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On soil genesis in temperate humid climate. VIII
The formation of a 'Udalfic' Eutrochrept

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Summary

Chemical and micromorphological studies of a profile in Holocene alluvial deposit have shown that the following soil-forming processes are active:
- formation along voids of illuvial cutans consisting of clay minerals, iron oxide, and fine matric components (matriferriargillans);
- differential movement of clay minerals, kaolinite being most mobile;
- partial transformation of smectites into kandites;
- disturbance of cutans by biological activity, resulting in the formation of papules;
- redox processes leading to the formation of micro-seggregation of iron oxide.

The difference in character and location of matriferriargillans and ferriargillans was shown and discussed. It was postulated that the former are synthesized in Holocene and the latter in Pleistocene times.
The soil was classified as a 'Udalfic' Eutrochrept.

Introduction

In certain young soils coatings with rough surfaces are found to be present on ped faces. Similar coatings occur as a recent feature in older soils. The chemical and micromorphological study of their characteristics and formation, together with geochemical changes in the profile, are the subjects of this paper.

Site and profile description

The soils studied are relatively high-situated Holocene alluvial soils along the river Geul, and have weak gley phenomena at a depth of more than 40 cm. The area is practically level and seldom flooded. The drainage is good and the water table fluctuates strongly. The lowest level of the groundwater is at 2 m depth. The altitude is about 115 m above mean sea level. The climate is characterized by a precipitation of 700 mm and an evaporation from free water surface of 725 mm annually; the average minimum temperature is —0.8°C and the average maximum +22.5°C. The soil has a moderate number of worm tracks down to 1 m depth and abundant fine roots in the layer of 0 to 30 cm, gradually decreasing to a depth of 90 cm. In the subsoil (> 125 cm) some partially decayed thick roots occur, indicating that the soil consists of a recent alluvial deposit above an older one, which once bore vegetation. The present vegetation is grass (meadow).

The soil horizons

A_{11}	0–8 cm	Greyish yellow brown (10YR 5/2, dry) silt loam with weak crumb structure; very friable. Rusty mottles along roots. Abrupt and smooth lower boundary.
A_{12}	8–35 cm	Dull yellowish brown (10YR 5/4, moist and rubbed) silt loam with weak, coarse prismatic structure; friable. Many, fine, prominent, reddish brown (5YR 4/8, moist) mottles. Clear and smooth lower boundary.
B_1	35–70 cm	Bright brown (7.5YR 5/6, moist and rubbed) silt loam with compound weak coarse prismatic and moderate medium angular blocky structure; friable. Surface colour of the peds is dull brown (7.5YR 5/4, moist). Diffuse and smooth lower boundary.
B_2	70–125 cm	Dull brown (7.5YR 5/4, moist and rubbed) silt loam with compound weak coarse and moderate fine to medium prismatic structure; friable. Surface colour of peds is brown (7.5YR 4/4, moist). Occasional reduction along root channels in lower part of the horizon. Clear and smooth lower boundary.
C	> 125 cm	Bright brown (7.5YR 5/6, moist) silt loam; macrostructureless and slightly sticky to friable. Many, fine to coarse, greyish yellow brown (10YR 5/2, moist) mottles. Reduction along root channels. Permanent reduction at a depth of 2 m.

Remarks: B_1 and B_2 horizons show prominent to distinct coatings on peds. The coatings do not form a smooth surface but show rounded ripple-marks. The A_{11} horizon is a fresh deposit probably originating from levelling by the farmer; the horizon was not sampled for this reason.

The geochemistry

Some general data are presented in Table 1. Grain size distribution suggests translocation of clay if it can be proved that the deposit was originally homogeneous. This is actually the case as will be shown later (Tables 2 and 3; section Micromorphology). Free and total Fe_2O_3 is practically constant indicating that the redox conditions are such (too short reduction periods) that a macro-translocation of iron has not yet occurred. However some local separations of iron oxides have been observed (see profile description and section Micromorphology).

The chemical composition (Table 2) of the horizons and their clay separates show that the profile is very homogeneous; the C horizons, however, has a slightly different composition. This can be seen clearly in Table 3 giving the norm-mineralogical composition of the soil and its separates.[1] The table shows that the (sand + silt) fraction

Table 1 General characteristics of the profile

Horizon	*Grain size distribution (%)*			*C (%)*	*pH*		*Fe_2O_3 (%)*	
	> 50 μm	*50–2 μm*	*< 2 μm*		*0.01 M $CaCl_2$*	*H_2O*	*free*	*total*
A_{12}	27.7	59.7	12.6	0.9	5.5	6.3	0.9	2.9
B_1	20.2	66.0	13.8	0.8	5.6	5.8	0.9	3.0
B_2	25.1	59.1	15.8	0.6	6.4	6.5	1.0	3.0
C	35.3	51.9	12.8	0.2	5.9	6.7	1.0	3.1

[1] The clay composition was calculated from its chemical composition according to the rules developed by van der Plas and van Schuylenborgh (1970), the composition of the non-clay fraction according to the epinorm rules (Niggli: see Burri, 1964) and that of the soil was composed of the two compositions taking into account the relative percentages of both fractions.

Table 2 Chemical composition of the profile (% w/w)

	A_{12}		B_t		B_2		C	
	soil	*clay*	*soil*	*clay*	*soil*	*clay*	*soil*	*clay*
SiO_2	81.3	47.0	77.5	46.3	81.4	46.2	84.2	46.0
Al_2O_3	5.7	21.2	6.2	22.1	6.2	22.6	5.7	22.7
Fe_2O_3	2.8	12.4	2.9	13.7	2.9	13.6	3.1	14.5
FeO	0.1	0.3	0.1	0.3	0.1	0.3	0.1	0.3
MnO	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1
CaO	0.4	—	0.4	—	0.4	—	0.3	—
MgO	0.4	1.6	0.4	1.7	0.4	1.6	0.3	1.5
Na_2O	0.7	0.2	0.7	0.2	0.7	0.2	0.5	0.3
K_2O	1.6	2.8	1.6	2.7	1.5	2.4	1.4	2.7
TiO_2	0.5	0.8	0.5	0.8	0.5	0.8	0.5	0.7
P_2O_5	0.1	0.4	0.1	0.4	0.1	0.4	0.1	0.4
H_2O+	2.0	10.4	2.3	11.0	2.2	11.6	2.4	11.9

has essentially a constant composition in the solum, whereas the C horizon is dissimilar. It can be concluded from this that the sediment in which the solum has been developed was originally homogeneous. Consequently, clay transformations or translocations can be deduced from differences in the clay composition (excluding the C horizon).

The clay composition shows Ill and Q contents decreasing with depth, an increasing Kaol content, Sm remaining constant.[2] There are two possibilities to explain this distribution pattern, viz transformation of Kaol into Ill, and differential clay mineral movement (Kaol being most mobile).

Table 3 Norm-mineralogical composition of the profile

Minerals [1]	A_{12}			B_t			B_2			C		
	clay	*sand* [2]	*soil*	*clay*	*sand* [2]	*soil*	*clay*	*sand* [2]	*soil*	*clay*	*sand* [2]	*soil*
Q	9.9	79.7	70.9	7.2	80.1	69.2	6.0	81.1	69.2	7.4	83.9	74.1
Fsp	—	13.6	11.8	—	13.2	11.4	—	13.7	11.5	—	8.6	7.5
Ms	—	3.5	3.1	—	3.9	4.2	—	2.6	2.2	—	5.0	4.4
Amph	—	1.7	1.5	—	1.6	1.4	—	1.5	1.3	—	1.1	1.0
Sm	38.0	—	4.8	38.0	—	5.2	37.8	—	6.0	34.2	—	4.4
Ill	28.3	—	3.6	26.6	—	3.7	23.8	—	3.8	26.9	—	3.4
Kaol	12.4	—	1.6	15.8	—	2.2	20.1	—	3.2	18.6	—	2.4
Go	10.2	1.1	2.2	11.1	0.9	2.3	11.0	0.7	2.3	11.6	1.1	2.4
Ru	0.6	0.4	0.4	0.6	0.4	0.4	0.6	0.4	0.4	0.6	0.4	0.4
Str	0.6	—	0.1	0.7	—	0.1	0.7	—	0.1	0.7	—	0.1
W [3]	12.0	1.5	2.8	12.2	1.6	3.1	13.0	0.4	2.4	12.9	1.6	3.0

[1] Q = free silica; Fsp = feldspars; Ms = muscovite; Amph = amphiboles; Sm = smectite; Ill = illite; Kaol = kaolinite; Go = goethite; Ru = rutile (anatase); Str = strengite.
[2] sand = (sand + silt) fraction.
[3] W = excess crystal water which can be allocated to Go to form amorphous ferric hydroxide, as no sign of the presence of Go was found in the X-ray patterns nor in the thin sections.

[2] This was confirmed by X-ray analysis showing lowest content of Ill and highest content of Kaol in the B_2 horizon; Sm was lowest in the C horizon and Q was practically constant.

The first possibility is unlikely as the reaction

$$3\ \text{Kaol} + 2\ K^{+} \rightleftharpoons 2\ \text{Ill} + H^{+} + 3\ H_2O$$

has a standard (25°C; 1 atm.) free energy change of + 16.8 kcal (Slager and van Schuylenborgh, 1970). Consequently, formation of illite is only possible if K^+ ions are accumulated in, or H^+ ions are withdrawn from the surface horizons, or both. This process is unlikely to occur in humid temperate climates.[3]

The second possibility is therefore the more likely. However, if Kaol is the most mobile constituent of the plasma, the other components should be enriched residually. This is true for Q and Ill, but not for Sm. It means that part of the smectite is transformed into kaolinite, which may have actually occurred as the reaction

$$\text{Sm} + 5H_2O \rightleftharpoons \text{Kaol} + 2H_4SiO_4$$

although having a standard free energy change of + 12.8 kcal (Slager and van Schuylenborgh, 1970), is favoured by the removal or orthosilicic acid which is a common process under conditions of good drainage. Also a transformation of Sm into Ill could have occurred according to:

$$3\text{Sm} + 2K^{+} + 12H_2O \rightleftharpoons 2\text{Ill} + 2H^{+} + 6H_4SiO_4$$

with a standard free energy change of + 55.2 kcal (Slager and van Schuylenborgh, 1970). However this is improbable for the same reasons as given in respect to the formation of Ill from Kaol.

The one possibility to explain the peculiar distribution pattern of the clay minerals in this profile is the preferential mobility of kaolinite. This phenomenon was also observed in some Ultisols and Alfisols by Slager and van Schuylenborgh (1970) and van Schuylenborgh (see: Mohr and van Baren, in prep.); it was observed in Dutch soils by Bouma et al. (1968) and Bouma and van Schuylenborgh (1969). This is also in accordance with the experimental results of Hallsworth (1963). It should be stressed, however, that kaolinite is not always the most mobile plasma constituent (Ranney and Beatty, 1969); we have the impression that the different mobility of the clay minerals largely depends on the climate characteristics and hydrological conditions.

Micromorphology

Thin sections of 8 × 15 cm were prepared of samples taken from the A_{12} horizon (15–30 cm), B_1 (45–60 cm), B_2 (80–95 cm) and the C horizon (135–150 cm). They were described according to the terminology proposed by Brewer (1964). The skeleton grains in all horizons have sizes between 2 and 250 μm, generally between 2 and 50 μm. They include quartz, micas, feldspars and amphiboles and are randomly distributed. The plasma consists of a mixture of clay minerals and amorphous iron compounds. The plasmic fabric is silasepic. Vughs (30–1000 μm) and channels have been observed in all horizons.

Single matric fecal pellets (up to 1000 μm) with a random distribution pattern occur in the A_{12} horizon. The A_{12}, B_1 and B_2 horizons contain ferric nodules (up to 200 μm) with rather sharp boundaries and tuberose shapes; they are randomly distributed. The ferric nodules in the C horizon are substituted by neoferrans (up to 1000 μm).

[3] It may occur in arid and semi-arid climates under a grass (savannah) vegetation as was experienced by Blokhuis (in prep.). The formation of micas by concentration of potassium as a result of biological recycling was observed in Hawaii by Juang and Uehara (1968).

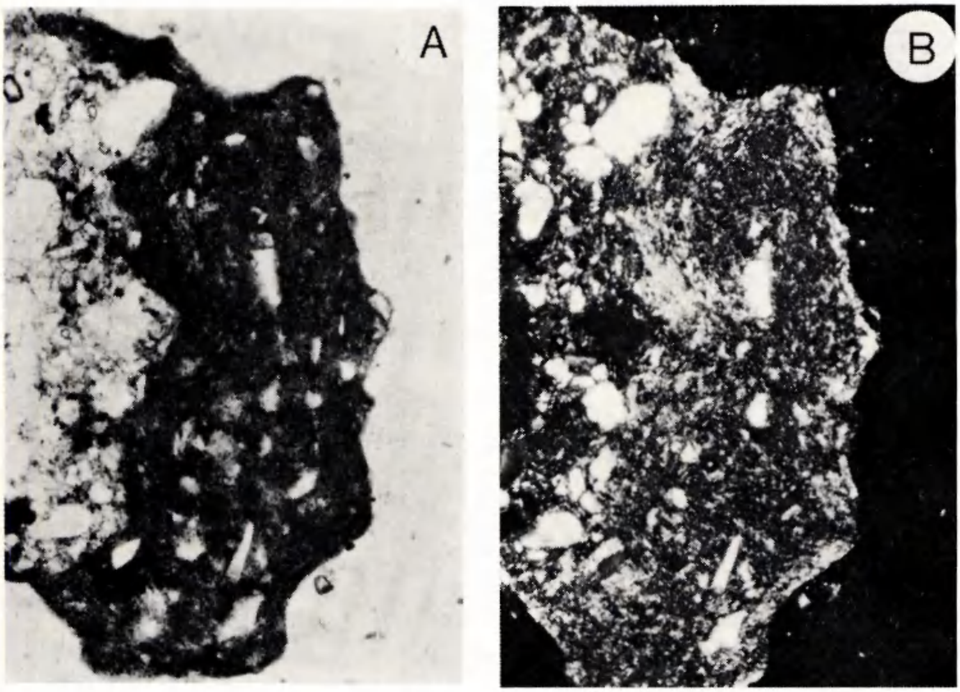

Fig. 1A. Matriferriargillan found in the B_2 horizon of a 'Udalfic' Eutrochrept. Normal transmitted light. Magnification × 100
B. As A, but with crossed nicols

Birefringent channel and normal void cutans occur in the B_2 horizon and, to a lesser extent, in the B_1 and C horizons; they consist of a mixture of oriented clay minerals, amorphous iron, non-oriented clay minerals, organic matter and fine skeleton grains. We propose to call these cutans matriferriargillans (matri derived from matrix); they are illustrated in Fig. 1. They consist for the greater part of oriented clay minerals and iron; the clay minerals are not continuously oriented in the cutan. These cutans are absent in the A_{12} horizon. However papules derived from the cutans mentioned occur in the A_{12}, B_1 and B_2 horizons. They are absent in the C horizon.
Some quantitative data has been collected on the occurrence of the matriferriargillans (Table 4). For this purpose a point-counting technique was applied on the thin section,

Table 4 Occurrence of matriferriargillans and papules (% of thin section surface area)

Depth (cm)	*Horizon*	*Matriferriargillans along voids with diameter (μm) of*					*Papules*
		< 100	*100–200*	*200–300*	*> 300*	*total*	
15–30	A_{12}	0	0	0	0	0	0.3
45–60	B_1	0.1	0	0.3	0.9	1.3	0.3
80–95	B_2	0.1	0.9	0.1	0.9	2.0	0.3
135–150	C	0.1	0.1	0.1	0.1	0.4	0

using a counting ocular with 7 points. One hundred microscope fields were counted in each section at a magnification of 125. The values in Table 4 should be read $\pm$ 10% relatively.

The table shows that the matriferriargillans occur rarely along voids smaller than 100 μm. They tend to accumulate around the largest voids except in the B_2 horizon with the maximum illuviation, where they occur along all voids larger than 100 μm. These phenomena were also observed in other profiles, but could not yet be explained. Finally, the table shows that the papules are evenly spread over all horizons, except the C, whereas the matriferriargillans show a maximum in the B_2 horizon, which is in agreement with its maximum clay content (Table 1).

In summary, it can be stated that the following processes have been and are probably still active in the formation of the profile:

— gleying (ferric nodules in the surface and subsurface horizons and neoferrans in the subsoil);
— biological homogenization which decreases with depth due to increasing gleying (no papules in the subsoil; neoferrans in the subsoil are not transferred into glaebules);
— illuviation of mainly clay minerals and ironhydroxide with an admixture of fine matrix components.

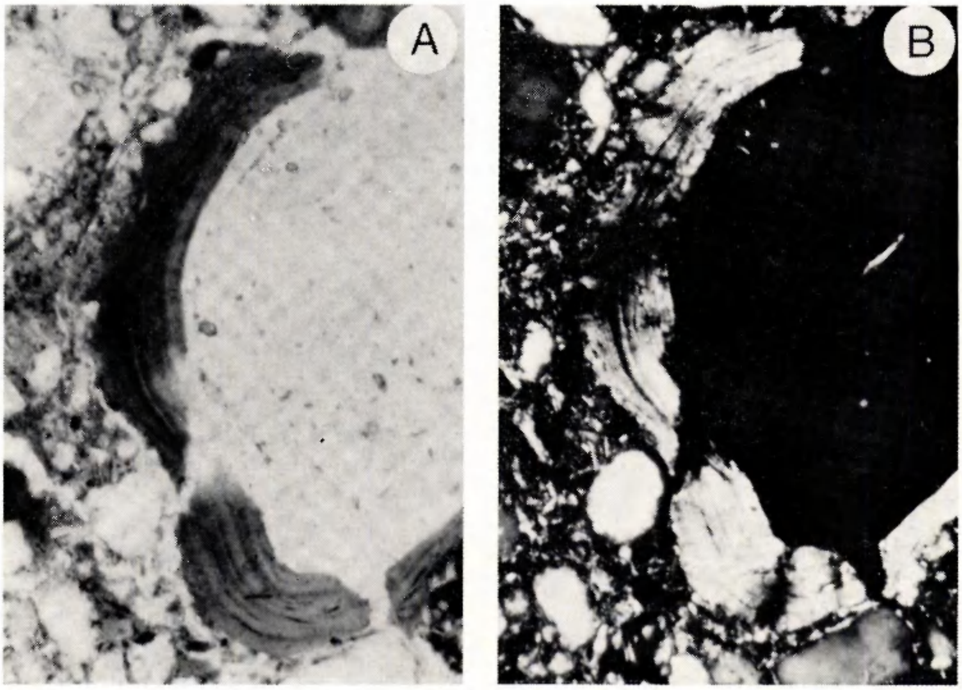

Fig. 2A. Ferriargillan with a continuous orientation pattern occurring in the B_2 horizon of a Typic Hapludalf. Normal transmitted light. Magnification $\times$ 140
B. As A, but with crossed nicols

Table 5 Comparison of illuviation cutans in a Typic Hapludalf (% of thin section surface area)

Depth (cm)	Horizon	Matriferriargillaceous		Ferriargillaceous	
		cutans	papules	cutans	papules
10–25	A_2	0	0	0	0.3
60–75	B_{2t}	0.2	0.6	1.3	2.9
80	B_{2t}	0.4	0.9	2.9	3.0
140–155	C	2.9	0.7	1.3	0.3
170	C	1.9	0.7	1.3	0.3
300–315	C	0.2	0.1	0.3	0

Comparison with older soils

In the southern part of the Netherlands relatively large areas with Pleistocene loess deposits occur, in which Alfisols have developed (e.g. Bouma et al., 1968; Bouma and van Schuylenborgh, 1969). These Alfisols commonly contain ferriargillans with a continuous orientation pattern (Fig. 2) and derived papules. The well-drained Alfisols in this area have besides the ferriargillans also matriferriargillans. The location of the latter in relation to the former indicates that the matriferriargillans result from a younger soil formation process. This was concluded from the fact that sometimes the two types of cutans occur next to each other around the same void, first the matriferriargillan and then the ferriargillan. Comparison of the present profile in the Holocene deposit with the Typic Hapludalfs in the Pleistocene deposits suggests that the formation of the matriferriargillans is a Holocene process, probably still in process, whereas the ferriargillans are the result of an older, probably Pleistocene soil forming process.

Table 5 shows that the maximum of the matriferriargillans occurs at a greater depth than the maximum of the ferriargillans. The total percentage of both types of cutans is about equal. The papules derived from the ferriargillans exceed the papules derived from the matriferriargillans. The papules are formed from the cutans by biological disturbance, as stresses resulting from swelling and shrinking are absent in this soil. It implies that the amount of cutans decreases due to biological activity. It is clear that the illuviation process which resulted in the formation of ferriargillans was either more intense or has been longer active than the process that formed the matriferriargillans.

Conclusions

Summarizing the geochemical and micromorphological data, the following soil forming processes can be distinguished in the investigated soil developed in Holocene deposits:

— translocation of plasma and fine matrix components, but predominantly of plasma (formation of matriferriargillans). Kaolinite is the most mobile constituent under the prevailing hydrological conditions;
— biological activity;
— partial transformation of smectite into kaolinite;
— redox processes which are too weak to cause macro-translocation of iron oxide; local micro-segregations occur, however.

Classification

The profile is characterized by an ochric epipedon and cambic horizon. As the reduction phenomena are very weak and base-saturation is certainly greater than 60% within 75 cm of the surface, the soil belongs to the Group of the Eutrochrepts, and can be classified as a Dystric Eutrochrept as carbonates are absent within 1 m. This classification does not express the fact that clay translocation has occurred and that this will certainly increase with growing age. The amount of illuviated clay is sufficient for an argillic horizon; however, the cutans do not meet the requirements of the 7th Approximation (Anon., 1967) and the clay enrichment does not take place within 30 cm. As plasma movement generally only takes place in 'dystric' (decalcified) material, one could classify the soil as a 'Udalfic' Eutrochrept.

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