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The morphology and genesis of pseudogley phenomena in a Pleistocene loamy sand in the Netherlands

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Summary

A loamy sand profile with a deep watertable, developed in Pleistocene deposits and displaying mottling patterns and fine-textured bands and tongues, was analysed chemically and micromorphologically. Four soil-forming processes could be established in this soil: (fossile) illuviation of complexes of fine clay and iron oxides, biological activity, pseudogleying, breakdown of the clay fraction at the upper side of the illuviation horizon. A theory for the explanation of the genesis of this soil was developed, stating that soil formation started where frost wedges occurred in this profile during the late Pleistocene and proceeded there further than in other parts of the soil.

Introduction

In many sandy soils, developed in Pleistocene deposits in the Netherlands, pseudogley phenomena occur as intricate patterns of brown to orange and grey or white bleached mottles amidst a brownish-yellow groundmass. In this groundmass fine-textured bands occur and in the mottling patterns fine-textured spots and tongues. Similar phenomena have been described earlier by Blümel (1962), Tavernier (1964) and Bouma et al. (1968). The genesis of these phenomena however is not well understood. In this paper, the macro- and micromorphology of a loamy sandy soil with pseudogley phenomena, occurring in Pleistocene coversands in the southwest of the Netherlands will be described and the genesis will be discussed.

Observations

Macromorphology (see Fig. 1)

Location of the profile: topographical map of the Netherlands, sheet 49E (1961), scale 1 : 25 000; co-ordinates 389, 390 N; 78, 440 E.

The profile is moderately well drained; the watertable lies several metres below the surface.

I AP	0- 53 cm	disturbed topsoil
I B2	53- 63/ 74 cm	colour-B horizon

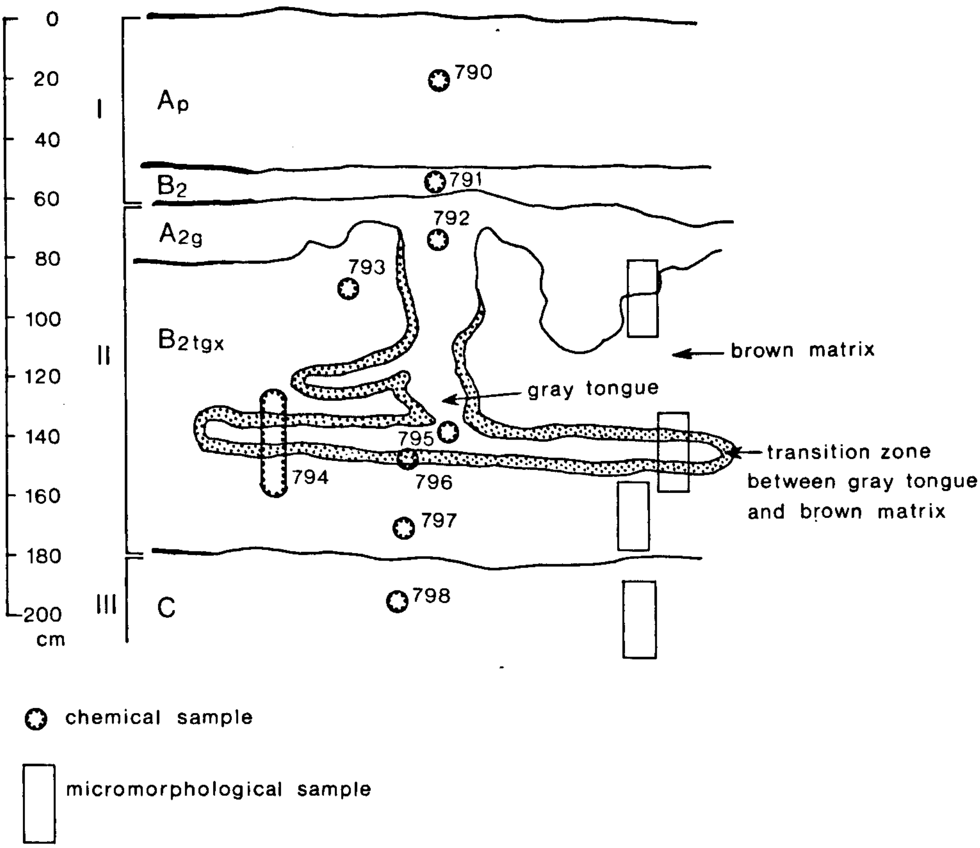

Fig. 1. Schematical presentation of the profile, indicating the location of the disturbed and undisturbed samples.

IIA2g	63/ 74- 73/103 cm	gray (10YR6/1), changing with depth into pale yellow (5Y7/3) loamy sand; no macrostructure; locally undisturbed stratification; diffuse and tongued on
IIB2tgx	73/103-103/180 cm	This horizon can be subdivided into three parts:

a) groundmass; pale yellow (10YR6/3) loamy sand with yellowish brown (10YR5/6) somewhat finer textured bands; undisturbed stratification

b) light gray (10YR7/1), irregularly shaped spots; in some places with stronger extension in vertical and in some places horizontal direction. The vertically elongated spots form an extension of the A2g horizon into the B2tgx horizon. These tongues become narrower with increasing depth and often have at a certain depth horizontal branches. The centre of the grey tongues has no macrostructure; towards the boundary, the stratification is less disturbed. The soil material in the centre of the vertical tongues becomes finer textured with increasing

		depth, as is the case in the horizontal tongues. Many root remnants occur in this finer textured material c) The transition between the groundmass and the irregular grey spots is formed by a bright coloured yellowish brown (10YR5/8), strong brown (7,5YR5/7) or reddish yellow (7,5YR8/7), some millimetres to some centimetres wide zone, which runs parallel to the outer boundary of the grey spots. This sandy loamy zone has a partly disturbed stratification. The boundary towards the grey spots is abrupt, to the groundmass diffuse. The boundary between the B2tgx and the IIIC horizon is abrupt and tongued.
IIIC	> 103/180 cm	very pale brown (10YR7/4) sand with mainly undisturbed stratification; here and there with some narrow (up to some millimetres), bleached, vertical wedges, up to some decimetres long, with a partly disturbed stratification. These wedges are extensions of the bleached tongues in the B2tgx horizon.

Micromorphology (For location of the undisturbed samples, see Fig. 1)

Horizon A2g

The groundmass of this horizon consists of a mixture of skeleton grains (mainly quartz with some micas, chalcedones and glauconites) and very few plasma. On some skeleton grains fragments occur of thin (less than 5 μm thick) yellowish-white clay cutans (primary cutans; De Coninck, 1964). The skeleton grains occur mainly in a random distribution pattern. The voids include simple packing voids and some channels. Special features are absent.

Transitional horizon IIA2g/IIB2tgx

The groundmass is similar to that of the IIA2g, except the occurrance of a primary cutan. Illuviation argillans are present on most of the skeleton grains and along some of the channel walls. These argillans are poor in iron oxides and are fully or for the greater part isotropic, with a grainy appearance. Some of them are weakly orientated. The degree of orientation increases with increasing depth.

Horizon B2tgx

This horizon consists of three parts:
a. the stratified brown groundmass;
b. the grey spots and tongues;
c. the orange brown transition between a and b.

The stratified, brown groundmass. The composition of the groundmass is identical to that in the transitional zone between the IIA2g and the IIB2gtx. With increasing depth the distribution pattern of the skeleton grains changes from mainly a random to a mainly banded pattern. The voids include simple packing voids, vughs and channels. The abundance of the vughs and channels decreases with increasing depth. The special features are restricted to free grain and channel ferri-argillans, which have a continuous orientation.

The grey spots and tongues. The skeleton grains have the same mineralogical composition as those in the brown groundmass. In the grey spots in the upper part of the IIB2tgx horizon and in the centre of the grey tongues the skeleton grains have a random distribution pattern; those in the outer zones of the tongues have a clustered and banded distribution pattern. The voids are of the same type as those in the brown groundmass; the channels and the packing voids are larger and some channels contain root remnants. The special features consist of free grain argillans with a continuous orientation and of channel argillans with a continuous or discontinuous orientation. The latter are most abundant in the lowest part to the grey tongues, where part of the channels are wholly filled up.

The orange-brown transition between the stratified brown groundmass and the grain spots and tongues. The mineralogical composition and the distribution pattern of the skeleton grains is identical to that of the skeleton grains in the brown groundmass. Also the voids are of the same type as in the groundmass. Large channels occur in this zone more frequently than in the groundmass, but less frequently than in the grey tongues. The special features are:

1) free grain and channel ferri-argillans with a continuous orientation. The iron oxide content of these ferri-argillans is here and there much higher than in the brown groundmass. This occurs in places were ferri-hydroxide segregations (see below) cover the clay cutans. The walls of some channels are covered with thick clay cutans; the part of the cutans next to the voids has a lower iron oxide content and a lower degree of orientation, the other part of the cutan has a higher iron oxide content than the ferri-argillans in the brown groundmass, but an identical orientation.

2) iron segregations occur as channel neoferrans and diffusely bounded ferric nodules.

Horizon IIIC

The skeleton grains mainly occur in a banded distribution pattern, here and there in a clustered pattern. Bands poor in plasma alternate with bands lacking plasma. The voids mainly consist of simple packing voids, but some channels occur. Special features are absent.

Chemical and mineralogical data (The location of the bulk samples taken from this profile is indicated in Fig. 1)

From the topsoil two samples were taken: 790 from the IAp (0-53 cm) and 791 from the IB2 (53-63/74 cm). Sample 792 was taken from the IIA2g (63/74-73/103 cm), sample 793 from the upper part (about 100 cm) and sample 797 from the lower part (about 160 cm) of the brown groundmass of the IIB2tgx horizon. Sample 795 is from the grey tongues in the IIB2tgx horizon (about 140 cm) and sample 796 from the transition zone in this horizon between the brown groundmass and the grey tongues (about 150 cm). Sample 794 is a mixture of samples 793, 795, 796 and 797. Finally, sample 798 comes from the IIIC horizon. Some analytical data are given in Table 1. From this table it appears that the clay percentage increases from the IIA2g horizon via the upper part of the brown groundmass to the lower part of the brown groundmass of the IIB2tgx horizon. Within this horizon clay and silt percentages show an increase from the brown groundmass via the transition zone to the grey tongues.

The organic carbon content decreases with depth, except for a slightly higher content in the grey tongues in comparison to the surrounding brown groundmass of the IIB2tgx horizon. The lowest free iron oxide content was found in the IIA2g, the highest content

Table 1. General data.

Designation	Sample No	Granulometry (%)			C (%)	H_2O (%)	pH 0.01 *M* $CaCl_2$	Fe_2O_3 (%)	
		> 50 μm	50-2 μm	2 μm				free	total
Ap	790	83.8	14.2	2.0	0.3	4.3	3.8	0.3	0.6
B2	791	84.8	13.9	1.3	0.2	4.0	3.9	0.3	0.6
IIA2g	792	81.1	17.5	1.4	0.1	3.9	3.7	0.2	0.6
IIB2tgx (brown matrix about 100 cm)	793	80.2	15.0	4.8	0.2	3.8	3.6	0.7	1.2
IIB2tgx (grey matrix about 140 cm)	795	59.6	24.9	15.5	0.3	3.7	3.4	0.6	1.6
IIB2tgx (transition matrix tongues about 150 cm)	796	71.3	19.3	9.4	0.3	3.9	3.5	2.1	2.7
IIB2tgx (brown matrix about 160 cm)	797	74.9	16.5	8.6	0.1	4.2	3.7	0.9	1.6
IIIC	798	94.0	3.2	2.8	tr.	5.0	4.9	0.3	1.0
Mixture of 793, 795, 796, 797	794	68.2	21.5	10.3	0.4	3.8	3.4	1.1	1.4

in the transition zone between the grey tongues and the brown groundmass of the IIB2tgx horizon. The grey tongues and the brown groundmass of this horizon show intermediate percentages.

The chemical composition of soil and clay expressed as oxide weight percentages is presented in Table 2. From this table the normative mineralogical composition of the sand and silt fraction (Table 3) was calculated by the method presented by van der Plas & van Schuylenborgh (1970). As shown by the differences in mica, hematite, strengite and miscellaneous minerals content, the profile can be divided into two and possibly three parts: part I including the topsoil (samples 790 (and 791)), part II the IIA2g and the B2tgx (samples 792 up to 797) and part III the IIIC (sample 798). Possibly part I and part II belong to the same sediment.

Interpretation

From the increase of the clay and free iron oxide content from the IIA2g to the brown groundmass of the IIB2tgx horizon and the presence of ferri-argillans in the groundmass it was concluded that illuvation of fine clay together with complexes of iron oxides occured. From the presence of channel ferri-argillans together with free grain ferri-argillans in the brown groundmass it was concluded that biological activity started before clay illuvation stopped. Because the grey tongues are connected with the IIA2 horizon and have a higher clay content than this horizon and the brown groundmass of the IIB2tgx horizon and also have more clay illuviation cutans than the brown groundmass, it is likely that a preferential illuviation took place in the grey tongues. This is ascribed to a preferential water movement, caused by the absence of stratification and consequently a looser packing in the centre of the tongues.

Groundwater was not encountered within several metres and the position in the landscape makes it very unlikely that the groundwater was high at any time. The grey tongues, however, are surrounded by a bright-coloured band caused by iron segregation in which the free iron oxide content is higher than in the IIA2g and in the IIB2tgx

Table 2. Chemical data (% w/w).

Designation	Sample No	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5	H_2O
A1	790 soil	91.2	2.5	0.6	tr.	0.1	0.2	tr.	0.6	0.7	0.2	0.1	1.5
	clay	60.0	18.2	7.2	0.2	0.1	–	1.3	0.4	2.7	1.3	0.3	9.9
B2	791 soil	89.2	3.1	0.6	tr.	0.1	0.2	0.1	0.7	1.1	0.2	0.1	1.4
	clay	54.3	19.3	11.2	0.3	0.1	–	1.7	0.5	2.5	1.2	0.3	11.3
IIA2g	792 soil	91.9	2.6	0.6	tr.	tr.	–	tr.	0.5	1.1	0.2	0.5	0.7
	clay	55.5	21.8	8.8	0.5	0.1	tr.	1.5	0.3	2.8	1.2	0.3	9.1
IIB2tgx (brown matrix about 100 cm)	793 soil	89.2	3.3	1.2	tr.	0.1	–	tr.	0.4	1.1	0.2	0.6	1.3
	clay	50.1	20.8	11.9	0.6	0.1	tr.	1.6	0.2	2.5	1.0	0.4	10.0
IIB2tgx (grey tongues about 140 cm)	795 soil	85.6	6.8	1.6	0.1	tr.	–	0.2	0.5	1.3	0.4	0.6	2.7
	clay	52.2	21.4	7.4	0.2	tr.	tr.	1.6	0.2	2.3	0.9	0.15	10.3
IIB2tgx (transition matrix – tongues about 150 cm)	796 soil	87.8	4.3	2.7	0.1	tr.	–	0.2	0.4	1.2	0.3	0.7	1.9
	clay	46.2	19.0	18.9	0.8	0.1	tr.	1.6	0.2	2.2	0.8	0.1	10.4
IIB2tgx (brown matrix about 160 cm)	797 soil	90.4	4.1	1.6	0.1	tr.	–	0.2	0.4	1.1	0.3	0.6	1.5
	clay	52.0	20.7	11.6	0.6	0.1	tr.	1.7	0.2	2.6	0.8	0.3	9.6
IIIC	798 soil	88.6	2.1	1.0	tr.	tr.	0.2	0.1	0.6	0.8	0.1	0.1	0.6
	clay	53.8	20.0	9.8	0.2	tr.	–	1.5	0.2	3.1	1.0	0.3	10.5
IIB2tgx (mixture of 793, 795, 796, 797)	794 soil	88.6	5.0	1.9	0.1	tr.	–	0.2	0.5	1.3	0.3	0.6	1.99
	clay	50.3	23.4	1.1	0.6	0.1	tr.	1.6	0.2	2.4	0.8	0.3	10.0

Table 3. Normative mineralogical composition of the sand and silt fraction (mol/100 ml).

Designation	Sample No	Q	Ms	Ab	Or	Hm	Ru	Str.	Misc.	W
A1	790	87.8	2.3	5.6	2.3	0.3	0.1	–	1.6	+3.6
B2	791	84.5	3.2	5.9	4.2	0.3	0.1	–	0.8	+3.5
IIA2g	792	87.4	1.8	4.8	5.2	–	0.1	0.7	–	+1.4
IIB2tgx (brown matrix about 100 cm)	793	87.5	2.8	4.0	4.5	0.1	0.1	1.0	–	+2.3
IIB2tgx (grey tongues about 140 cm)	795	84.4	5.3	4.9	4.2	–	0.2	0.9	0.1	+2.9
IIB2tgx (transition matrix tongues about 150 cm)	796	86.2	4.2	4.0	4.0	0.2	0.2	1.2	–	+2.7
IIB2tgx (brown matrix 160 cm)	797	87.8	3.2	3.9	4.0	–	0.1	1.0	–	+2.1
IIIC	798	88.4	–	4.5	5.4	0.6	0.1	–	1.0	+1.1
IIB2tgx (mixture of 793, 795, 796, 797)	794	85.7	3.9	4.9	4.1	0.2	0.2	1.0	–	+3.1

Q = quartz, Ms = micas, Ab = Na feldspar, Or = k feldspar, Hm = Hematite, Ru = Rutile,
Str. = Strengite, Misc. = other minerals, W = Water.

horizon. Therefore pseudogleying must have taken place (Bouma et al., 1968, 1969). This process is favoured by the higher organic carbon content, ascribed to partly decayed root remnants in the grey tongues. The transition zone contains ferri-argillans with partly higher, partly lower iron oxide contents than the brown groundmass. This indicates that pseudogleying occurred after clay illuviation.

The presence of the grey tongues in the B2tgx horizon, the fact that they are connected with the IIA2g horizon as well as the difference in morphology between the illuviation cutans in the brown groundmass of the IIB2tgx and in the transition IIA2g/IIB2tgx (in fact the former top of the IIB2tgx), points to a breakdown of the clay fraction in the top of this horizon under periodically wet conditions (Brinkman, 1979; Brinkman et al., 1974) and a deepening of the IIA2 horizon.

Discussion

Although the soil forming processes: illuviation of fine clay and iron oxides, biological activity, seggregation of iron oxides and breakdown of clay under periodically wet conditions are readily understood, their causal relation – if present at all – is not yet established. A tentative theory for the genesis of this profile might be the following. Under periglacial conditions with permafrost, prevailing in this area during the late Pleistocene, frost wedges were formed in the sediments designated as deposit II. Deposit I may not have been present at that time. During thawing periods and after the disappearance of the permafrost, the frost wedges were filled up with material of the surrounding groundmass. The absence of a sedimentary stratification and a looser packing in these parts of the profile, compared with the surrounding stratified material, made them the only sites in the profile where roots could penetrate (Slager, 1964, 1966). Further a preferent transport of water (possibly especially in case of heavy downpours) is supposed to have taken place through these tongues, accompanied by a preferential clay illuviation.

The occurrence of gley phenomena in this profile can not be ascribed to presence of a water-logging layer. Nevertheless gley phenomena occur around the spots and tongues with clay illuviation. This may be explained in the following way. The tongues in which the stratification is disturbed become narrower with increasing depth. Moreover illuviated clay accumulates at the bottom of the tongues, reducing pore space there. So water enters readily at the top side, but does not disappear with the same rate at the bottom. The consequence is periodical water-logging in the presence of organic matter from decaying roots in the tongues. The organic matter favours the mobilization of iron, which moves from the tongues to the brown groundmass, where it precipitates. The decomposition of the clay under periodically wet conditions follows from the same conditions as the seggregation of the iron compounds.

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