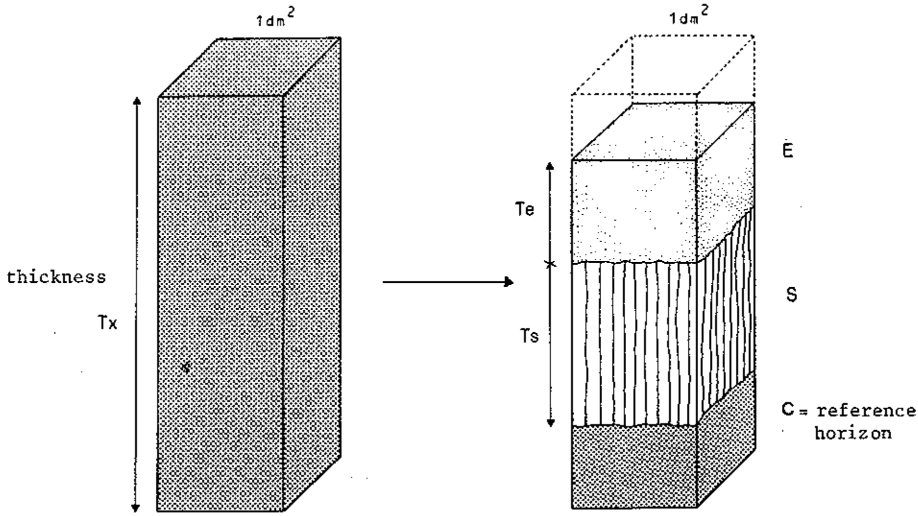
7. ISOQUARTZ BALANCES

7.1. The method : its choice and aims

The purpose of introducing these balances was to elucidate clearly whether the materials that had left the upper horizons had moved laterally of vertically, and whether the clay horizons result from absolute or from relative accumulation of clay (Baize; 1980b).

In an "open" system such as the soil mantle, the different compositions of the current horizons do not provide enough information on material gain of loss in each horizon. Such gains or losses can be determined either by hydrochemical and hydrological procedures for the investigation of current movements, or by chemical-mineralogical methods demonstrating absolute variations, in the course of time, of such or such constituent within a profile relative to an invariable constituent. One advantage of the isoquartz balance is that it relies on a constituent which is stable in temperate climates and abundant in the studied soils, hence subject to only slight estimation errors.

The material balances, which are established in relation to the presumably invariable quartz content, enabled us to evaluate absolute gains or losses of the major horizons relative to their original



IN THE BEGINNING	IN THE MEANTIME	TODAY
Hypothesis : Parent material was homogeneous and strictly identical with the current reference horizon in all respects.	*Hypothesis :* - Quartz has remained insoluble. - Neither erosion nor new deposit has occurred.	*Analytical knowledge of :* - thickness, - bulk density, - quartz content, - mineralogical and chemical amounts per cent. - particle size distribution.

FOR EACH HORIZON

↓

CURRENT WEIGHTS CALCULATION

ORIGINAL WEIGHTS CALCULATION

↓

LOSSES OR GAINS DETERMINATION

(Weights for a 1 dm^2 column, in absolute values)

Fig. 3.
Principles in establishing the isoquartz balances.

state. They also express the entire pedologic evolution throughout the period of time required for the profile's differentiation. Several processes distinct from those currently involved, may have occurred successively or conflictually. The global values obtained may represent the algebraic sum of different types of gains and losses. Thus, the chemical-mineralogical and hydro-chemical methods yield complementary rather then similar informations.

7.2. Principles and execution

The method used is derived directly from Marshall and Haseman (1942), who had chosen zircon as a basic invariable constituent. It allows the calculation of absolute weights of the various horizons of a pedon. Unlike the usual isoquartz expressions, this method takes into account the relative thicknesses of the horizons, so that one can compare the gains and losses possibly occurring at various depths of a profile. This type of balance relies on four hypotheses or conditions which cannot be readily verified in nature (figure 3).

First, it was necessary to determine the quartz contents of the main horizons. This preliminary work was not easy because the quartz could not be directly determined. It required complex and often "acrobatic" mineralogical reconstructions which were made as follows : (i) evaluation of the type of minerals present in significant amount (X-ray diffraction, microscopic examination, DTA); (ii) quantitative determination of the minerals other than quartz (thermogravimetric analysis, magnetic separation of the grain glauconite, chemical analysis, etc); (iii) percentage determination of the quartz either by selective dissolution of the phyllite minerals (Kiely and Jackson, 1965), or by simple calculation (% quartz = 100 - all other minerals). Various methods of calculation independant of each other have been used in order to be virtually certain of the good agreement between converging results.

Knowing the current weight and the original weight (before differentiation) of each horizon, it was possible to calculate their global weight change. It was then easy to compare the current weight of an element, a mineral or a granulometric fraction (= Z), with the original weight of Z and to infer the gains or losses of Z.

7.3. Results

A first isoquartz balance was made on a mineralogically simple soil (quartz + glauconite only) : the HERY profile. Another three balances were then established on soils showing different particle size distributions and mineralogical compositions. In these three cases, it has been proceeded under less favourable conditions (complex mixtures of many minerals, less analytical data), but according

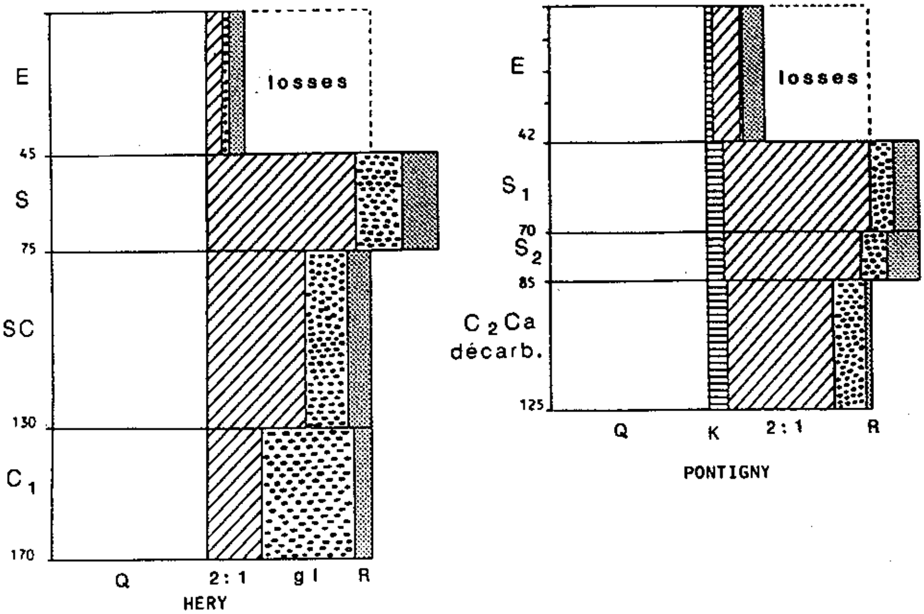


Fig. 4.
Diagrammatic presentation of the isoquartz balances calculated for HERY and PONTIGNY profiles (Q = quartz; 2.1 = glauconite + illites; gl = grain glauconite; k = kaolinite; R = another minerals and materials).

to the same principles as those adopted for the HERY profile.

7.3.1. Hêry profile

Quartz contents have been evaluated in six different ways. The following values (weighted averages) have been retained : 80.0 % in Eg, 39.2 % in S, 47.6 % in SC and 47.8 % in C horizons. The Eg horizon was considered to be representative of all the clay-poor upper horizons (down to a depth of 45 cm), and the S and SC horizons of the 45-75 and 75-130 cm soil layers respectively.

The global weight balance (table 5) already provides interesting information : the E horizons appear to be strongly impoverished (40 % weight loss), whereas the S horizon is markedly enriched (22 % gain). The 0.4 % gain noted in the SC horizon is not significant. The results concerning the six major chemical constituents (table 6) fully confirm the global balance : strongly impoverished E horizons, and markedly enriched S horizon. But irrespective of whether are considered total weights or oxides, material losses in the E horizons are never compensated by the gains in the S horizon (figure 4).

Table 5.
Global weight and thickness balances (Weights expressed in hg/dm^2, bulk density measured with membrane densitometer) in the Hêry profile.

Horizon	1 Present thickness (cm)	2 Present bulk density (g/cm^3)	3 Present weight (hg/dm^2)	4 Original weight (hg/dm^2)	Difference 4 - 3 (hg/dm^2)	Difference 4 - 3/4 (%)	5 Original thickness (cm)	6 Thickness difference 5 - 1 (cm)
Eg	45	1.51	67.95	113.61	-45.66	-40%	70.6	-25.6
S	30	1.28	38.40	31.48	+ 6.92	+22%	19.6	+10.4
SC	54	1.48	81.40	81.07	+ 0.33	+0.4%	50.4	+ 4.6
C_1	40	1.61	64.40	64.40	0	0	40	0

Table 6.
Balance of the 6 major chemical constituents (expressed in oxides) in the Hêry profile. Weight gains or losses (hg/dm^2, upper line) and as a percentage of the original weight (in brackets). The gains in S are not at all equivalent to the losses in E.

	SiO_2*	Al_2O_3	Fe_2O_3	K_2O	MgO	CaO
E	-23.56 (-28%)	-5.62 (-73%)	-8.41 (-76%)	-2.34 (-78%)	-1.23 (-88%)	-0.27 (-85%)
S	+ 2.56 (+11%)	+1.44 (+67%)	+1.02 (+33%)	+0.10 (+12%)	+0.08 (+21%)	-0.04 (-43%)
SC	- 1.09 (- 2%)	+0.03 (+0.5%)	-0.39 (- 5%)	+0.02 (+ 1%)	-0.08 (- 8%)	-0.04 (-18%)

* As quartz is supposed invariant, it is solely combined SiO_2.

Table 7 shows the chemical composition of materials lost in the E horizon to be very similar to both that of the grain glauconite and that of the < 2 µm fraction of the reference C horizon. This similarity reveals an impoverishment in 2:1 clay minerals. This impoverishment may result from lateral movement of particles out of the profile, or from total geochemical degradation of the clay minerals associated with the removal of all residues.

Table 7.
Chemical composition of the materials lost in the E horizons and comparison with that of the < 2 μm fraction of the reference horizon in the Héry profile.

Oxide	Losses in E horizons		Reference C horizon	
	Weight hg/dm^2	Chemical composition	Grain glauconite 100-200 μm	< 2 μm fraction
SiO_2	- 23.56	56.87	56.48	55.27
Al_2O_3	- 5.62	13.57	11.71	16.59
Fe_2O_3	- 8.41	20.30	21.90	18.39
K_2O	- 2.34	5.65	6.50	5.71
MgO	- 1.23	2.96	3.05	3.38
CaO	- 0.27	0.65	0.90	0.12
Na_2O	-	-	0.16	0.11
TiO_2	-	-	0.15	0.44
sum :	- 41.43	100.00	100.85	100.01

Gains in the S horizons consist of 49. % SiO_2, 27.7 % Al_2O_3, 19.6 % Fe_2O_3, 1.9 % K_2O and 1.6 % MgO. This composition is difficult to interpret because it has been obtained from figures of low absolute value, likely to be affected by strong relative errors.

The glauconite consisting of unweathered grains was isolated with a magnetic separator and its chemical composition determined. So, it was possible to estimate the glauconite contents of the silts and sands in the four major horizons. The isoquartz balances of this grain glauconite and of all the 2:1 phyllite minerals (particles of all sizes) are shown in table 8. They indicate that the glauconitic pseudo-sands disappear from the bottom to the top of the profile, and that the 2:1 phyllite minerals represent almost the entire losses of the upper horizons, and most of the gains of the S horizon. This causes no surprise, since we mentioned earlier that the mineralogical composition of the soil is confined to the quartz + glauconite association.

Therefore the "clay-content bulge" observed in the HERY profile does not result from absolute clay accumulation due to argilluviation, but from the combination of three phenomena of unequal importance : (i) marked conversion of the glauconite grains into clay, an upward moving process that increases with decreasing depth; (ii) considerable clay impoverishment of the upper horizons, a process

Table 8.
Isoquartz balance of grain glauconite and of the sum of 2:1 clay minerals (including grain glauconite) in the Héry profile. Weight gains and losses as a percentage of the original weight.

Horizon	Grain glauconite (silts + sands)		Sum of the 2:1 clay minerals		Global weight gains or losses of the horizon (cf. table 5)
	hg/dm^2	%	hg/dm^2	%	
E	- 29.7	- 92	- 43.9	- 84	- 45.7 hg/dm^2
S	- 4.4	- 49	+ 5.5.	+ 38	+ 6.9 hg/dm^2
SC	- 11.3	- 49	- 0.3	- 1	+ 0.3 hg/dm^2

laterally directed but leading to the progressive lowering of the claypan; and (iii) slight accumulation of illuviated clay, confined to the top of the S horizon. Thus, the clay horizons of the HERY profile are essentially weathered S horizons.

7.3.2. Other profiles

The detailed results concerning three other profiles will not be presented here : PONTIGNY (developed from a sandy and glauconi-

Table 9.
Estimated total weight gains or losses of the four studied profiles (hg/dm^2).

Profile	HERY	PONTIGNY	REBOURSEAUX	FLOGNY
Horizons	E : - 45.7	E : - 30.2	Eg_1 : - 30.2 Eg_2 : - 8.5 E & S : - 6.8	Eg : - 38.1
	S : + 6.9 SC : + 0.3	S_1 : + 5.4 S_2 : + 3.1	S_1 : - 1.8 S_2 : - 2.9 SC_1 : - 3.1	S_1 : + 4.2 S_2 : + 7.1
reference horizon	C_1 (glauconitic loamy sand)	C_2Ca (decarbonated) (silty clay)	SC_2 (clay)	C_2 (clay with 3,6 % $CaCO_3$)

tic marl of the upper Albian); REBOURSEAUX (cenomanian clay); FLOGNY (aptian calcareous clay). The estimated weight gains and losses of these soils are listed in table 9.

7.4. Conclusions

The four studied profiles show the following features : (i) major loss of material in the E horizons (30 to 45 % of the original weight); (ii) material gains in the upper part of the S horizons (except at REBOURSEAUX); (iii) these gains remain limited and do not compensate for losses in the E horizons. Thus, the materials lost in the surface horizons seem to have left the profiles. This lost material seems to consist only of particles < 2 µm (60 to 82 % of the original fraction).

8. ANALYSIS OF THE SUBSURFACE RUNOFF

At HERY, water samples were collected in a small pond which is the natural drainage way of the surface watertables. 11 samplings were made at 6 winter dates and 1 summer date. pH range was 4.8-6.8, resistivity 9,300-12,600 Ohm/cm, and the amount of material in suspension 2.7 to 32.2 mg/l. The presence of Ca, Mg, K and Na in solution is related to the bio-geochemical cycle, whereas the relatively abundant dissolved silica (10.5 to 20.0 mg/l SiO_2) might result from current weathering of the crystal lattices of some silicates.

A 60-1 sample was collected in February 1982 and the material in suspension separated by centrifugation at 50,000 g. The centrifugate only consisted of particles < 2 µm very similar in composition to the fine-clay fraction (< 5 µm) of the E horizons of the HERY profile. Furthermore, the XRD curves obtained with these residues showed similar features (presence of glauconite, smectites, interstratified minerals, and kaolinite) to those of the E horizons.

Water samplings were taken from little brooks. Thus, it is possible to answer the following question : what has happened with the clays lost by E horizons? These suspended materials have been drained through the hydrographic network. It must be noticed that, within the region, all the latest alluvial deposits are clays or heavy clays, in small as in large valleys.

9. GENERAL SYNTHESIS - SOIL GENESIS

In order to understand both formation and dynamics of these planosols, numerous approaches were used : macro-morphological observations, microscopic examinations of thin sections, arguments related to mapping or to particle size distribution, determination of heavy minerals, samplings of the subsurface runoff, analysis of the weathering complex, isoquartz balances, study of the soil water regime (based on various procedures). Each of them yielded data which were critically examined, enabling a partial synthesis to be drawn. The latter can be summarized as follows :

1. Originally, the parent materials were homogeneous;
2. today, the soils are developing in a medium marked by strong mineral acidity;
3. "morphological degradation" (of variable importance) occurs at the interface between Eg and S horizons;
4. only the finest clay minerals seem to be affected by weathering;
5. the profiles show strong textural differentiation (clay indices S/E range from 2.4 to 5.2, mean = 3.3);
6. the upper horizons have been strongly impoverished in clay;
7. there has been little vertical clay illuviation within the S horizons, only in their upper part;
8. the soil water dynamics is essentially lateral;
9. each year, 200 to 400 mm rain are removed by subsurface watertables;
10. the lateral runoff carries away (in brooks) some amount of clay in suspension.

To draw final conclusions about soil genesis, it was necessary to overcome some apparent contradictions between current phenomena (items above 2, 8, 9 et 10) and the integrated effects of earlier successive or simultaneous processes (items 4, 5, 6 and 7).

9.1. Hypothetical reconstruction of soil evolution

The textural evolution will be artificially presented separately from the physico-chemical evolution. The former can be subdivided in three stages :

STAGE 1. From a clay material, creating of a physical and biological macro-porosity down to an "abrupt structural change". Beginning of the lateral water circulation = beginning of clay impoverishing (cf. "pélosols brunifiés").

STAGE 2. Gradually the impoverishment increases, the "structural change" deepens and turns into an "abrupt textural change".

STAGE 3. The E horizons show an increasing porosity, while S horizons remain slowly permeable. The lateral water flow increases and impoverishing becomes self-accelerating. The planosolic morphology becomes more and more pronounced.

The physico-chemical evolution can be described as follows :

STAGE 1. Beginning of pedologic structuration and of weathering (iron release). Decarbonatation (if calcareous parent material). Clay formation from grain glauconite (case of the albian "green sands").

STAGE 2. Deepening of the three above-mentioned processes. Beginning of the base desaturation. Clay minerals remain stable. Tendancy to waterlogging of the surface horizons by rainfall.

STAGE 3. Occurrence of first real hydromorphic features at a shallow depth. Reduction/reoxidization cycles. Increase of the base desaturation and beginning of aluminization. Progressive opening of the micaceous clay layers.

STAGE 4. Increase of waterlogging. Rather strong mineral acidity. Secondary illuviation resulting in the degradation at the top of S horizons (in such a desaturated and temporarily reducing medium, clay is dissociated from iron and is able to be removed separately).

STAGE 5. Acidity and waterlogging continue to increase. Beginning of total acido-ferrolysis of some clay minerals. Podzolization is possible at the surface (due to alteration of the vegetation), but is not at all inevitable.

A number of factors can inhibit these evolutions or limit the downward movement of the abrupt textural change. These factors are as follows : (i) presence of $CaCO_3$ in the parent material (upward movement of Ca^{++} as a result of the bio-geochemical cycle); (ii) clay contents > 50 % (in such a case, there is a large amount of clay to be desaturated, removed or dissolved); (iii) slowly permeable parent material (bimodal particle size distribution, stratified and dense sedimentation), as a result of which all processes "hit" against a true claypan, water dynamics is only lateral, and the deepening of the abrupt textural change is much slower.

On the other hand, some factors accelerate the soil differentiation : (i) occurrence of sulfides in the parent material, the oxidation of which will cause the early release of a strong mineral acidity (occurrence of jarosite in the C horizons of some soils on "green sands"); (ii) presence of materials that are less rich in clay or more permeable; (iii) areas showing more intense water flow, hence faster clay impoverishment.

9.2. Comparison with other types of soils under humid temperate climates

No comparisons were made with other types of planosols that developed under other climates, in a totally different environment from that of the Champagne Humide. Instead, the present planosols were compared with two types of soils of common occurrence in northern France, which developed under the same humid temperate climate, in similar topographical positions, but on rather different materials (table 10) : "sols lessivés dégradés", differentiated from

Table 10.
Comparison between evolutions of "sols lessivés dégradés" of the Paris Basin, planosols of the Champagne Humide region and "pélosols brunifiés" of Lorraine. The different stages of evolution are numbered in roman figures.

	LOESSIC MATERIALS (PARIS BASIN)		CRETACEOUS CLAY MATERIALS (CHAMPAGNE HUMIDE)	TRIASIC CLAYS (LORRAINE)	
I	• Decarbonatation • Pedologic structuration.	I	• Decarbonatation (facultative). • Pedologic structuration. • Beginning of brunification (iron releasing...) • Clay formation from grain glauconite.	• Decarbonatation. • Pedologic structuration. (beginning).	I
II	• Brunification : iron releasing and moderate clay formation.			• Beginning of brunification, • Base desaturation and ← lateral illuviation.	II
III	• Beginning of desaturation and vertical primary illuviation. ↓	II	• Increasing of weathering. • Beginning of base desaturation. ← Beginning of lateral illuviation. Tendancy to waterlogging. Clay minerals remain unweathered.	Pedological structuration (continuation). Clay minerals remain unweathered.	
IV	• Increasing of base desaturation and beginning of aluminization. First hydromorphic features. • Progressive opening of the micaceous clay layers. ↓ Continuation of the primary illuviation.	III	• Increasing of base desaturation and beginning of aluminization. First hydromorphic features. • Progressive opening of the micaceous clay layers. ← Increasing of the lateral illuviation.		
V	↓ Increasing of waterlogging.		← Increasing of waterlogging.		

Table 10. (continued).

	↓	"Secondary" vertical illuviation and glossic-like degradation of the Bt horizon.		●	Rather strong mineral acidity.
				←	Lateral illuviation (continuation)
			IV	←	Secondary illuviation with a planic degradation at the top of S horizons.
		Interlayer hydroxy-Al ion fixation within the Eg horizons.			Interlayer hydroxy-Al ion fixation within the Eg horizons.
VI	←	Idem but with a planosolic tendancy.		←	Increasing of mineral acidity and of waterlogging.
			V		Beginning of acidoferrolysis of a part of clay minerals.
				●	Surface podzolization is possible.
				←	Lateral illuviation (continuation).

loessic materials in the northeastern Paris Basin (Jamagne, 1973, 1978; Pedro et al., 1978), and "pélosols brunifiés", formed from the Lorraine triasic clays (Nguyen Kha, 1973, 1975, 1976).

Circles in table 10 indicate the processes that tend to develop along a vertical line, hence to "go deeper" into the solum in the course of time (all forms of weathering). Vertical arrows indicate all essentially vertical translocations of material (vertical illuviations), while small horizontal arrows refer to transfers laterally directed as a result of the presence of a claypan. The two chronosequences on the left hand side share a number of common features. Their essential difference lies in the early occurrence of lateral movements in the case of soils overlying clays. The "pélosols brunifiés" can be considered as poorly developed soils that have only reached a primitive stage, but probably take place in the phylum leading to planosols.

9.3. Dominant factor of soil genesis

Parent material rather than local climate plays a predominant role in the formation of the planosols in the Champagne Humide. The early and definitive trend of soil genesis towards planosolic morphology and behaviour is specifically due to the occurrence of slowly permeable, sedimentary clay parent materials. Unlike the sandy or silty materials, where soil genesis develops initially (and for a long time) along a vertical axis, the clay materials examined in this study showed an essentially lateral dynamics.

9.4. Relationships between morphology and behaviour

As mentioned previously, the planosolic morphology now generates almost exclusively lateral water movements. Conversely, this lateral water flow has something to do with the existence of a planosolic morphology. Today, under highly acid, hence unfavourable physico-chemical conditions, fine clays are carried away in suspension by water at the rate of 3 to 32 mg/l. These clay minerals show the same chemical composition and the same XRD curves as the finest clays extracted from the Eg horizons. Besides, the water balances reveal that 200 to 420 mm of rainfall are drained laterally each year as temporary subsurface watertables. Thus, clay impoverishing still affects the upper horizons in current times. This process has probably existed for several thousands of years, and is the primary agent in the formation of the planosols studied here.

9.5. Classification

The clay-impoverished horizons of the FAO legend (1974) perfectly correspond to the definition of the E horizons, but not all of them deserve to be qualified as "albic" due to their ochre colour. This is a minor aspect. The planosols studied in this paper actually belong to the Planosols soil unit. The base saturation rate, determined by ammonium acetate (threshold at 50 %), is used in identifying eutric or dystric property of these soils. According to this criterion, some profiles such as the FLOGNY one, cannot be classified as dystric, even though its acidity is evidenced by KCl pH lower than 4 (including the clay S horizons)! This raises questions once again as to the determination of CEC by ammonium acetate at pH 7 for acid soils.

With reference to Soil Taxonomy (1975) the author does not agree to designate as argillic B horizons those clay horizons whose formation was little affected, or unaffected by clay illuviation, and which are chiefly inherited from sediments. These soils, or at least most of them, would be listed among Albaqualfs.

The French classifications and in particular the C.P.C.S. system (1967) could not satisfactorily take into account these soils. The new typology (Référentiel Pédologique, 2nd approximation, 1988) recognizes the concept of PLANOSOLS and defines three units of them (= REFERENCES). So, the studied soils can be referred to as "PLANOSOLS PEDOMORPHES, d'appauvrissement, dystriques".

ACKNOWLEDGEMENTS

The author gives his sincere thanks to E. RON and J. CHRISTIE for their help in translating this paper.

REFERENCES

Baize, D. (1976)
Notice carte pédologique de France à 1/100.000. Feuille Tonnerre. I.N.R.A., Versailles, 244 p.

Baize, D. (1980 a)
Granulométrie et homogénéité des profils. Application aux planosols de Champagne Humide, France.
Sci. du Sol, 2 : 83-112.

Baize, D. (1980 b)
Essai de bilan isoquartz sur un planosol du Bassin de Paris.
Ann. Agron., 31 (4) : 337-362.

Baize, D. (1983)
Les planosols de Champagne Humide. Pédogenèse et fonctionnement.
Thèse, I.N.R.A., Versailles, 360 p.

Baize, D. (1984)
Fonctionnement hydrique de planosols en Champagne Humide (France).
Colloque Fonctionnement hydrique et comportement des sols, A.F.E.S., Dijon, 21-32.

Begon, J.C. & Jamagne, M. (1973)
Sur la genèse de sols limoneux hydromorphes en France.
Pseudogley and Gley, C.R. Comm. V et VI A.I.S.S. : 307-318.

Begon, J.C., Hardy, R., Mori, A. & Roque, J. (1976)
Les sols du département de l'Oise.
I.N.R.A., Versailles, 333 p.

Carvalho Cardoso, J. & Texeira Bessa, M. (1973)
Planosols of Portugal.
Pseudogley and Gley. C.R. Comm. V et VI A.I.S.S. : 335-340.

C.P.C.S., (1967)
Classification des sols.
INRA, Orléans.

Conea, A., Oancea, C., Popovat, A., Rapaport, C. & Vintila, I. (1973).
Comparative study of Planosols in Romania.
Pseudogley and Gley. C.R. Comm. V et VI A.I.S.S. : 323-334.

Dudal, R. (1973)
Planosols.
Pseudogley and Gley. C.R. Comm. V et VI A.I.S.S. : 275-285.

F.A.O. - Unesco, (1974)
Soil map of the world. Volume 1. Legend.
Unesco, Paris.

Favrot, J.C. & Legros, J.P. (1972)
A propos d'un type de sol hydromorphe observé en France : le planosol lithomorphe.
Bull. A.F.E.S., 6 : 243-249.

Feijtel, T.C., Jongmans, A.G., Van Breemen, N. & Miedema, R. (1988)
Genesis of two planosols in the Massif Central, France.
Geoderma, 43 : 249-269.

Isambert, M. (1984)
Notice carte pédologique de France à 1/100.000. Feuille Châteaudun.
I.N.R.A., Orléans, 259 p.

Jamagne, M. (1973)
Contribution à l'étude pédogenétique des formations limoneuses loessiques du Nord de la France,
Thèse, Gembloux, 445 p.

Jamagne, M. (1978)
Les processus pédogenétiques dans une séquence évolutive progressive sur formations limoneuses loessiques en zone tempérée froide et humide.
C.R. Acad. Sciences, Paris, 286, série D : 25-27.

Kiely, P.V. & Jackson, M.L. (1965)
Quartz, feldspar and mica determination by sodium pyrosulfate fusion.
Soil Sci. Soc. Amer. Proc. 29, 2 : 159-163.

Marshall, C.E. & Haseman, J.F. (1942)
The quantitative evaluation of soil formation and development by heavy mineral studies : a grundy silt loam profile.
Soil Sci. Soc. Amer. Proc. : 448-453.

Morras, H.J.M. (1979)
Discussion sur les mécanismes de pédogenèse des planosols et d'autres sols apparentés.
Sci. du Sol, 1 : 57-66.

Nguyen Kha (1973)
Recherches sur l'évolution des sols à texture argileuse en conditions tempérées et tropicales.
Thèse, Nancy, 156 p.

Nguyen Kha & Paquet, H. (1975)
Mécanismes d'évolution et de redistribution des minéraux argileux dans les pélosols.
Sci. Géol. Bull. Strasbourg, 28, 1 : 15-28.

Nguyen Kha, Rouiller, J. & Souchier, B. (1976)
Premiers résultats concernant une étude expérimentale du phénomène de l'appauvrissement dans les pélosols.
Bull. A.F.E.S., Sci. du Sol, 4 : 259-267.

Pédro, G., Jamagne, M. & Begon, J.C. (1978)
Two routes in genesis of strongly differentiated acid soils under humid, cool-temperate conditions.
Geoderma, 20 : 173-189.

Référentiel Pédologique (deuxième proposition) (1988)
A.F.E.S. & I.N.R.A. Diffusion : I.N.R.A., Orléans.

Robert, M. et Barshad, I. (1973)
Transformation expérimentale des micas en vermiculites ou smectites, propriétés des smectites de transformation.
Bull. Gr. Franç. Argiles, t. XXIV : 137-151.

Trashliev, Ch. & Ninov, N. (1975)
Surface waterlogged soils in Bulgaria (in russian, with english abstract).
Bulg. Acad. Sciences, Sofia, 161 p.

U.S.D.A. (1975)
Soil Taxonomy : A basic system of soil classification for making and interpreting soil surveys.
US Dept. Agric., Soil Conserv. Service, Agric. Handbook 436, Washington, D.C., USA, 754 p.

Les Planosols de Champagne Humide, France : Etude multi-approches

Résumé

Des sols acides, fortement différenciés se sont développés à partir de sédiments argileux crétacés en Champagne Humide.

Des études granulométriques, physico-chimiques, minéralogiques et micromorphologiques ont été menées sur 7 solums sélectionnés à partir de 60 fosses. Le régime hydrique des sols a été suivi pendant 5 ans. 200 à 420 mm de pluies sont évacuées latéralement chaque année par des nappes perchées temporaires.

4 bilans isoquartz ont confirmé que la forte différenciation texturale résulte de l'entrainement latéral de particules argileuses hors des horizons de surface, sans accumulation notable dans les horizons profonds.

La formation de ces planosols "pédomorphes" est liée à deux facteurs stationnels : roches-mères argileuses peu perméables et position sub-horizontale. A la différence des matériaux sableux et limoneux, ces matériaux argileux connaissent dès l'origine une dynamique hydrique essentiellement latérale.

Planosols uit de vochtige Champagne streek, Frankrijk : een brede benadering

Samenvatting

Op de kleiige sedimenten van het Krijt in de vochtige Champagne streek hebben zich zure, sterk gediffentieerde bodems ontwikkeld.

Granulometrische, fysico-chemische, mineralogische en micromorfologische studies werden uitgevoerd op 7 geselekteerde profielen. Het bodemvochtregime ervan werd gevolgd gedurende 5 jaar. Hierbij werd aangetoond dat 200 tot 420 mm neerslagwater per jaar via laterale weg wordt geëvacueerd langs tijdelijke stuwwaterlagen.

De 4 uitgevoerde iso-kwarts balansen hebben aangetoond dat de

sterke textuur-differentiatie het gevolg is van een laterale afvoer van kleideeltjes uit de oppervlaktelagen, zonder dat hierbij een noemenswaardige accumulatie optreedt in de diepere horizonten.

De vorming van deze "pedomorfe" planosols wordt geassocieerd met 2 specifieke lokatie-gebonden faktoren : een weinig doorlatend klei-substraat en een subhorizontale ligging. In vergelijking met de zandige en lemige materialen, vertonen deze klei-afzettingen vanaf het begin een overwegend laterale vochtdynamiek.