

GEOMORPHOLOGICAL SIGNIFICANCE OF PALEOSOL ANALYSIS; A CASE STUDY OF A DRIFT SAND SECTION WITH FOSSIL PODZOLS ON THE ICE-PUSHED RIDGE WEST OF UELSEN, W. GERMANY¹

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ABSTRACT

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Geomorphologists have shown an increasing interest in soils. This also applies to paleosols, which provide information on past environments in terms of their age, landscape development and geomorphic processes. The nature of these aspects of paleopedology is demonstrated with the analysis of a sequence of buried podzols in drift sand overlying a truncated periglacial soil on the ice-pushed ridge of Uelsen, W. Germany. Evidence for the reconstruction of the geomorphic history of this area is derived from grain size, heavy mineral and pollen analyses. The sequence of buried soils reflects the same climatic periodicity as was observed in peat of Atlantic/Subboreal age found in the Wilsumer Moor, 4 km to the NE; dry phases with eolian activity were followed by humid phases with soil formation and splash erosion. The present surface is formed by an exhumed podzol of Atlantic/Subboreal age.

INTRODUCTION

The relationship between geomorphology and soil science is generally acknowledged. It is easily seen why this relationship should exist. Landforms as well as soils are shaped by climate working for a certain period on the materials at the earth's surface. There is also a mutual control: the relief of landforms influences soil development and specific soil characteristics in their turn influence landform development. It is reasonable to assume that this also applies to landforms and soils formed in the past. Evidently, information on past conditions buried in fossil soils can be used for the reconstruction of the geomorphic history of a landscape.

Geomorphologically relevant information that can be derived from paleosols falls into 5 categories: a) past environmental conditions, b) past geomorphic processes, c) age, d) past land forms and surfaces, and e) pedological control.

Ad a) Soil profiles reflect environmental conditions which also control geomorphic processes. Best-known is climate which, partly through vegetation, determines major soil features. A variety of techniques is available for the identification of paleoenvironments (see GERRARD, 1981, p. 150 ff.). In view of the nature of the pedological processes involved, many of these techniques use a chemical or mineralogical approach. Also palynology is widely used for this purpose.

Ad b) Present-day geomorphic processes like rain splash and slope wash leave a definite imprint on the soil material (RUHE, 1975) and on correlative colluvial deposits (KWAAD & MÜCHER, 1977). As the processes involved are mainly physical, grain size and fabric analyses are important tools in their understanding. Experimental research of geomorphic processes such as carried out by DE PLOEY (1980) and SAVAT (1982) is relatively recent and little of the results have penetrated the field of paleopedology.

Ad c) Knowing the age of a paleosol allows correlation with paleosols elsewhere. Perhaps it is more important to know the length of time it took for the paleosol to develop. Some argue that this is impossible because it presupposes knowledge of the rates of soil development which is not available even for modern soils, whereas others like BRUNNACKER (1965) make ample use of this type of evidence.

Ad d) Reconstruction of the past shape of a land form should be the main concern of geomorphologists studying paleosols, but paradoxically this has never been a major issue. In this respect, one of the most fundamental contributions of paleopedology to geomorphology is BUTLER's (1959) K-cycle concept (K from khronos = time). In his model, DAVIS' normal cycle of erosion in which landscapes develop by continuous downwasting of interflaves is substituted for a succession of soil cycles, each with its own ground surface development in terms of climate and time. DAN & YAALON (1968) expanded this model to include processes. Although BUTLER's concept is much more realistic than DAVIS' model, it remains surprising that it has been so little applied in geomorphological research outside Australia (KWAAD & MÜCHER, 1977).

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Ad e) Another aspect which has received little attention is the paleosol as a factor of landscape formation. Induration of illuvial horizons formed by past pedological processes may increase the resistance of surface materials and thus protect specific slope areas against erosion. ELBERSEN (1982) describes for Spain how soft calcic horizons have a planing influence on the relief but when locally hardened bring about the opposite. Indurated plinthite formed at the base of slopes and now capping hill crests in the humid tropics provides another example. Control may also be indirect: buried organic surface horizons in dune sands along the Dutch coast cause stagnation of water and erosion by overland flow (RUTIN, 1983).

The following study is an attempt to integrate these categories of information in the analysis of a paleopedological section. The land form concerned is a remnant of an ice-pushed ridge in W. Germany. Evidence of the remodelling of this land form during the Holocene is derived from a sequence of paleosols buried in drift sand deposits. Georef and Cab Abstract data bases were consulted for relevant literature.

SITE AND SECTION

The ice-pushed ridge of Uelsen was remodelled by a number of processes since its formation during the Saalian (RICHTER ET AL., 1951), and very little remains of its original surface (JUNGERIUS & WIGGERS, 1971). Outstanding features of the present-day geomorphology are parallel ridges and elongated hills of material rich in gravel, which are remnants of a long

period with selective erosion by slope wash. They could well be the product of the humid temperate climate of the Eemian interglacial, because the relief was suppressed by solifluction during later periglacial conditions (VAN DER HAMMEN, 1961). These phases of the erosional history of the area are reflected in correlative slope deposits preserved at sites of accumulation (BOS ET AL., 1971). The geomorphic processes of the Holocene have once more increased the relief. This also applies to eolian processes: the reduction of relief by the deposition of coversands during the Pleistocene was succeeded in the Holocene by the formation of dunes and blow-outs.

The investigated section was found in the drift sand area 3 km west of Itterbeck. The section consists of 4 podzol profiles, which slightly dip (2 degrees) to the north owing to their position on the flank of a small dune. A summary description of the section is given in Table I. Laboratory investigations included grain size distribution, heavy mineral and pollen analyses.

The framework of the following analysis is based on BUTLER'S (1959) K cycle. This is the sequence of events which commences with the creation of a new surface in the landscape, continues with the development of soils on that surface, and is concluded by the supersession of that soil surface by erosion or burial. The two aspects of each K cycle are the unstable phase and the stable phase. The unstable phase (Ku) is the initiation of a new K cycle, and is evidenced by erosion of soils and burial of soils. The stable phase (Ks) is the period of soil development. The chronological record runs backward in time, with K1 representing the present surface.

Table I: Summary description of sequence of buried paleosols in drift sand. s=sand, ls=loamy sand, nd=not determined.

Depth (cm)	Horizon	Colour	Texture	Humus %	pH (H20)	Special features
0-5	A	10YR2/2	s	1.1	5.1	
5-12	E	10YR7/3	s	nd	nd	
12-19	C1	10YR6/8	s	nd	nd	
19-29	C2	10YR6/4	s	.1	5.5	dark laminae, roots at base
29-41	2A	10YR2/2	s	.9	5.1	
41-45	2E	10YR7/2	s	nd	nd	
45-52	2Bh	10YR4/3	s	nd	nd	
52-70	2C1	10YR7/8	s	nd	nd	
70-76	2C2	10YR6/6	s	.1	5.1	dark laminae
76-83	3A	10YR2/1	s	1.2	4.9	
83-93	3E	10YR5/2	s	nd	nd	
93-97	3Bh	10YR4/3	s	nd	nd	
97-116	3C1	10YR6/8	s	nd	nd	
116-130	3C2	10YR5/8	s	.3	4.8	dark laminae
130-140	4A	10YR2/2	s	1.3	4.9	few small gravel
140-151	4E	10YR5/3	s	nd	nd	
151-155	4Bh	10YR4/4	s	nd	nd	
155-170	4C	10YR6/8	s	nd	nd	mottled 10YR3/4, brittle
170-180	4C2	10YR5/6	s	.2	4.9	dark laminae
180-185	IIC	10YR7/4	s	.2	5.1	stoneline
185+	IIICx	10YR6/2	ls	.2	4.7	mottled 10YR5/3, gravelly, fragipan

Table II: Relative increase (+) or decrease (-) of percentage by weight in grain size fractions of (fossil) surface horizons compared to parent materials.

Soil Horizons	grain size fractions (μm)								
	0-50	50-75	75-105	105-150	150-210	210-300	300-420	420-600	600-2000
A:C2	+	+	0	+	-	0	-	-	+
2A:2C2	+	+	+	+	-	-	-	+	+
3A:3C2	+	+	+	+	-	-	+	+	+
4A:4C2	+	+	+	+	-	-	+	+	+
IIC:IIICx	-	-	-	+	+	+	+	+	+

K7 CYCLE

The material at the base of the profile (IIICx) consists of gravelly sand (Table II). The fragipan is the oldest paleopedological feature in this section and dates from the time that the gravelly sand formed the surface soil. It shows the brittle consistence and mottling that were also found by VINK & SEVINK (1971) in an 'Arctic Soil' in the Dinkel valley, 25 km to the SE. This arctic soil was formed during the Upper Pleniglacial. The relationship between fragipan formation and permafrost conditions has recently been surmised by VAN VLIET & LANGOHR (1981). The periglacial soil of which the fragipan remains represents the stable phase of ground surface K7 which has now disappeared. Its former position in relation to the present surface or to the original surface of the ice-pushed ridge at the time of its formation is not known.

K6 CYCLE

The periglacial soil was truncated and replaced by a stoneline (IIC) which in a comparable situation in the Dinkel valley has been correlated with the Beuningen Gravel Bed of Upper Pleniglacial age (VINK & SEVINK, 1971, fig. 90). The stoneline corresponds to the description of the Beuningen Gravel Bed

by DOPPERT ET AL. (1975, fig. 2.1.10). It represents a pavement formed on a surface bare of vegetation. Such pavements are found on the ice-pushed ridge within 1 km to the north where they comprise ventifacts indicating erosion by wind. These ventifacts have the same sharp margins and distinct keels as antarctic ventifacts which are subjected to high velocity conditions (WHITNEY & SPLETTSTOESSER, 1982).

With this nearby evidence of strong wind erosion in the past, it is tempting to attribute the truncation of the periglacial soil to deflation. However, this is not clear from the grain size distribution. With respect to the subsoil, the surface horizon of that time has lost material from all fractions < .105 mm (Table II; Fig. 1). The resulting grain size distribution of the IIC horizon could point to turbulent flow such as provoked by falling raindrops during runoff (SAVAT, 1982). This will bring silt and clay in suspension and only these will be evacuated from very gentle slopes (POESEN & SAVAT, 1980). It is also possible that melting of snow provided the low-energy environment in which grains < .1 mm could be entrained.

Apart from snow meltwater, solifluction is also known to have had great influence on landscape formation in Western Europe during the last Glaciation (VAN DER HAMMEN, 1952). The action of this mass-wasting process is excluded here because it is characteristically non-selective as to grain size.

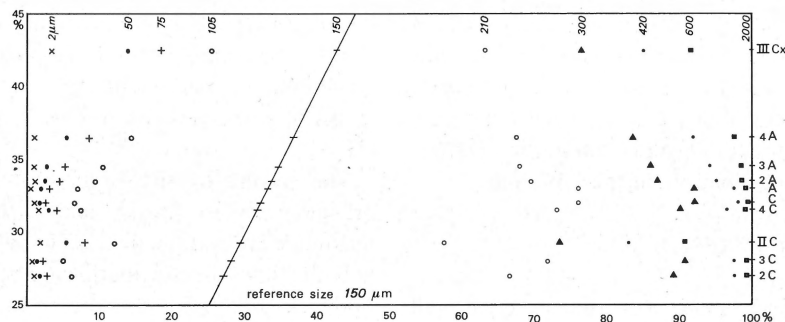


Fig. 1

Grain size distribution of paleosol sequence in drift sand. The position of a sample on the abscissa is determined by the percentage smaller than reference size which is 150 μm (See Doeglas, 1955). This is a fragment of Doeglas' original diagram in which the abscissa runs from 0% in the lower left hand corner to 100% in the upper right hand corner.

There are no traces left of the complex pedology of the Late Glacial as observed in areas of cover sand accumulation (SLAGER ET AL., 1976). Apparently the stoneline is all that is left of the long period between the Upper Pleniglacial and the accumulation of drift sand in the Holocene.

K5-K3 CYCLES

Profile characteristics

The erosion of the soil in the IIIC material was followed by intermittent sedimentation of wind-blown sand. The stable periods (K5s-K3s) separating the successive periods of accumulation (K5u-K3u) were sufficiently long for podzol profiles to develop. These profiles comprise a very dark brown humic A horizon overlying a very pale brown to brown eluvial (E) horizon and a dark brown B horizon in which organic matter accumulated. The whole sequence consists of very friable sand and has no structure. There are many circular spots of lighter colours which in recent podzols have been attributed to tree roots (SCHELLING, 1955). However, this interpretation has been challenged because the spots generally lack the elongated form which would follow from root growth (DR. IR. H. J. DE BAKKER, 1983, pers. comm.). All boundaries are clear but irregular due to root activity. The surface soil is poorly developed and has no B horizon.

The parent material is brownish yellow in its upper part (C1), and somewhat darker in its lower part (C2) due to the admixture of reworked organic matter derived from surrounding surface soils which were the first to be removed by erosion. The nearness of these soils follows from the fact that the humic skins of the grains were not rubbed off during transport. The organic matter is often present in fine bands. Similar bands in drift sand of the Veluwe have been attributed to interruptions in the sand accumulation which were too short to permit soil formation (SCHELLING, 1955).

The geomorphic implications of the profile sequence are clear. In the history of this area there was a time with drastic changes in the geomorphic system: periods with a reduced vegetational cover and bare surfaces allowing wind erosion and the deposition of wind-blown sand at protected places alternated with periods of stability with a closed vegetation and the development of podzol profiles. Laboratory analysis provides more detailed information on these periods.

The unstable phases (K5u-K3u)

The grain size distribution is characteristic for drift sand derived from cover sand (KOSTER, 1978). As the sand was deposited on the northern flank of a dune, it is reasonable to assume that it was carried by winds from the cover-sand plains in the south. There are small but systematic differences in the grain size distribution of the successive layers of the drift sand. From the 4C to the 2C horizon, the median diameter increases

(177, 180, 185 μm) as does the quartile skewness (3.1, 4.6, 9.8), while the kurtosis decreases (1.5, 1.4, 1.2). If these differences are translated in terms of dune topography (FOLK, 1971), it means a shortening of the length of travel, possibly because the dune crest in the south approached the investigated section. The trend is reversed from the 2C to the present surface material. In the same line of reasoning, this means that the dune crest shifted away again to the south. In a dynamic environment like an inland dune area, such shifts in topography are to be expected.

Fossil pollen is preserved in these soils and can be used for the reconstruction of the vegetational environment. However, caution is requested because the interpretation of pollen diagrams of soils is notoriously difficult (HAVINGA, 1964). In this specific case, complications arise from the simultaneous deposition, with the sand, of pollen grains derived both from existing soils and from the vegetation at the time of accumulation (DR. R. T. SLOTBOOM, 1983, pers. comm.). The latter source, in which *Pinus* and *Ericaceae*, notably *Calluna*, played an important role, is mainly responsible for the pollen content of the C horizons and provides background noise to the pollen spectra of the podzols (Fig. 2).

The stable phases (K5s-K3s)

Apart from the development of podzols, there are two other features characterizing the time of stability in between the periods of sand accumulation. The first of these is the heavy mineral distribution which shows a systematic difference between the A and C horizons, the former generally being more depleted of 'weatherable' minerals (Table III). VINK & SEVINK (1971) observed the same phenomenon in a podzol of Atlantic/Subboreal age in coversand found below Late Holocene drift sand in the Dinkel valley. They stated: 'The decrease in content of alterites, epidotes, amphiboles and pyroxenes accompanied by a relative increase of garnet etc., is presumably the result of a rather strong process of weathering' (p.175). However, in the present case the differences in heavy mineral distribution may well be due to syn-or postdepositional sorting as will be demonstrated below. Also, soil profile development of 10 to 20 cm in drift sand may not take more than 45 years (SCHELLING, 1955) and intervals of this length of time could be too short for weathering to have much effect.

The second feature is the systematic difference in the granulometry of the A and C horizons. Although the maximum is always in the .105 to .300 mm class, the fractions at both tails of the distribution are better represented in the A horizons (Fig. 1). Also, the texture of the A horizons is generally finer which can be inferred from the position on the .150 mm reference line in Fig. 1. Notable exception is the surface soil: A and C horizons are closely similar in granulometry which agrees with the poor profile differentiation observed in the field.

Table III: Heavy mineral analysis (.05-.5 mm)

	Horizon									
	A	C2	2A	2C2	3A	3C2	4A	4C2	IIC	IIIC
opaque	28	22	33	26	49	27	25	24	17	33
alterite	1	5	2	5	5	8	2	6	-	3
zircon	5	8	16	7	6	7	15	8	18	20
tourmaline	11	10	6	6	7	10	11	11	4	4
rutile	—	—	2	—	5	2	6	2	6	5
anatase	—	—	1	—	1	—	—	—	1	—
sphene	—	—	1	—	1	—	—	—	1	—
staurolite	4	5	3	3	8	5	4	5	2	4
garnet	44	32	26	42	30	14	24	16	33	13
kyanite	2	3	3	1	3	2	3	5	3	—
sillimanite	1	—	1	—	2	1	—	1	—	—
andalusite	—	—	2	1	—	1	1	1	—	2
pistacite	23	33	26	28	25	29	23	25	24	31
clinozoisite	1	1	1	—	—	3	1	3	1	4
zoisite	—	—	—	—	4	3	—	—	—	1
saussurite	—	2	—	2	1	5	1	3	—	2
amphibole green	3	6	9	9	7	15	10	17	7	13
amphibole brown	1	—	1	1	—	—	—	2	—	—
enstatite	—	—	1	—	—	—	—	—	—	—
augite	5	—	1	—	—	3	—	1	—	1
diopside	—	—	—	—	—	—	1	—	—	—

There are two explanations for the granulometric differences between the A and C horizons. The first of these implies the mechanisms of transport by wind. DE PLOEY (1980) demonstrated the simultaneous existence of 2 modes of sand transport during drift. At high levels the flow is well-sorted and consists of median-sized grains in saltation, whereas near the ground there is a dense basal drift with a relative concentration of coarse sand together with the finest fractions. It is possible that this basal drift was captivated by the colonizing vegetation which eventually formed the podzol.

According to the second explanation, the A horizons were affected by rain splash erosion during the time of soil formation. Rainfall simulator experiments on a number of sands showed that the coarsest and finest fractions were always deficient in the sands splashed out from the flume (POESEN & SAVAT, 1980). The high degree of sorting exhibited by colluvium derived from podzols elsewhere on the ice-pushed ridge (BOS ET AL., 1971) shows that splash erosion has been an effective process. However, the rate of soil erosion must have been slow because soil-forming processes could keep pace.

The pollen in the A horizons reflects the vegetation prevailing during the stable periods of soil formation (Fig. 2). *Alnus*, characteristic of conditions with a relatively high groundwater table scores high in the surface soils at the expense of *Pinus* and *Calluna*. The pollen diagram confirms the evidence of periodic changes from dry to humid provided by the soil profile sequence.

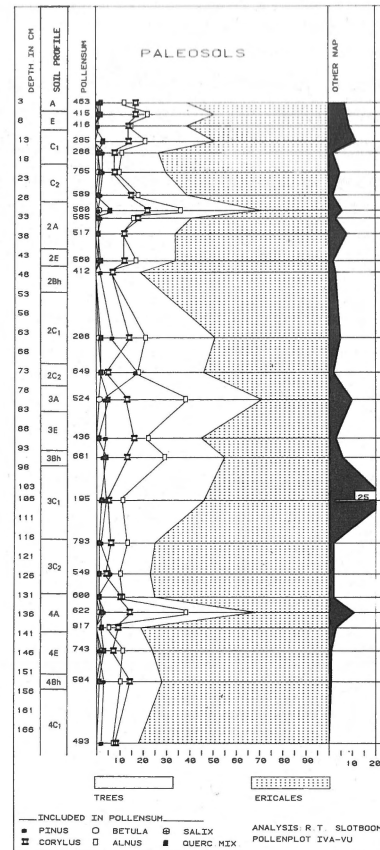


Fig. 2
Pollen diagram of a paleosol sequence in the drift sand area 3 km west of Itterbeck.

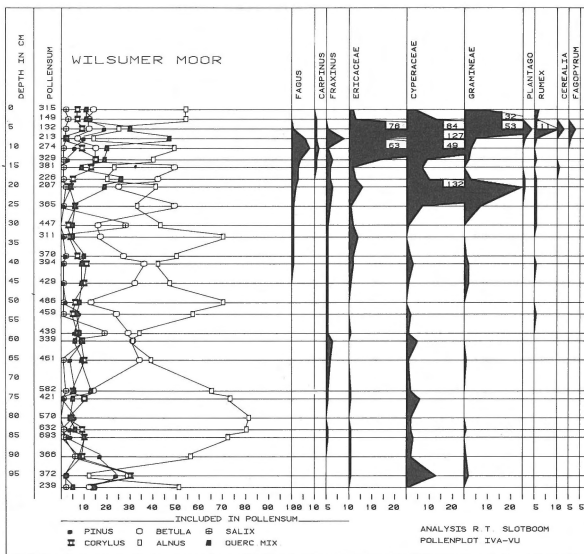


Fig. 3
Pollen diagram of reference section, Wilsumer Moor.

Dating

Pollen content places the sequence of drift sand and buried podzols in the Holocene, before the distribution of cerealia pollen by agricultural activities. The necessary reference for more precise dating was obtained from a peat section in the Wilsumer Moor, just north of the ice-pushed ridge. The relevant results are shown in Fig.3. The boundary between Firbas zones VII (Atlantic) and VIII (Subboreal) is at 40 cm depth, and between zones VIII and IX (Subatlantic) at 21 cm depth. Attention is drawn to the negative correlation between *Alnus* and *Betula* which is attributed to climatological variations in the Atlantic/Subboreal. During humid periods with

rising groundwater table, *Alnus* could occupy extensive areas on and around the ridge, whereas the growth of *Betula* on poorer soils was enhanced during dry periods with a low groundwater table. Cyclic periodicity of *Alnus* is known from literature. WYMSTRA ET AL (1971, p.409) and VAN GEEL (1978, p.268) found 80- and 32-year cycles in the Wietmarscher Moor, 25 km to the ENE.

It is postulated that the pollen in the sequence of buried soils reflect the same succession of drier and more humid periods as that in the Wilsum profile. It places the periodic change from landscape instability and wind action to landscape stability and soil formation in the Atlantic/Subboreal. This agrees with findings elsewhere. In the Dinkel valley, SEVINK ET AL (1970) found an increase of *Alnus*, *Corylus*, *Quercus* and *Calluna* at the boundary Atlantic-Subboreal and expected podzolisation from this time on, whereas VAN DER HAMMEN (1971) stated for the same area: 'also some older wind-blown deposits occur which are of Atlantic-Subboreal age'. Predominance of *Alnus* and *Corylus*, and abundant *Ericaceae* are reported by VANHOORNE (1962) for fossil podzols of Subboreal age in eolian sand in Belgium.

K2-K1 CYCLES

At first glance the uppermost solum appears to be the last of the sequence of podzols, representing the K1s phase. However, the pollen spectrum of the surface soil belongs to a period prior to human occupation, lacking cerealia and accompanying pollen grains of weeds (Fig.2). Therefore, the surface soil must have been formed as far back as perhaps the Atlantic/Subboreal, was buried under an unknown quantity of drift sand, and is now being exhumed by erosion processes. It is known from the dunes along the Dutch coast, that humic

Table IV: Summary of information on the geomorphic history of the site derived from paleosol analysis.

HORIZON	K CYCLE	AGE	CLIMATIC CONDITIONS	SURFACE COVER	GEOMORPHIC PROCESS	POSITION RELATIVE TO PRESENT SURFACE
A	K2s/K1u	Atlantic/ Subboreal	moist	open	deflation?	higher
C2	K2u	do	dry	open	eolian depos.	
2A	K3s	do	moist	closed	splash	lower
2C2	K3u	do	dry	open	eolian depos.	
3A	K4s	do	moist	closed	splash	lower
3C2	K4u	do	dry	open	eolian depos.	
4A	K5s	do	moist	closed	splash	lower
4C2	K5u	do	dry	open	eolian depos.	
IIC	K6u	Upper Pleniglacial	?	absent	wash	
IIICx	K7s	Upper Pleniglacial	peri- glacial	?	?	higher?

sand is not so easily eroded by wind as clean sand (JUNGERIUS ET AL., 1981). In fact, a widespread paleosol buried in the dune sand is locally exposed because the loose sand cover is stripped by deflation. There as here, it means that an unstable phase prevailing at the present day (K1u) coincides with the K2s phase. However, these paleosols when exposed cannot resist erosion for any length of time and their impact on slope form is short-lived.

CONCLUDING REMARKS

The investigated section contains in varying degrees all of the 5 categories of geomorphologically relevant information that can be provided by paleosols. The paleopedological analysis shows that the simple designation of the hilly area west of Uelsen as an 'ice-pushed ridge' is doing injustice to the complicated geomorphic history since the glaciers left the area. Some of the events can be reconstructed from fossil features like the paleosols described in this paper. Considering the age of the ridge, the periods covered by the paleopedological record is very short: a fraction of the Pleniglacial and perhaps a few hundred years of the Atlantic or Subboreal. Even within these short intervals the relief at the site of the investigated section was considerably modified in response to the changing environmental conditions (Table IV).

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