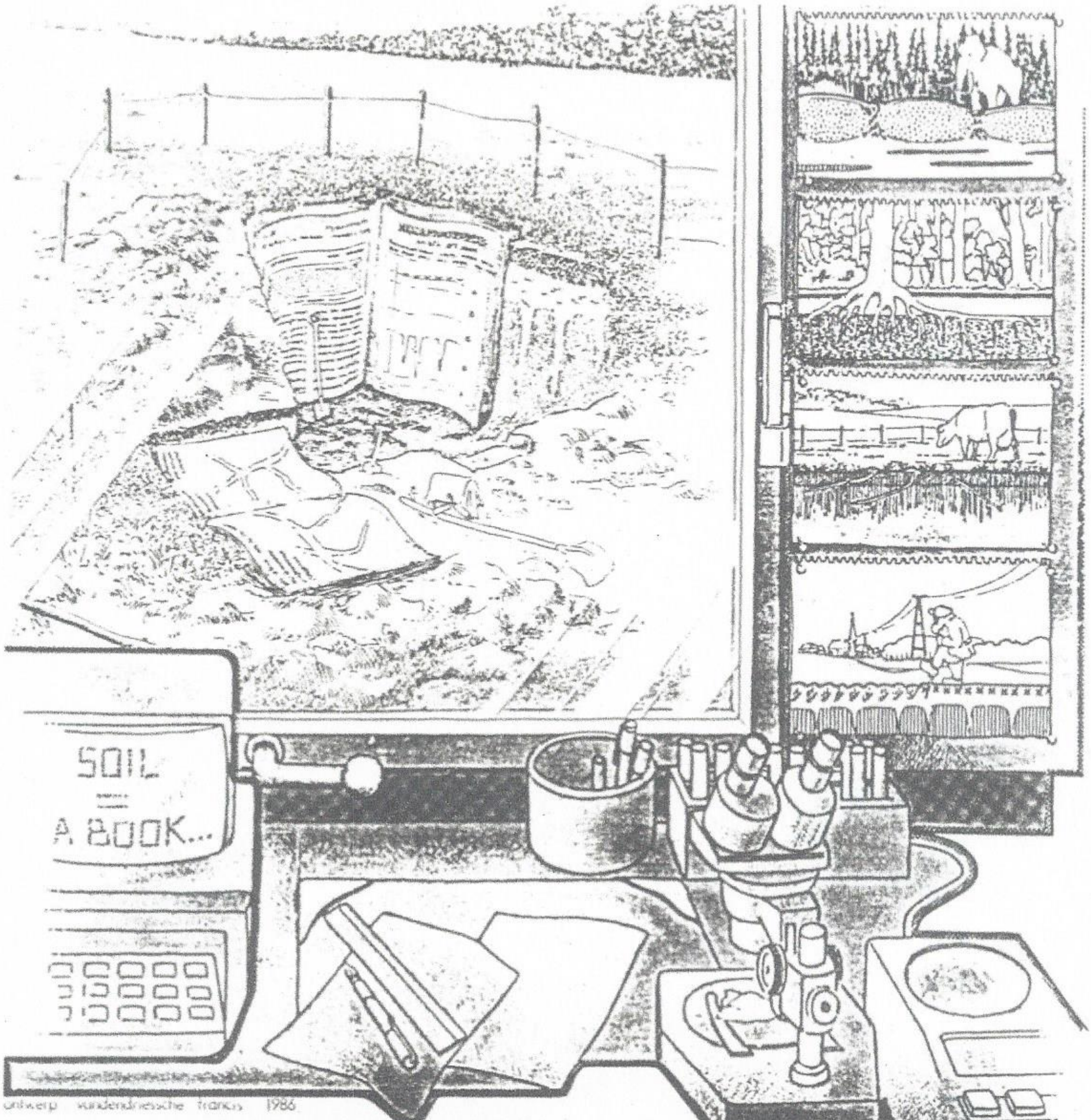
BELGISCHE BODEMKUNDIGE VERENIGING – SOCIÉTÉ BELGE DE PÉDOLOGIE – BELGISCHE BODENKUNDLICHE GESELLSCHAFT - BELGIAN SOIL SCIENCE SOCIETY

Pedologie-Themata
2000 – N° 8

Thematic Day
Soils and Palaeoenvironment Reconstruction Applications in Geo- and Archaeopedology

10 November 1999



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THEMATIC DAY BELGIAN SOIL SCIENCE SOCIETY, 10 NOVEMBER 1999
"SOILS AND PALAEOENVIRONMENT RECONSTRUCTION – APPLICATIONS IN GEO- AND ARCHAEOPEDOLOGY"

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Podzolisation, peat development and dopplerite - soil characteristics of a challenging profile at the Ramskapelle Polder (West Flanders - Belgium)

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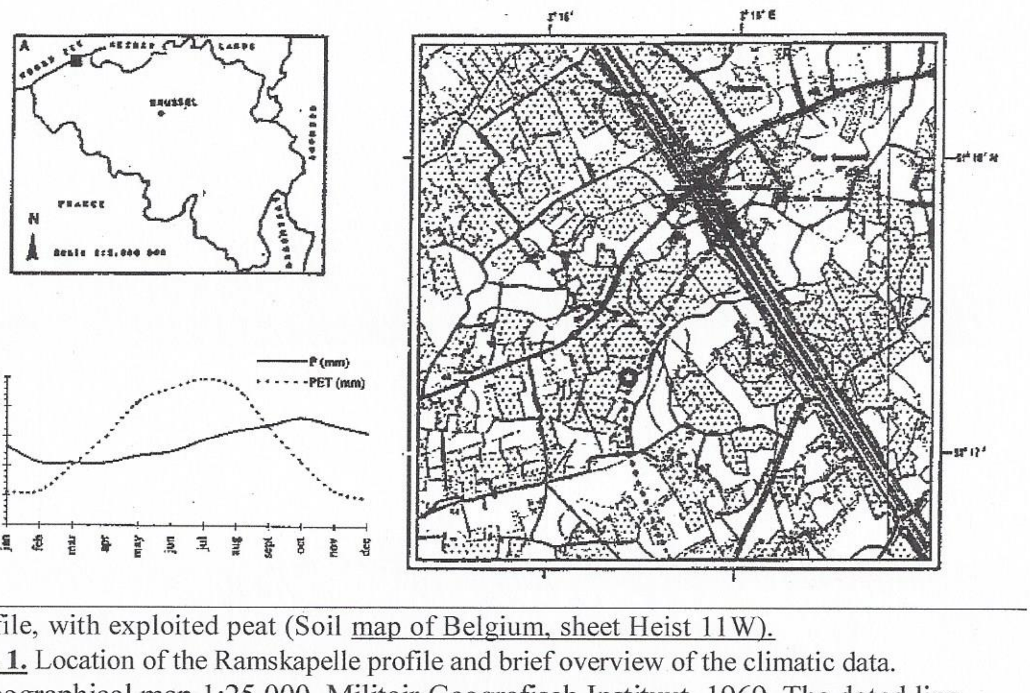
Keywords: Podzol; peat; dopplerite; clay migration; pipeline; West Flanders; Belgium

1. Introduction

The work presented here is part of a larger geopedological study (Becze-Deák, 1993) along the gas pipeline which was laid down through the province of West Flanders (Belgium) in 1992. Along this trench, buried Podzol profiles were observed over hundreds of meters distance in the area of Ramskapelle. The profile selected for this study is among the best preserved sections and is characterised by the occurrence of two types of organic matter accumulation horizons in a sandy sequence. The purpose of this study is the characterisation and the understanding of these accumulations.

The selected profile is situated in the Polder region of the Belgian coast (Fig. 1), where Late Pleistocene sands (Ameryckx, 1954, Soil map of Belgium, Heist 11 West) are covered by Subboreal peat (Allermeersch, 1984). Latter is buried by calcareous marine clays, deposited by a catastrophic change in the regional hydro-regime during the 4th and 10th century (Ameryckx, 1954, Baeteman, 1981, Louwye et al., 1993). The site is at 3 m above the sea level and today is characterised by a climate with excess of precipitation (P) over potential evapo-transpiration (PET). On a yearly basis these are 670 mm and 661 mm respectively at Middelkerke (Koninklijk Meteorologisch Instituut van Belgie 1992 and Becze-Deák, 1993). The deficit of precipitation is situated between April and August (Fig.1). On the soil map of Belgium the site is characterised as OU2, i.e. heavy clay



profile, with exploited peat (Soil map of Belgium, sheet Heist 11W).

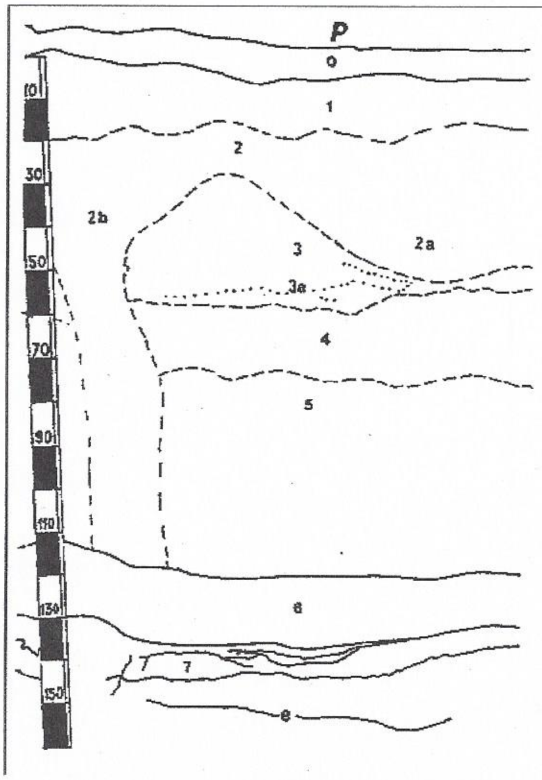
Fig. 1. Location of the Ramskapelle profile and brief overview of the climatic data. Topographical map, 1:25.000, Militair Geografisch Instituut, 1969. The doted line indicates the path of the gas pipeline.

2. Profile characterisation

2.1 Field observations

The field observations have been effectuated along a several meters long section. The sketch of the profile morphology is presented in Fig. 2, while the Table 1 is a short overview of some of the soil characteristics. Under the calcareous clay and peat, the sands are characterised by dark horizons, proved to be organic matter accumulations, both in the upper and lower part of the profile. The morphology of these accumulations is rather different however. Beside these, vertical streaks characterised by numerous dead roots and organic matter accumulation were observed. They go to a depth of 160 cm from the surface of the sands and in horizontal section they follow a polygonal pattern of several meters diameter.

Under the peat all the horizons are non-calcareous and sandy, with no observable differences in the texture throughout. Some clayey bands have been observed in the lower part of the profile. The pedality is massive all through, except the lowest horizon which display a 2-5 mm thick platy pedality.



P - polderclay;

O peat;

1 - Organic matter eluvial horizon (bE)

2 - Upper black organic matter accumulation horizon (**bB$_2$h**)

2a - old treefall with fragments from the eluvial horizon;

2b - vertical organic matter accumulation along cracks;

3 - Reddish organic matter accumulation horizon (**bB$_2$h**)

4 - Brownish transition horizon (**bBCh**)

5 - Lighter coloured transition horizon (**bBC**)

6 - Lower dark brown to black organic matter accumulation horizon (**bB$_2$h$_d$**)

7-8 - Non-calcareous sands (7) with 2 cm thick clayey bands(8) with sharp upper and less sharp lower boundary (**bBtC**)

Fig. 2. Profile sketch (horizon symbols see below)

Table 1. Overview of some of the main field observations (see also above

Horizon*	Brief characterisation	Colour m- moist d - dry	Consistency	Root distribution	Particular observations
P	50 cm thick calcareous clay				
bO	10 cm thick peat				
bE	Organic matter eluvial horizon	m: 10YR 6.5/1 d: 10YR 5.5/1	friable to slightly hard	no roots	
bB2h	Upper black organic matter accumulation horizon	m:2.5YR 1/2.5 d:5YR 2.5/1	friable to slightly hard	very few fine roots	trace of an old treefall (Fig. 2); organic matter accumulation and roots along vertical fissures (Fig. 2);
bB2h	Reddish organic matter accumulation horizon	m: 5YR 2.5/1 d: 7.5YR 3.5/3	friable to hard	few fine roots	
bBCh	Brownish transition	m: 10YR 4/4 d: 2.5Y 6/4	friable to slightly hard	no roots	
bBC	Lighter coloured transition	m: 10YR 6/1.5 d: 2.5Y 8/2	very friable	local concentration of decomposed root fragments	
bB2hd	Lower dark brown to black organic matter accumulation horizon	m: 10YR 3/2 d: 2.5Y 4.5/2	very friable to loose	no roots	accumulation consisted of irregular bodies with sharp upper and lower boundaries; the lower boundary coincides with the clayey bands;
bBtC	Non-calcareous sands with 2 cm thick clayey bands with sharp upper and less sharp lower boundary	m: 10YR 7/1 d: 5Y 7.5/2	loose	no roots	

* horizons symbols are according to FAO 1990; the symbol **hd** is introduced for the organic matter of dopplerite type (see discussion below), the **b** stands for the buried horizons and **B2** stands for the best developed B horizon.

2.2 Meso and micromorphological observations

The studied soil is characterised by a dense packing of the sand grains and very few or no biopores. As observed in the field, all the horizons are massive at the mesoscale. The microstructure is described in Table 2. The soil groundmass is composed of only coarse material. From the mineralogical point of view it is very homogeneous and it is composed of dominant quartz and quartzite grains. Some feldspar grains (up to 10-20 % frequency) with common alteration features are also present. As accessory minerals (less than 1% frequency) zircon, garnet, staurolite, hornblende, glauconite, tourmaline and tremolite have been identified. Layers of stratified finer sand have been observed in the bBtC horizon, which explains the slightly higher finer sand content obtained through the texture analyses (Table 3). This change in the grain size distribution is interpreted as a result of variations in the energy of winds during the sediment deposition.

As pedofeatures the various types of organic matter accumulations and some thin, yellow limpid clay coatings have been recorded. Their presence/absence is represented in the Table 2. Beside the monomorphic and polymorphic organic matter accumulations, typical for Podzol soils, a particular gelly-like accumulation has been identified throughout the profile both at the level of the meso and micromorphological observations. This accumulation is homogenous dark brown, rather shiny when moist and in opposition to the traditional monomorphic accumulation which is forming coatings, it is present in most of the cases irregular accumulations in packing pores and/or bridging the sand grains (Fig. 3 and 4). It always appears as ***the most recent observable feature of pedogenesis***. As its environmental significance is different from the other accumulations (see discussions below), its presence/absence has been recorded separately.

Table 2. Overview of the meso and micromorphological observations

Horizon	Micro-structure	C/F ratio	Polymorphic organic matter	Monomorphic organic matter (Fig. 3 and 4)		Limpid clay coatings	Particular observations
				reddish brown forming cracked coatings	dark brown to black with gelly-li ke aspect in the packing pores		
bE	IGM (60%) BG (40%); PG (>1%)	80/20	common	absent	very few	-	salt and pepper aspect; few plant remains including roots;
bB2h	IGM (50-30%) PG (40-60%) BG (10%)	70/30	common	few	few	-	few plant remains
bB2h	PG (90%) IGM (10%)	75/25	few	**abundant thick coatings**	few concentrations	-	very few plant remains;
bBCh	PG (80%) IGM (10%) SG (10%)	90/10	few	common concentration of organic matter (both finer sandy	common the monomorphic types) in the layers;	-	very few, strongly decomposed plant remains;
bBC	SG (70%) PG (20%) IGM (10%)	98/2	absent	very few	few to local concentrations	-	some traces of stratification;
bBhd	PG (50%) BG (50%)	80/20	absent	absent	**abundant (also coating the grains)**	-	
bBtC	SG (50%) PG (50%)	98/2	absent	absent	absent	+	traces of stratification;

Legend for Table 2:

Terminolo gy after Bullock et al. (1985)

Microstructure: IGM - intergrain microaggregate; BG - bridged grain; PG - pellicular grain; SG- single grain.
C/F : the coarse fine ratio here is based on micromorphological observations and refers to the proportion of mineral grains (coarse) and organic matter (fine).

Terminology for the organic matter description after De Conninck et al. (1986):

Polymorphic organic matter: amorphous organic matter without recognisable vegetal or fungal structure. It forms a discontinuous mass formed by the juxtaposition of polymorphic elements that have a globular from, with sharp or diffuse boundaries caused by differences in colour and density.
Monomorphic organic matter: amorphous organic matter without recognisable vegetal or fungal structure, which forms a continuous mass with relatively uniform colour and density. It is present in the form of coatings or irregular, angular or subangular units with sharp boundary.

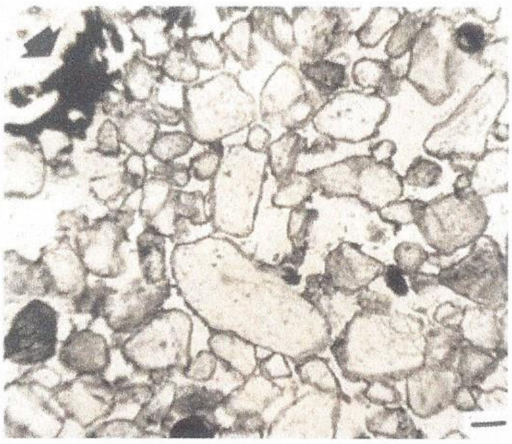


Fig. 3. Two types of monomorphic organic matter
One coating the grains, the second (of dopplerite type, see discussion below) forming irregular accumulations in the pores (arrow). Reddish organic matter accumulation (bB2h) horizon. Transmitted light. Scale bar: 147 µm

Fig. 4. Monomorphic organic matter of dopplerite type
(see discussion below) forming irregular accumulations in the p ores. Lower organic matter accumulation (bB2hd) horizon. Transmitted light. Scale bar: 92 µm

2.3 Analytical data

<u>Table 3.</u> Results of standard soil analyses

Hor.	OC	OM*	N	C/N	Total(%)			VFSa	FSa	MSa	CSa	VCSa
	%	%	%		Clay (0 -2 Lm)	Silt (2-50 Lm)	Sand (50-2000 Lm)	%	%	%	%	%
bE	1.65	2.11	-	-	1.2	3.9	94.9	21.0	68.0	5.7	0.3	0.0
bB$_2$h	3.25	3.24	0.084	38.7	1.7	3.2	95.2	19.5	68.5	7.0	0.3	0.0
bB$_2$h	2.43	3.59	0.069	35.2	0.8	2.3	96.9	25.0	67.3	4.4	0.2	0.0
bBCh	0.72	1.13	-	-	0.3	1.0	98.7	15.6	74.6	8.2	0.2	0.0
bBC	0.18	0.45	-	-	0.6	0.2	99.3	15.9	66.3	6.5	0.3	0.0
bBCh$_d$	0.63	1.33	0.036	17.5	0.0	1.0	99.1	18.2	71.9	8.9	0.1	0.0
bBtC	0.14	0.38	-	-	0.5	2. 1	97.5	28.0	68.5	1.0	0.0	0.0

Horizon	pH	CEC	Exchangeable cations				BS	Fe2O3	Al2O3	MnO
	H_2O	Am.Ac; pH=7 (cmol/100 g soil)					%	%	%	%
			Mg	Ca	Na	K		dithionite**		
bE	7.1	6.3	0.9	7.4	0.2	0.1	136	0.03	0.02	0.00
bB$_2$h	6.9	14. 5	2.3	15.3	0.3	0.1	124	0.04	0.22	0.00
bB$_2$ h	6.9	11.6	1.7	10.5	0.3	0.1	108	0.04	0.38	0.00
bBCh	6.9	4.9	0.9	5.4	0.2	0.1	134	0.04	0.14	0.00
bBC	6.3	1.6	0.6	1.8	0.2	0.2	175	0.05	0.10	0.00
bBCh$_d$	6.2	3.1	1.2	2.9	0.2	0.2	145	0.03	0.08	0.00
bBtC	6.7	3.0	0.9	1.5	0.1	0.2	90	0.04	0.20	0.00

* - Determined by heating to 550 °C during 8 hours.
** - By heating the samples at 550°C the upper three samples became white, while the others became comparably very weakly pinkish, ***showing that the Fe content of all the horizons is very low to absent.*** As the dithionite extractable Fe shows very low values, no oxalate analyses were made despite the fact that the discussion here concerns podzolisation processes. The absence of Fe is explained by the combined effect of **i.** very low Fe content of the original soil (composed mainly of sand sized quartz grains, see micromorphology and Table 3) and **ii.** possible remobilization of all the existing Fe, induced by the high ground-water levels that existed during the peat growth (see discussion below)

3. Discussion

The morphology of this profile with an organic matter accumulation horizon of the Podzol type under a peat cover, buried under calcareous marine clays, is an indicator of ***important environmental changes***. The podzolisation is a ***process characteristic for a leaching climate and good drainage conditions*** (Soil Survey Staff, 1960) and Podzols do not form in soils that are permanently water saturated (Mokma and Buurman., 1982). On the contrary the peat on top of this podzol profile ***is a clear indicator of an environment characterised by a permanent high water-table.***

The field and laboratory study clearly indicate two different types of organic matter accumulation. Their origin and environmental significance are discussed here together with few other particular soil characteristics.

3.1 Organic matter accumulation due to podzolisation processes

The upper part of the profile is characterised by the presence of polymorphic organic matter, with a particular concentration in the second horizon and a reddish-brownish monomorphic organic matter with particul ar concentration in the bB_2h and bBCh horizons, forming cracked coatings (Table 2 and Fig. 3). These organic matter accumulations are related with the podzolisation processes (De Coninck et al. 1986), i.e. accumulation and migration of organo-mineral complexes. Despite the fact that no Fe analyses by the oxalate method were performed to check the requirements for the Soil Classification, the field observations and the meso- and micromorphological analyses clearly indicate that the podzolisation process was active at a certain moment of the evolution of this complex.

The several traces of possible treefall, the presence of the roots up to several centimetres diameter at the depth of 160 cm, the charcoal fragments observed during the micromorphological study are all indicators of an *earlier vegetation cover with trees*. Based on pollen analyses it is known that on the drier sandy areas, during the climatic optimum of the Atlantic ***in the NW Europe***, the climax vegetation was largely a mixed Oak forest (Quercetum mixtum) and Brown Forest soils, characterised by a mull humus, were developed (Havinga, 1984). This soilscape considerably changed during the period between the Subboreal and Subatlantic, due to the gradual, natural and anthropic induced degradation and acidification of these soils. Such soil degradation is not surprising in these mainly quartzitic sandy (see micromorphological and analytical data) soils. As a result of this soil degradation the vegetation changed, and birch (Betula), beech (Fagus) and later heat (Calluna) associated with a mor humus became more and more important constituents of the vegetation (Havinga, 1984). The podzolisation processes were active during this period characterised by acid soil conditions. In fact ***for the studied section*** the soil characteristics observed are surely dated to before the peat development, which formed during the Subboreal (Allermeersh, 1984), ***indicating that here soil acidification and podzolisation was an earlier process*** than those what is mentioned by Havinga (1984). We can conclude that the soil degradation here is dating already to the Atlantic (second part?) or latest to the beginning of Subboreal. This time difference might be related with the very poor chemical characteristics of the soil, composed of quartzitic sands with nearly no silt and clay (see also the micromorphology and Table 3). However an earlier anthropic impact in the region can not be completely excluded neither.

An interesting aspect of the studied profile is the absence of a clear organic matter eluvial horizon. The meso and micromorphological study show that the upper, lighter coloured horizon contains a considerable amount of organic matter. This can be explained by a turbation processes induced by the fauna activity as well as by treefalls (Fig. 2).

The profile morphology shows that the morphology of the well developed podzol did not change under the influence with the subsequent rise of the groundwater table. A similar situation has been described by Havinga (1984). The chemical conditions on the contrary did change. The high pH and base saturation (Table 3) of the studied sequence are rel ated to the calcareous clay on the top of the section. These conditions are not favourable for the podzolisation processes (Mokma and Buurman, 1982), ***showing once more that the observed morphology is relict.*** A certain loss of iron from Podzol B horizon as a result of the increased anoxic conditions is not excluded neither. This process however is not detectable neither chemically nor morphologically.

3.2 Organic matter accumulation associated to the peat cover

The jelly-like, monomorphic organic matter accumulations observed in the packing pores throughout the profile (Table 2 and Fig. 3-4), but with a high concentration in the horizon bB_2h_d, is very similar with the organic matter sticking to the plant tissue fragments of a peat sample. Therefore it is supposed that ***this substance is originating from the peat cover***. Its occurrence throughout the profile and covering the soil characteristics related with the former podzolisation is a further argument for an origin related with the peat. In fact the macromorphological aspects of this accumulation are very similar with the feature described as "waterhard" layers by Koopman (1988) and Dekker et al. (1991) in The Netherlands. The

waterhard layer is a brown layer, with sharp upper and lower boundary, consisting of a dense (1.82 g/cm^3) sandy matrix with some organic matter (1.3-4.7 %, by ignition method), occurring locally in the coversands which are covered by peat. The lower boundary of these accumulations coincides with a less permeable layer. They consist of individual bodies of 2-200 meters long, which do not conform to the topography of the present-day surface, but they tend to be horizontal and are restricted to the slightly elevated topographic positions and are missing from the depressions. The above mentioned authors agree that this organic matter is issued from the overlying peat and they consider that it resembles the mineral known as ***dopplerite***. The dopplerite was firstly reported in 1849 by Doppler (Vaughan et. al., 1989) and it was considered first a result of interaction between colloidal solution of humic acid with calcium ions (Milks, 1908 in Vaughan et. al, 1989), subsequently a salt of humic acid (Schenider, 1922 in Vaughan et. al., 1989). Recent more sophisticated chemical analyses have shown that the dopplerite has its origin in the sphagnol component (a lignin-like polymer) of the Sphagnum sp. moss (Vaughan et. al., 1989).

The accumulation of dopplerite in the packing pores or as coatings throughout the profile, suggest a dynamics related with illuviation of the colloidal material in dispersion conditions, as proposed also by Koopman (1988). The field record of the sharp upper and lower boundary of the accumulation, as well as the lower boundary marked by a less permeable layer is a further argument for the illuviation processes. It should be underlined however the special character of this illuviation, as its formation is related with an environment of high groundwater table. Particular to the studied sequence is the presence of the calcareous marine clayey deposits on top of the peat. The role of these clays in the dynamics of the accumulation can not be deduced from the available data. However, as we have evidences of illuviation, we can only presume that the calcium brought in the system must have stopped the migration process. This means that the formation of the studied waterhard layer is ***not active*** in the studied soil. This is different from the case reported by Koopman (1988), who suggest a present day active process in a site which is not covered by calcareous sediments. It should be considered however that the Na^+ ions present during the period of accumulation of the marine sediments might have contributed to the dispersion of the organic colloids. More systematic observations of the presence/absence of associated features could provide more information on the above discussed hypotheses.

To summarise the enrichment of organic matter observed in the lower part of the section corresponds to the substance known as dopplerite, it is related with the p eat deposit; its accumulation is most probably related with an illuviation processes. According to the available data is only possible to affirm that the ***dopplerite formation in the studied section is belonging to the time span of the Subboreal*** (period of the peat growth) and ***up till the 4th century AD***, when the marine clays started to be deposited.

Beside the various organic matter accumulations the environmental significance of two other soil characteristics will be briefly discussed.

Cracking pattern

The vertical cracking pattern, forming polygons *in the sands* , reaching a depth of at least 160 cm can be best explained as a result of thermal contracti on of an ice rich frozen ground. This type of structure has been described as one of the possible characteristics of permafrost (Lachenbruch, 1962). As the studied sands are Late Weichselian deposits (Ameryckx, 1954, Soil-map Heist 11W) and as, according to the paleoclimatic record, permafrost was continuous in NW France, Middle and North Belgium and The Netherlands in the Younger Dryas period (Van Vliet and Langohr, 1981, Langohr, 1983), ***we conclude that these fissures most probably are recording this important cold event of the Tardiglacial.***

3.4 Clay coatings

The thin limpid clay coatings observed in the deepest soil horizon (Table 2) indicate a ***climate with an excess of precipitation, at least on seasonal basis, and a site characterised by good drainage conditions***. The physico-chemical conditions favourable for clay migration are represented by a pH range of 5.5-6.5, i.e. conditions of little exchangeable Al, Ca and Mg on the colloidal soil fraction (McKeague, 1983). Considering the dominant quartzitic sandy character of this soil, such pH conditions can be only explained by a weakly calcareous character of the original sediment, which by decarbonatation fulfilled the requirements of the clay migration processes. This means that this clay illuviation can be considered as a fingerprint of an evolution stage which dates from before the podzolisation. The original weakly calcareous character could not be traced in the studied sections , as the decalcification depth in these landscape positions was deeper than the available trenches. Nevertheless subsequent observations along the gas-pipeline trench (Becze-Deák, 1993) confirmed the above assumption.

4. Conclusions

The study of soil characteristics, from macro down to micromorphological level, permitted to detect fingerprints of subsequent, very variable environmental conditions.

The deep vertical polygonal cracking pattern in the sands witness ***permafrost conditions*** *most probably* ***dating back to the Tardiglacial***. The traces of clay migration suggest the calcareous character of the original sediment as well as a ***leaching climate*** (at least seasonal excess of precipitation) and ***good drainage conditions in the time span*** after the sediment deposition and before the podzolisation, i.e. covering ***the Late Glacial and the beginning of the Atlantic***. The two generations of organic matter accumulation indicate further changes in the environmental conditions. The first one is characterised by polymorphic and monomorphic organic matter and is related ***with podzolisation due the soil degradation, in a leaching climate and good drainage conditions. This is probably related to the period between the second part of the Atlantic and the beginning of the Subboreal***. *This soil degradation seems to occur here earlier than what is mentioned in the literature*. The peat accumulation in the upper part of the sequence, and the associated jelly-like organic matter accumulations, in the lower part of the profile, testify an ***important rise of the groundwater table during the Subboreal and up till subrecent periods. In fact we assist to a change from well drained soil conditions towards a nearly permanently inundated environment. The last phase of this evolution is marked by the dynamic tidal floods.***

Finally the authors wish to emphasise the importance to associate soil scientist to the works of pipeline digging. Such works represents unique opportunities to increase considerably the knowledge about soilscape evolution in a period where there is little or no more founds for soil survey. The continuos trenches in particular allow to select the best suited landscape positions for more detailed studies.

Acknowledgements

We wish to express our sincere thanks to Georges Stoops for the thin sections of peat provided and for the repeated very helpful discussions on the micromorphological aspects. We strongly appreciated his contribution in the administrative struggle for the fellowships, which made this study possible. These fellowships were provided by the Ghent University (1991-1992) and by the Flemish Community (1992-1993).

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