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Barbara Manikowska*
Łódź

AEOLIAN ACTIVITY DIFFERENTIATION IN THE AREA OF POLAND DURING THE PERIOD 20–8 KA BP

Abstract

Three regions, which differ in the effects of aeolian processes in the period 20–8 ka BP, have been distinguished. In the southern region accumulation of loess up to about 15–12 ka BP took place. Locally, at the margin of patches, loess became superimposed with younger sand cover. The middle and northern regions are areas of accumulation of aeolian sand deposits. This regions belong to the European "sand belt", but the former is within the limit of the Vistulian glaciation while the latter beyond this limit. In the middle region three stages of aeolian activity have been recognized. The first stage (20–15 ka BP) is marked by intense deflation, formation of aeolian pavements, aeolisation of surface material, and incorporation of wind born grains into fluvial deposits and into sands that infill ice wedges. In the second stage (14–10 ka BP) accumulation of aeolian deposits, which gave rise to sand covers and dunes, occurred. In the Oldest Dryas widespread sandy-dusty covers and some dune hillocks were produced, in the Older Dryas accumulation of covers went on and huge dunes developed, in the Younger Dryas merely transformation of dunes occurred and small sand lenses were accumulated on the dune slopes and in the immediate neighbourhood. In the third stage, during the older Holocene the pedogenetic processes interrupted with episodes of very little accumulation on the dune slopes followed.

The breaks in aeolian activity are expressed as the fossil soils in dunes. Initial soil dates back to the Bølling, weakly developed podzolic soil or pedolith – to the Allerød, while well-developed rusty soil – to the Preboreal. From the Boreal Phase the process of podzolization began.

The northern region was exposed to wind action after retreat of the Vistulian ice sheet. At first pavements and sandy infillings of ice wedges were produced, afterwards during the Older and Younger Dryas sand covers and dunes originated with the Allerød fossil soil inside.

The northern region reveals no Oldest Dryas aeolian sands but loess of this age is present. As opposed to the middle region, there was here more abundant accumulation of sand in the Younger Dryas than in the Older Dryas period. Less frost cracks in aeolian deposits were found in the North. Appreciable differences in abrasion of aeolian grains have been observed. In the middle region wind abrasion persisted throughout the Vistulian, and was extremely intensive during the Upper Plenivistulian. This resulted in aeolo-fluvial sediments which became the source of the Late Vistulian aeolian sands. In the northern region wind abrasion began after the last ice sheet had retreated and aeolian sands originated from unchanged glacial material. Distinct aeolian abrasion of dune and cover sands in the middle region is inherited from the Plenivistulian processes and the Late Vistulian aeolian cycle introduced the slight changes, if any.

Differentiation in the effects of aeolian processes followed from the variation of environment. Over the 20–15 ka BP northern Poland was covered with the ice sheet. In middle Poland the cold desert existed. In southern Poland the tundra dominated. It was the period of intense deflation in middle Poland and of loess accumulation in the southern Polish uplands. About 15 ka BP, in the lowlands of middle Poland the discontinuous tundra vegetation appeared, which favoured the formation of sandy-dusty covers. From ca. 12.5 ka BP advancing trees gave rise to the dune building. The fixing of dunes occurred during the Allerød when the forest spread over their surfaces, and in the Preboreal Phase when the Holocene period of pedogenesis began.

* Department of Soil Science and Palaeopedology, University of Łódź, 91–735 Łódź, ul. Źródłowa 47, Poland.

INTRODUCTION

The interval 20–8 ka BP is the time of intense aeolian activity in the European periglacial zone to which the area of Poland belonged. This large increase in aeolian processes was, however, a continuation of preceding activity.

The course of aeolian processes during the period 20–8 ka BP varied in Poland regionally. The area beyond the ice sheet remained under the influence of aeolian activity throughout the discussed period, while the glaciated territory experienced these processes only after the ice mass had melted away. In southern Poland loess occurs in the shape of large patches, whereas middle Poland is a classical area of aeolian sand accumulation. In each zone sandy and dusty deposits tend to intercalate, but their proportion and distribution in the aeolian mass vary. Differentiated course of aeolian processes during the discussed period in Poland gives the reasons for the following regionalization:

1. the southern region – accumulation of typical loess, occasionally finished with superimposition of aeolian sand covers;

2. the middle region – intense abrasion and deflation, afterwards accumulation of aeolian cover sands with a mixture of dust, and formation of dunes;

3. the northern region – local accumulation of loess-like sediments, and next formation of aeolian cover sands and dunes.

The first region is located in the uplands of southern Poland. The lowlands of middle and southern Poland, beyond the limit of Baltic ice sheet, belong to the second region. The third region there is in northern Poland, within the limit of last glaciation (Fig. 1).

Covers of sand at the top of loess series occur locally. Such phenomenon was controlled by the immediate neighbouring of sandy areas and, generally, by the decay of loess supply. The end of loess accumulation is dated at 15–12 ka BP. More detailed information on the age of overlying sand covers is not available (Jersak, *et al.*, 1992; Maruszczak, 1991; Mycielska-Dowgiałło, 1965). Evolution of loess areas is presented in the other article of this volume (Śnieszko, Dwucet).

The richest and most complete pattern of aeolian processes in the period 20–8 ka BP has been reconstructed to the middle Poland region. There were made basic investigations on stratigraphy and lithology of dunes (Baraniecka, 1982; Chmielewska, Chmielewski, 1960; Dylikowa, 1964, 1969; Izmaiłow, 1975; Krajewski, 1977; Kobendzina, 1961; Manikowska, 1982, 1985; Maruszczak 1964; Pernarowski, 1958; Rotnicki, 1970; Szczypek, 1986; Tobolski, 1969; Urbaniak-Biernacka, 1976; Wasylikowa, 1964; Wojtanowicz, 1972) as well as detailed analyses of the fossil soils in

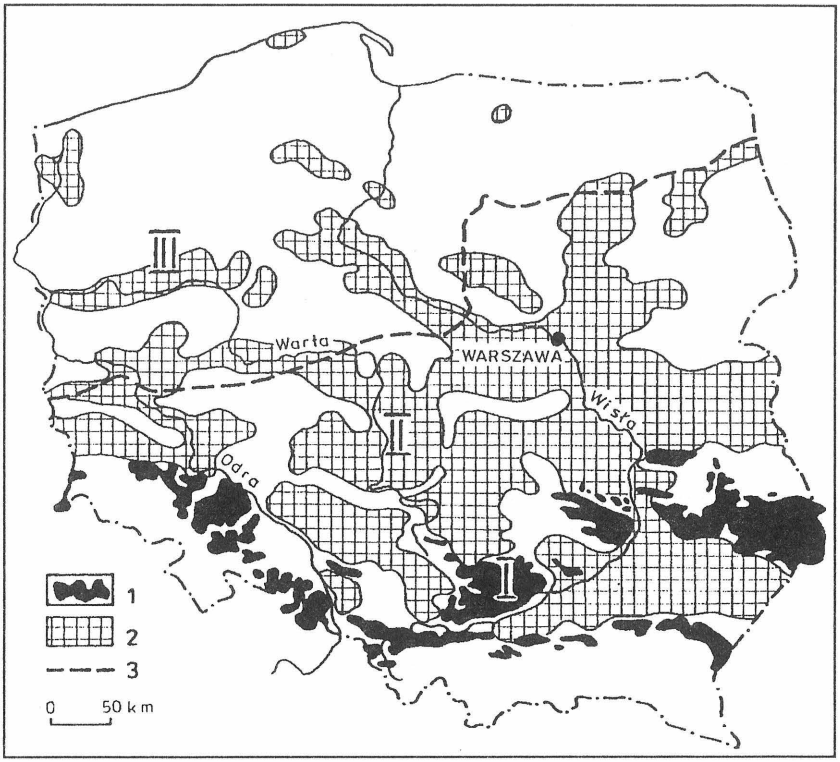

Fig. 1. Regional diferentiation of aeolian activity in the area of Poland

I - southern region; II - middle region; III - northern region; 1. area of loess accumulation; 2. area of aeolian sand (dune) accumulation; 3. extent of North Polish (Vistulian) ice sheet - the limit between middle and northern region

dunes by means of palaeopedological methods (KONECKA-BETLEY, 1981, 1982, 1991; MANIKOWSKA, 1985, 1986; MANIKOWSKA, BEDNAREK, 1994). Moreover, the effects of aeolian activity before the Late Vistulian dune-forming stage were recognized (BURACZYŃSKI, 1993; DYLIK, 1969; GOŹDZIK, 1980a, 1981, 1986; MANIKOWSKA, 1985, 1993).

Dunes of northern Poland have been studied from many years (BOGACKI, 1969; GALON, 1959; GRZYBOWSKI, 1981; KOZARSKI, 1978; KOZARSKI *et al.*, 1969; KOZARSKI, NOWACZYK, 1992; MRÓZEK, 1958; STANKOWSKI, 1963; URBANIAK, 1967). Recently the data on aeolian activity have become completed here with the analyses of loess-like deposits and coarse aeolian residuals (KOZARSKI, NOWACZYK, 1991a, 1992). The work by Nowaczyk (1986) has provided with vast information on dunes to the whole area of Poland against the background of Europe, whereas KOZARSKI (1990) and NOWACZYK (KOZARSKI, NOWACZYK, 1991b) have given the short latest summary.

Presented article deals with the effects as well as the variation of aeolian processes in the period 20–8 ka BP within the second and third regions, namely these revealing the distinctive prevalence of aeolian sand deposition and being regarded as part of the European "sand belt". Both regions offer an opportunity to distinguish: firstly – the stages that differ fundamentally in the manner of aeolian action, secondly – the phases showing the different pattern of accumulation with inactivity or weakened operation in between.

Terminology concerning aeolian deposits of the European "sand belt" has been ordered by KOSTER (1982), who suggested a distinction between a e o l i a n c o v e r s a n d s and a e o l i a n d u n e s a n d s. Previously, in the Netherlands, the term cover sands was used to all Weichselian aeolian deposits which originated under periglacial conditions, provided there was no direct relation to a former shoreline or a river course. According to KOSTER, increasing proportion of dune deposits within the Weichselian aeolian sediments eastwards, within the "sand belt", justifies the above division, despite the frequent lithologic identity of both formations.

The commoness of cover sands causes the Netherlands to be the area of classic investigations (*cf*. SCHWAN, 1988). Inland dunes are there rather rare and not very large, as if "sunk in a sea" of undulating sand covers. In Poland, so further eastward, many areas reveal distinct dune pattern and these very forms especially attract the researchers' attention. The Late Vistulian aeolian covers, available widely in Poland, provide no basis for chronological recognition, whereas the dunes contain many dateable fossil soils, which became fundamental to chronostratigraphy of aeolian deposits. In Poland, a mere one special work on aeolian cover sands of the small area in the western part of country exists (NOWACZYK, 1976), nevertheless the authors dealing with the aeolian deposits and the Pleistocene stratigraphy fairly often mention them, especially in publications that refer to middle Poland.

The distribution of aeolian sands in Poland is inferred from the extent of dune fields with distinct convex forms. Isolated flat covers may elude the observation. On the other hand, it is known that thin aeolian layers in the soil profiles of periglacial plains occur practically everywhere, and distinct (>1 m thick) aeolian deposits in central Poland may occupy about 50% of some sheets of geological maps at a scale of 1:50,000 (KLATKOWA 1984). The mapping of all aeolian sand covers in Poland as well as the full evaluation of their age and environmental influence, particularly of their control over the present-day soil, are still a question of time.

KOSTER accepts the name c o v e r s a n d s to be applied also to the aeolian sand deposits older than the Netherlands' O l d e r C o v e r S a n d s I, thus these coming from more than about 27 ka BP (KOLSTRUP, 1980; VAN DER HAMMEN, 1971), but this term is rectricted to sands of the aeolian origin, and can not be used to the other ones, which in some publications is given (e.g. BURACZYŃSKI, 1993).

A dune in geomorphological terms is, according to KOSTER, the form at least 5 m high and maximum slope greater than 5–6°. Cover sands may create either undulating surfaces (5.0–0.5 m, 5.0–0.5°) or plains (<0.5 m, <0.5°).

KOSTER does not use the term c o v e r s a n d s to describe the aeolian deposits younger than the Late Glacial and Early Holocene formations. To the aeolian material, in origin of which relatively young local resedimentation of terrestrial deposits (usually cover and dune sands) is involved, the name d r i f t s a n d s is employed. Drift sands rest on a clearly developed soil profile and/or are characterized by yellow-greyish colour, a loose to moderately loose grain-packing, an absence of periglacial structures and a presence of layers rich in organic matter. They are the anthropogenic sediments, though not always result immediately from man's activities. Drift sands could have been involved in dunes and covers, however the latter are not called "cover sands". Resulting landscape is chaotic, small-hummocky; drift sands are often superimposed on the older, gentler aeolian relief.

Drawing conclusions on the time of aeolian activity, a cautious approach to the wind born deposits developed in the environment of fluvial operation is advisable. It is possible for fluvial deposits exposed along the river channels to be permanently transported by the wind, even when the climatic conditions are not favourable. Differences between the aeolian activity along rivers and on interfluves have certainly been the reason for determining the separate sediment category in the Netherlands, namely the r i v e r d u n e d e p o s i t s (KOSTER, 1982).

The terms proposed by KOSTER can be successfully employed to the deposits and the aeolian pattern of Poland. To complete the terminology, the f l u v i o - a e o l i a n deposits resulting from a combination of aeolian and fluvial transport need to be considered. Such deposits contain wind abraded grains, which evidences aeolian activity. Palaeoperiglacial fluvio-aeolian deposits are thought to be the material consisting of laminated sands and silts as well as occasionally lenses of coarser sand, which infills pleniglacial valleys in the Netherlands (VANDENBERGHE, VAN HUISSTEDEN, 1988; VAN HUISSTEDEN, 1990).

Considering the origin of periglacial aeolian deposits, the possibility of accumulation of sand (also dust) together with snow or sand alternating with snow that melts out afterwards, has been taken into account as well. Such kind of deposits are named n i v e o - a e o l i a n (DÜCKER, MAARLEVELD, 1957; KLATKOWA, 1965; KOSTER, 1988; KOSTER, DIJKMANS, 1988; RUEGG, 1983; SCHWAN, 1988).

In the Pleistocene stratigraphy of the northwest Europe the period 20–8 ka BP belongs to part of the W e i c h s e l i a n named U p p e r

Pleniglacial and Late Glacial (VAN DER HAMMEN, 1971). The Late Glacial – Pleniglacial boundary is placed in the Netherlands after accumulation of the Beuningen Gravel Bed and the Older Cover Sands II and before deposition of the Lower Loamy Bed and/or the peat layer ascribed to the Bølling Interstadial s.l. (i.e. the period between the rise of *Artemisia* curve in the pollen diagrams and the beginning of Older Dryas). KOLSTRUP (1980) has found in the Netherlands the Epe organic horizon, dated 14,000 ± 150 years BP, which according to the palaeobotanical data represents warming – a rise in temperature of July up to 12°C at least, of January up to –8°C. Since the data from Great Britain have suggested yet slightly earlier moment of such tendency to be possible (COOPE, 1977), she does not settle the beginning of Late Glacial warming but evidences the climatic amelioration in comparison with the period 19–15 ka BP. KOLSTRUP has not decided to move the Pleniglacial–Late Glacial boundary at the Epe Phase (Tab. I).

In the Scandinavian as well as Polish palaeobotanical publications, the name Earliest Dryas (or Oldest Dryas) is employed for the phase prior to the Bølling s. s. fluctuation (i.e. the period from the rise of *Betula* curve to the beginning of Older Dryas) that stops together with the end of fitodeposition. The lower limit of this phase is neither palynologically nor chronologically precisely determined.

In middle Poland, many years ago, basing on the investigations by means of geological, palaeobotanical and archaeological methods (CHMIELEWSKA, CHMIELEWSKI, 1960; DYLIKOWA, 1964, 1968; WASYLIKOWA, 1964) three Late Glacial phases of dune formations, named Oldest, Older and Younger Dryas, were distinguished. The names were in relation to the Scandinavian terminology, assuming that the whole initial dune-forming period prior to the Bølling Phase s. s. is the Oldest Dryas. This way the lower limit of the Oldest Dryas was determined sedimentologically. Chronology of such defined Oldest Dryas was recognized later through the radiocarbon dating of immediately older organic deposits (GOŹDZIK, 1980a; MANIKOWSKA, 1982). Their age was established at about 14.5 ka BP, thus the Oldest Dryas in Poland has been located between 15–14 ka BP – the Kamion Phase and 12.5–12.0 ka BP – the Bølling Phase s. s. (Tab. I).

There was also found out that the oldest aeolian deposits of middle Poland overlie deposits being comparable with the Beuningen Gravel Bed in the Netherlands, therefore they can be correlated to the Older Cover Sands II that are included there to the Upper Pleniglacial, not to the Late Glacial. The Epe horizon is older than the Older Cover Sands II, thus is comparable in age with the Kamion horizon in middle Poland (MANIKOWSKA, 1991b).

Table I

The Netherlands (VAN DER HAMMEN, 1971, KOLSTRUP, E., 1980)

		chronostratigraphical units	lithostratigraphical units		ka BP
Holocene		Atlantic			
Holocene		Boreal			– 8 –
Holocene		Preboreal			– 10 –
Weichselian	Late Glacial	Late Dryas	Younger Coversand II		
Weichselian	Late Glacial	Allerød	Usselo Bed or soil		
Weichselian	Late Glacial	Earlier Dryas	Younger Coversand I		– 12 –
Weichselian	Late Glacial	Bølling	Lower Loamy Bed		
Weichselian	Pleniglacial	Upper Pleniglacial	Older Coversand II		
Weichselian	Pleniglacial	Upper Pleniglacial	Beuningen complex	Epe bed	– 14 –
Weichselian	Pleniglacial	Upper Pleniglacial	Beuningen complex	Gravel Bed	– 16 –
Weichselian	Pleniglacial	Upper Pleniglacial	Beuningen complex	Stokersdobbe Bed	– 18 –
Weichselian	Pleniglacial	Upper Pleniglacial	Beuningen complex	Staphorst Bed	
Weichselian	Pleniglacial	Upper Pleniglacial	Beuningen complex	Soil or surface	– 20 – – 22 –
Weichselian	Pleniglacial	Upper Pleniglacial	Older Coversand I		

North – West Poland (KOZARSKI, NOWACZYK, 1991, 1992; NOWACZYK, 1986)

deposits, soils		phases
podzol		Atlantic Boreal
dunes and cover sands		Preboreal Younger Dryas
podzolic soil		Allerød
dunes and cover sands		Older Dryas
organic layer 12 770 ± 190 12 130 ± 140 loess		Bølling Oldest Dryas
ventifacts sand wedge fillings, cover deposits with aeolian sand admixture	North-Polish Glaciation	Pomeranian Poznań Leszno
peat layer * 22 050 ± 450 22 230 ± 480		Konin–Maliniec II
fluvio–aeolian sands		

Central Poland (MANIKOWSKA, 1977, 1985, 1991, 1993)

		phases	deposits, soils	RM grains mean %	frost wedge structures	Vegetation (WASYLIKOWA 1964; BALWIERZ in the same volume)
Holocene		Atlantic Boreal Preboreal	iron–humus podzol sand bed iron podzol sand bed (pedolith) rusty soil 87 20 ± 80, 9380 ± 50, 9740 ±100			pine forest
Vistulian		Younger Dryas	sand covering dunes	52.5	single frost (?) cracks	park steppe tundra
Vistulian	Late Glacial	Allerød	weakly podzolised soil, pedolith			pine forest birch forest
Vistulian	Late Glacial	Older Dryas	big dunes, cover sands	51.9	small ice wedge casts – occasional in dunes, fequent in cover sands	park tundra
Vistulian	Late Glacial	Bølling	initial soil 11 980 ± 70, 12 235 ± 260			open park like forest
Vistulian	Late Glacial	Oldest Dryas	small dunes cover loamy sands	52.4		steppe tundra
Vistulian	Late Glacial	Kamion	brown alluvial soil 14 300 ± 300, 14 590 ± 270			grass tundra(?)
Vistulian	Plenivistulian	Upper Plenivistulian	cold desert soil, aeolian pavement aeolo–fluvial sands and gravels, aeolian sands filling frost wedges	55.5 57.3	large sand wedge casts and ice wedge cats	pioneer communities (grasses and sedges) cold desert
Vistulian	Plenivistulian	Kuców	tundra soil 21200 ± 220, 21970 ± 810 **		large ice wedge casts	grass tundra
Vistulian		Middle Plenivistulian	fluvio–aeolian silts and sands with organic layers	40.3		

* PAZDUR *et al.*, 1979; ** BARANIECKA, 1980.

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For Poland, the Plenivistulian–Late Vistulian boundary at about 15–14 ka BP as well as the Kamion (Epe) horizon as the equivalent of the beginning stage of Late Vistulian are suggested (KOZARSKI, NOWACZYK 1991b; MANIKOWSKA, 1991a, 1991b) for two reasons: (1) all dune deposits belong to one period; (2) there are proofs of the climatic changes about 15–14 ka BP.

It should be noted that the term Vistulian, commonly used in Poland, corresponds with the western European term Weichselian. The last cold period has received its name after the Latin name of the major Polish river – Vistula. The Plenivistulian glaciation is called in Poland – North Polish Glaciation or Baltic Glaciation, and comprises four recessional phases: Leszno Phase, Poznań Phase, Pomorze Phase, Gardno Phase.

MIDDLE REGION

STAGES OF AEOLIAN ACTIVITY

Following stages of aeolian activity in the 20–8 ka BP period can be identified in the middle region:

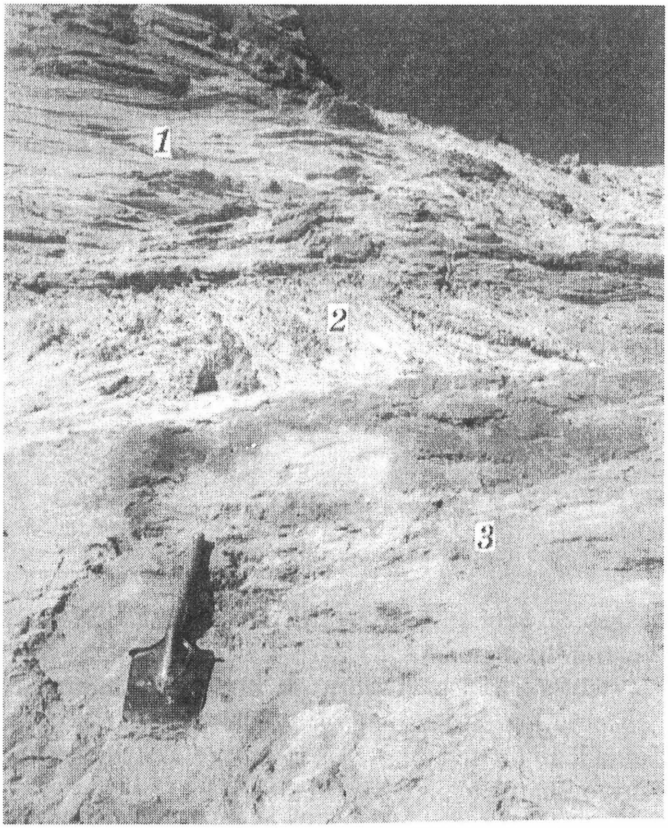
stage I – of aeolian transport, abrasion of surface material and its incorporation into non-aeolian deposits (ca. 20–15 ka BP)

stage II – of accumulation of aeolian covers and dunes, occurred in three phases (ca. (15) 14–10 ka BP)

stage III – of pedogenesis and retouching of dune slopes (ca.10–8 ka BP)

Stage I. The effects of aeolian activity have been detected through the studies on abrasion of sand grains involved in non-aeolian deposits (BURACZYŃSKI, 1993; GOŹDZIK, 1980a, 1981; MANIKOWSKA, 1977, 1985, 1993, 1994; ROTNICKI, 1970). The examination of Vistulian depositional sequences showing the gradual increase of constituents which reveal signs of wind erosion points to intensification of aeolian abrasion to the maximum in the 30–15 ka BP period.

The largest proportion of rounded mat (RM) aeolian grains was registered in deposits dated back to the Upper Plenivistulian i.e. about 20–15 ka BP (Tab. I). Sediments of this age in middle Poland are the sandy deposits of braided rivers, several metres thick in major valleys, and thiner sandy-gravely deposits that were accumulated by episodic waters in small, dry at present, valleys (Pl. 1). The content of wind-abraded grains in such sediments is either similar or even greater than in the Late Vistulian cover sands and dunes of the region. The proportion of rounded mat – RM grains according to the morphoscopic method (CAILLEUX, TRICART, 1959) – reaches 40–60%, and the proportion of rounded γ grains – according to the graniformametric method (KRYGOWSKI, 1964) is – 20–30%. Compared

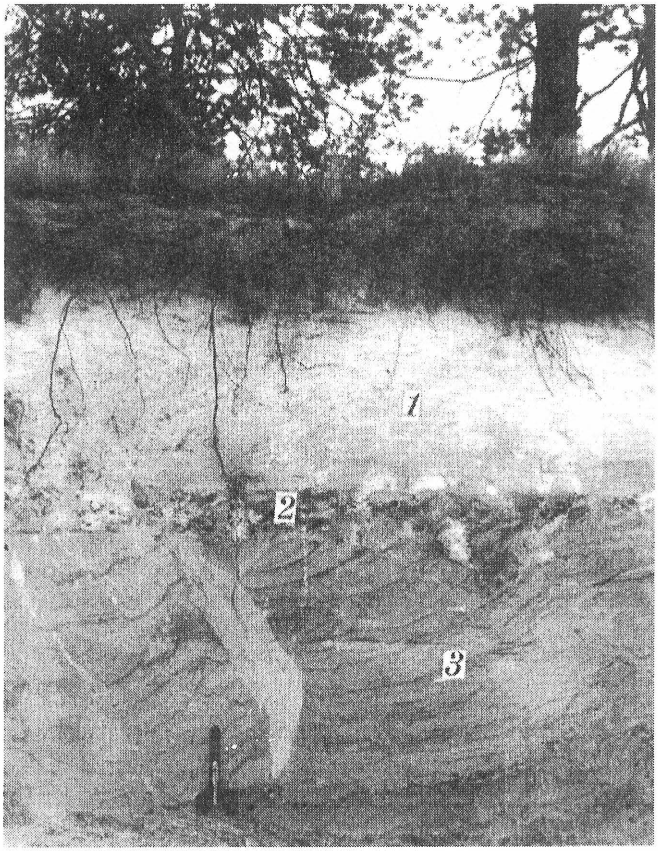


Pl. 1. Aeolo–fluvial sandy-gravelly deposits of Plenivistulian age (ca. 20–15 ka BP) in small dry valley at Bełchatów opencast mine

1. aeolian cover sand; 2. aeolo–fluvial sand and gravel; 3. fluvio–aeolian silt and sand

with the source glacial material there are about two, three times more of these typical aeolian grains. Almost all remaining constituents of sands reveal partial aeolian abrasion, and aeolisation of material is nearly total.

In terms of stratigraphy the deposits in question have been defined as the sandy series of braided rivers (TURKOWSKA, 1990, 1994) or the sandy-gravely fluvial series (MANIKOWSKA, 1987, 1992) of the Upper Plenivistulian. Locally they have been called the Świętojanka Gravel Member (GOŹDZIK, KRZYSZKOWSKI, 1987; KRZYSZKOWSKI, 1990). KLATKOWA (1985) describes them as the over snow deposits in which the registered disturbances of fluvial stratification are due to the melting-out of simultaneously accumulated snow. In general, they are typical fluvial deposits, largely coarse-grained, deposited by turbulently flowing waters. No sufficient sedimentologic-structural analysis, which would help to identify the layers deposited immediately by the wind, has been carried out. Anyway, the deposits were aeolically sup-



Pl. 2. Rogowiec. Upper Plenivistulian frost wedge infilled with vertically laminated, wind abraded sand, under the aealian sand cover

1. aeolian cover sand; 2. aeolian pavement; 3. fluvioglacial sand; shovel is 0.5 m long

plied, thus can be named the aeolo-fluvial deposits; if snow involved – the aeolo-niveo-fluvial deposits.

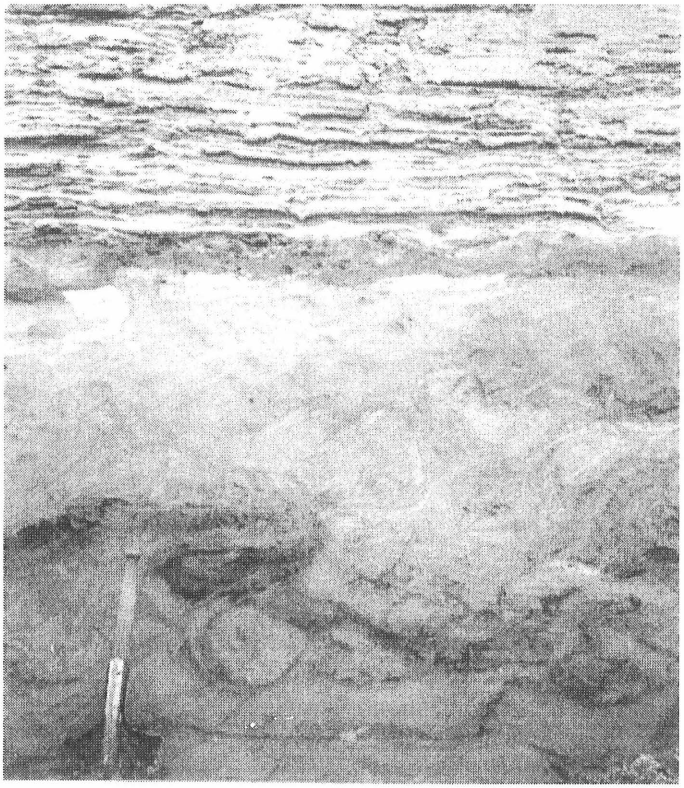
The typical sandy aeolian deposits either of the 20–15 ka BP period or of the earlier Vistulian phases, which are known in the Netherlands and Belgium (KOLSTRUP, 1980; MAARLEVELD, 1976; VANDENBERGHE, 1985; VAN DER HAMMEN *et al.*, 1967), have not been identified in Poland so far. There is no in Poland the aeolian equivalent of the Older Cover Sands I, which are regarded in the Netherlands as the separate sedimentological unit deposited at about 27–22 ka BP, before accumulation of the Beuningen Gravel Bed that corresponds to the sandy-gravely series of middle Poland.

Appreciable aeolian abrasion has been recorded in sands of the Plenivistulian frost wedge casts (Pl. 2). The infillings of the sand wedges, developed before 15 ka BP, contain no less of aeolised grains than

Pl. 3. Wola Zaradzyńska. The residual pavement on the surface of periglacially disturbed fluvioglacial deposits, covered with thin aeolian sand

the Upper Plenivistulian aeolo-fluvial sandy-gravely deposits. Thus, they evidence intense long-term aeolian abrasion before incorporating into wedges (GOŹDZIK, 1986; MANIKOWSKA, 1993; MANIKOWSKA, BALWIERZ, 1987). Although the abrasion of wedge sands is undoubtedly the result of wind action, it is hard to regard them as the typical aeolian deposits, even if they got inside by the wind. Development of the frost wedges infilled with sand is associated with the culmination of Vistulian cold in the period 20–15 ka BP.

Another evidence for the wind operation in the discussed stage is the pavement consisting in great part of the wind worn stones (Pl. 3). The pavement developed on most interfluve surfaces during the Upper Plenivistulian. It reveals residual or congelifluction-residual features. Occasionally, within depressions, the sandy-gravely deposits are replaced by the pavement which separates the silty-sandy series from the aeolian cover deposits (Pl. 4). The content of ventifacts in the pavement reaches 40% (among >2 cm constituents).



Pl. 4. Folwark. Thin stony layer between silty–sandy deposits of Plenivistulian age and Late Vistulian cover sands

Therefore, the first stage is characterised by very intense aeolian activity yet the type aeolian deposits are absent. Surface material was carried many times by the wind (perhaps alternately with the other mode of transport), which resulted in its very well aeolian abrasion. Afterwards it was swept into depressions and introduced into non-aeolian deposits – the fluvial or slope ones. It was possible for finer particles to be blown away and then be deposited as loess in the southern uplands. Convex forms suffered from deflation. Ephemeral aeolian sand deposits could have been produced (their remains can be seen in the infillings of ice wedge casts), nevertheless aeolian formations representing a separate stratigraphic unit have not been preserved.

S t a g e I I. Throughout this stage the formation of aeolian sediments took place on a vast scale. The accumulation occurred in several phases separated with either reduction or decay of aeolian activity. The breaks in sedimentation are expressed by development of fossil soils, which are characteristic for the dunes of the whole area of Poland.

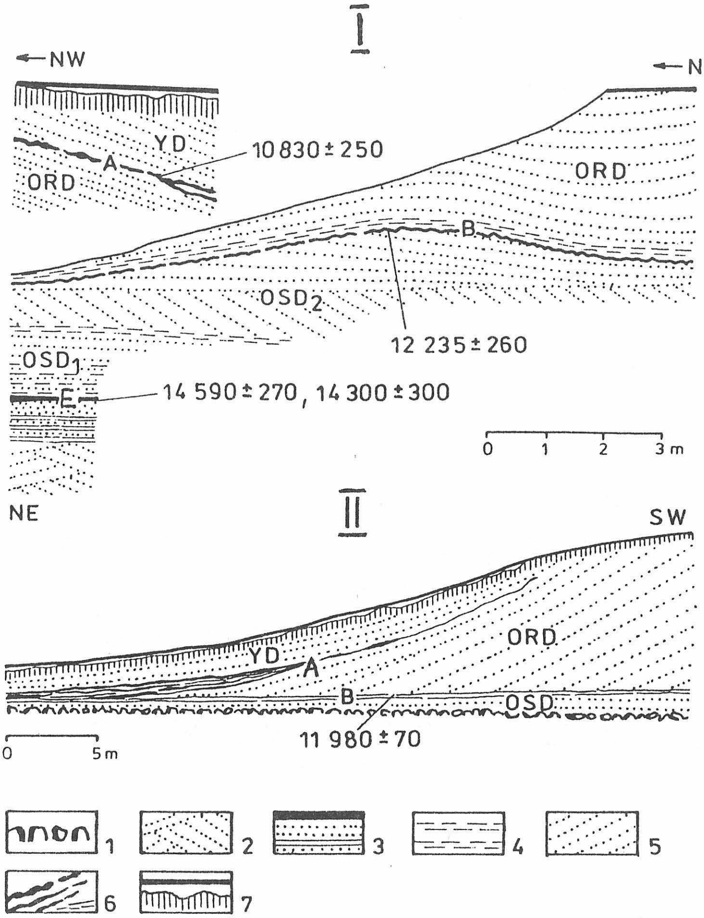
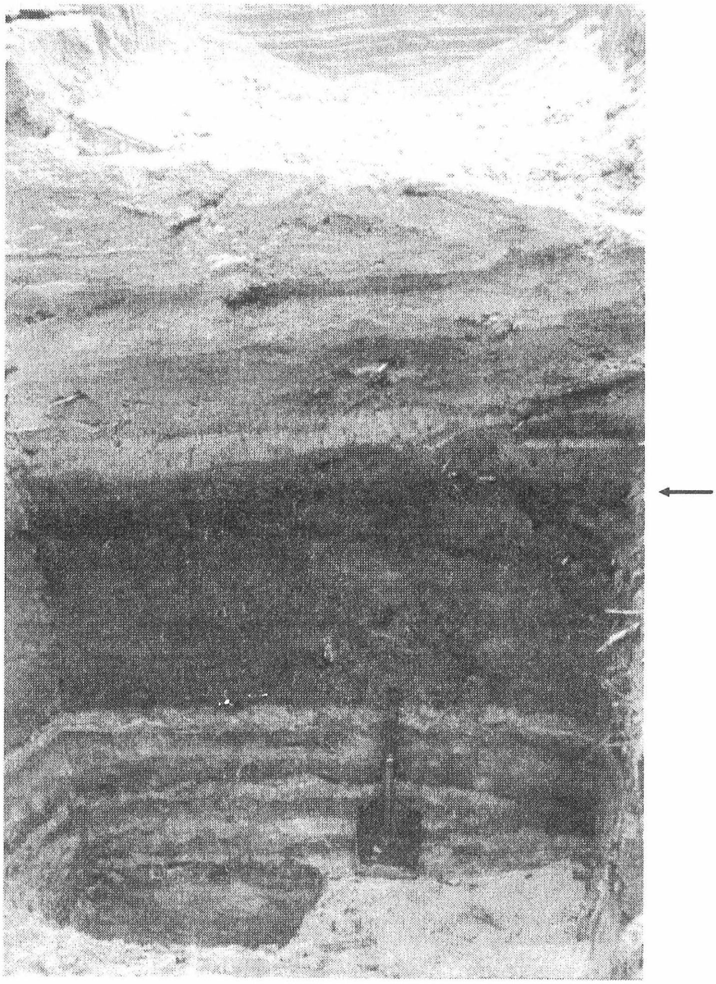


Fig. 2. Three parts of the Late Vistulian dunes in Central Poland

I – Kanion-Młodzieszynek site near Wyszogród; II – Kopiec site near Annopol; Dune deposits: OSD – Oldest Dryas; ORD – Older Dryas; YD – Younger Dryas; Fossil soils: E – Epe (Kamion); B – Bølling; A – Allerød; 1. weathred Albian sandstone; 2. braided river sand and gravel; 3. floodplain silt, sand and organic layers; 4. aeolian dusty layers; 5. aeolian sands; 6. soil humus horizons; 7. podzol soil profile. Radiocarbon dates in years BP (after MANIKOWSKA, 1985)

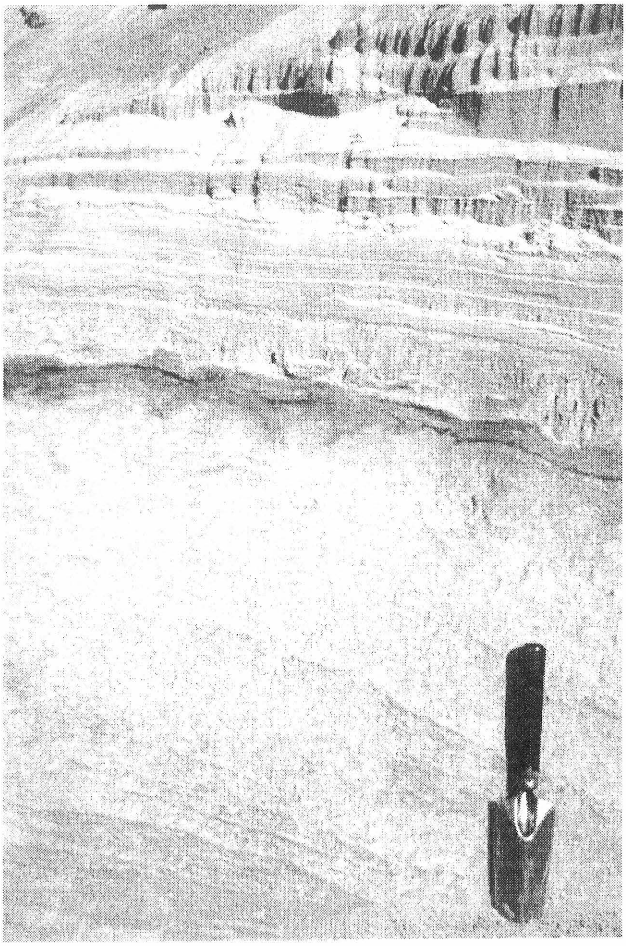
The complete cycle of aeolian accumulation during the Vistulian decline and the beginning of Holocene has been dated by radiocarbon method in middle Poland – in the Łódź environ (GOŹDZIK, 1991; KRAJEWSKI, 1977; KRAJEWSKI, BALWIERZ, 1985; MANIKOWSKA, 1977, 1982, 1985, 1991a, 1994) and in the vicinity of Warsaw (BARANIECKA, KONECKA-BETLEY, 1987; KONECKA-BETLEY, 1977, 1981, 1991).

The tripartition in aeolian deposits of the Vistulian decline confirms the identification of three phases of accumulation: the Oldest-, the Older- and the Younger Dryas (Fig. 2).



Pl. 5. Kamion. Fossil soil with humus horizon dated 14,590 ± 270 and 14,300 ± 300 years BP in the top part of Plenivistulian terrace overline with the Oldest Dryas dune sands

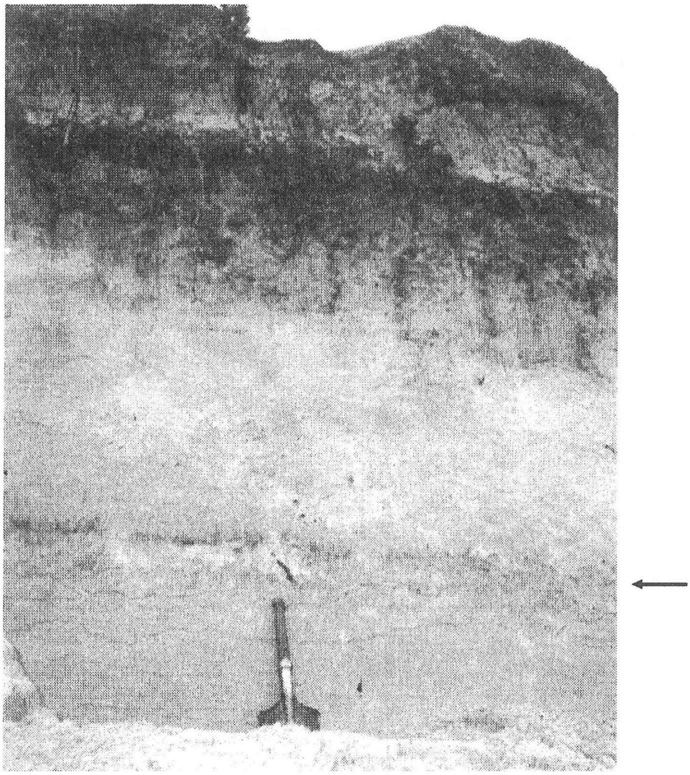
The organic deposit immediately older than the oldest aeolian series has been dated at: (1) the "Bełchatów" opencast mine 14,350 ± 570 years BP (GOŹDZIK, 1980a), (2) the Kamion site near Wyszogród – 14,590 ± 270 and 14,300 ± 300 years BP (MANIKOWSKA 1982, 1991). At Kamion, on the Pleni- vistulian terrace of the Vistula river, not only the humus horizon but also the signs of subaeral soil-forming processes recorded (ferric oxide, decalcification) indicate that the terrace became dried up due to the erosional dissection and vegetated (Pl. 5). The above mentioned phenomena falling on about 15–14 ka BP provide evidence of the climatic amelioration. This time-span has been called the K a m i o n P h a s e. In this time the vegetation spread out over the previous cold desert of Upper



Pl. 6. Kamion. Fossil initial Bølling soil dated 12,235 ± 260 years BP in the dune sands; shovel is 0.5 m long

Plenivistulian, which has been registered not only at Kamion and Bełchatów but also at some more sites (FLOREK, *et al.*, 1987; KLATKOWA, 1984, 1989).

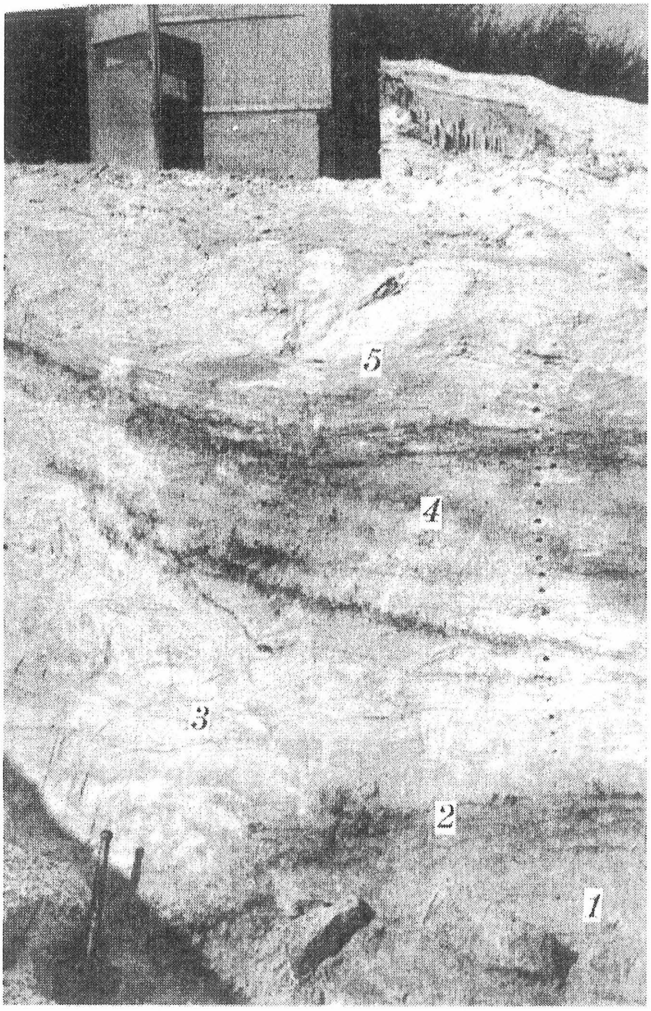
At the top of the Oldest Dryas dune deposits, one or two tiny layers of the organic matter can be observed occasionally. They are initial soil humus horizons (Pl. 6). Plant macrofossils (*Pinus, Juniperus*) of this horizons have been dated at 11,980 ± 70 years BP – the Annopol site (MANIKOWSKA, 1977), at 12,235 ± 260 years BP – the Kamion site (MANIKOWSKA, 1982), at 12,030 ± 160 years BP – the Cięciwa site (KONECKA-BETLEY, 1991). The above radiocarbon dates enable the soil to be associated with the Bølling Phase, and locate the series of the Oldest Dryas dune deposits between (14.5) 14.0 and 12.5 (12.0) ka BP.



Pl. 7. Szynkielów. Allerød fossil soil dated 10,860 ± 120 years BP in the Late Vistulian dune sands; subsurficial podzol developed during Atlantic phase overline with drift sand

Beyond dunes, the ^{14}C dates have been obtained for organic matter of the dusty-sandy layer dividing aeolian cover sands at the Bełchatów opencast mine. They are as follow: 12,400 ± 240, 13,670 ± 240 years BP (Goździk, 1991) and 11,040 ± 290, 14,900 ± 190 years BP (Manikowska, 1992). Such discrepancy for the same thin layer makes the reliable age and, consequently, the Bølling Phase impossible to accept.

The second series of aeolian deposits originated during the Older Dryas Phase. Its accumulation finished as the surface became fixed by the vegetation and by the soil of the Allerød Phase. The fossil Allerød soil (Pl. 7) is common in dunes, where separates the major body of Older Dryas sands from the Younger Dryas thin deposits. Within isolated patches of cover sands the soil is absent. It is weakly developed podzolic soil or the formation called pedolith (Manikowska, 1985) with small humus content and numerous plant macroremains, largely of pine but also juniper and willow. Pedoliths, which were produced under control of

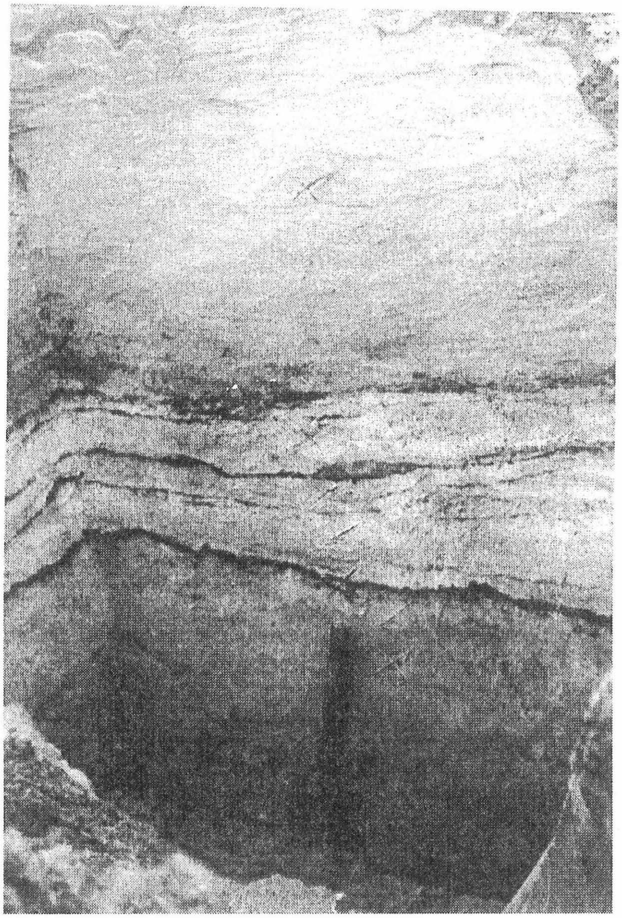


Pl. 8. Annopol. Allerød and Bølling fossil soils within the dune
1. the Oldest Dryas sand; 2. Bølling humus horizons – 11,980 ± 70 years BP; 3. the Older Dryas dune; 4. pedolith of Allerød age; 5. the Younger Dryas dune sand

soil-forming process interrupted by the episodes of thin sand layers' accumulation, commonly occur along the fossil slopes of dunes. (Pl. 8).

Numerous radiocarbon dates for this soil range widely from about 10.5 to over 12 ka BP in the oldest horizons of pedoliths. Most dates, however, fall on the period that in the light of pollen studies is assumed to be the Allerød Phase (Ralska-Jasiewiczowa, 1991; Ralska-Jasiewiczowa, Starkel, 1988), i.e. about 11,000–11,800 years BP.

The youngest Vistulian aeolian deposits complete the formerly fashioned dune pattern. These additional segments either tend to cloak dune



Pl. 9. Dobroń. Pedolith of Allerød age – the lower humus horizon dated 11,770 ± 80 years BP

slopes or feed their fore-sets. A distinctive feature is their position over the fossil Allerød soil (Pl. 9).

The aeolian processes of the Younger Dryas in middle Poland reworked dunes, though their shapes have not changed radically. Such processes concerned only dunes and their immediate neighbourhood. No new dune forms dated back to the Younger Dryas have been observed here. The circumstances in which the material was exposed to aeolian processes due to river activity are the exceptions (e.g. the small dune at Całowanie in the Vistula river valley – SCHILD, 1982).

There is no evidence for assuming the formation of the new cover sand deposits beyond existent dune fields during the Younger Dryas in middle Poland.

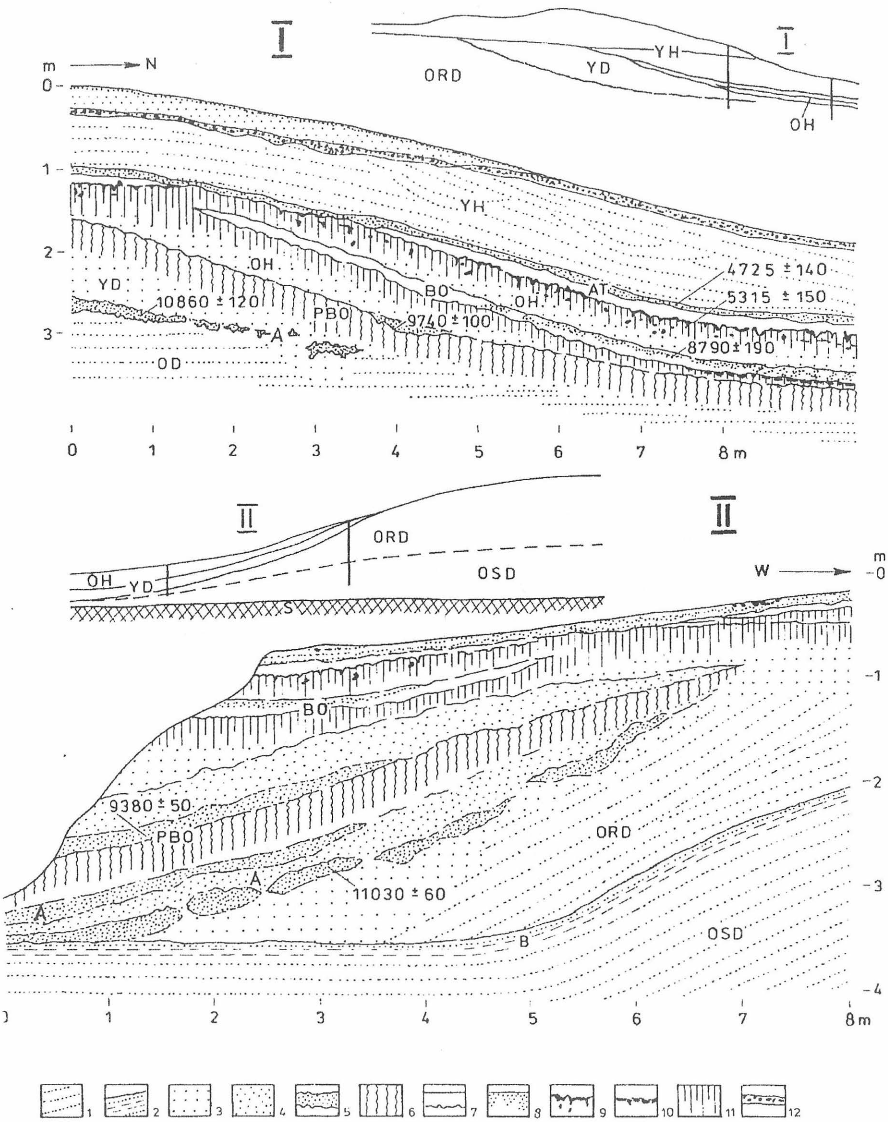


Fig. 3. Soil complex on the dune slopes in Central Poland

I – Szynkielów site near Sieradz; II – Bełchatów site near Piotrków Trybunalski; Dune deposits: OSD – Oldest Dryas; ORD – Older Dryas; YD – Younger Dryas; OH – Old Holocene; Fossil soils: B – Bølling; A – Allerød; PBO – Preboreal; Bo – Boreal; 1. stratified dune sands; 2. dust and sand lamina; 3. non-stratified sand; 4. sand with the humus admixture; 5. humus soil horizon; 6. B horizon of rusty soil; 7. bleached horizon of podzol; 8. bleached horizon with small content of humus; 9. hard illuvial iron-humus horizon of podzol; 10. hard illuvial iron soil horizon; 1. illuvial soil horizon; 2. undecomposed plant remains; Radiocarbon dates in years BP (after MANIKOWSKA, 1985)

Pl. 10. Rogowiec. The Younger Dryas sand (1) covering the Allerød fossil soil (2) developed on the surface of the Older Dryas dune (3)

Stage III. In this stage the aeolian activity became retarded and episodic, little accumulation appeared on the slopes of dunes. Thin layers of deposits formed then were completely reworked by the subsequent soil-forming processes. In such a way the Old Holocene pedolith has been produced (MANIKOWSKA, 1985). The sequence begins with the Preboreal rusty soil, afterwards the sand layer changed next into the Boreal iron podzol soil follows, finally there is one more layer which was transformed into the iron-humus podzol of Atlantic Phase (Fig. 3; Pl. 11). Such pattern has been reported from several sites in the vicinity of Łódź, and also from the Cięciwa site near Warsaw (KONECKA-BETLEY, 1991). The results of investigations obtained so far suggest the just outlined formation to be representative of middle Poland. Most likely it was generated independently of man, who promoted aeolian activity from the second part of Atlantic Phase.

Rusty soil, which originated as the first Holocene soil on dune deposits, marks the last member of the discussed 20–8 ka BP period. The oldest radiocarbon dates obtained for plant macroremains of this soil are 9,740 ± 100 and 9,380 ± 50 years BP (MANIKOWSKA, 1986, 1994), though in some cases the age is 8,720 ± 80 (MANIKOWSKA, BEDNAREK, 1994), 8,770 ± 110 and even 8,320 ± 110 years BP (KONECKA-BETLEY, 1991). Afterwards the rusty soil either underwent the gradual podzolization maintaining the

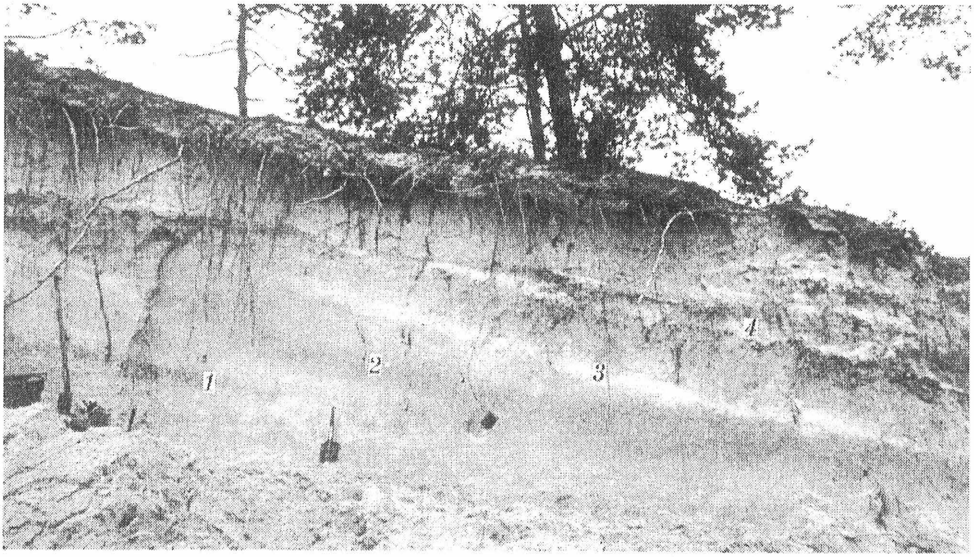
Pl. 11. Kamion. Fossil Oldest Dryas dune hillock, covered with the Older Dryas dune sands

characteristic rusty horizon in the profile or became covered with sand on which the Atlantic podzol developed. Thus, the rusty soil within dune forms is the key horizon separating the Vistulian deposits from the Holocene ones.

On aeolian cover sands, outside dunes and their vicinity, since the Allerød throughout the discussed period, the Late Vistulian–Holocene soil was developing. The fossil Allerød soil, which is common within dunes, is absent in cover sands. Doubtless, not being separated with any deposit from the Holocene soil, it has been involved in the surface soil formation.

LITHOLOGY OF AEOLIAN DEPOSITS

Oldest Dryas deposits are most widespread. There are extensive flat covers and occasional small hillocks up to 4 m high, which have been preserved up to day inside the dunes. In places, the hillocks are coated with the dusty layer of probably the Bølling age. Dust lamina accompany sometimes thin soil organic horizons dated back to the Bølling Phase. Occasionally the Oldest Dryas deposits contain more dusty layers. In some cases (e.g. at the dated Kamion site – Manikowska, 1985), the Oldest Dryas series consists of two members differing in stratification and in dusty lamina involved. One of this members is the flat, horizontally stratified cover, the second generates the small dune hillock with inclined and truncated layers (Pl. 11).

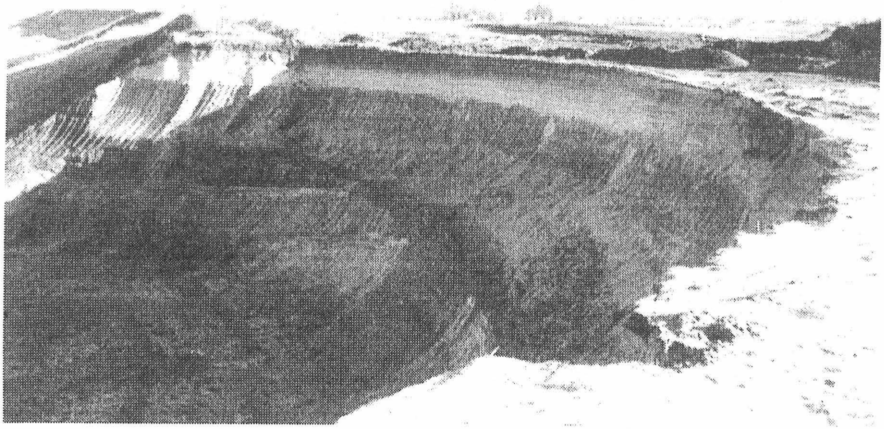


Pl. 12. Szynkielów. Complex of fossil soils on the dune slope
1. weakly developed podzolic Allerød soil; 2. Preboreal rusty soil; 3. Boreal podzolic soil; 4. iron-humus podzol developed in Atlantic phase (see also Fig. 3)

The Oldest Dryas series occurs at the base of dunes, but it also can be found in the large areas where forms the cover with no younger blanket. In central Poland, the aeolian covers consisting at the bottom part of thinly, horizontally laminated sand whereas at the top part of sand with an admixture of dust, generally non-stratified, are fairly common. Their origin may be located at the Oldest Dryas and the Bølling Phase. Such complex is about 1–2 m thick most often. The content of dust (together with a slight admixture of clay) ranges from several to about 40%.

O l d e r   D r y a s   d e p o s i t s generate the huge dune forms, most often of west-pointing parabolas. In this time the dunes reached up to 15 m in height while their horns up to 5 km in lenght. The Older Dryas sands are free of dusty layers and, in general, are slightly coarser than sands of Oldest and Younger Dryas (MANIKOWSKA, 1985). The layers are often considerably inclined, truncated, and indicate the migration of dunes. Beyond the dunes, the sand of the Older Dryas forms the covers with thin horizontal layers, which are either superimposed on the Oldest Dryas and Bølling deposits or occur individually (Pl. 13).

Y o u n g e r   D r y a s   d e p o s i t s are relatively small in volume. They occur as thin sand lenses resulting from displacement of material from the surfaces of dunes to their slope and foot. Outside dune fields, there are no covers of this age. The Younger Dryas dune sediments are well sorted, medium- and fine-grained sands.



Pl. 13. Aeolian cover sands of the Oldest and the Older Dryas deposited on the Plenivistulian and Eemian sediments filling closed basin in the Bełchatów opencast mine area

Q u a r t z - g r a i n   a b r a s i o n of the middle-Polish aeolian sands has attracted the attention of a number of researchers. This property has been studied by means of the morphoscopic CAILLEUX method, the graniformametric method proposed by KRYGOWSKI and scanning electron microscopy. Obtained results show the very large amount of grains abraded by the wind in the Late Vistulian aeolian deposits of the presented area. The content of both typical aeolian round mat grains (RM) and partly wind abraded grains (M) usually exceeds 90%, yet it is not larger than in the non-aeolian deposits of Upper Plenivistulian in this region (*cf*. p. 131 and Tab. I). Such proportion of wind abraded grains in aeolian deposits differs considerably from the values registered in the parent glacial deposits (in which a mixture of angular components and abraded grains due to various agents occurs) but is comparable with the content of aeolian grains in the sandy-gravely deposits and in the sands filling frost wedges of the Upper Plenivistulian (GOŹDZIK, 1980a, 1981; MANIKOWSKA, 1966, 1985, 1993).

No clear tendency to the variation in abrasion within the dune deposits of middle Poland has been found (KRAJEWSKI, 1977; MANIKOWSKA, 1985; SZCZYPEK, 1986). Instead, it was recorded that the degree of wind abrasion of aeolian deposits decreases northwards – in the vicinity of Łódź and Warsaw it is highest, the mean values have been registered near to the

Content of rounded mat RM grains and round grains in the dune deposits at Teodory (Middle Polish Glaciation area) and Przysieczna (North Polish Glaciation area). After MAROSIK (1988)

Table II

site	RM %			γ %		
	min.	max.	mean	min.	max.	mean.
Teodory	20.0	64.0	40.2	17.0	46.0	30.3
Przysieczyn	7.0	22.0	13.6	6.0	23.0	14.1

boundary of last glaciation, the poorest aeolian abrasion occurs in the area of North Polish Glaciation (GOŹDZIK, 1991; MANIKOWSKA, 1985, 1991b; MAROSIK, 1988; URBANIAK-BIERNACKA, 1976).

In general, abrasion of the middle-Polish aeolian sands is distinct and fairly uniform. Aeolian RM grains and γ type grains are here 2–3 times more numerous than within primary glacial material. Similar differences in the content of aeolian grains have been noted between the dunes of middle Poland and the dunes of the North Polish Glaciation area; the comparison of two forms from these areas is a case in point (MAROSIK, 1988; Tab. II). Whereas the difference in the content of aeolian particles between the dunes of northern Poland and their glacial substratum is tenuous (GOŹDZIK, 1991).

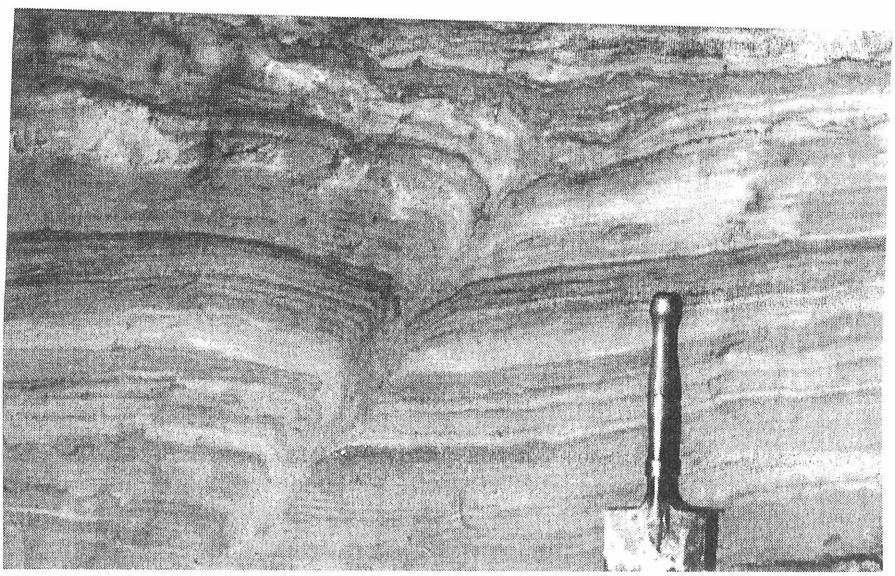
Obtained results allowed to assume the pre-Late Vistulian aeolian activity, especially intense in the 30–15 ka BP period, to be the major control of abrasion of sands which form middle-Polish dunes and aeolian covers. Their distinct abrasion could not have followed the Late Vistulian dune-forming process but is the effect of entire sum of aeolian activity which affected surface material throughout the Vistulian. In comparison with the previous aeolian influence, especially with the Upper Plenivistulian one, the Late Vistulian control seems to be minimal.

As for mineralogical composition, the main constituent of the Late Vistulian aeolian deposits of middle Poland is quartz. The mean content of feldspars (0.5–0.75 mm fraction) is 4.8%, carbonates are absent. Compared with the source glacial material, heavy minerals are enriched in stable particles, first of all in garnets, also in tourmalines and others; on the other hand they are impoverished mainly in amphiboles, but also in pyroxenes and epidotes (GOŹDZIK, 1980b; MANIKOWSKA, 1985, 1993; SZCZYPEK, 1986; URBANIAK-BIERNACKA, 1976). Such changes should be attributed to aeolian transport causing the soft minerals to be crushed and worn down, which result in the relative enrichment in hard minerals. The content of garnets (among transparent minerals of 0.1–0.25 fraction) within the aeolian deposits of middle Poland reaches 50% and is about two times greater than in glacial sediments. Enrichment in garnets is regarded as characteristics of aeolian deposits (MYCIELSKA-DOWGIAŁŁO, 1980).

One should stress that the aeolian deposits of middle Poland are appreciably poorer in resistant minerals than the dune deposits in the area of last glaciation. The latter may contain carbonates, and feldspars may be almost two times more numerous (MAROSIK, 1988).

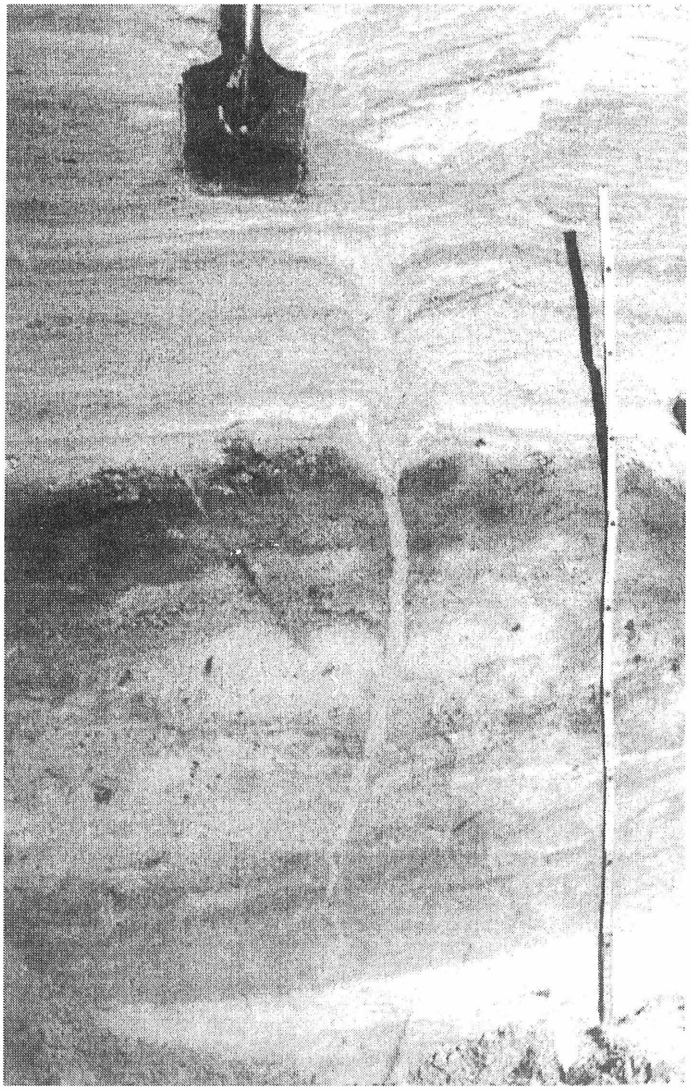
FEATURES INDICATIVE OF PERIGLACIAL ENVIRONMENT

Ice wedge casts and frost cracks in middle Poland are fairly common within the flat aeolian covers of the Oldest and the Older Dryas (GOŹDZIK, 1973; MANIKOWSKA, 1985). They are either wide structures due to the melting of ground-ice, which correspond to more stabile surfaces that are generally covered with dust (Pl. 14, 15), or a number of thin annual cracks developed syngenetically with the accumulation of deposit (Pl. 16). Ice wedges are especially frequent within the Oldest Dryas deposits. Sometimes the dust cover is superimposed, in the shape of spots and streaks, on the Oldest Dryas aeolian sand cut by the ice wedge casts (Fig. 4; Pl. 17).



P. 14. Lubiaszów. Ice wedge cast within the Oldest Dryas aeolian deposits

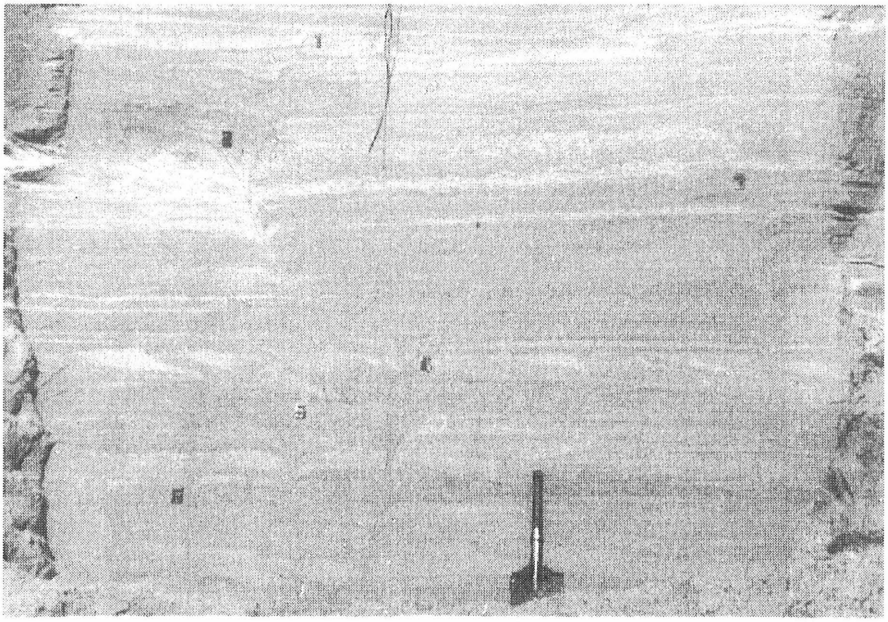
After the Plenivistulian development of wedges primary infilled with sand, the formation of ice wedges during the Oldest Dryas follows. This change evidences the transformation of climate which became less continental and slightly milder, though remained cold.



Pl. 15. Słupia. Ice wedge cast cutting the oldest Dryas aeolian sands and fluvioglacial substratum

As opposed to the cover sands, the Older Dryas dunes hardly ever reveal the frost wedge pattern. Only the bottom parts of their slopes provided more favourable water conditions and, consequently, only in such position the frost structures can be seen occasionally.

No ice wedge structures, apart from vertical cracks of obscure origin above the Allerød soil (MANIKOWSKA, 1985), have been found in the aeo-



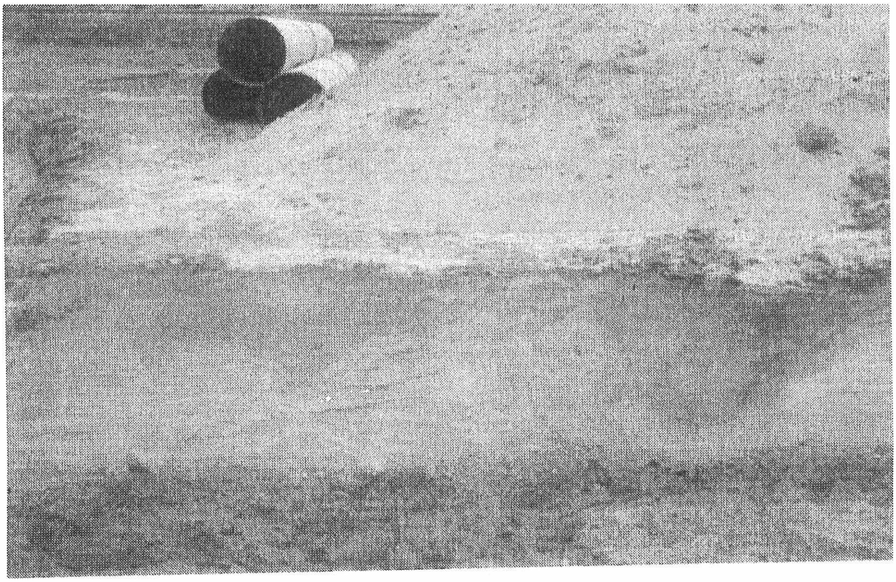
Pl. 16. Rogowiec. Syngenetic annual frost cracks in the Older Dryas cover sands

lian deposits of the Younger Dryas. Considering that the Younger Dryas deposits constitute the slopes of dune hillocks, one should suggest the absence of ice wedges to be the result of unsuitable water conditions for ground ice formation. Perhaps seasonal, ice-free cracks developed.

Similar observation of the frost cracks within aeolian deposits has been made in the Kraków–Wieluń Upland (SZCZYPEK, 1986), although the Younger Dryas age of one ice wedge cast has been assumed despite insufficient proofs.

Numerous frost cracks and ice wedge casts as well as their syngenetic origin within the Oldest and Older Dryas aeolian deposits evidence the aggradation of permafrost that was probably discontinuous in the nature (see GOŹDZIK in this volume). Available data for the cracks within the Younger Dryas aeolian deposits provide no sufficient information to draw a conclusion on permafrost in that time.

Further symptoms of the cool climate during the period of Late Vistulian aeolian deposition in middle Poland are the denivation structures in dunes. Their examples have been recorded at some sites (Kamion, Rogowiec, Kozłówki, Szynkielów) in the shape of slides and flowage structures (Pl. 18) observed on the steep (15–25°) fossil slopes of dunes, close to the Allerød soil (MANIKOWSKA, 1985). Originally they were considered to be a consequence of the movements of sand mass cemented with plant roots and soil. Description of denivation phenomena on the sur-



Pl. 17. Andrzejów. Silty-sandy cover overlying the Oldest Dryas cover sands (see also Fig. 4)

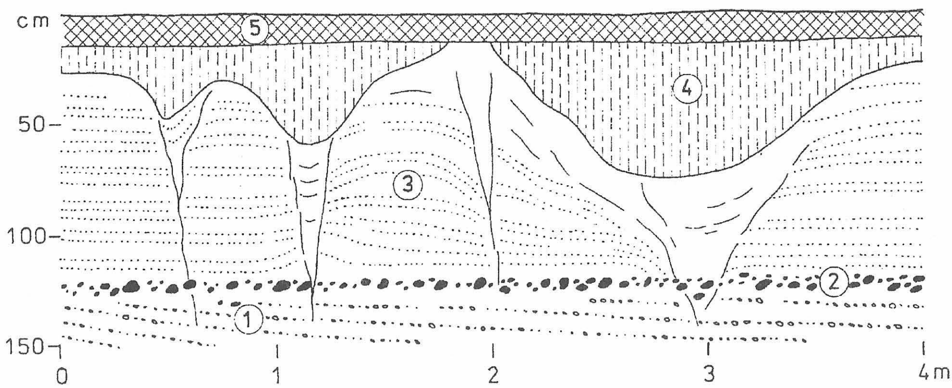
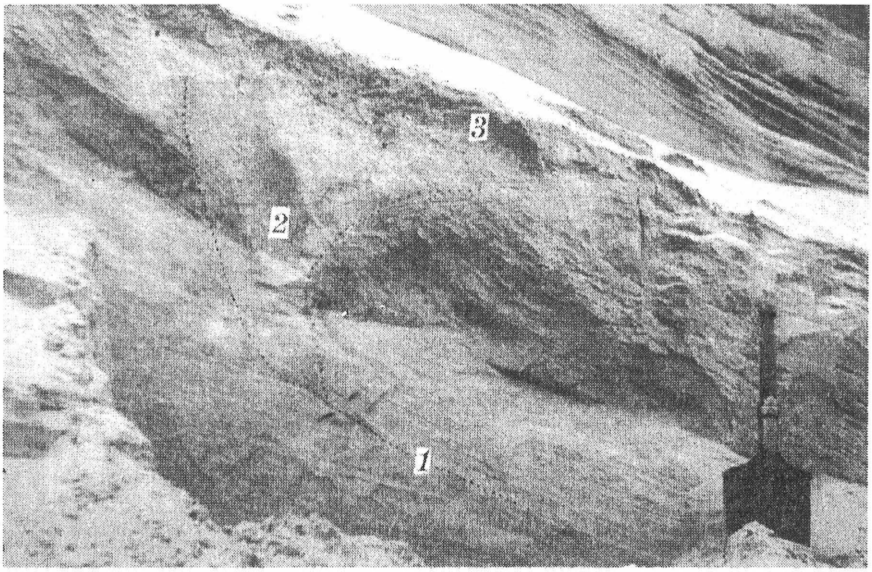


Fig. 4. Łódź–Rokicińska. Ice–wedge casts in Oldest Dryas aeolian cover sands coated with the dusty discontinuous cover

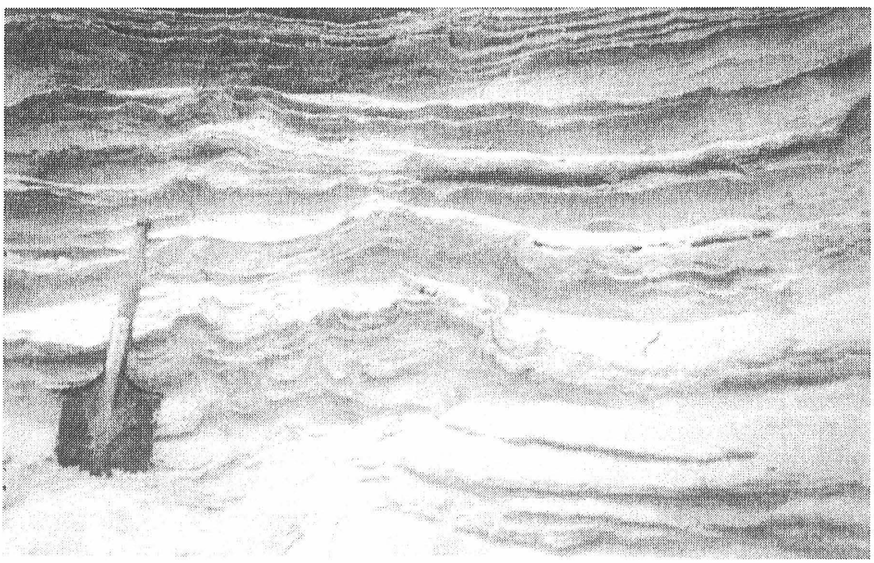
1. fluvioglacial sand and gravel; 2. stone pavement; 3. aeolian fine stratified cover sand; 4. non–stratified dusty sand; 5. soil humus horizon

face of dunes in Alaska (KOSTER, DIJKMANS, 1988) enables the fossil slides in mid-Polish dunes to be associated with the melting-out of included snow.



Pl. 18. Rogowiec. Denivation slide structure on fossil dune slope covered with Allerød soil

1. slide niche; 2. slide surface; 3. Allerød



Pl. 19. Folwark. Undulating layears of aeolian cover sands

Minor folds created by the melt-out of snow and ice are fairly common in the middle-Polish cover sands containing dust layers (Pl. 19). According to SZCZYPEK (1986) the patterns of small faults within the aeolian sands of the Kraków–Wieluń Upland are due to the subsidence of niveo-aeolian material on flat surfaces.

In some researchers' opinion (SCHWAN, 1988) the presence of dusty layers (loessic) and bands deposited by water, preasumably from the thawing snow and ground ice, also evidences the accumulation of aeolian cover sands under periglacial conditions. Fluvial intercalations occur occasionally in the cover sands of middle Poland.

Moreover, the question of f r a g i p a n s in aeolian sands in Poland is being considered (MANIKOWSKA, 1985). In the Netherlands, the fragipans observed in cover sands are being associated with the ground ice development (VINK, SEVINK, 1971). Ground ice might have also controlled formation, probably in the Younger Dryas, of iron stripes superimposed on the Allerød soil. These iron fibres are the impressive feature of the fossil soil of this age.

NORTHERN REGION

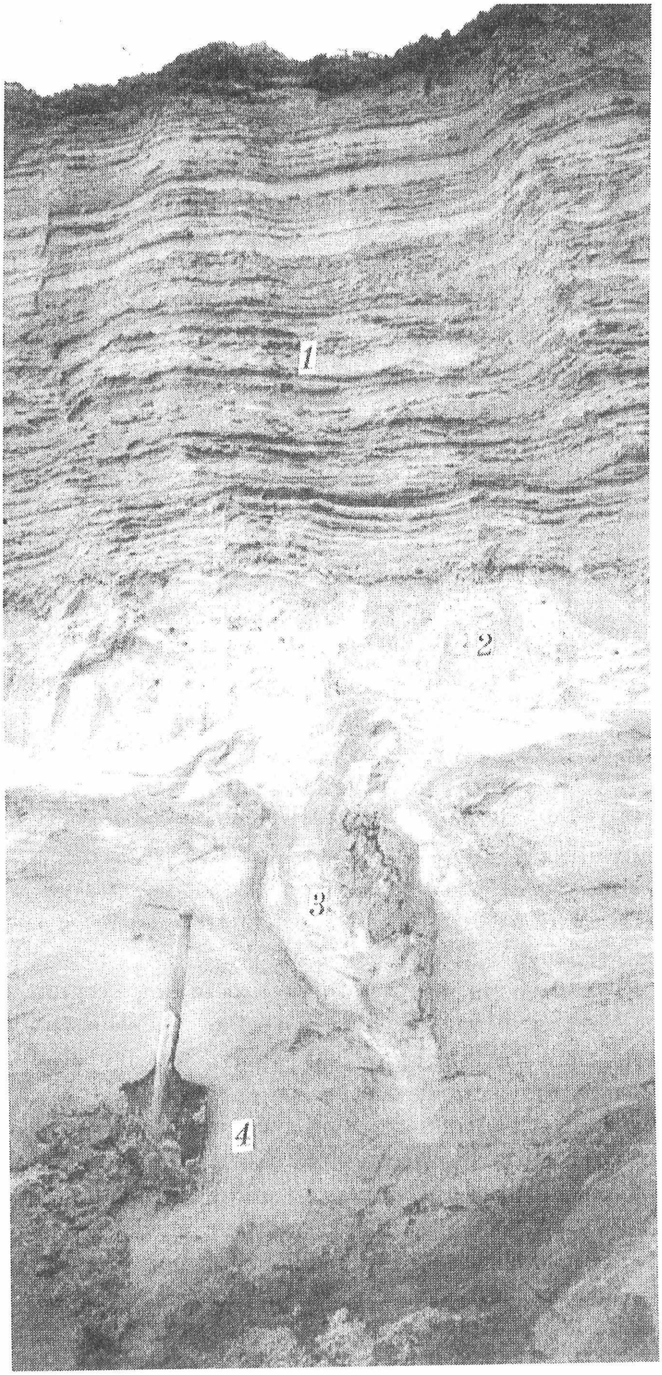
STAGES OF AEOLIAN ACTIVITY

The course of aeolian processes in the region of last glaciation has been recognized most fully in its northwest part (KOZARSKI, NOWACZYK, 1991a, 1991b, 1992; NOWACZYK, 1986; STANKOWSKI, 1963).

The Plenivistulian aeolian activity, which has been inferred from very well aeolian abrasion of sandy periglacial deposits covered with the sediments of last glaciation (GOŹDZIK, 1981), was stopped for a time of ice advance and then renewed.

Employing the division proposed for the middle region, i.e. into the stages of the Plenivistulian, the Late Vistulian and the Holocene aeolian activity (Tab. I), then the stage I in NW Poland was merely marked by the wind worn stones on the outwash plain surfaces and by the sandy infillings of frost cracks produced in tills during the Poznań and Pomorze Phases of last glaciation (GOŹDZIK, 1986; KOZARSKI, NOWACZYK, 1992).

S t a g e I I, similarly to the course in middle Poland, exibits the phases in aeolian activity. In the oldest phase, in some places the patches of loess were deposited, immediately over glacial sediments. This process dates back no later than to the Oldest Dryas, which apart from the stratigraphic position is supported by the TL dates for loess (Klępicz – 17.0 ± 2.0, Golice – 15.0 ± 2.5 ka BP, KOZARSKI, NOWACZYK, 1991b). In northern Poland, neither the Oldest Dryas aeolian sands nor the Bølling soil in aeolian deposits have been recognized. The Żabinko site, south of Poznań, displayed,



Pl. 20. Folwark. Vistulian deposits of aeolian origin

1. horizontally stratified aeolian cover sand; 2. sandy-gravelly aeolo-fluvial deposits disturbed by meltout processes; 3. sand filling the frost wedge cast; 4. fluvio-aeolian silt and sand

at the top part of bifurcation terrace of the Warsaw–Berlin Pradolina, the biogenic deposit under the dune. In the light of radiocarbon dates obtained for this organic material, (the oldest – 12,770 ± 190 years BP, the youngest – 12,210 ± 130 years BP), it can be dated back to the Bølling Phase (NOWACZYK, 1986). Thus, aeolian sand accumulation began here in the Older Dryas. The equivalents of widespread middle-Polish sands of the Oldest Dryas have not been found in the northern region, except for the isolated patches of loess-like deposits.

In the second and third phases, i.e. in the Older and Younger Dryas, aeolian sands were accumulated as dunes and covers. The Allerød soil in dune deposits registered at Budzyń (KOZARSKI, *et al.*, 1982), at Czmoń (NOWACZYK, 1986) and at Grodno (BORÓWKA, *et al.*, 1982) documents the break in accumulation. In many places the aeolian and palynologically established Allerød biogenic deposits are intercalated (NOWACZYK, 1986). On the other hand, there are areas in which, despite detailed studies, the Older Dryas deposits have not been found (regions of the lower Odra river and the lower Warta river – KOZARSKI, NOWACZYK, 1992) as well as sites where sediments of this phase are smaller in volume in relation to Younger Dryas deposits. The above mentioned facts have led to regard the Younger Dryas as the main dune-forming phase of northwestern Poland (KOZARSKI, 1978). As opposed to middle Poland, the evidence of widespread, and isolated from dunes, fields of cover sands being the Younger Dryas in age have been registered in the northern region (KOZARSKI, NOWACZYK, 1992).

According to the researchers dealing with northern Poland, the Younger Dryas aeolian accumulation extended up to the Preboreal Phase of Holocene. They consider the Younger Dryas–Preboreal period, up to about 9,200–9,000 years BP, to be the last climatically controlled dune-forming phase (KOZARSKI, NOWACZYK, 1991b). The Preboreal fossil soil, which in dunes of middle Poland occurs as the distinctive horizon of rusty soil, has not been identified here.

The researchers are coming to the conclusion that after the Younger Dryas–Preboreal phase of accumulation, only the man-made interference in the natural environment of dune fields was responsible for aeolian activity. Thus, the processes were initiating variously according to the place and time. The archaeological discoveries and the radiocarbon datings locate the oldest palaeo-soils occuring in aeolian sands in the Mesolithic (8,000–4,400 years BP) and the Early Neolithic (4,400–3,500 years BP).

The Old Holocene stage of natural development of dunes (pedogenesis and weak aeolian processes on the dune slopes) distinguished in middle Poland, has not been identified in the northern region. Appreciable intensification of aeolian activity at the end of Atlantic Phase (about 5,000 years BP) is observed in the whole area of Poland owing to agricultural revolution in this time.

LITHOLOGY

Oldest Dryas deposits in northern region are fashioned as the dust cover, up to 3 m thick, occurring locally on the glacial substratum. In particular profile there are 30–50% of 0.05–0.02 mm particles, which is comparable to the content in typical loesses of southern Poland. Carbonates approximate several percent. This loess deposit reveals small faults due to the snow and ice melt-out process as well as vertical cracks of syndepositional desiccation or thermal contraction. Loess itself may be massive, thinly-laminated and stratified; dip of layers, frequently following the slope, evidences the aeolo-deluvial origin (Kozarski, Nowaczyk, 1991b).

Older and Younger Dryas aeolian deposits are fine- and medium-grained dune and cover sands. The deposit of particular site varies depending upon grain-size composition of the source material (Nowaczyk, 1986). The northern region exhibits closer than in middle Poland relationship between the composition of dunes and the primary material. Processes of both phases produced the dunes several metres high as well as the flat covers of aeolian sands. Stratification of some covers evidences that they were originally involved in dunes (Nowaczyk, 1976).

Quartz-grain abrasion of the aeolian deposits of northern Poland was largely analysed by the graniformametric method. Obtained results show rather small amount of round γ grains. The values recorded for aeolian sands are essentially similar to the ones for glacial substratum (Goździk, 1991; Kozarski, Nowaczyk, 1992; Marosik, 1988; Nowaczyk, 1986). Compared to the aeolian sands of middle region the content of γ type grains is 2–3 times smaller.

Slight abrasion registered in huge dunes of this region proves that the duration of the Late Vistulian aeolian processes was insufficient to transform quartz-grains evidently. Also, the Late Glacial dunes from southern Sweden display no aeolian abrasion at all (Mycielska-Dowgiałło, 1993).

Mineralogical investigations of the aeolian deposits in the northern region are few (Kamińska, *et al.*, 1986; Marosik, 1988; Urbaniak-Biernacka, 1976). Nevertheless the results show a larger amount of non-resistant minerals than in dunes of the middle region. Aeolian deposits originated here from unweathered material and wind transport reworked them insignificantly. At the Liszyno site (Kamińska, *et al.*, 1986), situated immediately north of the limit of last glaciation, the gradual decrease in less resistant heavy minerals of younger and younger dune series has been marked. Such regularity is preasumably connected with the progress in aeolian activity. From the mineralogical studies of middle-Polish dunes it follows similar (Manikowska 1985), although the analytic data on this are still insufficient.

PERIGLACIAL STRUCTURES

Frost cracks within the aeolian deposits of northern Poland very seldom occur. They have been registered only in the dunes near Nowy Tomyśl (STANKOWSKI, 1963) and in the dune at Budzyń near Chodzież (KOZARSKI, *et al.*, 1982). The latter exhibited fairly wide structures associated with the horizon of the Allerød fossil soil. Their origin dates back to the end of the Older Dryas or to the beginning of the Younger Dryas. Detailed investigations carried out in the lower course of the Warta and Odra rivers have not showed any frost structures in aeolian deposits which are of the Younger Dryas age (KOZARSKI, NOWACZYK, 1991b).

By analogy with the middle-Polish area, the ice wedge casts within the Oldest Dryas loess-like deposits one would expect, yet they have not been found. Instead the frost wedge casts infilled with probably wind-blown sand occur at the till plains of this region. Perhaps sandy infillings vary slightly in abrasion according to the stadial of glaciation, but they are decidedly less abraded than the infillings of Plenivistulian ice wedge casts of middle Poland (GOŹDZIK, 1986).

CONCLUSIONS

1. The area of Poland during the period 20–8 ka BP was undergoing the climatically controlled aeolian activity, manifested in deposits and aeolian relief. This activity was spatially and temporarily differentiated.

2. Differentiation of the results of aeolian processes allows to distinguish following areas in Poland: (1) the southern region of loess accumulation; (2) the middle region of intense deflation followed by formation of sand covers and dunes; (3) the northern region of accumulation of loess-like deposits and cover sands and dunes afterwards.

3. The southern region is the upland area of South Poland covered with loess patches. In the 28–15 (12) ka BP period, the upper younger loess was accumulated. Locally, near to the sources of sand, loess became overlain posed with thin aeolian sand cover of undefined age.

4. The middle region includes the widespread areas of central Poland and the loess-free lowlands of southern Poland. This region displays the richest aeolian sandy deposition, preceded by the intense deflation. Wind action before about 15–14 ka BP caused the abundance of aeolian quartz-grains in non-aeolian deposits. The 20–15 ka BP period is marked by the deposition of sandy-gravely fluvial sediments, supplied with aeolian material, revealing aeolo-fluvial features. Moreover, the ice wedges infilled with strongly aeolised sand originated. After about 15–14 ka BP, the accu-

mulation of the typical aeolian deposits in the shape of cover sands and dunes began.

5. The northern region is limited to the extent of last glaciation. At first thin loess was accumulated, afterwards formation of dune and cover sands followed. The accumulation began after the ice sheet had retreated. The Plenivistulian periglacial deposits (dated at more than 22 ka BP) of distinct aeolian abrasion have been registered beneath glacial drift.

6. In the middle region three stages in the course of aeolian processes in the period 20–8 ka BP can be identified: (a) deflation, abrasion of surface material, its sweeping into depressions and incorporation into non-aeolian deposits, (b) accumulation of aeolian sandy deposits, occurred in three phases, (c) pedogenesis and poor sand accumulation on the slopes of dunes.

The first stage finished at about 15–14 ka BP, during the Kamion (Epe) Phase. The second stage, in the time span 14–10 ka BP, includes the phases of the Oldest Dryas, Older Dryas and Younger Dryas separated with the Bølling and Allerød phases. In the Oldest Dryas widespread cover sands and small dunes were produced, in the Older Dryas huge dunes developed and accumulation of cover sands was continued, in the Younger Dryas transformation of dunes occurred and small sand lenses were accumulated on the dune slopes. The dunes fairly often contain weakly podzolized Allerød soil, while the initial Bølling soil very seldom occurs and there are frequently the dusty layers instead. The third stage dates back to the beginning of the Holocene, when mobile in the Younger Dryas dunes became vegetated. In the 10–8 ka BP period, thin sandy layers, separating the subsequent soils, were produced on the dune slopes. In this manner the natural Old Holocene pedolith initiated with Preboreal rusty soil and topped with Atlantic iron-humus podzol was formed.

7. In the northern region, the local sedimentation of loess in the Oldest Dryas occurred while in the Older and Younger Dryas sands were accumulated. The Oldest Dryas sands are absent whereas the phase of Younger Dryas accumulation seems to be more intense than in the Older Dryas time. The Allerød fossil soil is rather scarce phenomenon. The fossil Preboreal soil has not been identified here, thus it seems possible for the Younger Dryas aeolian activity to be extended up to the Preboreal phase.

8. There is an essential difference in abrasion and mineralogical composition between aeolian sands of the regions. Noticeably better abrasion of middle-Polish deposits results from the previous, Plenivistulian, distinct aeolian transformation of the source periglacial materials, whereas the deposits of northern Poland inherited the features of unchanged glacial material. The Late Vistulian cycle of aeolian transport and accumulation brought slight, if any, changes in quartz-grain abrasion neither in the area

of last glaciation nor in the older one. For a larger amount of unstable minerals in the northern region it is the same reason. Aeolian deposits of middle Poland became impoverished in non-resistant minerals because of Eem–Vistulian long weathering and aeolian transport before the Late Vistulian cycle of aeolian accumulation. There are bases for the presumption that in the borderline belt of glaciations the source material mixed (newly delivered by the ice sheet and previously abraded by the wind in the periglacial zone), which resulted in medium abrasion of aeolian deposits.

9. Differentiation in the effects of aeolian processes is associated with the variation of palaeoenvironment in Poland during the period of the Vistulian–Holocene transition. In the first stage (20–15 ka BP) there existed the cold desert in middle Poland. Strong winds resulted from the anticyclone over the ice sheet with which northern Poland was covered. The surface in middle Poland was undergoing strong deflation, sand, grains were wind abraded and accumulated as old-aeolian deposits in the depressions, fine particles were swept away and accumulated as loess in the southern area.

In the first phase of the second stage (the Oldest Dryas – 14–12.5 ka BP) from the climatic amelioration during the Kamion Phase (15–14 ka BP), the discontinuous vegetation of the sparse tundra developed probably in the Polish lowlands as well as the ice sheet withdrew from the north of Polish territory. The resultant lighter winds and limited areas of the removal of dust caused the end of loess accumulation in the uplands of southern Poland. In the lowlands, the deposition of dust was conditioned by the tundra vegetation and wetter places. In middle Poland, the widespread but thin sandy-dusty covers characteristic of the Oldest Dryas originated. The process of dust accumulation in northern Poland, despite being spatially limited, resulted in thicker loess deposits. The absence of sand covers of this age in the northern area could have been the consequence of appreciably wet ground immediately after the ice sheet retreat.

In the second and third phases of the second stage (12–10 ka BP), the whole lowlands of Poland was exposed to the aeolian sand accumulation, but the Older Dryas deposits prevail in the middle region while in the northern region the deposits of the Younger Dryas seem to be more common. Development of inland dunes in a vast scale should be correlated with the appearance of trees. The first groups of trees in the Bølling (12.5–12.0 ka BP) initiated the storage of sands in places as well as gave rise to elongated aeolian forms and to displacement of sands in the shape of migrating dunes in the Older Dryas. This process was commonly stopped in the Allerød as the forest spread over the whole surface. In the Younger Dryas forest became sparse, which caused transformation of the Older Dryas dunes. In northern Poland the new dune fields developed in places. Perhaps, more intense aeolian activity in NW Poland in this time corresponds to the conditions characteristic of Western Europe, where the Younger Dryas cooling seems to be marked more distinctly than in the eastern part of the continent.

In the third stage (10–8 ka BP) the soil-forming processes, being interrupted with the accumulation of thin sand layers which separated the subsequent soils, occurred. In central Poland this episodic accumulation seems to be due to natural factors. The succession of phenomena observed here repeats in many places, and indicates non-accidental, but general changes in the environment. Rapid development of the vegetation at the beginning of the Holocene resulted in central Poland in the rusty soil on dunes already in the Preboreal Phase.

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