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THE LISZYNO DUNE IN THE VISTULA VALLEY (EAST OF PŁOCK)

Abstract

In the dune at I iszyno, developed in the edge zone of the present-day terrace lying above the Vistula flood plain, in the eastern part of the Płock Basin (Central Poland), three horizons of fossil soils have been distinguished. Basing on radiocarbon dating of charcoal contained in these horizons and on morphological and chemical analyses of the soils the authors have determined the time of their formation: soil 1 – between the Allerød and Younger Dryas, soil 2 – between the pre-Boreal and the Boreal period, soil 3 – the sub-Boreal period. The initial dune was formed in the Older Dryas. The direct cause which initiated aeolian processes was the incision of the Vistula channel into the valley bottom, constituting the present day terrace lying above the flood plain, and the lowering of the ground water level. On the base of a textural analysis of deposits which have formed the aeolian sand series and the soil horizons an attempt was made of reconstruction of the morphodynamic processes which have formed the investigated dune.

The investigated locality lies on the right bank of the Vistula, within the eastern part of the Płock Basin. It is situated next to the maximum reach of the continental glacier of the Vistulian glaciation.

The dune at Liszyno is one of the forms developed on the terrace lying above the Vistula floodplain. The terrace is 60 – 65 m above sea level and it rises to ca. 8 m above the present-day Vistula channel. It is covered by dunes reaching 15 m of height. The dune discussed in the present paper is lower, it is ca. 7 m high. It was formed along the edge which separates the floodplain terrace from the one lying above and it overlays the level formed along this edge (Fig. 1). It may be then supposed that it was formed after the period when the river was cutting into the above-floodplain terrace and during the formation of the floodplain terrace. When the ground-water level dropped there occurred favourable conditions for deflation processes, particularly within the higher situated levees.

Up to now the opinions concerning the age of those two terrace surfaces have varied. SKOMPSKI (1969) connects the accumulation of the above-floodplain terrace with the Older Dryas and that of the floodplain terrace with early Holocene, while BARANIECKA *et al.* (1978) reckon the floodplain terrace to have been formed as early as the Older Dryas and the Alleröd.

The right-bank side of the Vistula valley, in the investigated sector, is formed of Pleistocene and Holocene fluvial deposits which lie on Pliocene clays. The roof of Pliocene clays reaches 30 – 40 m above sea level (SKOMPSKI, 1969). The above-

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floodplain terrace is built in the roof of fine- and medium-grained sand, in some places interbedded with silt. Downwards this series changes into coarse-grained sand, gravel and pebbles.

Owing to considerable sand mining and deep digging in the dune at Liszyno, in its north slope, three horizons of fossil soils separating four dune sand horizons, have outcroped as well as the roof of fluvial deposits which form the above-floodplain terrace and the levee (Fig. 1). Two lower horizons of fossil soil can be seen only on the dune slope. In its central part they have been destroyed and only the uppermost horizon has been preserved.

Three lower series of dune deposits, the fluvial deposit underlying the dune and the horizons of fossil soils have been comprehensively analysed in their textural and structural aspects. The uppermost horizon of dune sand, of increasing thickness, on the north slope, was not included in the analysis because of its reiterated transformation due to the exploitation of sand.

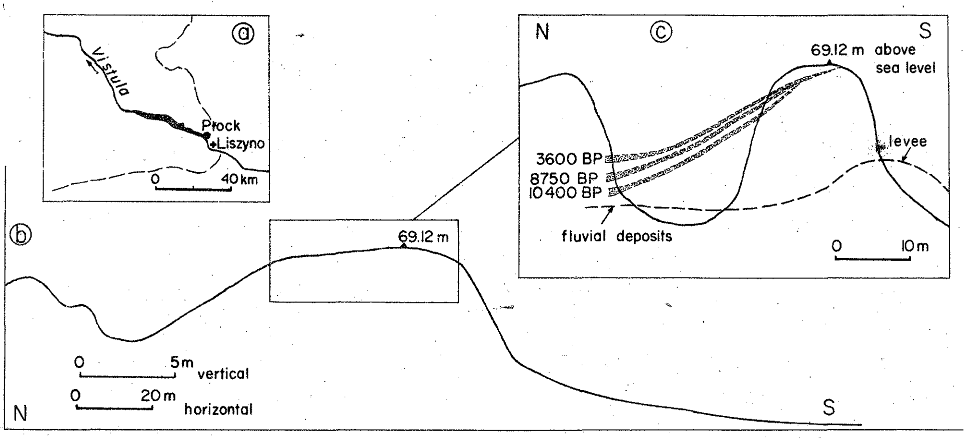


Fig. 1. Location of the Liszyno dune in the Vistula valley near Płock (a), cross profile through the dune before sand exploitation (b), cross profile through the dune at the time of investigations (c). The roof horizon of fluvial deposits and the probable strike of fossil soils have been marked

The formation of fossil soils in the investigated dune suggests that the main mass of dune sand was accumulated before the formation of the oldest fossil soil (Fig. 1). The stratification of the lee side preserved in this deposit shows that west winds accumulated the dune. A detailed textural analysis of the deposits was carried out in two opposite walls of a ditch running from the west to the east. As it has been said above, in the north wall of the ditch three horizons of different-age fossil soils outcropped and were dated by the radiocarbon method [1]. The

[1] The ^{14}C analysis was done by dr M. F. Pazdur in the Laboratory of the Institute of Physics, Silesian Engeneering College, Gliwice; the authors wish to express him their sincere thanks. The analysis was financed by the Committee of Quaternary Research of the Polish Academy of Sciences.

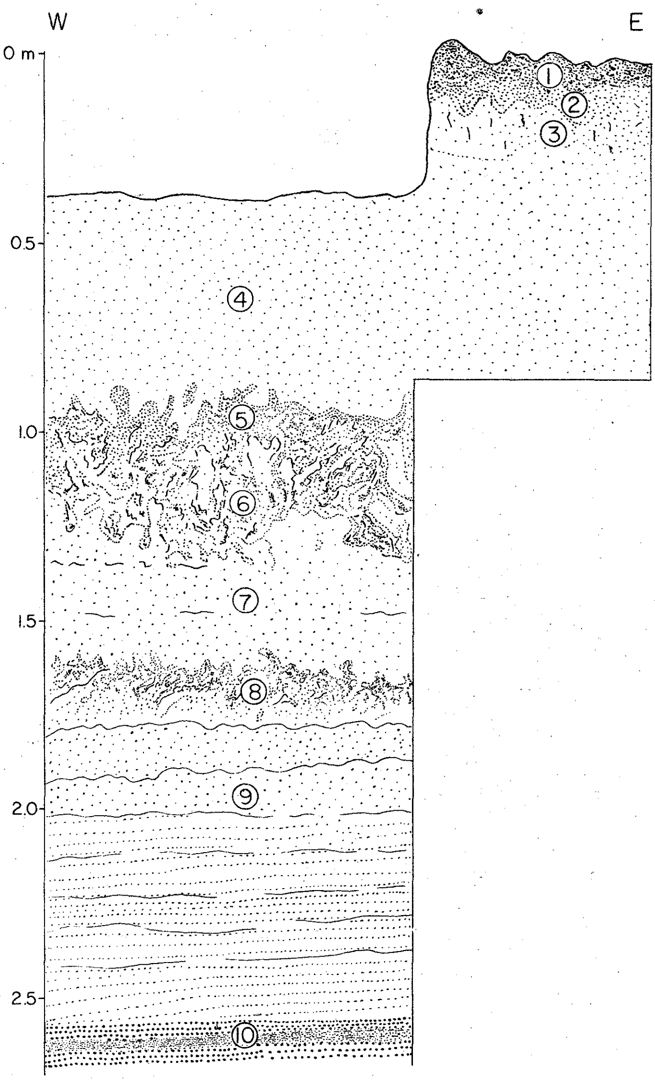


Fig. 2. North wall of the ditch-outcrop 1

1. horizon A_1 of soil 3, faintly marked humus horizon, light grey with charcoal dated 3610 ± 120 years BP; 2. horizon A_2, eluvial, greyish; 3. horizon B, illuvial, yellow-brown, fairly compact; 4. horizon C, matrix – sands of the third dune horizon; 5. horizon A_1 of soil 2, probably deluvial humus horizon with a great quantity of charcoal dated 8750 ± 100 years BP; 6. horizon $A_{1+2}Bv$ with grey and whitish or rusty-yellow spots and a faintly marked podsolization process; 7. horizon BvC, faintly marked rusting horizon changing downwards to yellow sand of the dune horizon. Single ferric fibres; 8. horizon A_1 of soil 1, faintly marked humus horizon with ferric fibres and a large quantity of charcoal dated 10,400 ± 180 years BP; 9. horizon C, matrix – sands of the first dune horizon with ferric fibres; 10. fluvial coarse-grained sand, interbedded with silt

Table I

Liszyno. Some physico-chemical properties of fossil soils in outcrop 1

Soils	Depth (cm)	Genetic horizons	pH (KCl)	Free Fe_2O_3 (Jackson's method) %*	Shifting figure of free Fe	Free Fe %	Total C %	Free Fe / total C in horizon B
Soil 3	0–15	A_1	4.24	undetermined		undetermined	0.48	
	15–25	A_2	4.33	0.057		0.039	0.02	
	25–40	B	4.44	0.117	2.08	0.081	0.17	0.48
	40–80	C	4.65	0.087		0.060	traces	
Soil 2	80–100	A_1 with charcoal	4.54	0.087	2.35	0.060	0.34	
	100–130	A_{1+2} Bv	4.59	0.205	0.55	0.143	0.10	1.43
	130–160	BvC	4.61	0.117		0.081	0.03	
	160–180	(A_1)	4.46	0.070	not calculated owing to absence of horizon B	0.048	0.02	not calculated owing to absence of horizon B
	180–220	C	4.57	0.070		0.048	traces	

*The analysis was made by dr D. Czępińska-Kamińska to whom the authors express sincere thanks.

morphology of those soils is as follows (Fig. 2, Pl. 1, 2): horizon A_1 of the uppermost soil (3) is covered with a 2.5 m thick sandy dune deposit, much transformed by anthropogeneous factors. Horizon A_1 occurs at 64.12 m above sea level. This altitude has been adopted as zero level in the description of the whole profile (Fig. 2, Tab. I).

Soil 3.

0.0–0.15 m A_1 weakly marked humus horizon, light-grey, with some charcoal; granulometric composition of slightly clayey sand. ^{14}C dating of charcoal 3610 ± 120 BP (Gd-2027),

0.15–0.25 m A_2 eluvial horizon, white and greyish; granulometric composition of slightly clayey sand,

0.25–0.40 m B iluvial horizon, yellow-brown, compact but not cemented; granulometric composition of slightly clayey sand,

0.40–0.80 m yellow matrix; granulometric composition of loose sand.

There is no framework in the whole profile, coarse sand occurs in very small quantities while the contents of medium- and finegrained sand is about the same.

Soil 2.

0.80–1.00 m A_1 humus horizon probably deluvial, with grey spots on yellow-grey background, large quantity of charcoal; granulometric composition as in the overlain soil. ^{14}C dating of charcoal – 8750 ± 100 BP (Gd-1540),

1.00–1.30 m A_{1+2} Bv humo-eluvial horizon with grey and whitish or rusty-yellow spots; faintly marked podsolization process; granulometric composition of loose sand,

1.30–1.60 m BvC faintly marked rusting horizon, rusty-yellow, changing to yellow in the bottom of the profile, with single ferric fibres; granulometric composition of loose sand.

Both horizons described above are characterized by a predominance of fine sand and a higher content of coarse sand as compared with soil 3.

Soil 1.

1.60–1.80 m A_1 faintly marked humus horizon, light-grey with light-yellow or whitish spots and ferric fibres; large quantity of well preserved charcoal; granulometric composition of slightly dayey sand changing to loose sand. Charcoal dated 10,400 ± 180 BP (Gd-2028)

1.80–2.20 m horizon of yellow matrix cut by ferric fibres which occur in places where the granulometric composition is slightly changed (admixture of fine sand, dust or coarse sand). In some places the fibres are damaged by pockets resembling former root forms.

In the second outcrop situated in the same line on the dune but 8 m east of the first outcrop (Pl. 3) the structure is somewhat different. The three soils described in the first outcrop overlap one another and their surface is situated at 62.5 m above sea level.

0.00 – 0.10 m A_1 deluvial humus horizon, light grey; granulometric composition of silightly clayey sand and C content = 0.42%,

0.10 – 0.15 m A_1 humus horizon *in situ*, grey; granulometric composition of slightly clayey sand and C content = 0.55%,

0.15 – 0.25 m A_2 eluvial horizon, whitish or white-grey; granulometric composition of loose sand, C content = 0.28%,

0.25 – 0.45 m B_H illuvial horizon, brown-grey, cemented with iron and organic compounds (may be former A_1 of rusty soil); granulometric composition of slightly clayey sand, C content = 0.44%,

0.45 – 0.60 m B_s and B_V illuvial level with larger amount of aluminium, overlapping an older rusting horizon, rusty-brown; granulometric composition of slightly clayey sand, C content = 0.33%,

0.60 – 0.40 m C matrix horizon, yellow; granulometric composition of loose sand; C content = 0.17% in the roof, 0.01% in the bottom,

0.90 – 1.20 m A_1 faintly marked humus horizon, probably that of soil 1 formed on a dune of the Older Dryas (Alleröd?); granulometric composition of loose sand, C content = 0.10%,

1.20 – 1.50 m C matrix horizon of weakly marked initial soil, light, yellow loose sand, C content = 0.06%.

It should be also mentioned that on the other side of the ditch on the dune, under the triangulation point, almost on its surface there has been preserved, at some places, a soil which might be reckoned among ferric podsols. This soil, though its A_1 horizon is destroyed, has a well-preserved white eluvial A_2 horizon and an illuvial horizon cemented with iron and aluminium compounds. Owing to drier conditions the organic substance together with iron, in the form of complex humus-iron-aluminium compounds, did not shift in this soil.

It results from the above given descriptions that the morphologically distinguished genetic horizons of the three soils of outcrop 1 "overlap" one another in outcrop 2.

The types of soil were distinguished according to some physicochemical properties – mainly the movement of free iron in the soil profile and the proportion of free Fe to the total C in the B levels.

In soil 1 the shifting of free iron from top horizons to deeper ones does not occur; the iron is mobile but not shifted. The ratio of free Fe to the total C has not been calculated since the illuvial horizon is not continuous.

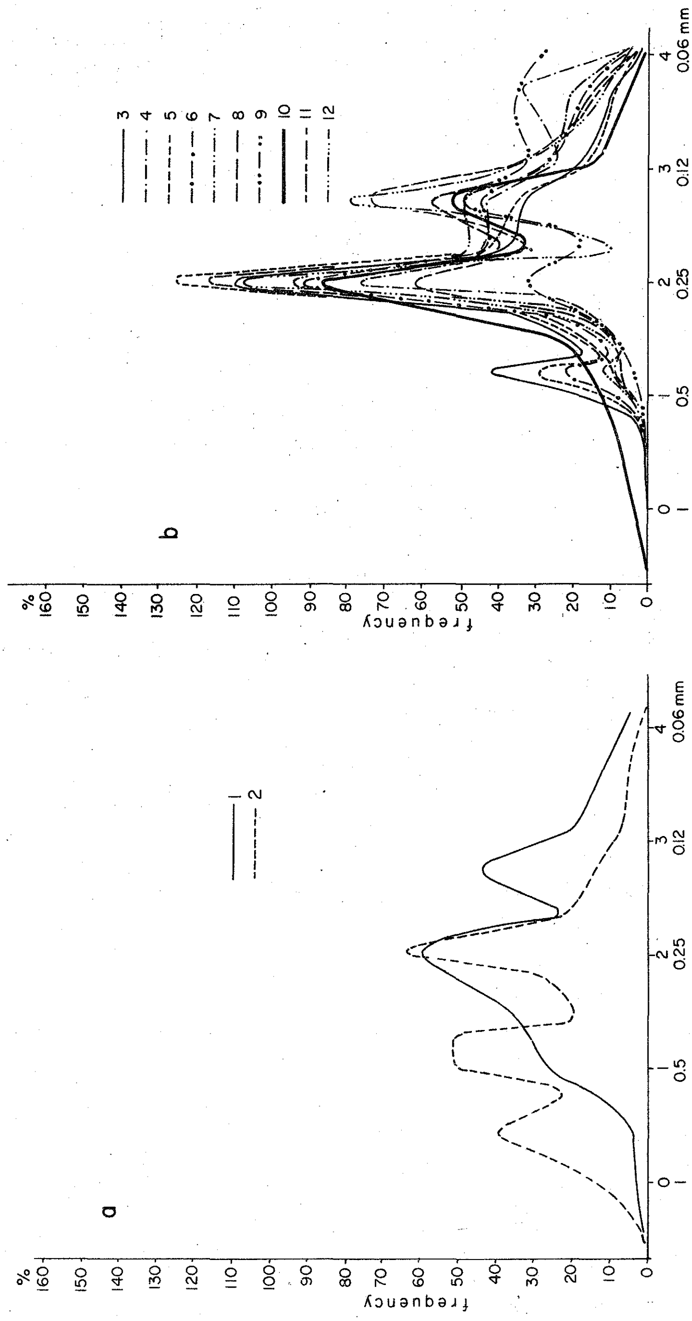
In soil 2 the shifting figure slightly exceeds 2 if the three distinguished horizons are considered a whole (A_1 with coals, A_{1+2}Bv and Bv). However, if horizon A_1

with coals is treated as somewhat younger (as is indicated by its morphology and ^{14}C dating) then the shifting figure for the other two horizons drops below 1. There only occurs intensive weathering of aluminosilicates in drier conditions. This is favourable to the movement of different elements, also of free iron. The small quantity of organic substances restrains, however, the shifting of this element deeper into the soil profile, in the form of complex humo-ferric compounds. The ratio of free Fe to the total C, which equals 1.43, means that the podsolization process is weak or does not occur at all.

The youngest soil (3) in the outcrop investigated is characterized by the shifting both of iron and of the total C. The shifting figure of iron is over 2 and the ratio of free iron to the total C is characteristic, according to FAO criteria, of proper podsol soils tending towards humo-ferric podsols, and it equals 0.48. A slightly higher content of total C in horizon A_1 of this soil, as compared with the older soil, creates favourable conditions for the shifting of complex humo-ferric compounds deeper into the profile. The oldest soil 1, ^{14}C dated $10{,}400 \pm 180$ years BP according to coals occurring in its roof, may be defined as a weakly developed soil with marks of podsolization. It was probably formed on an Older Dryas dune. Its characteristic feature are ferric fibres, probably younger than the soil, which occur mainly in horizon C at the point of contact of two layers of different granulometric composition, but also in horizon A_1 and horizon BvC of the overlying soil (Pl. 1, 2). The formation of soil 1 started probably in the Alleröd interstadial and was covered with sand after a fire in the second half of the Younger Dryas. It is then a late-glacial soil where pedogenic processes have not been too strongly marked.

Soil 2, partly formed on a Young Dryas dune and partly on aeolian sands of the pre-Boreal has been defined as proper rusty soil and – in places – as rusty and weakly podsolized soil. The coals in its upper humus part, younger than the horizons occurring in the bottom, are radiocarbon dated 8750 ± 100 years BP, i.e. of the mid-Boreal. The dual horizons of this soil: A_1 with coals and A_{1+2}Bv without coals are surprisingly thick. It may suggest the occurrence of diluvial processes and of gramineous vegetation which would mean a lesser density of trees which had by then entirely consolidated the dunes. It is most probable that in this last phase of existence of the soil before the fire hydrologic conditions prevailing on the dune were different. Since the horizon of dated coals is not strictly connected with the underlying rusty soil it cannot be excluded, that horizons $A_1 + $Bv and C are older and were formed at the end of the pre-Boreal and the beginning of the Boreal period (which has been confirmed by other authors: SCHILD, 1969, 1977, 1982; KONECKA-BETLEY, 1977, 1982; MANIKOWSKA, 1977, 1982), while horizon A_1 – in the Boreal (as indicated by radiocarbon data).

The radiocarbon age of the youngest soil in the investigated outcrop is 3610 ± 120 years BP, i.e. of the middle phase of the sub-Boreal period. It is a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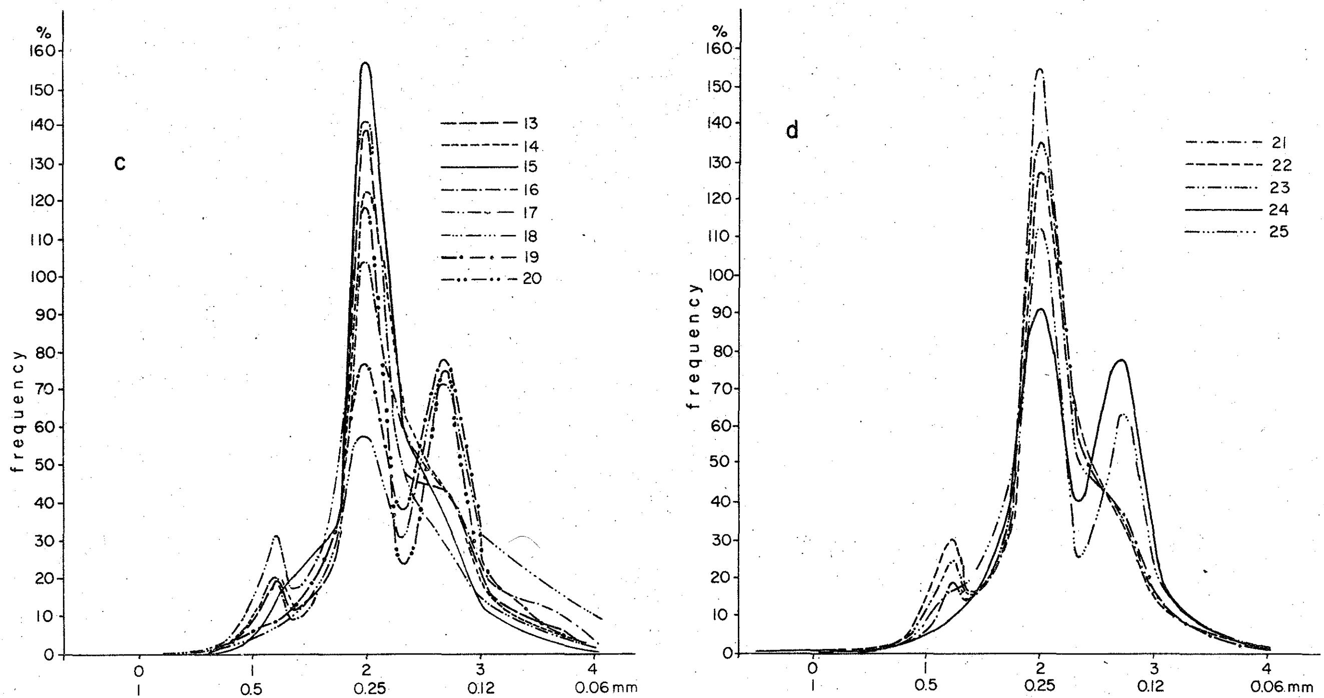


Fig. 3. Frequency curves

a. fluvial sands of the dune basement; b. sands of the first dune horizon; c. sands of the second dune horizon; d. sands of the third dune horizon. 1 — 25 — numbers of samples collected in the four chosen horizons podsol soil showing not far-advanced podsolization manifested by a slight shifting of free Fe and C compounds to the illuvial horizon B. Morphologically the process is weakly marked. It seems that at the close of the Atlantic period and the beginning of the sub-Boreal period the investigated dune must have undergone strong deflation. This is proved by the absence of Atlantic soil which commonly occurs in the dunes of Central Poland.

As it has been mentioned above, soil 3 occurs as the only one in the central part of the dune and nearly reaches the present-day surface. In the illuvial horizon of this soil, or a little lower, there occur sporadically fragments of pottery generally dating from the X – XI century A.D.[2] They probably got into a soil of an older age than theirs. However, their presence is important in the investigated profile since it determines the time of accumulation of aeolian sands which have covered the youngest fossil soil. This youngest dune-forming process must have taken place about a thousand years ago and has formed the fourth, youngest horizon of aeolian sand.

In order to determine the characteristics of the geographical environment at the time of the formation of the investigated dune a number of textural analyses were made of the aeolian deposits separating the soil horizons and of the deposits building those horizons. On the base of the granulometric analysis indices of granulation were calculated according to FOLK and WARD'S formulas (1957). Curves of frequency were also plotted to illustrate the granular composition of the deposits and to determine the fraction of maximum frequency (Fig. 3). With the use of the automatic graniformameter (KRYGOWSKI, 1964, modified by Z. MŁYNARCZYK) the degree of roundness of quartz grains was determined in two fractions: 0.6 – 0.75 mm and 0.75 – 1.0 mm. Besides, an analysis of heavy minerals was made in fraction 0.1 – 0.2 mm[3].

The granulation of the basement is visibly different from that of the oldest dune series underlying soil 1 (Fig. 4). The basement deposits are very badly sorted and they have low values of skewness. The overlying oldest horizon of dune sand is built of a better sorted deposit (though the worst of all three dune series investigated), which contains the largest part of fine-grained sand in relation to the fraction of maximum frequency. It is well illustrated by the highest values of skewness (Fig. 4) and the run of the frequency curves (Fig. 3). The upper horizon of dune sand, lying between the second and third soil horizon, is characterized by the highest degree of sorting and the lowest share of the fine-grained fraction in relation to the fraction of maximum frequency (Fig. 4). The frequency maximum

[2] Oral information from Mrs. H. MACKIEWICZ, Institute of Material Culture History, Polish Academy of Sciences.

[3] The analysis of heavy minerals was done by E. CICHOSZ-KOSTECKA to whom the authors wish to express their gratitude.

of grains is situated within the same fraction ($2\Phi = 0.25$ mm) both in the lower and the upper horizon, nevertheless the share of this fraction vary in the whole deposit. In the lower series the frequency maximum of this fraction never exceeds 120 units while in the upper horizon it ranges from 120 to 160 units.

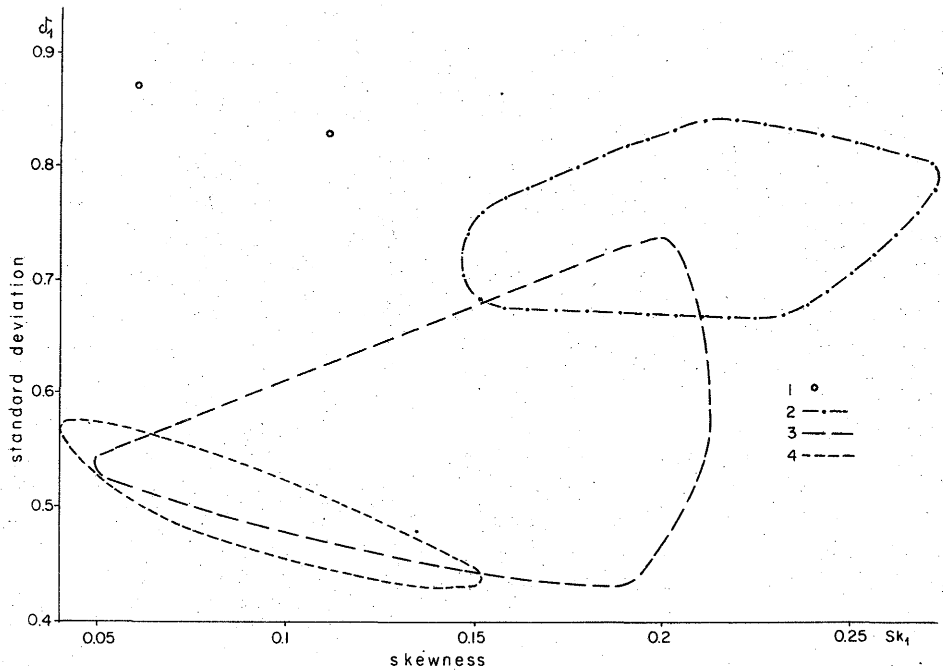


Fig. 4. Values of standard deviation (γ_1) and of skewness (S_{k1})

1. basement deposits; 2. deposits of the first dune horizon; 3. deposits of the second dune horizon; 4. deposits of the third dune horizon

The middle horizon (between soil horizons 1 and 2) takes an intermediate place, nearer to the upper horizon (Fig. 3).

A similar disposition of sorting degree indices as in the basement of deposits and the three dune and horizons at Liszyno was previously observed by K. ROTNICKI (1970) in a dune at Węglewice. There, two, the basement sand was most poorly sorted, then came the sands of the oldest dune series accumulated in the Older Dryas. The two upper series – the same as at Liszyno – were characterized by a much higher degree of sorting.

The above-presented data suggest that the lower dune series was formed in the Older Dryas by winds of greater dynamism and changeability than in the case of the upper series, while the uppermost dune series was formed by winds of low dynamism and equal strength during the formation of the whole series. It seems that at the time of accumulation of the middle and upper dune series the main activity of the wind was limited to the sorting of previously deposited sandy material and to its enrichment with the fraction which was most favourable for aeolian transport (0.25 – 0.3 mm) by blowing away finer deposits. As for the coarser fraction than the maximum of frequency (0.43 – 0.5 mm) it has been observed in all three series. Generally, however, its share is somewhat higher in the lower series than in the two others. This seems to prove that the absolute values of wind velocity must have been higher during the accumulation of the lower series than of the two upper ones. We may refer to the data presented by A. DYLIKOWA (1969) and concerning the velocity of dune-forming winds. In the proper phase, which may be correlated with the formation of the oldest dune series at Liszyno, the average speed of dune-forming winds was 6 – 8 m/sec. and its maximum was 10 m/sec. The phase of transformation which most probably corresponds with the formation of the second dune-sand series of Liszyno was built by winds of an average speed of 3 m/sec., while the phase of destruction (the third series of dune sand of Liszyno), like the second series, was influenced by winds of 2.5 – 5 m/sec. of average speed. Thus the first dune-forming phase was

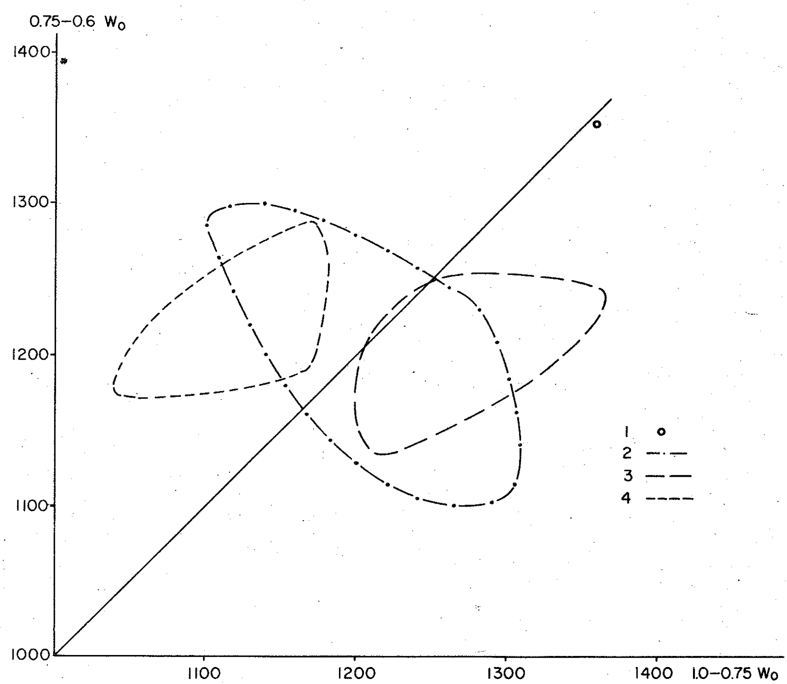
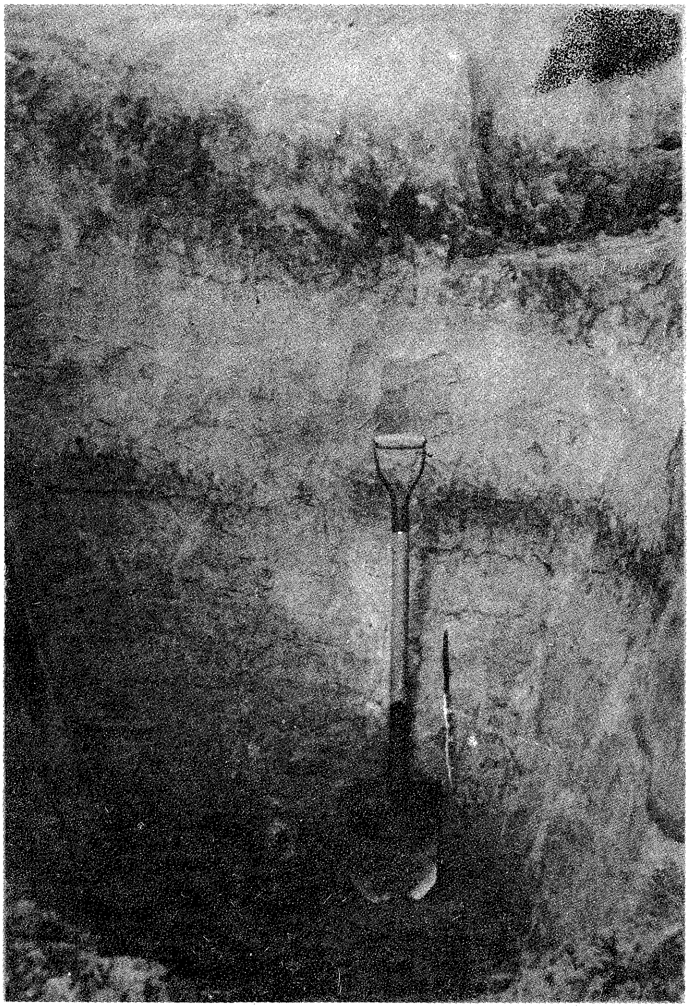


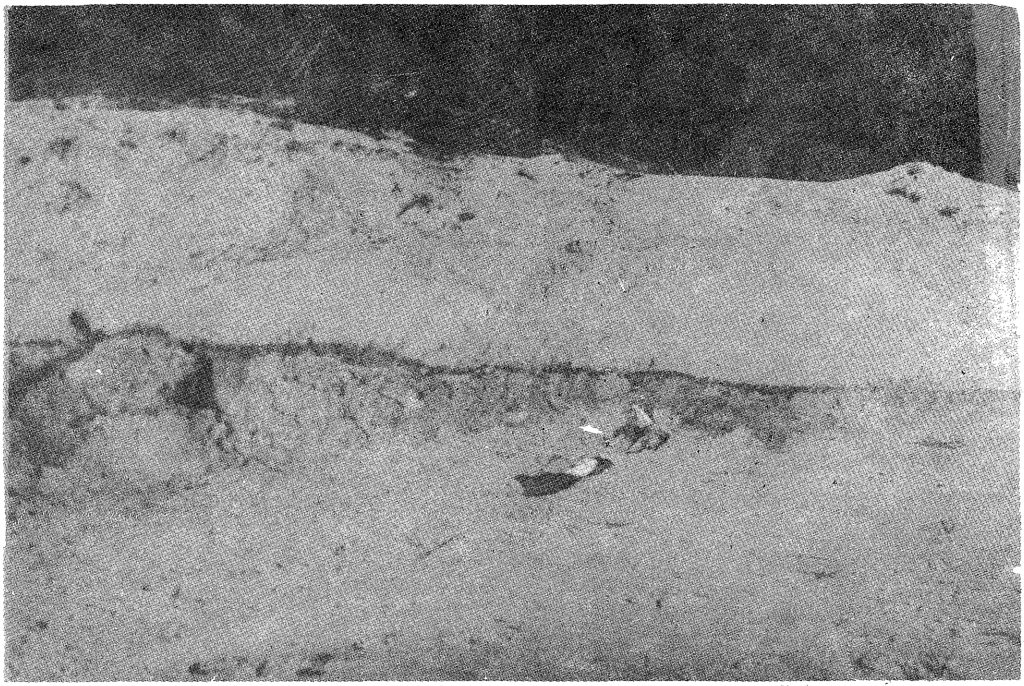
Fig. 5. Values of the roundness index (W_0) calculated for quartz grain fractions 0.6 – 0.75 mm and 0.75 – 1.0 mm

1. basement deposits; 2. deposits of the first dune horizon; 3. deposits of the second dune horizon; 4. deposits of the third dune horizon



Pl. 1. North wall of the ditch-outcrop 1. Below, fluvial sands can be seen turning into deposits of the first dune horizon. In the latter soil 1 has developed. There are visible ferric fibres. Over soil 1 there lie the sands of the second dune horizon topped with soil 2

Pl. 2. North of the ditch-outcrop 1. A fragment of the exposure shown in Pl. 1



Pl. 3. Outcrop 2. One soil horizon is visible; it consists of three horizons "overlapping" one another

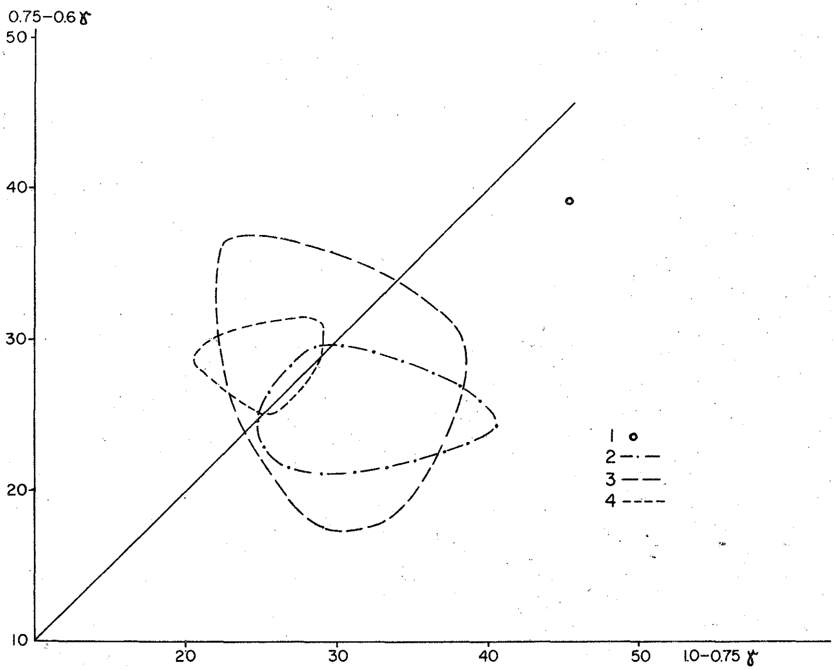


Fig. 6. Proportional share of group γ in quartz grains of fractions 0.6 – 0.75 mm and 0.75 – 1.0 mm

1. basement deposits; 2. deposits of the first dune horizon; 3. deposits of the second dune horizon; 4. deposits of the third dune horizon

distinguished by the highest average speed of dune-forming winds and by their considerable changeability.

The problem is differently interpreted by K. ROTNICKI (1970), who explains differences of granulation in the particular dune-sand series by the mechanics of transportation and the sedimentation of deposits in an aeolian environment, and considers them to be the function of the duration of the activity of aeolian processes. He thinks that all the dune horizons were accumulated in the same interval of wind velocity, 3 – 3.5 m/sec. which changed in gusts to 8 – 9 m/sec. This question will be discussed later.

Owing to an analysis of quartz grains roundness made in an automatic graniformameter it was possible to compare values of W_0 indices (KRYGOWSKI, 1964) and the percentage of γ group (comprising the best rounded grains) in two fractions: 0.6 – 0.75 mm and 0.75 – 1.0 mm (Fig. 5, 6). It appears that both in the basement and in the lower dune series there prevails a better rounding of grains in the coarser fraction and a higher share of group γ grains in this fraction (Fig. 5, 6). The middle series displays great variability. In some layers the general roundness

Mineral composition of the heavy fraction of basement deposits, aeolian sands

	Dune basement	Lower series of dune sands			
	sample 2	sample 9	sample 10	sample 11	sample 12 soil 1
Opaque minerals	26.9	26.2	22.2	27.6	24.2
Transparent minerals	73.1	73.8	77.8	72.4	75.8
Amphibole	16.1 (22.0)	9.4 (12.8)	21.2 (27.3)	11.5 (15.9)	12.6 (16.6)
Pyroxene	2.2 (3.1)	3.7 (5.0)	2.8 (3.6)	2.8 (3.8)	1.2 (1.6)
Epidote	17.5 (23.9)	23.6 (31.9)	10.7 (13.8)	14.9 (20.6)	18.9 (26.5)
Garnet	22.8 (31.2)	27.5 (37.2)	22.8 (29.5)	27.6 (38.1)	28.6 (37.7)
Zirconium	1.1 (1.5)	0.5 (0.7)	0.8 (1.0)	–	–
Tourmaline	2.5 (3.4)	1.1 (1.4)	4.4 (5.7)	2.5 (3.5)	5.8 (7.7)
Rutile	0.5 (0.6)	1.1 (1.4)	0.6 (0.8)	–	–
Disthene	0.7 (0.9)	–	0.4 (0.5)	0.2 (0.3)	0.2 (0.3)
Staurolite	2.9 (4.0)	2.9 (3.9)	2.2 (2.9)	3.0 (4.1)	3.9 (5.1)
Andalusite	1.1 (1.5)	0.3 (0.4)	0.2 (0.3)	0.7 (1.0)	0.7 (1.0)
Sillimanite	0.7 (0.9)	–	1.0 (1.3)	0.5 (0.6)	0.2 (0.3)
Biotite	2.5 (3.4)	1.6 (2.1)	5.9 (7.5)	3.9 (5.4)	1.9 (2.2)
Muscovite	–	–	2.4 (3.1)	2.3 (3.2)	0.2 (0.3)
Apatite	0.5 (0.6)	–	0.6 (0.8)	0.7 (1.0)	0.2 (0.3)
Feldspars	0.5 (0.6)	–	0.4 (0.5)	–	–
Carbonates	0.6 (0.9)	0.5 (0.7)	0.2 (0.3)	–	–
Glauconite	–	–	0.2 (0.3)	0.2 (0.3)	–
Phosphates	–	–	–	–	0.7 (1.0)
Other	1.1 (1.5)	1.8 (2.5)	0.8 (1.0)	1.6 (2.2)	0.7 (1.0)

Non-bracketted figures denote the percentage of the particular minerals in relation to the total ones.

of quartz grains and the share of group γ is higher in the coarser fraction while, frequently in adjoining layers, it is higher in the fine-grained fraction. In the upper series finer quartz grains seem to be better rounded and there occur more γ group grains in that fraction. This suggests a greater strength of the wind and its changeability at the time of accumulation of the dune sand which forms the lower horizon than at the time of accumulation of the upper horizon of dune sand. The middle series of dune sands must have been accumulated by winds of medium strength but of considerable changeability.

The results of both analyses suggest that the speed of the wind varied during the accumulation of the particular dune series. The strongest and most changeable winds prevailed during the accumulation of the oldest dune series (of the Older Dryas). During the accumulation of the middle series (at the close of the Younger Dryas and the beginning of the pre-Boreal period) dune-forming

Table II

and fossil soils of the dune at Liszyno (% of volume)

Middle series of dune sands			Upper series of dune sands	
sample 18	sample 19	sample 20 soil 2	sample 23	sample 25 soil 3
21.9	26.6	28.8	25.9	30.3
78.1	73.4	71.2	74.1	69.7
13.8 (17.7)	12.4 (18.0)	9.3 (13.1)	11.3 (15.2)	10.8 (15.5)
2.0 (2.5)	2.0 (2.9)	1.1 (1.6)	2.3 (3.0)	1.5 (2.2)
12.3 (15.7)	16.6 (24.0)	18.9 (26.5)	15.8 (21.3)	11.9 (17.1)
40.0 (43.5)	28.8 (41.7)	29.9 (42.1)	33.8 (45.6)	33.6 (48.1)
0.7 (8.0)	–	–	0.3 (0.3)	–
4.4 (5.6)	2.2 (3.2)	4.9 (6.9)	4.5 (6.1)	4.3 (6.2)
–	0.4 (0.6)	–	0.3 (0.3)	–
0.2 (0.3)	0.4 (0.6)	0.4 (0.6)	0.3 (0.3)	0.4 (0.6)
2.9 (3.7)	2.2 (3.2)	3.3 (4.7)	2.3 (3.0)	3.7 (5.3)
0.4 (0.6)	0.7 (1.0)	0.7 (0.9)	0.7 (1.0)	0.7 (0.9)
0.9 (1.1)	–	1.1 (1.6)	0.9 (1.2)	0.4 (0.6)
2.9 (3.7)	2.4 (3.6)	0.4 (0.6)	0.9 (1.2)	1.1 (1.6)
2.0 (2.5)	–	0.2 (0.3)	0.5 (0.6)	–
0.2 (0.3)	0.4 (0.6)	–	–	–
–	–	–	–	–
–	–	–	–	–
–	–	–	–	–
–	–	–	–	–
1.5 (1.0)	0.4 (0.6)	0.9 (1.3)	1.3 (1.9)	0.7 (0.9)

Bracketted figures mean the percentage of the particular minerals in relation to the transparent ones

winds had a lower velocity but a considerable changeability, while during the accumulation of the upper series (at the close of the Atlantic period and the beginning of the sub-Boreal) the speed and changeability of winds were the lowest of all the three series. The fourth horizon of dune sand (formed ca. 1000 years ago) has unfortunately not been investigated as regards the textural features of the deposit, hence are no data concerning the speed and changeability of the wind that formed this deposit.

The third analysis of textural features of the deposits concerned heavy minerals (Tab. II). For the above-presented analyses of granulation and quartz-grain roundness only samples of aeolian sands underlying the soil horizons were collected. In the analysis of the composition of heavy minerals there were considered both the differences among the three dune horizons and the difference in the percentage of the particular minerals in the dune sands and in the soils which developed in those sands. The analysis aimed at showing the participation of mechanic abrasion, during the aeolian transport, which led to the selection of minerals in favour of those which were more resistant to mechanical destruction; it also aimed at showing chemical weathering processes within the soil horizons.

As far as the composition of heavy minerals is concerned there are distinct differences between the particular dune-levels (Tab. II). It can be particularly well observed in three minerals: garnet, pyroxene and biotite. In the lower series the amount of garnet is the lowest – 30–38%; it grows to 42–44% in the middle series and up to 46–48% in the upper series. The share of garnet does not change in the soil horizons. As is well known, garnet is a mineral of medium resistance to chemical weathering processes (RACINOWSKI, RZECHOWSKI, 1969), but it is highly resistant to mechanical abrasion (MORAWSKI, 1965; MYCIELSKA-DOWGIAŁŁO, 1980). The enrichment in this mineral of the upper dune series as compared to the lower series proves that there occurred a selection of the deposit in the process of repeated winnowing of aeolian material and that the deposits of fluvial origin which form the basement and surroundings of the dunes were hardly used. We should refer here to W. STANKOWSKI (1963a, b) and K. ROTNICKI (1970) who have distinguished two phases of deflation: deep and surface deflation. Deep deflation prevailed in the first dune-forming phase – the material was mainly drawn from the basement deposits; surface deflation, characteristic of the later dune-forming phases, was limited to the destruction of windward slopes of the dunes and to transferring the material onto the lee slopes. On the basis of investigations in the Vistula valley it may be supposed that deep deflation was simultaneous with the time when the terrace lying above the floodplain was being cut and the flood terrace was formed; instead, surface deflation prevailed in the period of relative stabilization of the Vistula valley bottom at the level of the flood terrace. At the same time the latter was more conditioned by the density of vegetation. It is probable that areas covered with fluvial deposits, from the beginning of a strong expansion of vegetation between the Younger Dryas and the Holocene constitued a more favourable base for the development of vegetation than the dry and well sorted dune sands. This was the reason why aeolian sands were more subject to the frequent action of deflating processes than fluvial deposits.

The second mineral, the percentage of which varies in the three successive dune horizons, is pyroxene. Its content in the lower dune series ranges from 3.6 to 5.0% and decreases in the soil horizon, which covers this series, to 1.6%. In the middle dune series the share of pyroxene falls to 2.5–2.9% and then to 1.6% in the soil horizon topping that series. In the upper dune series the share of pyroxene is slightly higher than in the middle series (3.0%) and decreases again in the soil horizon (2.2%). Pyroxene belongs to the group of minerals least resistant to chemical weathering (RACINOWSKI, RZECHOWSKI, 1969) and fairly resistant to mechanical abrasion (MORAWSKI, 1965). Its visible decrease in the soil horizons seems to confirm this opinion.

The third mineral, the share of which changes according to the dune level, is biotite. In the lower series it ranges from 2.1 – 7.3%. It is relatively low in the soil level (2.2%). In the middle dune series the percentage of biotite generally decreases (3.6 – 3.7%) and falls visibly in the soil horizon (0.6%). In the upper dune horizon it is still lower (1.2%). In the soil horizon of this series this percentage is similar (1.6%).

Biotite is numbered among minerals of lowest resistance to chemical weathering (RACINOWSKI, RZECHOWSKI, 1969) and to mechanical abrasion (TURNAU-MORAWSKA, 1955). The selective decrease of its content in the upper dune horizon, as compared with the lower horizon, and its lowering share in the soil horizons especially in the two lower ones seem to confirm such an opinion.

The same fact of the decreasing content of undurable, easily weathering minerals in fossil soils as compared with underlying dune sands can be observed in the dune at Wiązowna-Piekiełko, south-west of Warsaw (in Alleröd soil; KONECKA-BETLEY, 1982). Investigations of heavy minerals in dune sands and in the basement carried out in four regions of Central Poland (URBANIAK-BIERNACKA, 1976) are not sufficient for such detailed conclusions, particularly concerning transformation among the respective dune horizons since the successive series have been treated jointly in different dunes. Nevertheless there is a visible enrichment in garnet of the dune sand as compared with the basement sand. It means that there occurred a selective enrichment in garnet during the deflation process and aeolian transport, due to the destruction of all less resistant minerals through mechanical abrasion.

Beside the minerals mentioned above, other ones, well resistant to chemical weathering, such as staurolite, tourmaline and disthene are richer in the respective soil horizons at Liszyno in relation to dune sands in which the given soil was formed, without changing their proportional content according to dune series. Amphibole, a mineral of very low resistance to chemical weathering, reduces its proportion in the soil horizons in the same way (it is particularly well visible in the two upper horizons).

The above presented data concerning chemical changes in the soil horizons, reflected in the content of heavy minerals, should be treated as an introduction to a discussion on finding additional criteria in defining the extent of chemical weathering processes in the particular soil horizons towards the close of the glaciation and in the Holocene.

To end the conclusions which may be drawn from the analysis of the content of heavy minerals it should be noted that there occurs a much richer group of minerals with poorer rounding, in the basement and the lower dune series than in the two upper series. It seems to confirm the former conclusion that deep deflation prevailed at the time of accumulation of the lower dune series while surface deflation took place during the formation of the two upper horizons.

Table III

Changes of selected physico-geographical phenomena in the Late Glacial and the Holocene observed in the dune of Liszyno near Płock

Stratigraphy	Origin, structural and textural features of deposits	Soils	Age based on ^{14}C dating and artifacts	Morphodynamical, fluvial and aeolian processes
Subatlantic	Sand deposits of the highest (fourth) dune series much transformed anthropogenically	At present the soils on dunes are wholly destroyed or initial	Ceramic fragments of the tenth century, covered with the dune sand	Last dune-forming processes initiated about the 10^{th} century. Sand accumulation mainly on north slopes. South dune-forming winds
Sub-Boreal	No data			No data
	Soil horizon developed in deposits of upper dune series. Among heavy minerals reduction of pyroxene, enrichment in disthene and staurolite in relation to deposits unchanged by soil processes		3,610 ±120 BP	Temporary set-back of deflation processes lasting till the 10^{th} century. Formation of soil. Expansion of vegetation interrupted by fires
Atlantic	Structureless sand deposits of the upper dune series; highest degree of sorting (of all three horizons) and lowest values S_{k1}. Quartz grains of fraction 0.6–0.75 mm better rounded than in fraction 0.75–1.0 mm. Highest content of garnet, lowest of biotite			Intensive surface deflation in the already existing dunes. Thorough destruction of Atlantic soil. Accumulation of the upper dune series
	No dune deposits	No data. The formation of soils known in other dunes of Central Poland excluded		No data

	No data		8,750 ± 100 BP	No data
Boreal	Soil horizon formed in deposits of the middle dune series. Among heavy minerals reduction of amphibole and pyroxene, enrichment in tourmaline and staurolite in relation to deposit unchan ed by soil processes	Rusty podsolized soils and proper rusty soils		Temporary set-back of deflation processes due to expanding vegetation and soil formation. In the second half of the period denudation processes in the ridge parts of dunes and formation of deluvial horizons. At the end of the period traces of fire
Pre-Boreal Younger Dryas	Sand deposits of the middle series, structureless, medium sorting degree as compared with the two other series. Highly changeable mutual relation of quartz grain rounding degree of fractions 0.75–1.0 mm and 0.6–0.75 mm. Enrichment in garnet, reduction of pyroxene and biotite as compared with deposits of lower dune series			Stabilization of the Vistula channel at the level of the present-day flood terrace. Surface deflation mainly within the already existing dunes. Decay of soil 1 in the ridge part of the dune
Alleröd	Soil horizon formed in deposits of lower dune series. Fairly rich group of heavy minerals, with less pyroxene but richer in tourmaline and staurolite in relation to deposit unchanged by soil processes	soils with weak podsolization	10,400 ± 180 BP	Temporary set-back of deflation processes by the expansion of vegetation and soil formation. At the end of the period traces of fire
Older Dryas	Deposits of the lower dune series, poorly sorted though better than the fluvial deposits of the basement. High S_{k1} value, better quartz grain rounding in fraction 0.75–1.0 mm than 0.6–0.75 mm. Rich group of heavy minerals resembling basement deposits. Higher percentage of garnet than in the basement			Further incision of Vistula channel and formation of the present-day flood terrace. At the level of the terrace lying above the floodplain deep deflation and formation of dunes by west winds of considerable velocity and great changeability

cont.

Stratigraphy	Origin, structural and textural features of deposits	Soils	Age based on ^{14}C dating and artifacts	Morphodynamical, fluvial and aeolian processes
Bölling	Levee deposits underlying the dune. Fine-grained sand interbedded with coarse sand and small pebbles			Incision of Vistula channel in the present-day terrace lying above the floodplain. Accumulation of levee along the nascent edge. Lowering of ground water level.
Oldest Dryas	Fluvial deposits forming the present-day terrace lying above the floodplain, underlying the dunes. Fine- and medium grained sands interbedded with silt, horizontally stratified. Poorly sorted deposit, low S_{kl} values. Better rounding of quartz grain in fraction 0.75–1.0 mm than in fraction 0.6–0.75 mm. Rich group of heavy minerals; generally a higher percentage of non-resistant minerals than in overlying dune sands			Accumulation of the present-day terrace lying above the floodplain with the participation of water of high discharge dynamics, with braided channel system. Aeolian processes in elevated parts. Deposits with aeolian abrasion accumulated in river channels

FINAL CONCLUSIONS

The results of investigations are presented in table III. Below, the most important conclusions have been summarized in a few points:

1. The direct cause which initiated aeolian processes was the incision of the Vistula channel into the valley bottom which constitutes the present-day terrace lying above the flood plain, and the lowering of the ground water level.

2. The initial dune form at Liszyno appeared in the Older Dryas; it was probably ca. 5 m high.

3. The deposit which formed the dune in the Older Dryas originated from deflated fluvial sand which constituted the immediate basement of dunes. At the time dune-forming winds had considerable velocity and great changeability.

4. In the dune of Liszyno four dune series have been distinguished separated by three ^{14}C dated fossil soils. The oldest (first) soil with charcoals dated 10,400 $\pm$ 180 radiocarbon years BP (Gd-2028) is poorly podsolized. It contains ferric fibres. Its development was interrupted by a fire in the second half of the Younger Dryas. At the end of the Younger Dryas and the beginning of the pre-Boreal it was covered with a new series of aeolian sand.

The second soil with charcoals dated 8750 $\pm$ 100 radiocarbon years BP (Gd-1540) is a dual soil (proper rusty soil and podsolized rusty soil). It was partly developed on a dune of the Younger Dryas and partly on aeolian sand of the pre-Boreal. In the Boreal period its formation was interrupted by a fire. The soil was covered with the next series of aeolian sand. The third soil with charcoals dated 3610 $\pm$ 120 radiocarbon years BP (Gd-2027) is fairly or poorly podsolized, its formation began in the half of the sub-Boreal period. Its development was definitely interrupted about the tenth century as is indicated by fragments of ceramics. The soil was covered by the youngest (fourth) series of aeolian sand.

5. The second and third series of aeolian sand were formed by the deflation of formely deposited aeolian sands. The second series (between the first and the second soil horizon) was accumulated by winds of a lower speed than in the case of the previous series, but of great changeability. The third series of aeolian sands (between the second and the third soil horizon) was accumulated by winds of the lowest speed and changeability in relation to the two previous series.

6. The process of repeated winnowing was marked in the composition of heavy minerals by the enrichment in minerals of great resistance to mechanical abrasion (garnet) and a decrease in the content of non-resistant minerals (pyroxene and biotite).

7. Soil-forming processes in all three soil horizons were marked by a change in the composition of heavy minerals. Minerals which were not resistant to chemical weathering underwent impoverishment, those well resistant were enriched.

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