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A STUDY OF THE LATE-GLACIAL AND HOLOCENE VEGETATIONAL HISTORY OF THE WOLBROM AREA (SILESIAN-CRACOVIAN UPLAND)

Późnoglacjalna i holoceńska historia roślinności okolic Wolbromia na Wyżynie Śląsko-Krakowskiej

ABSTRACT. Three profiles from the peatbog at Wolbrom were examined by pollen analysis and one profile was analysed for its plant macrofossil content. The palaeobotanical results are supplemented by 19 radiocarbon dates. Eleven pollen assemblage zones were distinguished in the pollen diagrams and served as a basis for the description of the vegetational history of the Wolbrom area from the Oldest Dryas to the Subatlantic period. The profiles studied showed that there was a cool fluctuation in the climate around 12 000 years B. P. which corresponds to the Older Dryas. Four plant macrofossil assemblage zones have been distinguished on the diagram. They illustrate the changes in the local vegetation in the peatbog — the succession from shallow bodies of water, through eutrophic and mesotrophic systems to raised bog communities. The likelihood that river capture intensified within the peatbog during the Alleröd, the younger part of the Atlantic period and the Subboreal period was confirmed. At the transition between the Younger Dryas and the Preboreal period the water level in the peatbog probably fell, and the contemporaneous water flow was intensified.

INTRODUCTION

The Wolbrom peatbog has long been a topic of interest to palaeobotanists, and some of the earliest Polish pollen diagrams come from there (Trela 1928). Palaeobotanical studies were renewed there in the 1970's (Latałowa 1976, Obidowicz 1976). The interesting results of these investigations, and in particular, the discovery of an uninterrupted sequence of Late-Glacial sediments there made it possible for this site to be included in IGCP project No. 158B New palynological studies have therefore been set in motion (M. Latałowa), plant macrofossils have been analysed (D. Nalepka), and the sediments have been radiocarbon-dated (E. Gilot and M. F. Pazdur).

The Wolbrom peatbog is a reference site in the Silesian-Cracovian Upland subregion (Silesian-Little Poland Uplands type region) in southern Poland

(Ralska-Jasiewiczowa 1982). Its significance becomes especially apparent in the light of the fact that there are no lakes or other peatbogs in this subregion. This is the only site found so far where it has been possible to reconstruct the post-glacial history of the vegetation of this extensive area.

DESCRIPTION OF THE STUDY AREA

Location, geomorphology, water regime, climate

This site is located about 200 km south of the most southerly extent of the Vistulian glaciation (Fig. 1).

It lies on the Silesian-Cracovian Upland within a wide tectonic depression (Fig. 2B) which Gilewska (1972) has called Brama Wolbromska (Wolbrom Gate). The bottom of this depression is filled mainly by Tertiary formations. The hills surrounding the Wolbrom Gate are of Upper Jurassic and Cretaceous limestones which have been subjected to continuous karst processes. The highest point in the vicinity of Wolbrom is 461 m above sea level.

A considerable part of the Silesian-Cracovian Upland and the Miechów Upland adjoining it to the east was covered having a thickness of than several meters to more than 10 meters during the last glaciation with a layer of loess. In the river valleys, also in the neighbourhood of Wolbrom, the older formations are overlaid with Quaternary sands (Czeppe 1972a).

Most of the Silesian-Cracovian Upland suffers from a serious shortage of water. The few rivers are supplemented by a fairly dense network of temporary drainage channels which appear even after a short period of rainfall. Also of importance is the fact that this is a karst area and so rain water accumulates in deeplying water-bearing strata (Michalik 1974).

The depression in the vicinity of Wolbrom is one of the areas rather better supplied with water, where the Biała Przemsza and Szreniawa have their sources. The peatbog straddles the watershed between these two rivers. The Centary, a tributary of the Biała Przemsza, flows out of the western side of the bog, while the Szreniawa drains its eastern side. The latter river is up to 3 m deep in its cause across the peatbog, but is already 6 m deep at the point where it leaves the bog area. The erosion level of the Szreniawa is much lower than that of the Biała Przemsza and that is why typical river capture has occurred here. According to Lewiński (1914) this capture took place before the Pleistocene. Now the process is being repeated, except that this rejuvenated capture is occurring at a higher erosion level and is cutting back into the largely Pleistocene surface strata of the old valley. The catchment area of the Szreniawa is still tends to extend in a westerly direction (Dynowska 1963).

The main climatic features of the Wolbrom area are shown in diagrammatic form (Fig. 3). The average annual precipitation is not high (712 mm), although

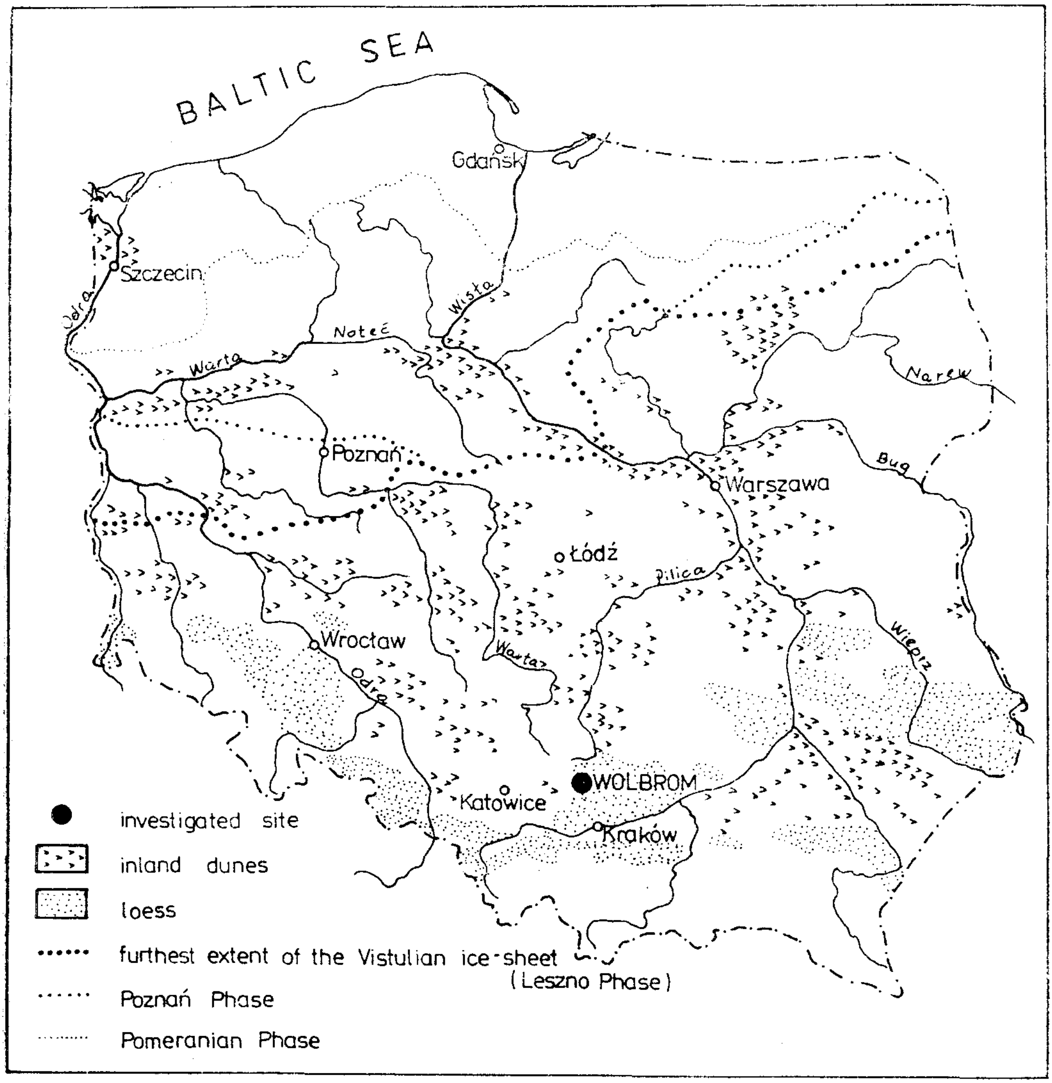

Fig. 1. Location of Wolbrom in relation to the extend of the last glaciation, loess areas and inland dunes (after Maruszczak 1983 — slightly simplified)

in particular years large variations may occur both in the actual total rainfall figure and in the level of humidity during the year. The ratio of low annual precipitation to high annual precipitation is 1 : 2. The mean annual temperature is 6,6° C. The amplitude of monthly temperature fluctuations is often more than 20° C. Winter usually commences at the end of November and lasts about 100 days. The ground is covered with snow for an average of 80 days Kleczkowski 1972). The prevailing winds are westerly (Schmuck 1959).

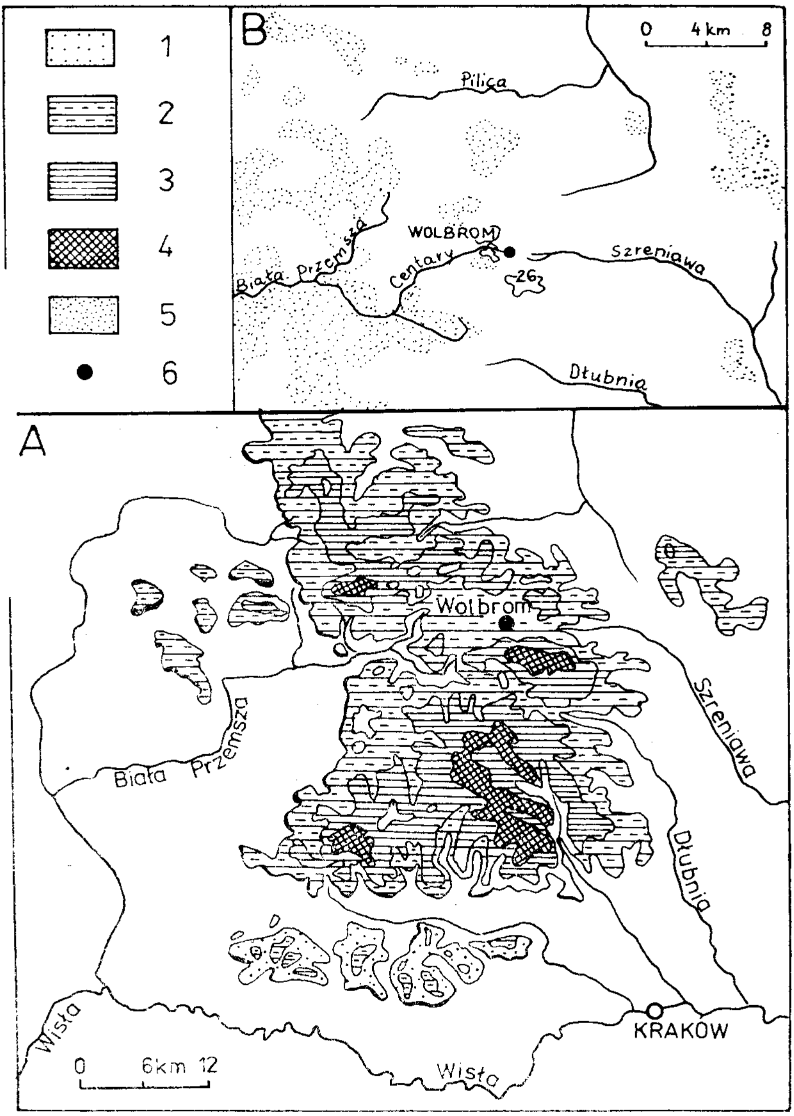

Fig. 2. Location of Wolbrom on a morphological map of the area (after Lencewicz from Kondracki 1967 — simplified) — A and in relation to the river system and loess areas — B. 1 — 350 m a.s.l., 2 — 400 m a.s.l., 3 — 450 m a.s.l., 4 — 500 m a.s.l., 5 — loess, 6 — investigated site

Soils and vegetation

The varied relief and quality of substrate of the upland terrain around Wolbrom are responsible for the differentiation of soils and vegetation in this area. The dominant soils here are formed from loess; podzolised loess soils, the much

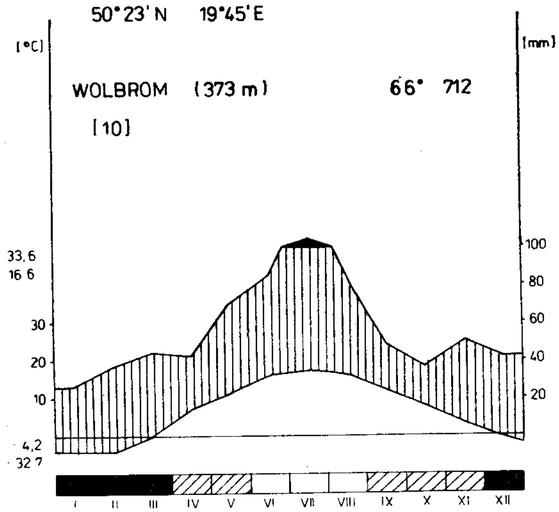

Fig. 3. Climatic diagram of the Wolbrom station drawn by the Gaussen-Walter method (Walter 1955)

rarer chernozems, and brown earths decalcified to varying degrees. These soils are very much exposed to all forms of erosion. Podsols, pseudopodsols and pseudo-brown soils are also to be found overlying sandy formations in river valleys. Rendzina soils are usually found where Jurassic and Cretaceous rocks outcrop. The waterlogged bottoms of the wide depressions are covered with anmoor warp soils (Kozłowska 1923, Czeppe 1972b, c, Michalik 1974).

Fields are the dominant feature of the present-day landscape of the Silesian-Cracovian Upland. Except for a few small patches of pine wood *(Vaccinio myrtilli-Pinetum)* on the poorest soils, and meadows in the damp depressions, the whole area around Wolbrom is arable land.

However, the natural vegetation of the Upland consisted mostly of deciduous and mixed woodland, traces of which survive in the patches of the *Fagetum carpaticum*, *Pino-Quercetum*, *Tilio-Carpinetum* and *Phyllitido-Aceretum* association. The now rare *Ficario-Ulmetum* association occurs in places in the upper reaches of the river valleys, while there are alder woods lower down. Only on the limestone rocks and landslip debris have natural sward communities always existed (Kozłowska 1923, Medwecka-Kornaś 1952, Michalik 1974, Szafer 1975).

The Wolbrom peatbog lies just within the Silesian-Cracovian Upland and is contiguous with the Miechów Upland, an area almost completely deforested and characterised by a few localities of the xerothermic sward associations *Inuletum ensifoliae*, *Seslerio-Scorzoneretum purpureae* and *Stipetum capiliatae* (Kozłowska 1923, Szafer 1975).

CHARACTERISTICS OF THE SITE AND THE LOCALIZATION OF THE PROFILES

The peatbog is about 1.5 km long and about 0.5 km wide and is a part of a larger area of bogs (c. 880 ha). Because of urbanisation and extensions to the railway system in the area, the peatbog vegetation here has been totally destroyed. The gradual degradation of these communities had begun much earlier: peat-cutting had been going on since at least the beginning of this century, and some drainage work was done in 1942.

The first floristic information (Kozłowska 1923) shows that at the beginning of the 20th century, the bog flora of the eastern part of the peatbog was already impoverished. This was the result both of natural hydrological processes taking place in this area (Lewiński 1914) and of peat exploitation. The western part of the deposit was at that time well supplied with water and typical raised-bog

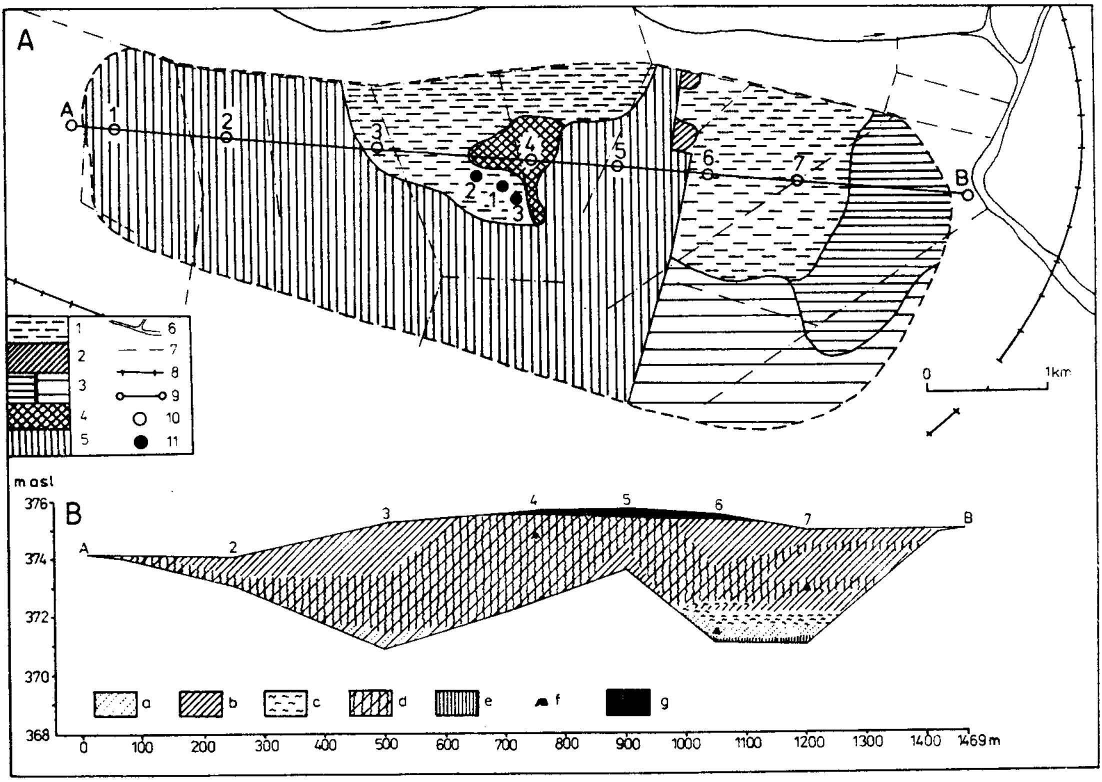

Fig. 4. A. Contemporary plant communities on the Wolbrom peatbog (according Michalik 1976) and coring locations; 1 — *Oxycocco-Sphagnetea* and *Scheuchzerio-Caricetea fuscae*, 2 — *Juncetum effusi*, 3 — cf. *Junco-Molinietum* and *Molinietalia*, 4 — *Nardo-Callunetea*, 5 — plantation with *Alnus glutinosa* and *Betula verrucosa*, 6 — streams, 7 — drainage ditches, 8 — *railway track*, 9—10 — location of borings worked out by Obidowicz (1976), 11 — location of the pollen profiles. B. Longitudinal section of the peatbog (according Obidowicz 1976); a — *Bryaleti* peat, b — *Cariceti* peat, c — *Sphagnum teres* peat, d — *Cariceto-Phragmiteti* peat, e — silt, f — tree stumps, g — degree of peat humification over 70 percentage

communities flourished there. Kozłowska mentions *Sphagnum rubellum*, *Polytrichum strictum*, *Drosera rotundifolia*, *D. longifolia*, *Oxycoccus quadripetalus*, *Andromeda polifolia* and *Eriophorum vaginatum* as being among the most characteristic species. She also noted *Salix livida*, a relic plant from the glaciation period.

Phytosociological records made in the 1970's (Michalik 1976) indicate that by then only traces of the former communities could be found. The state of the vegetation reflected the very serious degradation of the *Oxycocco-Sphagnetea* communities. Much of the peatbog had been afforested with young stands of alder and birch, while in other parts *Molinietalia* meadow communities or poor *Nardo-Callunetea* swards were dominant (Fig. 4A).

The structure of the peat deposit was investigated by Obidowicz (1976). The cross-sections of the deposit prepared by him show that the basin was characterised by large differences in relative depth, which must have had a bearing on the different types of succession in the peat-forming communities in the different parts of the peatbog (Fig. 4B).

MATERIAL AND METHODS

The material for this study was taken from three sites in the central part of the basin (Fig. 4A). Three cores were taken: the WOL. 1 profile was obtained with a 5 cm diameter Instorf corer in 1969, the WOL. 2 profile with a Więckowski corer in 1972, and the WOL. 3 profile with an 8 cm diameter Instorf corer in 1979.

Pollen analysis

This study presents the results of the pollen analysis of three profiles: the WOL. 1 profile (Latałowa 1976) for its hitherto unpublished ^{14}C data (Fig. 6), the WOL. 2 profile (Fig. 7) which served only as material for correlating the other two profiles with the ^{14}C data and the results of the study of the botanical composition of the peats, and the WOL. 3 profile (Figs. 8, 9) in which the analysis of the Late-Glacial and Early Holocene parts of the deposit was repeated.

The samples were acetolysed by Erdtman's method (Faegri & Iversen 1975). Mineral constituents were removed by decanting and treatment with hydrofluoric acid. Samples from the WOL. 3 profile were taken with a 1 cm^3 sampler; tablets containing *Lycopodium* spores were added in order to calculate the sporomorph concentration (Stockmarr 1971).

The calculation of percentages were based on the sum AP +NAP from which pollen grains from aquatic and marsh plants, spores and pre-Quaternary sporomorphs were excluded.

Plant macrofossil analysis

A through investigation of the plant macrofossils in the WOL. 2 profile (Fig. 11) was made, but those sections of the core sent for radiocarbon dating were not analysed. Only supplementary analyses were done for the WOL. 1 (Tab. 5) and WOL. 3 (Tab. 6) profiles.

The samples to be analysed for plant macrofossils and for the botanical composition of the peat were boiled in water containing 10% KOH, then rinsed on a 0.2 mm mesh screen. Plant macrofossils from WOL. 2 were counted in 40 to 60 cm^3 samples. All the fruits, seeds and tissues in this profile were identified; Fig. 11 shows the numbers of these macrofossils calculated for 50 cm^3 of sediment. The biometric method was used to identify nutlets and birch scales (Białobrzeska & Truchanowiczówna 1960).

The birch fruits were damaged to varying extents. Only intact nutlets and fragments of them which included the stigma counted as single specimens.

Concerning sedges, intact achenes, a suitable number of walls or fragments of them, and utricles containing achenes or empty utricles if the sample contained no achenes were counted as single specimens. In a few samples there were seeds containing the remains of a much-decayed pericarp similar to sedge achenes in appearance (cf. *Carex* on Fig. 11).

The study material contained numerous *Sphagnum* sporangia; number of specimens in the diagram corresponds to the number of opercula, which were always more abundant than sporangia without opercula. A scale was introduced for other macrofossils that proved difficult to count, such as the spindles of ***Eriophorum vaginatum***, and the leaves of ***Scheuchzeria palustris***, *Oxycoccus* sp., *Calluna vulgaris*, and ***Betula*** sp.: + denoted a single specimen, ++ up to 100 specimens, and +++ more than 100 specimens.

The botanical composition of the peat was determined by analysing from each sample an average of 5 microscope slides from the WOL. 2 profile and 2 slides from the WOL. 3 profile; the percentage of each taxon present was estimated. The results of the analyses of the WOL. 2 profile are given in a separate column on the left-hand side of Fig. 11. A taxon was included only if there was at least 1% of it present. "Bryales" include branches of mosses not identified because of their poor state of preservation; "other mosses" include *Calliergon* sp., *Aulacomium palustre*, ***Meesia triquetra*** and ***Paludella squarrosa***. Table 6 provides information on the preliminary analyses of the WOL. 3 profile.

Description of the sediments

Cores WOL. 2 and WOL. 3 were described according to Troels-Smith's system (1955) using a simplified version of the symbols on the diagrams. Colours are given in accordance with Munsell's scale (1954). The description of core WOL. 1 has been simplified.

The extent to which the peat had decomposed was determined microscopically from fresh material; percentage estimations were made and these have been included in the diagram (Fig. 11).

THE SEDIMENTS

The WOL. 1 profile

0—375 cm	Black-brown, mediumly decomposed *Carex* peat; extent of decomposition increases from ±175 cm downwards; there is a dry layer between 275 and 312 cm. *Carex fusca*, *C. diandra* and *Menyanthes trifoliata* nutlets and *Nuphar* seeds present (125—137 cm);
375—456.5 cm	black-brown, strongly decomposed moss peat with traces of sand; 40% of the upper part consists of the remains of *Sphagnum teres*, but the lower part comprises mainly brown mosses of the genera *Calliergon*, *Drepanocladus*, and also *Scorpidium scorpioides* and *Helodium* cf. *lanatum*;
456.5—481 cm	black-brown *Carex*-moss peat with high sand content; extent of decomposition over 80%;
481—500 cm	medium-grained sand with admixtures of silt and a small quantity of humus;
500—504 cm	grey-black medium-grained sand with high humus content;
504—530 cm	grey-brown coarse-grained sand containing precipitated iron compounds;
530—543 cm	irregular thin layers of dark brown, medium-grained sand and grey-olive silt;
543—571 cm	mud and grey-brown silt with traces of humus, irregularly interbedded with fine-grained sand;
571—575 cm	grey, fine-grained sand with an admixture of silt and mud.

The WOL. 2 profile

10—18 cm	*Eriophorum-Scheuchzeria palustris* peat, dark brown with a reddish tinge, fairly well compacted. Traces of burnt blades of grass and burnt moss branches. Lim. sup. 4, nigr. 3, strf. +, elas. 1, sicc. 3, col. 5YR 3/2, $Th^2 4$, extent of decomposition 30%;
18—30 cm	dark brown *Eriophorum* peat with traces of sand and burnt blades of grass between 18 and 23 cm. Lim. sup. 0, nig. 3, strf. 0, elas. +, sicc. 2, col. 5YR 2/2, $Th^{2+}4$, Ga(+), extent of decomposition 45%;

30—56 cm	spongy, unhomogeneous *Sphagnum-Eriophorum* peat, dark brown with a reddish tinge; traces of sand between 46 and 51 cm, and traces of burnt blades of grass and moss branches between 36 and 56 cm, Lim. sup. 1, nig. 2, strf. +, elas. 1 +, sicc. 2, col. 5YR 3/3, Th^{2+}4, Tb^{3}+ +, Tl +, extent of decomposition 50%;
56—180 cm	dark brown, spongy *Carex*-moss peat; traces of sand between 56 and 61 cm and between 111 and 116 cm, traces of burnt blades of grass and burnt moss branches between 116 and 210 cm. Lim. sup. 0, nig. 2 +, strf. 0, elas. 2, sicc. 3, col. 5YR 2/2, Th^{2}3, Tb^{3}1, extent of decomposition 30%;
180—272 cm	*Carex-Phragmites* peat, black-brown to dark brown in colour; traces of burnt blades of grass between 213 and 246 cm. Lim. sup. 2, nig. 3, strf. 0, elas. 1, sicc. 2, col. 5YR 2/1 at the top to 5YR 2/2 at the bottom, Th^{2+}4, Tl +, extent of decomposition 35%;
272—315 cm	dark brown moss peat with *Sphagnum teres*, with single grains of sand, traces of burnt blades of grass from 282 to 286 cm and from 293 to 302 cm. Lim. sup. 0, nig. 3, elas. +, sicc. 2.5, col. 5YR 2/2, Tb^{2}4, Th^{2}+ +, Ga +, extent of decomposition 45%;
315—348 cm	black-brown moss peat, crumbly, single grains of sand are visible. Lim. sup. 0, nig. 3.5, strf. 0, elas. +, sicc. 3, col. 5YR 2/1, Tb^{2}4, Th^{3,5}+, Ga +, extent of decomposition 55%;
348—372 cm	brown, crumbly, unhomogeneous, sandy peat, impossible to identify. Lim. sup. 0, nig. 3, strf. 0, elas. 0, sicc. 3, col. 5YR 3/1, Th/Tb^{4}3.5, Ga 0.5, extent of decomposition 80%, there is a thin layer of grey mud at the bottom;
372—410 cm	grey-brown, silty sand, unhomogeneous with precipitated iron compounds. Silty part: nig. 1.5, strf. +, elas. 0, sicc. 3, col. 7, 5YR 4/2, As/Ag 3, Ga1, Sh +; sandy part: nig. 1, strf. +, elas. 0, sicc. 3, col. 7,5YR 7/2, Ga 4, As +, Ag +, Lf(+);
410—433 cm	homogeneous, light-grey sand with plant remains. nig. 1, strf. 0, elas. 0, sicc. 3, col. 10YR 7/2, Ga 4, As/Ag +, Tb^{1}+, Lf(+);
433—453 cm	grey, irregularly layered silty sand containing precipitated iron compounds. Lim. sup. 0, nig. 1 +, strf. +, elas. 0, sicc. 4, col. 10YR 6/1, changes from 7/1—6/3, precipitated iron compounds 6/6, Ga 3, As 0.5, Ag 0.5, Lf +, Tb^{1}+ +, Th^{1}+;
453—472 cm	"marble-like" sandy mud, from light grey to grey-olive in colour, contains the roots of herbaceous plants; irregular precipitation of iron compounds. Lim. sup. 1, nig. 1 + to 0.5, strf. 0, elas. 0, sicc. 4, col. 2,5Y 7/2—6/4 Ag 4, As +, Ga +, Th^{3}+, Lf +;

472—482 cm	slightly compacted sand, from light grey-beige to dark grey-beige in colour with ferruginous interbedding, and containing vertical roots of herbaceous plants; the lower boundary of the sand is sloping. Lim. sup. 3, nig. 1.5, strf. +, elas. 0, sicc. 4, col. 2,5Y 8/2—5/2, Ga 4, As/Ag + +;
482—496 cm	homogeneous mud, grey tinged with olive, compact, traces of burnt herbaceous plants from 482 to 487 cm. Lim. sup. 3, nig. 2, strf. 0, elas. 0, sicc. 4, col. 2, 5Y 6/2, Ag 3, As 1, Ga + +, Th^3 +, Lf(+);
496—510 cm	light grey, unhomogeneous, sandy mud containing precipitated iron compounds. Lim. sup. 3, strf. 0, elas. 0, sicc. 4; muddy part: col. 5Y 7/2, Ag 3, As 0.5, Ga 0.5, Th^3(+); sandy part: col. 10YR 6/8, Ga 4, As +, Ag +, Lf +, Th^3(+).

The WOL. 3 profile

200—342 cm	Spongy *Carex* peat, brown tinged with red; wood fragment at 311—315 cm. Lim. sup. 1, nig. 3, strf. 0, elas. 1 +, sicc. 2, col. 5YR 2/2, $Th^2$4, extent of decomposition 40—50%;
342—360 cm	brown, spongy moss-*Carex* peat. Lim. sup. 0, nig. 3 +, strf. 0, elas. 1, sicc. 2, col. 5YR 2/1, $Tb^1$3, $Th^1$1, extent of decomposition c. 25%;
360—435 cm	brown, spongy *Carex*-moss peat, fragments of periderm and pieces of wood in the top part. Single grains of sand from 380 cm downwards. Lim. sup. 1, nig. 3, strf. 0, elas. 1, sicc. 2, col. 5YR 2/2, $Th^2$2, $Tb^2$2, Ga(+), extent of decomposition c. 30%;
435—465 cm	light brown moss peat. Lim. sup. 1, nig. 3 + strf. 0, elas. 1, sicc. 2, col. 5YR 2/1, Tb^{1-2}3, Th^{1-2}1, Ga(+). extent of decomposition from 40 to 25%;
465—485 cm	dark brown moss peat; a piece of wood at 470 cm. Lim. sup. 1, nig. 3 +, strf. 0, elas. 1, sicc. 2—1, col. 5YR 2/1, $Tb^3$4, Ga + +, up to $Tb^3$2, Ga 2, extent of decomposition 50%;
485—493 cm	grey-brown sandy silt with high content of decomposed plant detritus. Lim. sup. 1, nig. 3, strf. 0, elas. 1, sicc. 2, col. 2YR 4/2, Ag/As 2, Ga 1, $Ld^2$1;
493—495 cm	slightly silty, grey, medium-grained sand. Lim. sup. 1, nig. 2, strf. 0, elas. 0, sicc. 2, col. 10YR 5/3, Ga 3, As/Ag 1, Sh +.

RADIOCARBON DATING AND RATE OF ACCUMULATION

There are a number of radiocarbon dates available for the Wolbrom peatbog profiles (Table 1). 14 samples from WOL. 1 and WOL. 2 were dated by E. Gilot at the Laboratoire du Carbonne-14 of the University of Louvain in 1979, and

Table 1

^{14}C dates from the Wolbrom profiles

Profile	Symbol of sample	Depth (cm)	^{14}C age (B. P.)
WOL. 1	Lv — 996	16—39	2300±70
	Lv — 997	39—50	2420±70
WOL. 2	Lv — 998	30—36	5850±70
	Lv — 999	70—87	7020±75
	Lv — 1000	172—182	8390±80
	Lv — 1001	197—205	8800±110
	Lv — 1002	267—272	10110±130
	Lv — 1089	287—292	10300±100
	Lv — 1003	292—297	10670±100
	Lv — 1004	310—315	9410±120
	Lv — 1054	315—320	11800±110
	Lv — 1005	328—333	11560±120
	Lv — 1006	343—353	11630±150
	Lv — 1007	365—370	12340±160
WOL. 3	Gd — 2341	265—270	9010±110
	Gd — 1853	315—320	9140±110
	Gd — 2339	355—360	9740±160
	Gd — 1854	390—395	10460±110
	Gd — 2340	457—462	12130±160

5 samples from WOL. 3 were dated by M. F. Pazdur at the C-14 Laboratory of the Silesian Polytechnic in Gliwice in 1985. The datings from Louvain were based on a ^{14}C half-life of 5570 years, whereas the Gliwice datings assumed a ^{14}C half-life of 5568 years.

The series of dates from the WOL. 2 and WOL. 3 profiles made it possible to plot graphs of the rate of accumulation of the peat deposits at Wolbrom (Fig. 5). Similar rates of accumulation (0.40—0.49 mm/year) were found in the lower parts of both profiles where mostly Late-Glacial moss peats and *Sphagnum teres* peat were deposited. The rate of accumulation became distinctly faster (0.53—0.67 mm/year) at the start of the Holocene when bog communities with *Dryopteris thelypteris* were common in this locality (see Figs. 6, 7, 8).

A very high peat accumulation rate (3.85 mm/year) was recorded in WOL. 3 in layers dated at c. 9000 B. P. The description of the sediments shows that this part of the profile comprises mostly remains of the genus *Carex*. As at locality WOL. 2, communities of high sedges from the order Magnocaricetalia were probably dominant here. Only very rarely does one come across such a high rate of sediment accumulation. Similar values have been found for *Phragmites* peats which are formed under similar conditions (Żurek 1976). There may well be an element of error in this calculated rate of accumulation, but the rapid growth

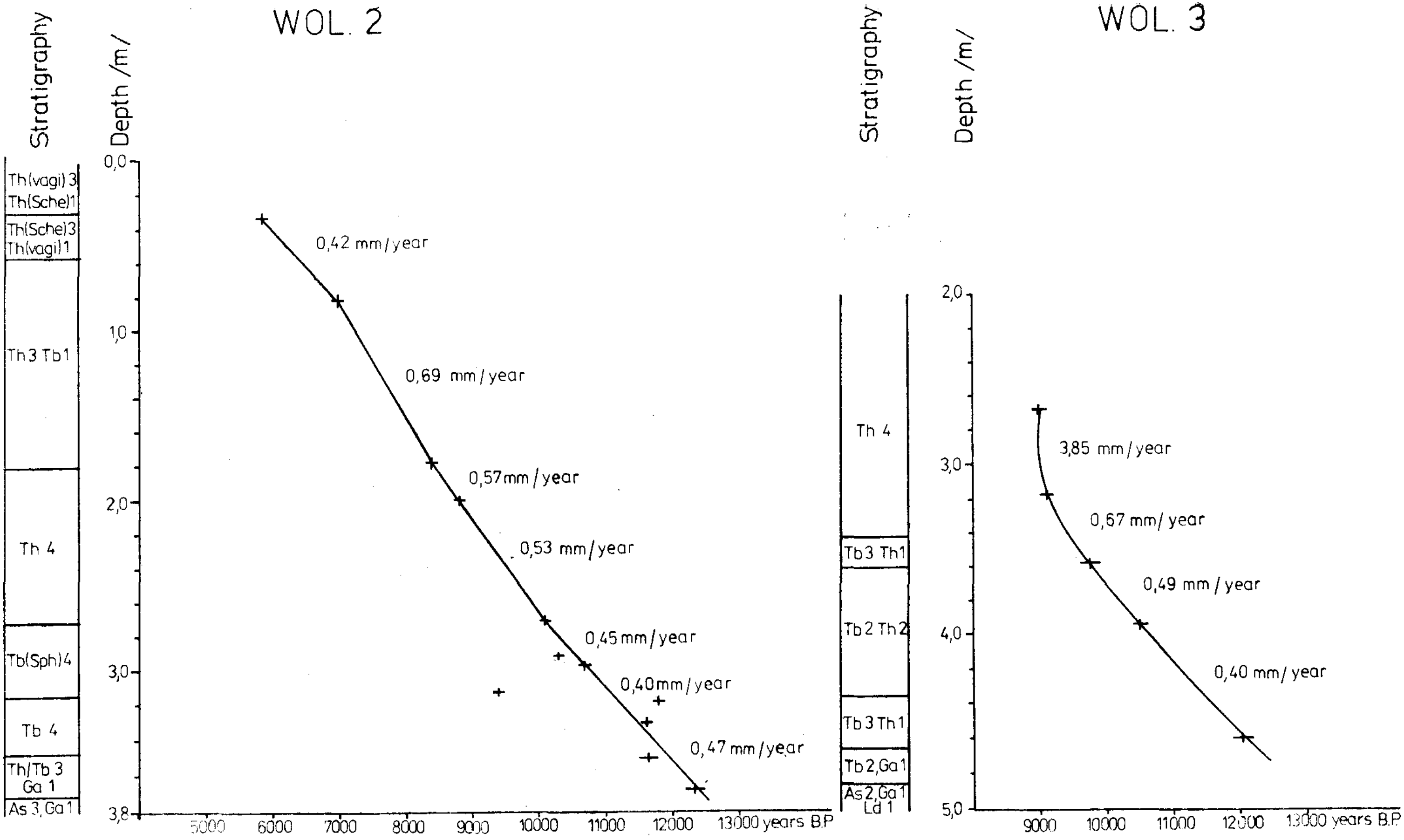

Fig. 5. Accumulation rate of peat deposits recorded in the WOL. 2 and WOL. 3 profiles

of the peat deposit in this part of the profile is also shown to have been possible by the "extended" palynological picture in the percentage diagram (Fig. 8), which in comparison with Figs. 6 and 7 is characterised by i.a. a considerable distance between the rational boundaries of *Ulmus* and *Corylus*. The fact that the substantial increase in sporomorph concentration (Fig. 9), typical for the beginning of the Holocene, is missing, could also be indirect proof of the high rate of accumulation in this section of the profile.

RESULTS OF POLLEN ANALYSIS

Description of pollen assemblage zones (PAZ)

Local pollen assemblage zones have been distinguished in each of the diagrams (Figs. 6, 7, 8, 9). The names of the zones indicate the characteristic features of the various sections of the diagrams, while the symbol numbers represent the efforts to find features which all three profiles have in common. The most important data are given in Tables 2, 3, 4.

Correlation of pollen zones

Each pollen diagram covers a different period of time (Fig. 10). The oldest sediments were found in diagrams WOL. 1 and WOL. 2, but only the WOL. 1 profile contained incomplete sediments of the younger Holocene. Disturbances in the upper parts of the profiles were very likely caused by reclamation work and peat cutting.

There is an notably great variation in the content of the Late-Glacial pollen zones. This is a consequence of the specific bottom relief of the basin (great variation of depth – Fig. 4B). The shape of the bottom of the basin during the Late-Glacial affected the level of the water table, and thus determined which plant communities grew where on the peatbog. This in turn was responsible for the variable rate of deposition of the peat. Very probably there were also spots where peat formation was periodically halted.

In the diagrams this is reflected in the varying rates at which equivalent pollen zones developed, for example, in the differences in zone 2 (Bölling). In WOL. 1 this zone is represented by a thin layer of mineral sediment containing a large amount of humus; in WOL. 3, there are the well-developed sediments of a shallow body of water with a gradually thickening layer of moss-*Carex* peat, and in WOL. 2 the zone comprises silty sand changing into sandy peat towards the top. The great thickness and division into two distinct parts of the WOL_3—6 pollen zone as compared with WOL_1—6 are due to the same causes. These differences are less obvious in zones 7 and 8 when the surface of the peatbog probably to a large extent became levelled off.

Table 2

Local pollen assemblage zones and subzones in the WOL. 1 profile

Local PAZ	Depth (cm)	Name of PAZ	Description of pollen spectra
WOL$_1$-11	0	*Quercus-Corylus-Sphagnum*	Curves of *Corylus* (mean 17.7%), *Quercus* (mean 11.2%), *Alnus* (mean 10.3%) dominate; pollen of *Carpinus*, *Fagus* and *Abies* disappear; human indicators are absent; high frequency of *Sphagnum* spores
WOL$_1$-10	28	*Carpinus-Fagus-Abies-Sphagnum*	Curves of *Ulmus* (mean 2%), *Corylus* (mean 5.7%), *Picea* (mean 2%), *Fraxinus* (mean 0.9%), *Tilia* (mean 0.9%) fall; an increase in curves of *Carpinus* (mean 3.4%), *Fagus* (mean 7.4%) and *Abies* (mean 7.8%); Cerealia and culture indicators are present; *Sphagnum* spores are abundant; upper limit — curves of *Carpinus*, *Fagus* and *Abies* decline, *Corylus* and *Quercus* increase
WOL$_1$-9	60	*Ulmus-Fraxinus-Corylus-Sphagnum*	Sharp decline of *Pinus* curve by 38% (mean 24.7%); Curves of *Corylus* (mean 11.8%), *Ulmus* (mean 8.6%) *Fraxinus* (mean 5%) and *Quercus* (mean 6.7%) dominate; high frequency of *Sphagnum* spores; upper limit—curves of *Ulmus*, *Corylus*, *Fraxinus* and *Tilia* decline; *Carpinus*, *Fagus*, *Abies* appear
WOL$_1$-8	100	*Corylus-Quercus-Tilia-Alnus*	Curve of *Pinus* (mean 53%) declines gradually; curves of other tress increase: *Corylus* (mean 9%), *Ulmus* (mean 4.5%), *Picea* (mean 3.2%), *Quercus* (mean 2.3%), *Alnus* (mean 3%), *Tilia* (mean 1.2%), *Fraxinus* (mean 1.5%); upper limit — *Pinus* curve rapidly declines, increase of *Alnus*, *Corylus*, *Ulmus*, *Quercus*, *Fraxinus*
WOL$_1$-7	230	*Pinus-Picea-Ulmus-Corylus-Polypodiaceae*	*Pinus* dominates (mean 67%, max. 78%); among other trees well represented are *Picea* (max. 4%), *Ulmus* (max. 5%), *Corylus* (max. 5%); spores of *Polypodiaceae* (cf. *Dryopteris thelypteris*) are very abundant; upper limit — *Pinus* decreases, *Tilia*, *Quercus*, *Alnus* exceed 1%
WOL$_1$-6	325	*Pinus-Filipendula*	*Pinus* is rapidly increasing by 20%, *Picea* curve is increasing gradually; NAP (heliophytes in particular) fall; relatively high values of *Filipendula* appear (max. 2.5%); upper limit — *Pinus* decreases, *Picea* exceeds 1%, beginning of *Ulmus* curve
WOL$_1$-5	355	*Betula-Larix-Juniperus-Artemisia*	Decline in *Pinus* curve by 27%, increase in *Betula* (max. 16%) and NAP (max. 51%); culmination of: *Larix* (max. 4%), *Artemisia* (max. 4%), *Cyperaceae* (max. 44%); upper limit — *Pinus* curve increases while NAP and heliophytes decrease
WOL$_1$-4 WOL$_1$-4b	375	*Pinus-Betula* *Pinus-Betula-Sphagnum* cf. *teres* (?)	*Pinus* increasing (mean 53%), decrease in *Juniperus*, *Salix*, NAP; spores of *Sphagnum* cf. *teres* (?) are abundant; upper limit — *Pinus* curve falls while NAP, *Juniperus*, *Larix*, *Artemisia* decrease
WOL$_1$-4a	455	*Pinus-Betula-Potamogeton*	Sharp rise of *Pinus* curve (mean 30%), mean *Betula* pollen values are 15%; NAP and *Juniperus* (mean 1.5%) decrease; culmination of *Potamogeton* (max. 4%); upper limit — an increase in *Pinus* and decrease in NAP curves
WOL$_1$-3	482	*Betula-Juniperus*	*Juniperus* (max. 5%) and *Salix* (max. 5%) peaks appear; NAP curve rises (*Cyperaceae* max. 40%); *Pinus* curve declines by 17%; upper limit — an increase in *Pinus* curve and NAP decrease
WOL$_1$-2	495 511	*Pinus-Betula-NAP*	Sum of NAP decreases to 55%, *Pinus* curve rises (max. 32%); maximum value of *Betula* is 14%; heliophytes abundant: *Juniperus* (mean 3%), *Salix* (mean 2%), *Artemisia* (mean 1.5%); upper limit — *Pinus* curve declines, an increase in NAP and heliophytes pollen values
WOL$_1$-1 WOL$_1$-1b	520	*Pinus*-NAP *Pinus*-NAP-*Artemisia-Cyperaceae*	*Pinus* falls to 5%; pollen values of *Helianthemum*, *Caryophyllaceae* and *Chenopodiaceae* decrease; at first *Gramineae* (max. 50%) and later *Cyperaceae* (max. 75%) rise; upper limit — NAP decreases and *Pinus* increases
WOL$_1$-1a	545 573	*Pinus*-NAP-*Artemisia-Helianthemum*	NAP curve (mean 63%) dominates the AP curve. Mean values of *Pinus* 20.8%, of *Betula* 7%; heliophytes are abundant: *Juniperus* (mean 3%), *Salix* (mean 1%), *Artemisia* (mean 3%), *Helianthemum* (mean 2%); upper limit — *Pinus* decreases, NAP increases

Table 3

Local pollen assemblage zones and subzones in the WOL. 2 profile

Local PAZ	Depth (cm)	Name of PAZ	Description of pollen spectra
WOL$_2$-9	17	*Corylus-Quercus-Sphagnum*	Continuous decline of *Pinus* curve (mean 18%), culmination of: *Corylus* (mean 16%, max. 23%), *Quercus* (mean 9%), *Ulmus* (mean 8%), *Alnus* (mean 11.7%); high frequency of *Sphagnum* spores
WOL$_2$-8	85	*Corylus-Quercus-Tilia-Alnus*	*Pinus* is decreasing (mean 53%), while curves of other trees are rising: *Corylus* (mean 4%), *Quercus* (mean 2.5%), *Tilia* (mean 1.6%), *Ulmus* (mean 4.3%), *Alnus* (mean 4.4%) upper limit — *Pinus* is rapidly decreasing, *Alnus*, *Ulmus*, *Fraxinus*, *Quercus* are increasing
WOL$_2$-6, 7	195	*Pinus-Picea-Ulmus-Polypodiaceae*	*Pinus* dominates (mean 60%); low values of other trees: *Picea* (mean 1.3%), *Ulmus* (mean 1.6%), *Alnus* (mean 1.2%), *Corylus* (mean 1.4%); high frequency of *Polypodiaceae* spores; upper limit — *Pinus* curve decreases, pollen values of broad-leaved trees increase
WOL$_2$-3, 4, 5	265	*Pinus-Betula-Sphagnum* cf. *teres* (?)	Mean percentage of *Pinus* is 68.8% and of *Betula* 9%; high frequency of *Sphagnum* (cf. teres?) spores; upper limit — decrease of *Pinus*, beginning of *Picea*, *Ulmus* and *Alnus* curve
WOL$_2$-2	355	*Pinus-Betula-Salix-Artemisia*	*Pinus* curve rises up to 30.4%; high values of *Salix* (max. 6.8%) and *Juniperus* (max. 4.4%); upper limit — *Pinus* is rapidly increasing while NAP and heliophytes are decreasing
WOL$_2$-1 WOL$_2$-1b	375	*Pinus*-NAP *Pinus*-NAP-*Artemisia*-*Cyperaceae*	Sharp rise of NAP (by 35%) — mainly *Cyperaceae*; *Artemisia* and *Helianthemum* pollen values are increasing; lateglacial minimum of *Pinus* (6.2%); upper limit — *Pinus* increases, NAP decrease
WOL$_2$-1a	460 484	*Pinus*-NAP-*Artemisia*	NAP sum (mean 61.6) dominates AP; *Pinus* — max. 34%, high values of *Artemisia* (mean 4.2%); upper limit — *Pinus* curve declines, NAP (mainly *Cyperaceae*) increase

Local pollen assemblage zones and subzones in the WOL. 3 profile

Local PAZ		Depth (cm)	Name of PAZ		Description of pollen spectra
WOL$_3$-8		201	*Corylus-Quercus-Tilia-Alnus*		*Pinus* curve decreases (mean 60.7%); rise in the curves of broad-leaved trees which attain the following mean values: *Ulmus* — 3.2%, *Corylus* — 8.8%, *Quercus* — 2.3%, *Tilia* — 1.3%, *Fraxinus* — 0.5%, *Alnus* — 1.3%
WOL$_3$-7		233	*Pinus-Picea-Ulmus-Corylus-Polypodiaceae*		*Pinus* curve dominates (mean 71%); maximum values of other trees are: *Picea* — 3%, *Ulmus* — 4%, *Corylus* — 3.2%; upper limit — *Pinus* curve decreases, rise of broad-leaved trees curves
WOL$_3$-6	WOL$_3$-6b	310	*Pinus-Betula*	*Pinus-Betula-B. t. nana-Polypodiaceae*	*Pinus* and *Betula* curves cross; *Betula* t. *nana* is rising (mean 1.2%); *Picea* and *Ulmus* exceed 1%; *Polypodiaceae* spores (cf. *Dryopteris thelypteris*) very abundant; upper limit — an increase in *Picea, Ulmus, Corylus* curves
	WOL$_3$-6a	343		*Pinus-Filipendula*	*Pinus* is rapidly increasing (max. 77%), *Picea* curve is rising (mean 0.8%); NAP and heliophytes are decreasing; *Filipendula* is abundant (max. 1.2%); upper limit — *Pinus* decreases, *Betula* increases, *Filipendula* decreases
WOL$_3$-5		357	*Betula*-B. t. *nana-Larix-Juniperus-Artemisia*		The percentage of *Pinus* pollen falls (mean 48%), an increase in the percentages of *Betula* (max. 15%), *Larix* (max. 2.1%), *Juniperus* (max. 5%), *Betula* t. nana (max. 2%), *Artemisia* (max. 3.6%); upper limit — *Pinus* is rapidly increasing, NAP and heliophytes are decreasing
WOL$_3$-4		400	*Pinus-Betula-Cyperaceae*		The rise of the *Pinus* pollen curve (mean 54%), mean value of *Betula* is 8.5%; pollen of heliophytes in small quantities; *Cyperaceae* are dominant among the herbs (mean 23.6%); upper limit — *Pinus* curve decreases, NAP and heliophytes increase
WOL$_3$-3		447	*Betula-Juniperus-Cyperaceae*		*Pinus* is rapidly decreasing (by 35%), whereas NAP *(Cyperaceae)* curve is rising; *Juniperus* and *Betula* t. *nana* values decrease; upper limit — *Pinus* curve increases NAP decreases
WOL$_3$-2		453 495	*Pinus-Betula*-B. t. *nana-Potamogeton*		*Pinus* (mean 36%) and *Betula* (mean 11.5%) curves rise; high values of heliophytes: *Juniperus* (mean 1.6%), *Betula* t. *nana* (mean 3.4%), *Salix* t. *polaris* (mean 1.2%), *Artemisia* (mean 1.3%); *Potamogeton* and *Pediastrum* abundant; upper limit — *Pinus* decreases, NAP increases

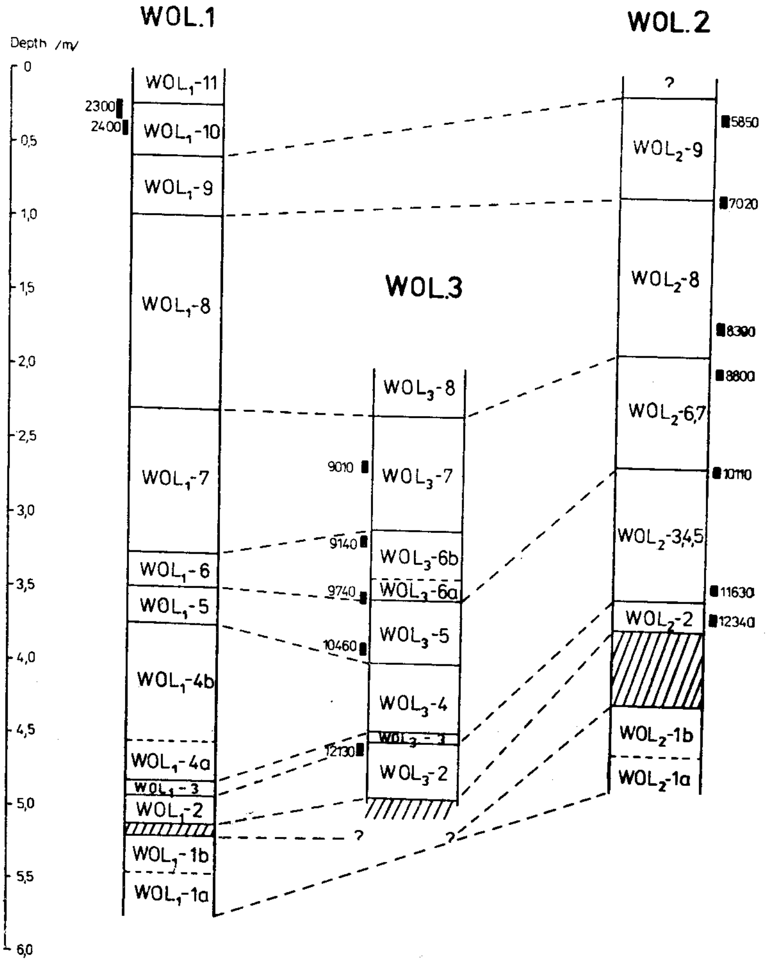

Fig. 10. Correlation of local pollen assemblage zones. The synchronic sandy layer is shown hatched

Another consequence of the differentiation of former plant communities on the peatbog are the varying percentage values of the individual constituents of the pollen zones. There are, for example, significant differences between the pollen pictures in the WOL$_1$-4 (peat with *Sphagnum teres*) and WOL$_3$-4 (moss-*Carex* peat) zones. The NAP values in diagram WOL. 1 are rather low, whereas in WOL. 3 they are high and are due mainly to the pollen of sedges which at this spot on the peatbog were an important component of the then existing communities.

Correlation of pollen zones is also made difficult by the disturbances found in the Late-Glacial section of the sediments in profile WOL. 2. Not only are there discrepancies in the radiocarbon dates but also distortions in the palynological picture. This is difficult to put down to natural causes. Maybe the peat was trampled upon by animals.

Description of plant macrofossil assemblage zones (PMAZ)

The presence of particular taxa in diagram WOL. 2 is the criterion according to which it has been divided into plant macrofossil assemblage zones (PMAZ). Besides Latin names, the symbols WOL_2 I—IV are used to describe the zones. Because the removal of samples for radiocarbon dating had left gaps in the profile, the boundaries between zones were established with the aid of the sediment descriptions.

Not many organic remains are present in the lower section of the core below 343 cm: single *Characeae* oospores, seeds of *Caryophyllaceae*, *Typha* sp., and *Juncus* sp., *Carex* sp. achenes and *Betula* sp. nutlets; there are howerer, too few of them to distinguish plant macrofossil assemblage zones. The results of analyses of random samples of seeds, fruits and tissues found in the lower sections of the WOL. 1 and WOL. 3 profiles (Tables 5 and 6) provide supplementary material for the interpretation of this part of the core.

Sphagnum teres-Drepanocladus PMAZ WOL_2-I (343—272 cm)

This zone is not completely uniform. Prevalent in its lower part are the remains of mosses of the genera *Drepanocladus*, *Meesia*, *Paludella* and *Calliergon*; the upper part, however, is dominated by *Sphagnum teres* branches with attached leaves, which are accompanied by a small number of *Sphagnum* sporangia. Also in this upper part there are *Ericaceae* macrofossils: periderm, leaves and leafy branches of *Calluna vulgaris* and leaves *Oxycoccus* sp. and *O. quadripetalus*. Single seeds and fruits of *Viola* cf. *silvestris*, Viola sp., *Comarum palustre* and *Typha* sp. were also noted in this section of the core. A few fragments of birch periderm and nutlets from *Betula* sect. *nanae* and *albae* are present. Most numerous in the carpological material are sedge achenes (mostly *Carex rostrata* and *Carex* sp.), although tissues of this genus are quite rare.

Betula-humilis-Carex-Phragmites PMAZ WOL_2-II (272—180 cm)

A considerable quantity of birch macrofossils was found in this zone. They included numerous nutlets, scales and leaves from shrub (mainly *Betula humilis*) and tree species. Below 220 cm, tissue remains were largely those of grasses and *Phragmites communis* (single caryopses of *Phragmites* were also noted), but above this depth there is a considerable increase in *Carex* sp. tissues while *Betula* macrofossils gradually disappear. *Pinus sylvestris* periderm is present. The whole zone is distinguished from the previous one by the complete absence of brown mosses, *Sphagnum* and *Ericaceae*.

Because of the occurrence of birches and the varying relationships between *Carex* and *Gramineae* tissues, this zone has been divided into two subzones:

Fruits, seeds and tissues determined in the bottom samples from the WOL. 1 profile

Depth (cm)	Fruits and seeds																	Tissues						
	Betula sp.	*Betula* sect. *albae*	*Betula* sect. *nanae*	*Betula nana*	*Carex* sp.	*Carex rostr.*/ *vesicaria*	*Carex* sect. *Paniculatae*	*Caryophyllaceae*	*Characeae* oospores	*Coenococcum geophilum*	*Dianthus*	*Gramineae caryopses*	*Isöetes* sp. macrospore	*Juncus* sp.	*Menyanthes trifoliata*	*Pinus* sp.	*Potamogeton* sp.	*Betula nana* leaves	*Calluna vulgaris* flower	*Eriophorum vaginatum* spindles	*Hippophaë rhamnoides* stamens	*Scheuchzeria palustris* leaves	Mosses	*Sphagnum* sp.
425 —437	+	+			+	+				+					+	+		+					+	+
437 —450		+			+	+	+	+							+		+			+			+	
450 —456,5		+			+	+	+	+	+		+	+									+		+	
456,5—464			+		+				+	+							+						+	
464 —475		+	+		+	+			+								+						+	
475 —481			+		+	+			+	+							+	+					+	
481 —495			+		+	+	+		+	+				+			+	+	+				+	
495 —500									+	+			+										+	
500 —504	+			+	+	+			+								+	+					+	
504 —507																								
507 —513					+					+														
513 —519												+											+	
519 —525					+				+	+		+											+	
525 —529,5					+			+				+								+			+	
529,5—550				+	+			+		+		+										+	+	
550 —556					+			+		+				+									+	
556 —561					+													+						
561 —571	+		+		+			+		+		+												
571 —575								+		+		+											+	

Table 6

Fruits, seeds and tissues determined in the bottom samples from the WOL. 3 profile

Depth (cm)	Fruits and seeds										Mosses											Other tissues									
	Betula sp.	*Betula* sect. *albae*	*Betula* sect. *nanae*	*Carex* sp.	*Carex rostr./vesicaria*	*Caryophyllaceae*	*Eriophorum vaginatum*	*Pinus* sp.	*Polypodiaceae* (sporangia)	*Potamogeton* sp.	*Bryales*	*Calliergon* sp.	*Calliergon giganteum*	*Drepanocladus* sp.	*Drepanocladus fluitans*	***Meesia triquetra***	*Paludella squarrosa*	*Scorpidium scorpioides*	*Tomenthypnum nitens*	*Sphagnum teres*	*Sphagnum* sp.	*Alnus* sp.	*Betula* sp.	*Carex* sp.	*Carex limosa*	*Ericaceae*	*Gramineae*	*Menyanthes trifoliata*	*Phragmites communis*	*Scheuchzeria palustris*	*Typha* sp.
320								+	+													+	+	+			+				+
335		+		+					+													+	+	+			+		+		+
348	+			+	+	+					+						+	+					+	+			+		+		
355				+							+						+							+			+		+		
365			+	+	+		+				+			+		+		+						+			+		+		
370				+							+	+		+						+				+			+		+		+
376											+	+							+					+			+				+
392																								+			+		+		
405											+	+		+					+		+			+			+	+	+		
415				+							+	+		+		+			+	+	+	+	+	+		+	+	+	+	+	
420											+			+		+				+		+	+	+	+		+		+		
435											+			+		+								+	+		+				
444											+		+	+		+								+			+				+
464	+			+							+		+	+	+									+							
479				+				+		+		+	+											+							

the *Betula humilis* WOL_2-IIa subzone (272—220 cm), in which *Gramineae* tissues prevail and *Betula humilis* nutlets dominate the carpological material. Numerous sedge fruits (including sect. *Paniculatae*) are also present.

the *Carex* WOL_2-IIb subzone (220—180 cm) in which the number of sedge tissues show a considerable increase and the number of birch macrofossils diminish. This subzone demonstrates features transitional between those of WOL_2-IIa and WOL_2-III.

Carex sp.-*Carex limosa-Bryales* PMAZ WOL_2-III (180—80 cm)

This zone consists almost entirely of *Carex* sp. tissues, and a large part of these are *C. limosa* remains. The presence of mosses is obvious — there are branches with traces of leaves, unidentifiable as to genus. Achenes of sedges like *Carex lasiocarpa* and *C.* sect. *Paniculatae* are present all the way through the zone. There are single seeds of *Typha* sp. and *Menyanthes trifoliata.* Macrofossils of *Betula* sect. *nanae* and *albae* are fairly common; most of them are found between 146 and 126 cm.

Sphagnum PMAZ WOL_2-IV (80—10 cm)

This zone is characterised primarily by large quantities of *Sphagnum* sp. sporangia. Plant macrofossils from the classes *Scheuchzerio-Caricetea fuscae* and *Oxycocco-Sphagnetea* also occur. Division of this zone into four subzones illustrates the changes in the proportions between the species of these two classes.

The *Carex-Betula-Sphagnum* WOL_2-IVa subzone (80—56 cm), like the WOL_2-III zone, consists mainly of *Carex* sp. tissues. Unlike that zone, however, *Sphagnum* sp. sporangia, and remains of *Scheuchzeria palustris* (mostly the lower leaves with the hydatode) and *Eriophorum vaginatum* appear. Also present here are the seeds of *Pedicularis palustris, Juncus* sp., and *Comarum palustre,* achenes of *Carex lasiocarpa* and *C.* sp., fruits of *Cicuta virosa,* caryopses of *Phragmites communis* and a large number of birch macrofossils.

The *Scheuchzeria-Betula-Ericaceae-Sphagnum* WOL_2-IVb subzone (56—30 cm) is characterised by the dominance of *Scheuchzeria palustris* tissues. Remains of sclerenchymatic spindles and other tissues of *Eriophorum vaginatum,* and of *Ericaceae* (mainly *Oxycoccus quadripetalus* — berries, seeds, leaves, periderm) are increasing. Birch macrofossils are still numerous.

The *Eriophorum vaginatum* WOL_2-IVc subzone (30—18 cm) is built up chiefly of *Eriophorum vaginatum* tissues. Birch macrofossils occur singly.

The *Eriophorum-Scheuchzeria-Sphagnum* WOL_2-IVd subzone (18—10 cm) comprises roughly equal numbers of *Scheuchzeria palustris* and *Eriophorum vaginatum* tissues.

Plant macrofossil assemblage zones and the genetic typology of peats

Apart from dividing the core into plant macrofossil assemblage zones, the genus and species of peat have been distinguished according to the genetic classification proposed by Tołpa, Jasnowski and Pałczyński (1967). The results are set out in Table 7.

Table 7

A comparison of the genetic clasification of peats and the plant macrofossil assemblage zones (PMAZ) in profile WOL. 2

Plant macrofossil assemblage zones		Depth (cm)	Species and genera of peats	
Sphagnum IV	*Eriophorum-Scheuchzeria-Sphagnum* IV d	10—18	?	*Ombro-Sphagnioni*
	Eriophorum vaginatum IV c	18—30	(*Eriophoro-Sphagneti*)	
	Scheuchzeria-Betula-Oxycoccus-Sphagnum IV b	30—56	(*Sphagno-Scheuchzerieti*)	*Minero-Sphagnioni*
	Carex-Betula-Sphagnum IV a	56—80	(*Sphagno-Cariceti*)	
Carex sp. — *Carex limosa-Bryales* III		80—180	*Bryalo-Parvocaricioni* (*Cariceto-Bryaleti*)	
Betula humilis-Carex-Phragmites II	*Carex* II b	180—220	*Magnocaricioni* (*Cariceti*)	
	Betula humilis II a	220—272	*Alnioni* (*Saliceti*)	
Sphagnum teres-Drepanocladus I		272—343	*Bryalo-Parvocaricioni* (*Bryaleti*)	

The criteria on which these two divisions were based differ:

— plant macrofossil assemblage zones are distinguished on the basis of the entire tissue and carpological material; moreover they take into account macro-

fossils of allochthonic origin, which may not have come from plants growing on the peatbog itself;
— the genetic classification is based on connections between the peat content and the communities of peat-forming plants.

The genetic classification of the peats in profile WOL. 2 indicates that the bottom and central sections are made up of low-bog peat. Three genera of peat were distinguished: *Bryalo-Parvocaricioni* with *Bryaleti* and *Cariceto-Bryaleti* species, *Alnioni* with *Saliceti* species, and *Magnocaricioni* with *Cariceti* species. The upper section of the sediments were classified as *Minero-Sphagnioni* transition-bog peat with two species: *Sphagno-Cariceti* and *Sphagno-Scheuchzerieti*. The topmost section of the profile is clearly similar to *Ombro-Sphagnioni* raised-bog peat. It will be seen from Table 7 that there is good agreement between the two methods of division. The division into PMAZ emphasises particular features of the diagram in a more precise way, e.g. the occurrence of large numbers of *Betula humilis* macrofossils in the WOL_2-II zone.

Comments on certain species of plants

Betula. There were a very great number of birch macrofossils in the Wolbrom deposits. They include nutlets without wings (1436 specimens), seeds (6 specimens), fruit scales (148 specimens), also a male inflorescence and a part of one containing pollen from *Betula* sect. *albae*. The nutlets and scales were identified as being from *Betula nana*, *B. humilis*, *B.* sect. *nanae*, *B.* sect. *albae*, *B.* sp.; the leaf fragments were from *B. nana* and *B.* sp.

The shape-and-size-line method (Białobrzeska & Truchanowiczówna 1960) was used to identify nutlets whose identity was difficult to determine. A drawing of each one was produced (scale 7 : 1) with the aid of a drawing apparatus. The measurements made on the drawings were accurate to within 0.1 mm. The following features were measured or calculated: 1. Length of nutlet, 2. Breadth of nutlet, 3. Ratio of length of nutlet to its breadth, 4. Apical angle of nutlet, 5. Base angle of nutlet, 6. Position of the broadest part of the nutlet as a percentage of its length. Because the macrofossils were badly damaged, and because there were hardly any wings, the greatest attention was paid to features 3 and 5 when analysing the drawings. Shape-lines were produced for 134 specimens.

In order to illustrate the variability of the study material, Figs. 12, 14 and 16 show all the measured nutlets from the three samples in which birch macrofossils reached a maximum, whereas Figs. 13, 15 and 17 show the shape-lines of selected specimens.

Ericaceae. Of particular interest in the macrofossils of this family is the extremely well preserved *Calluna vulgaris* flower (Pl. I, 3a) which was found in the WOL. 2 profile in the sandy interbedding from the Oldest Dryas. Another

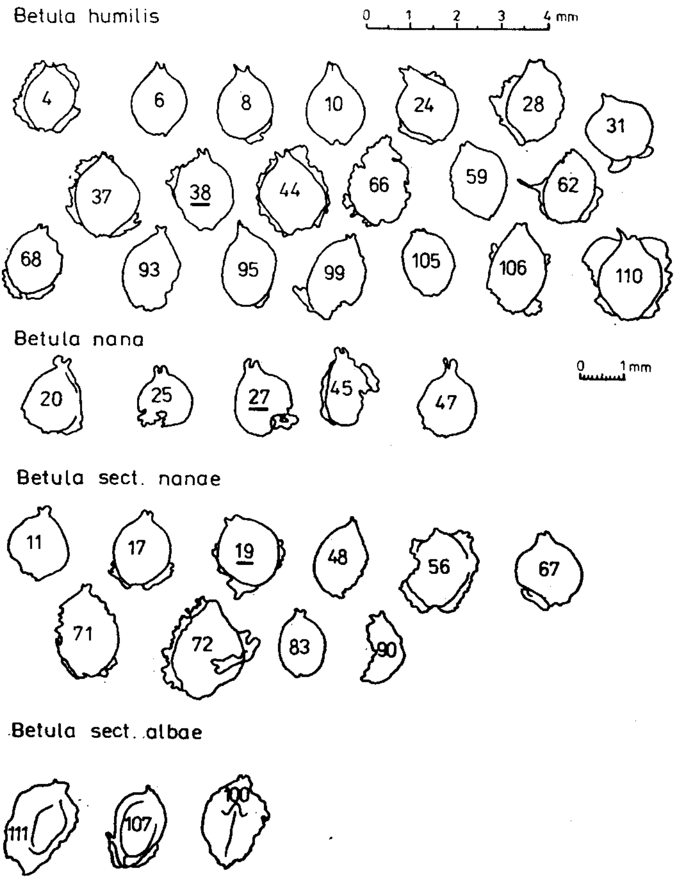

Fig. 12. The *Betula* nutlets from layer 56—61 cm of the WOL. 2 profile; the numbers of the nutlets whose shape-lines are represented in Fig. 13 are underlined

flower of this species was found in the WOL. 1 profile in an analogous stratigraphic position.

Moreover, leaves and a leafy branch of *Calluna vulgaris* (Pl. I, 3b), leaves of *Oxycoccus quadripetalus* and *Oxycoccus* sp., and *Ericaceae* periderm were found in the *Sphagnum teres* peat stemming from the Alleröd period.

Fruits, seeds, leaves and periderm of *Ericaceae* are also present in the Atlantic *Minero-Sphagnioni* peat and are one of the elements forming a link with the *Ombro-Sphagnioni* type.

Interesting macrofossils found in the upper part of the deposit are the lower leaves of *Scheuchzeria palustris* with hydatode (Pl. I, 1) and the sclerenchymatic spindles of *Eriophorum vaginatum* (Pl. I, 2a, 2b). Macrofossils like these are preserved in peat and can be identified unequivocally (Grosse-Brauckmann 1972).

A large number of *Sphagnum* sporangia in the upper section of the WOL. 2 profile was noted. The almost complete absence of branches and leaves of this

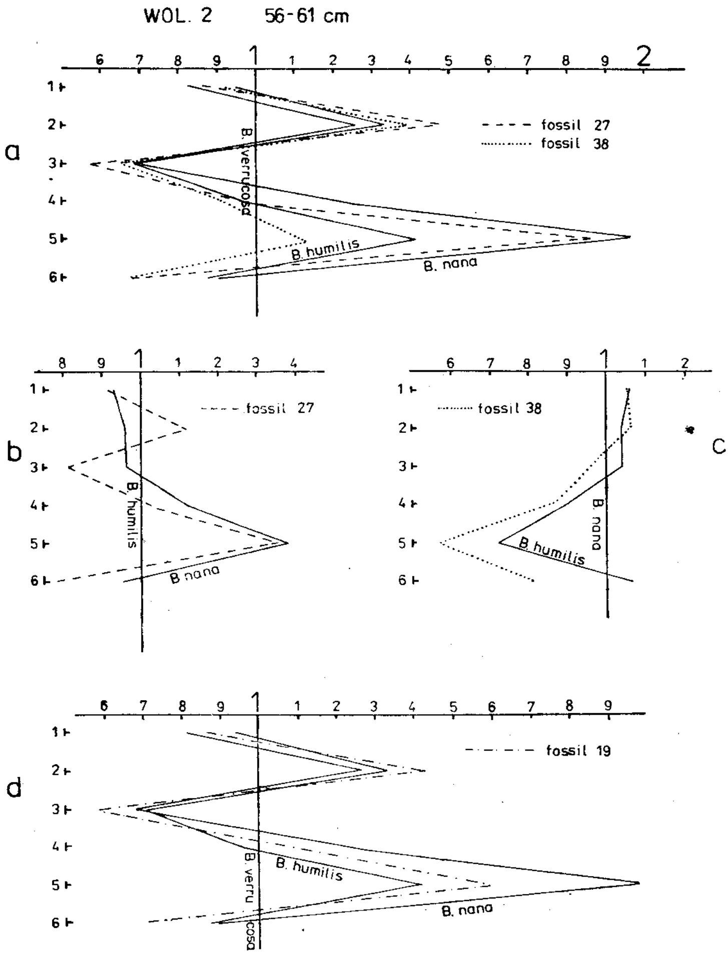

Fig. 13. Shape-lines of *Betula* nutlets from layer 56—61 cm of the WOL. 2 profile (see Fig. 12): a — fossil nutlets 27 and 38 and present-day nutlets of *B. humilis* and *B. nana* in relation to *B. verrucosa*; fossil nutlet 27 most resembles *B. nana* and fossil nutlet 38 resembles *B. humilis*; b — fossil nutlet 27 and present-day nutlets of *B. nana* in relation to *B. humilis*; c — fossil nutlet 38 and present-day nutlets of *B. humilis* in relation to *B. nana*; d — fossil nutlet 19 and present-day nutlets of *B. nana* and *B. humilis* in relation to *B. verrucosa*; fossil nutlet shows the intermediate features between *B. humilis* and *B. nana* and it was classified as *B.* sect *nanae*

plant in the same layers is probably due to extensive peat decomposition. In the same zone on the WOL. 2 pollen diagram there was a huge increase in the percentage of *Sphagnum* spores.

THE HISTORY OF THE VEGETATION

Changes in the plant cover of the Wolbrom area

The development of the vegetation of the Wolbrom area has been described on the basis of the characteristic features of pollen zones distinguished in all three diagrams. Names of periods (like the Alleröd or Atlantic period) are used,

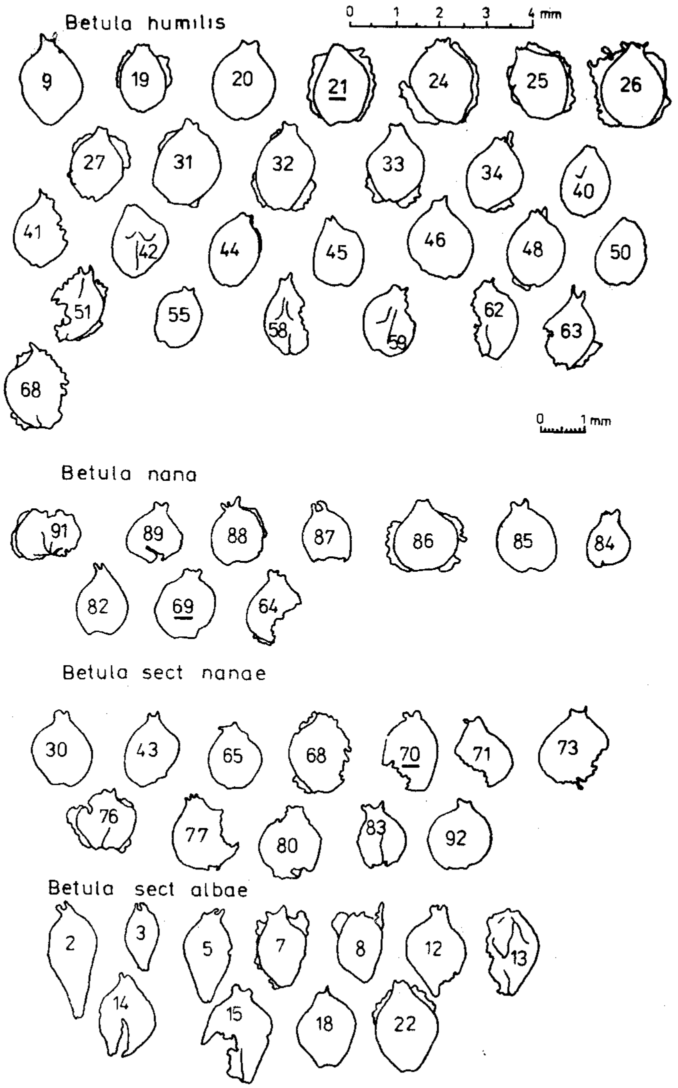

Fig. 14. The *Betula* nutlets from layer 131—133 cm of the WOL. 2 profile; the numbers of the nutlets whose shape-lines are represented in Fig. 15 are underlined

but because establishing the precise dates of the boundaries between the zones was not possible, these names have no strict chronostratigraphic significance.

Pollen zone WOL$_{1,2}$-1

The landscape in the first stage the development of the vegetation as could be elicited from the Wolbrom diagram was treeless. The very low percentages of tree pollen are evidence for the tundra vegetation with bryophytes, sedges,

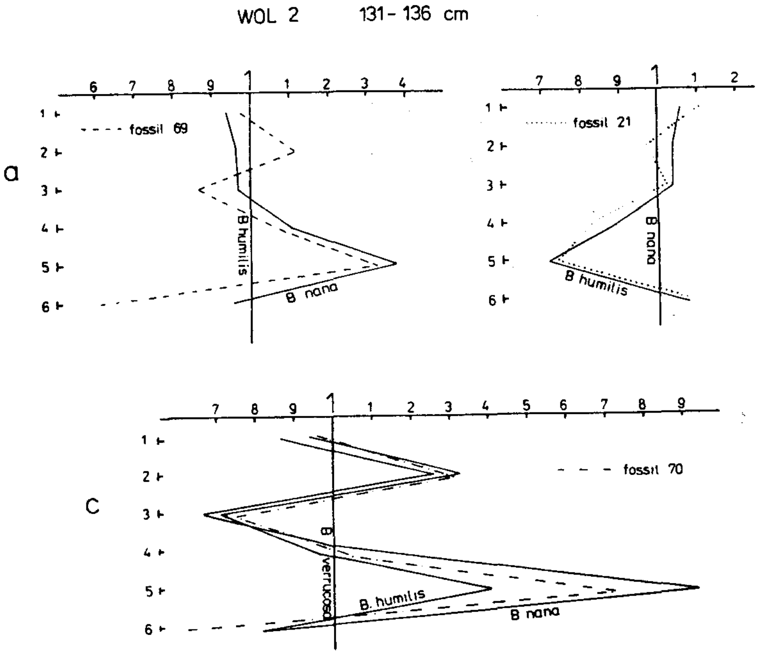

Fig. 15. Shape-lines of *Betula* nutlets from layer 131—136 cm of the WOL. 2 profile (see Fig. 14) a — fossil nutlet 69 and present-day nutlets of *B. nana* in relation to *B. humilis*; fossil nutlet resembles *B. nana*; b — fossil nutlet 21 and present-day nutlets of *B. humilis* in relation to *B. nana*; fossil nutlet resembles *B. humilis*; c — fossil nutlet 70 and present-day nutlets of *B. nana* and *B. humilis* in relation to *B. verrucosa*; fossil nutlet shows the intermediate features between *B. humilis* and *B. nana* and it was classified as *B.* sect *nanae*

willows, *Betula nana* and *Selaginella selaginoides* which grew in damp habitats. Prevalent on the dry habitats were juniper thickets within which there probably grew single specimens of birch, *Hippophaë rhamnoides*, possibly also *Ephedra distachya* and *Pinus cembra* (pollen grains of *P.* t. *haploxylon* were found in both profiles). Heliophilous communities on dry substrates were also formed by *Artemisia*, *Helianthemum*, *Armeria*, *Sanguisorba minor* and *Chenopodiaceae*. The very low percentage pollen values of pine suggest that at this time *Pinus silvestris* did not occur in the vicinity of Wolbrom, or was present only as single specimens.

Pollen zone WOL$_{1,2}$-1 probably corresponds to the Oldest Dryas. At the top of this zone there is a layer of fine sand, possibly wind blown, practically without sporomorphs. This layer is a good guide zone for correlating the diagrams (Fig. 10).

Pollen zone WOL$_{1,2,3}$-2

This zone is characterised by the development of woodland communities, at the outset, of mixed birch and pine, but changing towards the end to pinewoods with large numbers of birches. Aspen and larch were also to be found. In the

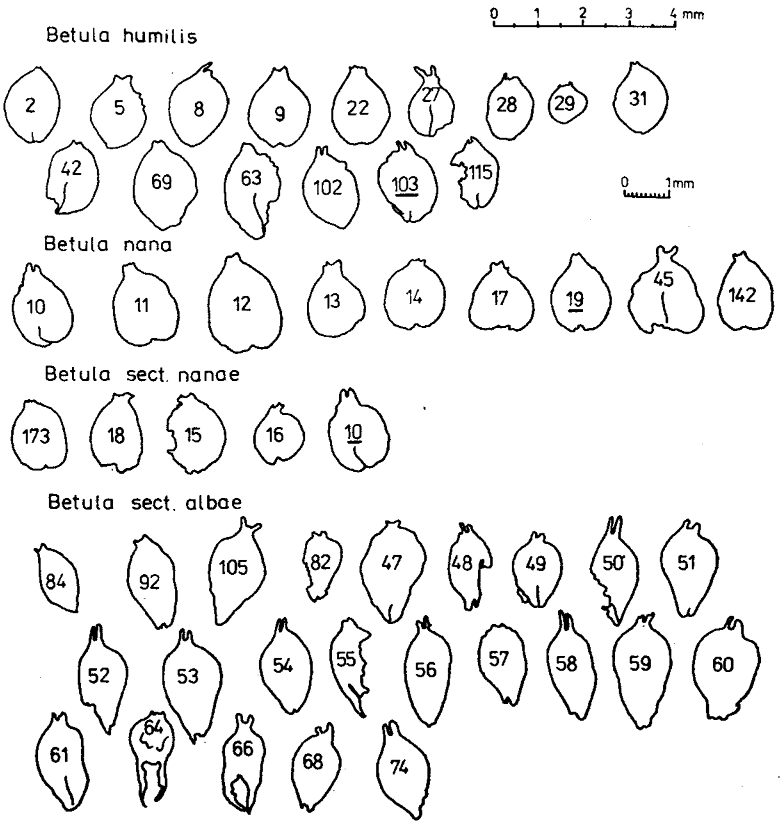

Fig. 16. The *Betula* nutlets from layer 254—260 cm of the WOL. 2 profile; the numbers of the nutlets whose shape-lines are represented in Fig. 17 are underlined

shrub layer of these woods and in open habitats there were thickets of *Juniperus* with other heliophytes like *Artemisia* and *Helianthemum*; these communities became much less important during the younger part of the phase. Damp tundra vegetation with *Betula nana*, dwarf willows, *Arctostaphylos* sp., and several species of *Gentiana* and *Saxifraga* grew in the neighbourhood of the peatbog and in patches on the bog itself. Patches of herbaceous vegetation with *Urtica, Filipendula* and *Thalictrum* also thrived. Willows were of great importance in the local communities.

This zone can be identified with the Bölling s. str.; its age is confirmed by two radiocarbon dates: 12340±160 (WOL. 2) and 12130±160 (WOL. 3).

Pollen zone WOL$_{1,3}$-3

This zone indicates a deterioration of the climate. The diminishing *Pinus* and *Larix* pollen curves and the increasing amounts of pollen from herbaceaous plants (chiefly *Cyperaceae*) not only on the percentage diagrams but also on the sporomorph concentration diagram (Fig. 9) could mean that the woodland was

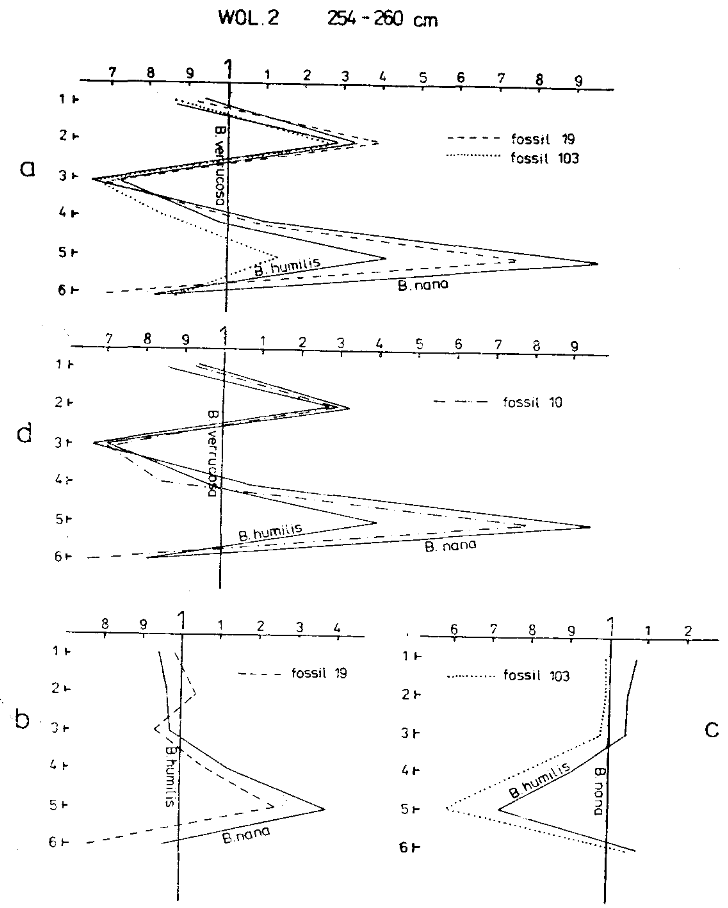

Fig. 17. Shape-lines of *Betula* nutlets from layer 254—260 cm of the WOL. 2 profile (see Fig. 16); a — fossil nutlets 19 and 103 and present-day nutlets of *B. nana* and *B. humilis* in relation to *B. verrucosa*; fossil nutlet 19 resembles *B. nana* and nutlet 103 resembles *B. humilis*; b — fossil nutlet 19 and present-day nutlets *B. nana* in relation to *B. humilis*; c-fossil nutlet 103 and present-day nutlets of *B. humilis* in relation to *B. nana*; d — fossil nutlet 10 and present-day nutlets of *B. nana* and *B. humilis* in relation to *B. verrucosa*. Fossil nutlet shows the intermediate features between *B. humilis* and *B. nana* and it was classified as *B.* sect. *nanae*

becoming more open. That a secondary expansion of heliophilous communities was taking place is indicated only by the peaks in the *Juniperus* and *Salix* curves. The *Artemisia* curve does not culminate.

Pollen diagrams WOL. 1 and WOL. 3 are undoubtedly a record of a cool fluctuation in the climate. It is difficult to say, however, to what extent this fluctuation affected the plant communities. The *Juniperus* peak suggests that the range limit of the forest had shifted. It is just as likely, though, that the vegetation changes were limited mainly to a lowering of the biological vitality of some species, for instance, the restricted flowering of pines.

The $WOL_{1,3}$-3 zone can be correlated with the Older Dryas; this is confirmed by the ^{14}C date of 12130±160 for the layer just beneath the lower boundary of the zone (Fig. 8).

Pollen zone $WOL_{1,3}$-4

This zone reflects the successive phases of woodland development around Wolbrom during the Alleröd. In the first phase, represented by the WOL_1-4a subzone, there were birch-pine forests in which heliophilous plants were of great importance, especially *Juniperus* and *Hippophaë* (the *Hippophaë* stamens found among the macrofossils, came from this subzone — Table 5), but also *Artemisia, Helianthemum* and others. Where the ground was waterlogged, willows and *Urtica* were very common. Taxons showing that some elements of tundra flora, like *Betula nana*, *Saxifraga* t. *stellaris*, were surviving still appear on the diagram.

Pine woods dominated the second phase (WOL_1-4b and WOL_3-4), and the numbers of heliophytes diminished. The almost continuous *Picea* curve in the diagram WOL. 1 and the continuous curve of this tree in diagram WOL. 3 indicate with a high degree of certainty that, besides larch, spruce was also present in the woodland. The fact that A. Obidowicz identified some fragments of wood from the profile WOL. 1 (depth 387—400 cm) as having come from *Alnus* sp. (Latałowa 1976) is interesting. This would mean that despite the irregular occurrence of *Alnus* pollen in the diagrams, alders did grow on the peatbog towards the end of this phase.

Pollen zone $WOL_{1,3}$-5

This zone suggests that the woodland was thinning out. *Pinus* was declining, but for *Larix* this was a particularly good period in this area. Spruce was still present. Juniper thickets began to expand at this time, as did the so-called "cold-steppe" communities dominated by *Artemisia*. Indeed, the *Artemisia* pollen maximum is noted in this zone in the Wolbrom diagrams. A continental climate is shown to have been prevailing then by the presence of *Pleurospermum austriacum* in samples from near the lower boundary of the zone, and also by the decline in the curves of plants from damp habitats, e.g. *Thalictrum, Urtica* and *Salix*. The pollen diagrams show that vegetation best described as "park tundra" with abundant steppe-like communities was widespread then.

Palynological information and radiocarbon dates from profile WOL. 3 indicate that this zone corresponds to the Younger Dryas.

Pollen zone $WOL_{1,3}$-6

The development of pine woods with admixtures of birch and spruce, as well as the spread of elm, are characteristic of the Preboreal period which this zone represents. There is now less pollen from *Juniperus*, *Artemisia* and other heliophytes, which shows that the woodland was relatively dense. *Larix* was much less prominent. Alder probably grew where the water table was very high, although the elevated percentage pollen values of *Alnus* and *Picea*, and the single pollen grains of *Fagus*, *Quercus* and *Tilia* in samples 351 and 355 from profile WOL. 3 are probably due to contamination with younger material (these are samples from the upper section of the corer).

In the first phase of this zone, patches of herbaceous vegetation with *Filipendula ulmaria* and *Urtica* developed around the peatbog and in some places on it. This phase was followed by the spread of bog communities with *Betula humilis* (macrofossils) and *Dryopteris thelypteris* (its spores with their perine intact and entire sporangia were very common in the pollen spectra). *Betula nana* was also present on the peatbog.

Pollen zone $WOL_{1,3}$-7

This zone probably covers the older and middle part of the Boreal period. Pines were the dominant trees in the woodland around Wolbrom at that time, though spruce, elm and hazel were gradually increasing in number. *Fraxinus*, *Quercus* and *Tilia* occurred infrequently. Along with the rising proportion of broad-leaved tree species in the Wolbrom flora, an increasing diversification of the woodland communities was taking place. By degrees, pine was being replaced on the more fertile soils on the margins of the valleys by swamp communities with elm and later also with ash. On the more fertile soils on the hilltops, oak and lime were gradually superseding pine. Some parts of the sunny slopes not covered by dense woodland were very likely overgrown with thickets of hazel. Scanty alder swamps with *Dryopteris thelypteris* came into existence in the river valleys and just beyond the peatbog.

Pollen zone $WOL_{1,2,3}$-8

The radiocarbon dates suggest that this zone should be correlated with the younger part of the Boreal period and the early phase of the Atlantic period. The occurrence of pines in the woods around Wolbrom was decreasing while the development of diverse deciduous woodland phytocenoses, which had begun during the previous phase, continued. Pine forests in a relatively pure form probably survived on the sandy soils near the peatbog.

A number of grains of Viscum pollen and the single grain of *Vitis* cf. *silvestris* pollen which were found in the pollen spectra of profile WOL. 1 indicate that the climate during this phase was warm.

Pollen zone $WOL_{1,2}$-9

The WOL. 1 pollen diagram from a depth of c. 60 cm upwards and the WOL. 2 diagram from about 17 cm upwards show that the topmost parts of the profiles are incomplete, so pollen zones 9, 10 and 11 do not reflect all the changes that took place in the vegetation around Wolbrom.

The $WOL_{1,2}$-9 PAZ illustrates the changes that took place probably in the middle and late phase of the Atlantic period. A significant change was the diminishing of Pinus communities and the increase in the areas of woodland communities typical of moist habitats *(Alnus, Ulmus, Fraxinus)*, probably elm-ash woods. These changes are linked with concurrent hydrological changes taking place in the peatbog itself (a high frequency of *Sphagnum* spores). It has to be stressed that the upper and lower boundary of this zone, particularly in profile WOL. 1, appear to be "artificial" and are almost certainly connected with the slowing-down of peat-forming processes or with the compaction of this part of the deposit. These occurrences could well be due to both the natural hydrological changes which were taking place during this period and to later reclamation work done there.

Pollen zone WOL_1-10

The ^{14}C dates of 2420 ± 70 and 2300 ± 70 B. P. and the palynological picture of this part of the diagram indicate that the hiatus lasted for at least the whole Subboreal period, and that zone WOL_1-10 represents only a small part of the Subatlantic period. A characteristic aspect of this phase in the history of the Wolbrom vegetation is the development of quite new woodland communities. First were beech-fir forests, probably analogous to the present day *Fagetum carpaticum*, which occupied mainly the fertile, calcium-rich soils — rendzinas and shallow loess soils on a limestone substrate — and oak-hornbeam woods which were somewhat similar to the *Tilio-Carpinetum* associations found nowadays. These woods formed primarily in mixed oak-elm-lime woodland habitast. The elm-ash woods became less important. The floors of the river valleys were still covered with alder woods, while the patches of sandy soils around Wolbrom supported pine forests.

Pollen zone WOL_1-11

This zone is impossible to interpret. The sudden breaking off of the *Carpinus*, *Fagus* and *Abies* curves and the simultaneous disappearance of culture plant pollen indicates that the upper part of the profile must have been damaged by peat cutting or when drainage ditches were dug.

Traces of human activities

There is little palynological proof of man's presence on the Wolbrom diagrams. This is due to the lack of the uppermost parts of the profiles and also to the hiatus extending throughout the Subboreal period. Only in diagram WOL. 1 at a depth of 63—22 cm was pollen complex found that could be indicative of man's activities. It included the pollens of corns *(Secale* and t. *Triticum)*, *Plantago lanceolata*, and also *Fagopyrum* and *Centaurea cyanus*. The composition of the pollen spectra and the ^{14}C dates point to Iron Age settlement, probably the La Tène period or the beginnings of Roman influences. It is important to remember that the pollen percentages of these plants are not high, so it can be concluded that settlement in the immediate vicinity of Wolbrom was not very intensive at this time. The radiocarbon dates endorsed the preliminary hypothesis (Latałowa 1976) about the chronological position of this settlement phase; it did not, however, support the suggestion that there might be a connection between the spread of hornbeam and beech-fir woodland around Wolbrom and the deforestations that were effected during late Roman times (Ralska-Jasiewiczowa 1977). Because of the hiatus, the existence of which has been verified by the datings and which extended throughout the Subboreal period, the Wolbrom diagram cannot be used in support of the above-mentioned connection.

In the profiles charred layers containing burnt herbaceous plant tissues, and the burnt fruit and seeds of peatbog plants are present. Carbon dust was also found in the thin sections examined under the microscope. Occasional traces of burning are visible in the peat already from the end of the Late-Glacial, but from the start of the Holocene they occur regularly in most of the samples. A typical charred layer was found in profile WOL. 3 at a depth of 325 cm and at 315—305 cm. The material there was so badly burnt that pollen analysis at 310 cm was impossible.

These fires could have been due to natural causes, but their frequency suggests that man was responsible for at least some of them. A further argument in favour of the anthropogenic origin of these fires is that the rapid spread of fire from the woodland areas adjoining the peatbog or from single trees growing on the peatbog itself (cf. Borowik-Dąbrowska 1985) would have been extremely unlikely in view of the fact that the water level in the bog at this time was particularly high.

It is known from archaeological sources (J. K. Kozłowski & S. K. Kozłowski 1977) that the rocky areas of the central Polish uplands were inhabited by man during the Palaeolithic and Mesolithic ages. The finds from this region come mainly from caves. It is highly probable that the extensive areas of peatbogs which had been developing in the Wolbrom depression since the Late-Glacial were an excellent habitat for birds and many animal species. Perhaps this was a hunting area regularly used by the local Stone Age people, and the traces of burning are the effects of flushing out the game by fire.

The succession of local communities

The succession of local communities on the Wolbrom peatbog has been reconstructed from the analyses of tissues and plant macrofossils (Fig. 11, Tables 5 and 6), supplemented by the results of pollen analysis and the data contained in the article by Obidowicz (1976).

At the beginning of the Late-Glacial, during the Oldest Dryas, a series of shallow water bodies with a poor flora came into existence on the terrain now occupied by the peatbog. Only a few pollen grains of Potamogeton and single *Characeae* oospores were found in the layers from this period. Much more abundant in species were the damp habitat communities which grew up around these sheets of water. Many fragments of brown mosses were found in the sediment, together with *Betula nana* and *B.* sect. *nanae* macrofossils, numerous unidentified sedge achenes and grass caryopses, seeds of *Juncus* sp. and *Caryophyllaceae. Selaginella selaginoides* microspores are also present in the WOL. 1 diagram. These remains demonstrate that typical damp tundra communities were flourishing here at this time.

With the start of the Bölling there came a distinct floristic enrichment of the aquatic vegetation. Apart from macrophytes such as *Characeae*, *Potamogeton* sect. *Coleogeton*, *P.* sect. *Eupotamogeton*, *Isoëtes* sp., *Ceratophyllum* sp. and *Hippuris vulgaris*, algae of the genus *Pediastrum* were abundant.

The length of time that these water bodies existed varied in different parts of the investigated basin and was dependent on the bottom relief. It was probably as a result of the lowering of the water level in some places already towards the end of the Bölling (WOL. 3) and in others during the early Alleröd (WOL. 1 and WOL. 2) that peat-forming centres first appeared. Moss communities with *Drepanocladus* sp., *Aulacommium palustre*, *Paludella squarrosa*, *Calliergon giganteum*, *Meesia triquetra* and *Sphagnum teres* began to expand. Obidowicz (1976) also mentions *Helodium lanatum*, *Camptothecium nitens* and *Scorpidium scorpioides*. All these species are constituents of present-day mossy tundra communities, but they are also found in Poland as glacial relics in low-lying bogs in river valleys. They occur most often in the *Caricetum diandrae* association, in mesotrophic habitats located at some distance from the river bed, beyond the reach of flood waters. These communities are always waterlogged; throughout the growing season, the ground water level is constantly around zero (Oświt 1973).

In the younger part of the Alleröd and during the Younger Dryas, part of the peatbog was occupied by a community whose dominant species was *Sphagnum teres* (WOL. 1 and WOL. 2). It was accompanied by species of the *Scheuchzerio-Caricetea fuscae* class *(Comarum palustre, Viola* cf. *palustris)* and by *Carex rostrata* and *Oxycoccus quadripetalus.*

At present *Sphagnum teres* frequently colonises flat, slightly raised hummocks in the mesotrophic variant of the *Caricetum diandrae* association, which is a succession stage leading to communities nourished exclusively by capillary and rain waters (Oświt 1973).

During the same period in other parts of the peatbog (WOL. 3), particularly along its edges (Obidowicz 1976), brown mosses were still prevalent. Moss and moss-sedge communities survived here even until the end of the Younger Dryas.

A significant change in the type of vegetation took place at the beginning of the Holocene. At this time, the peatbog began to dry out somewhat and the brown moss and *Sphagnum teres* communities were superseded first by herbaceous communities with *Filipendula ulmaria* and *Urtica (dioica)*, as recorded in the pollen diagrams (WOL. 1 and WOL. 3). This stage was followed by an invasion of ferns *(Dryopteris thelypteris)*, *Betula humilis* and sedges. Apart from these species, *Phragmites communis* and other grasses were quite numerous and *Typha* sp., *Comarum palustre* and *Viola* sp. appeared in small numbers. Tree birches *(B. pubescens?)* and pine (seeds and periderm from *Pinus* sp. were found among the macrofossils) probably also grew in the peatbog too. Brown mosses entirely disappeared in this phase of the plant succession.

It was approximately at the start of the Boreal period that the local communities came to be dominated by sedges. The expanding plants included *Carex limosa*, *C. lasiocarpa*, and otner, unidentified species from the *Paniculatae* section. *Phragmites communis*, *Typha* sp. and *Menyanthes trifoliata* grew in small numbers. In the younger part of the period, brown mosses reappeared (unidentifiable because of the extremely bad state of preservation), and *Betula humilis* and *B. nana* were spreaing.

About 7000 years ago, plants typical of transition bogs began to assert themselves more in the local communities. A large proportion of species from the class *Scheuchzerio-Caricetea fuscae* were recorded: *Scheuchzeria palustris*, *Carex lasiocarpa*, *Carex limosa*, *Comarum palustre*, *Pedicularis palustris*, the raised bog species *Eriophorum vaginatum*, and *Ericaceae* macrofossils. They were accompanied by many unidentifiable *Sphagna* which had survived in the peat only in the form of sporangia. Birch *(Betula humilis*, *B. nana* and *B.* sect. *albae)* was again occurring in greater numbers.

The macrofossil analysis of the upper part of core WOL. 2 indicates the continuing spread of raised bog species (very numerous sclerenchymatic fibres of *Eriophorum vaginatum* and *Oxycoccus quadripetalus* leaves) during the period younger than 5800 years.

Because the topmost part of the profile is missing, it is difficult to state definitely how long this kind of community dominated this site. It should be emphasised, though, that the maximum (percentage) values of *Sphagnum* spores, which were accompanied by single pollen grains of *Drosera rotundifolia*, were maintained, according to pollen diagram WOL. 1, until at least 2000 years B. P. Raised bog plants continued until recently to survive in the presentday vegetation of this peatbog (Michalik 1976).

One interesting aspect of the succession of local communities in the Wolbrom peatbog is the history of the birches. It can be seen from Fig. 11 and Tables 5 and 6 that undoubted macrofossils of *Betula nana* are found already in the Oldest Dryas, whereas roughly 11600 years ago both *Betula nana* and *B. humilis* were growing in this locality. At the same time, tree birches were growing around the edges of the peatbog, and maybe in it as well — this is indicated by the nutlets which occur quite commonly in the oldest layers of moss peat.

Macrofossils of *Betula nana* and *B. humilis* regularly occur in profile WOL. 2

almost to the very top. This shows that about 6000 years ago relict loclities of both these species were still in existence in the Wolbrom peatbog. The nearest fossil locality of *Betula nana* from the Atlantic period is at Konopiska near Częstochowa (Błaszczyk 1954).

LOCAL HYDROLOGICAL CHANGES IN THE LIGHT OF PALAEOBOTANICAL INVESTIGATIONS

The Wolbrom peatbog straddles the watershed between the rivers Biała Przemsza and Szreniawa; river capture has taken place here (see p. 76). Dynamic changes in the river network were thus the driving force behind the vegetational changes in this locality.

The material upon which the following discussion of the Late-Glacial and Holocene changes in the hydrology of the area subfossil plant communities. It must be admitted at once, however, that despite the large number of analyses done, it has not been possible to unravel all the problems. This is because of the lack of the topmost part of the profiles owing to peat-cutting, gaps in core WOL. 2 as a result of samples having been removed for ^{14}C dating, and the natural properties of the studied sediments which were decomposed to a high degree and contain small numbers of preserved fruits and seeds (only birch fruits were present in any great quantity).

The shallow, water-filled depressions which formed in the Oldest Dryas and became enlarged during the Bölling had probably come into existence as a result of the disappearance of the permafrost. They were isolated from the direct influence of moving river waters; the water in them was stagnant — proof of this are the large numbers of *Pedaiastrum* caenobia in the sediment.

Between the end phase of the Bölling and the start of the Alleröd, a lowering of the water level took place and there followed an invasion of brown mosses on to a large part of the water body.

During the Alleröd, *Sphagnum teres* spread on to some parts of the peatbog; in the opinion of Obidowicz 1976), this was due to decreased evaporation during the younger phase of the Alleröd and in the Younger Dryas. It would seem, however, that these changes were not brought about by a higher water level than in the previous phase. They were more likely due to a lower level of ground water and, above all, a change towards ombrogeneity. They may have been local autogenic changes which resulted from a faster rate of growth of the peat deposit, for example in the central part of the peatbog (WOL. 1 and WOL. 2). Another cause could have been the intensification of river capture, especially as in Obidowicz's stratigraphic section (Fig. 4B), the *Sphagnum teres* invasion is evident in the eastern part of the deposit, which is exceptionally well drained by the Szreniawa river.

A distinct hydrological change was observed at the turn of the Younger Dryas and the Holocene. The expansion of herbaceous plant communities, with

Filipendula ulmaria and *Urtica dioica* noted on the diagrams, was probably connected with the intensification of the river water flow, which affected the water regime in the peatbog.

The short-lived herbaceous phase was replaced by *Betula humilis* and *Dryopteris thelypteris* phytocenoses, which included both immersive reed species (*Phragmites communis*, *Typha* sp.) and typical emersive plants (*Comarum palustre*, *Viola* sp.). Trees began to grow in the bog — *Betula* (*pubescens?*) and *Pinus sylvestris*. The fact that this type of community could thrive shows that water flow must have been somewhat restricted and that the water table was now lower than during the Sphagnum teres phase.

In the Boreal period and the older part of the Atlantic period (up to c. 7000 years B. P.), the hydrological regime in the Wolbrom peatbog was relatively stable. Along with the thickening of the peat deposits, the number of eutrophic species in the communities was decreasing but the number of mesotrophic species was increasing. This may indicate that the plants were gradually losing contact with ground waters and that transition bog communities were encroaching on to the peatbog.

An abrupt change in the vegetation, at least in the centre of the peatbog, took place about 7000 years ago. First of all, considerable numbers of *Sphagnum* and *Eriophorum vaginatum* appeared, and there ensued a rapid succession leading to a raised bog. The speed of these changes, which are illustrated by the macrofossil diagram (Fig. 11) and the pollen diagrams WOL. 1 and WOL. 2 (Figs. 6 and 7), shows that the natural process of ombrophilous community formation had been accelerated by some outside factor. Presumably, renewal of river capture and the flow of water from the peatbog had again made themselves felt. The effects just described were accompanied by changes in the woodland communities surrounding the peatbog. Synchronously with the rise in the number of *Sphagnum* spores, the curves of *Alnus*, *Ulmus* and *Fraxinus* rise on the pollen diagrams WOL. 1 and WOL. 2. It can therefore be assumed that elm-ash woods spread in the eastern part of the Wolbrom depression as a result of the increased flow of water in the Szreniawa which may also have included serious flooding in spring.

The Wolbrom diagrams do not supply much information upon which an interpretation of the hydrological changes in the Subboreal and Subatlantic periods can be based. As far as hydrological changes are concerned, the break in peat accumulation (hiatus) during the Subboreal period (WOL. 1) deserves consideration. The peat deposit of this profile did not reveal any distinct differences, and such a hiatus was deduced from the shape of the tree pollen curves and from radiocarbon dates (profiles WOL. 1 and WOL. 2); nevertheless, further data are provided by Trela's description of the profiles (1928) and by the descriptions contained in "Dokumentacja geologiczna..." (1957). Both these sources describe layers containing wood fragments. Trela, on the basis of his pollen analysis, dated the 20—50 cm layer dry, strongly decomposed *Sphagnum* peat with wood fragments as belonging to the Subboreal period. These were identified as *Pinus* and *Betula* remains. Trela had carried out his investigations a good many years before extensive drainage work began on the peatbog. As a result of ditch digging, the upper part of the deposit became much drier, became oxidised and very probably sank. The secondary changes in the WOL. 1 profile peat which subsequently took place may well be the reason why this layer was not distinguished in the macroscopic description of the sediments.

The existence of a hiatus (profile WOL. 1) or a dried out, strongly decomposed *Sphagnum* peat with wood fragments (Trela 1928) indicates that the water deficit in the peatbog was getting worse. This could have been due to climatic factors (Chotiński & Starkel 1982), though it was more likely river capture that was again responsible. That trees were encroaching on to the peatbog and that its development had been brought to a standstill by river capture had already been mentioned by Kulczyński (1940).

The uppermost part of the peat in the WOL. 1 profile is dated as belonging to the Subatlantic period. After the stagnation in the Subboreal, the raised bog communities probably regenerated themselves once the climate had become distinctly moister (Chotiński & Starkel 1982, Gaillard 1985).

DISCUSSION AND SUMMARY OF RESULTS

The Wolbrom diagrams illustrate the vegetational history from the Oldest Dryas up to the Atlantic period. They also provide some information on the Subboreal and Subatlantic periods. Apart from the changes which occurred in the plant cover surrounding the peatbog, the succession of local vegetation was also reconstructed. The information obtained has made it possible to draw conclusions about certain climatic changes and local palaeohydrological changes.

The complete Late-Glacial sequence has so far been recorded in only a few diagrams from Poland. The vegetational changes occurring in this whole period are best illustrated by investigations made in the sand dune areas of lowland Poland (Wasylikowa 1964, Tobolski 1966). The Wolbrom peatbog is situated in a different morphological landscape (upland) within the range of loess formations, and lies far to the south of the previously mentioned localities. In general, then, the information in the present article supplements the data obtained so far and gives some idea of the conditions obtaining in upland areas during the Late-Glacial.

In the Oldest Dryas, the vegetation of the Wolbrom area was treeless tundra, as in southern Wielkopolska (Great Poland) (Tobolski 1966) and central Poland (Wasylikowa 1964), and also in many regions of north-western Europe. The dearth of identified taxons, both pollen grains and macrofossils, does not permit a fuller description of the vegetation and climate of that period in the vicinity of Wolbrom.

The climate became distinctly warmer and wetter at the beginning of the Bölling (s. str.). Around Wolbrom birch and pine began to expand rapidly. The

Bölling, with pine predominating in the woodland communities, was confirmed at localities in Wielkopolska (Tobolski 1966, 1985), whereas the diagram from Witów (Wasylikowa 1964) shows the dominance of birch. The boundary between pine and birch woodland ran through central Poland at that time.

The Wolbrom diagrams record the climatic oscillation of the Older Dryas. The changes which then took place in the vegetation are difficult to interpret unambiguously. The fall in the percentage and concentration of pine pollen can mean both that the intensity of the pollen rain from these trees was declining and that the woodland communities were becoming more open. During this phase there was a slight increase of juniper in this area. Other heliophytes, like *Artemisia,* do not reach their culmination.

Distinguishing the Older Dryas on pollen diagrams from north-western Europe has long been discursed (Watts 1980). The existence of a climatic fluctuation around 12000 years B. P. is not usually gainsaid; it is the stratigraphic rank of this period that is the subject of the controversy (Verburggen 1979, Watts 1980).

The changes which the Wolbrom diagrams illustrate were probably caused by an increase in the continentality of the climate which could have had a particularly strong effect on the plants growing on the unstable loess and sandy substrates. The fact that the most readily distinguishable Older Dryas phase in Polish diagrams comes from dune localities (Wasylikowa 1964, Tobolski 1966) endorses this theory; this phase is also easily recognisable in profiles from the loess area of Germany (Müller 1953).

The expansion of birch-pine woodland, followed by pine woodland, in the Alleröd has been recorded almost everywhere in Poland. The existence of thin birch-pine woods during this period has been recorded only by Hjelmroos-Ericsson (1981) in north-west Poland. Alder and spruce were probably growing near Wolbrom at this time. The presence of Picea has also been confirmed in the Carpathians (Koperowa 1962, Ralska-Jasiewiczowa 1972) and in upland areas (Mamakowa 1962, Szczepanek 1971).

The vegetational changes in the plant cover of the Younger Dryas are very clearly visible in the Wolbrom diagrams. The cool, continental climate caused the woodland to thin out and communities with large numbers of *Artemisia* and *Juniperus* to expand. Larch was an important tree around Wolbrom at this time. As in other parts of Poland, the vegetation was of the park tundra type. At this time, only northern Poland was characteiised by larger proportions of juniper and by a sparse covering of pine and tree birches (Hjelmroos-Ericsson 1981, Latałowa 1982, Pawlikowski et al. 1982). The results obtained here uphold the view that this was the coolest period of the Late-Glacial (Coope & Joachim 1980; Watts 1980).

About 10000 years ago, the countryside around Wolbrom was dominated by pine woodland also containing birch, larch and spruce. Elm and probably alder were present then. Hazel began to expand here about 9100 years ago; oak, lime and ash did so some 8000 years ago. It cannot be deduced from the

Wolbrom diagrams when hornbeam, fir and beech began to spread. All that is known is that these trees had already formed phytocenoses by the beginning of the Subatlantic period.

Definite evidence of human activities in the Wolbrom diagrams is found only in the uppermost part of diagram WOL. 1; radiocarbon datings confirmed earlier suppositions (Latałowa 1976) that it is are a reflection of Iron Age culture. Also put forward is the hypothesis that the traces of burnt plant macrofossils found in many layers of all the profiles could be due to the presence of Palaeolithic and Mesolithic man.

The analysis of the plant macrofossils is a good guide to the local changes in the hydrological regime. The local plant succession suggests that during the Alleröd, the younger part of the Atlantic period and the Subboreal period, intensified river capture took place, leading to the drainage of the investigated part of the peatbog. Only at the turn of the Younger Dryas and the Preboreal period was there a distinct flow of water in the neighbourhood of the site from which the profiles were taken.

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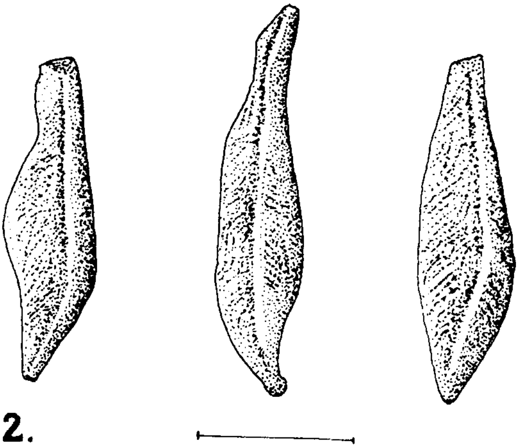
Plate I

1. *Scheuchzeria palustris* L. — lower leaves with hydatode
2. *Eriophorum vaginatum* L. — single sclerenchymatic spindles
3. *Calluna vulgaris* (L.) Salisb. — a — flower; b — branches with leaves

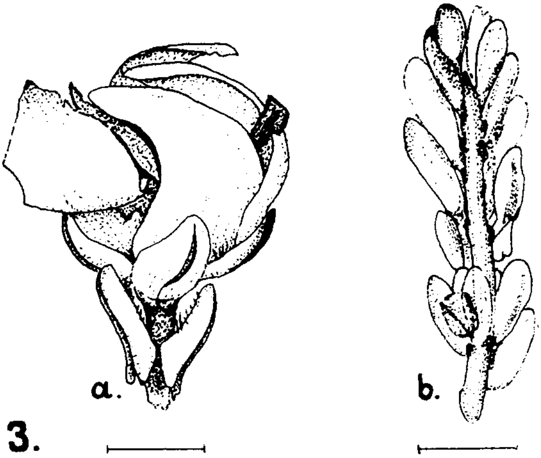
Scale 1 mm

Plate I

1.



2.



3.

a.

b.

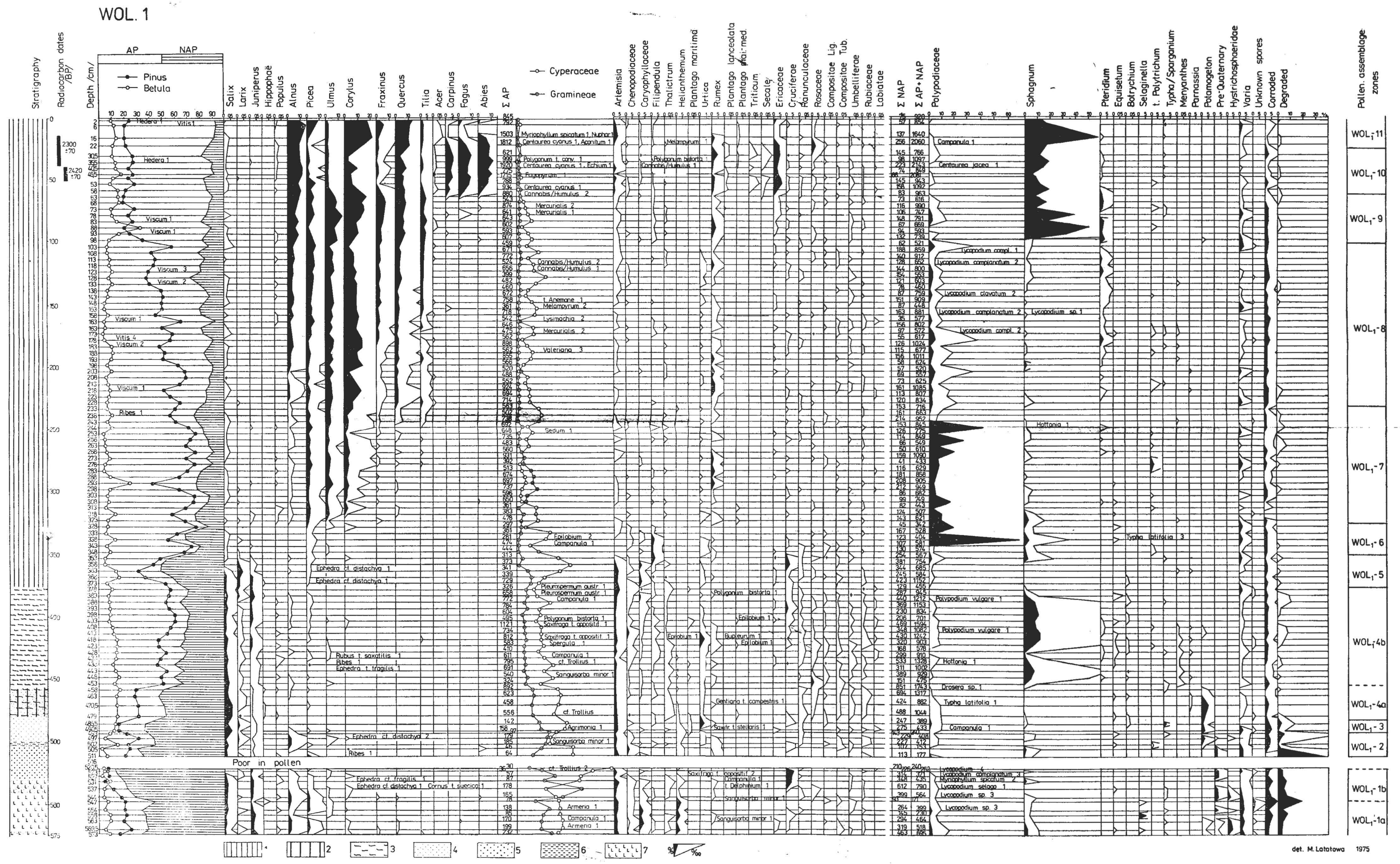


Fig. 6. Percentage pollen diagram from the WOL. 1 profile. 1 — partially decomposed *Carex* peat, 2 — strongly decomposed *Carex* peat, 3 — moss and *Sphagnum* peat, 4 — fine sand, 5 — medium-grained sand, 6 — amorphous humus, 7 — mud and silt

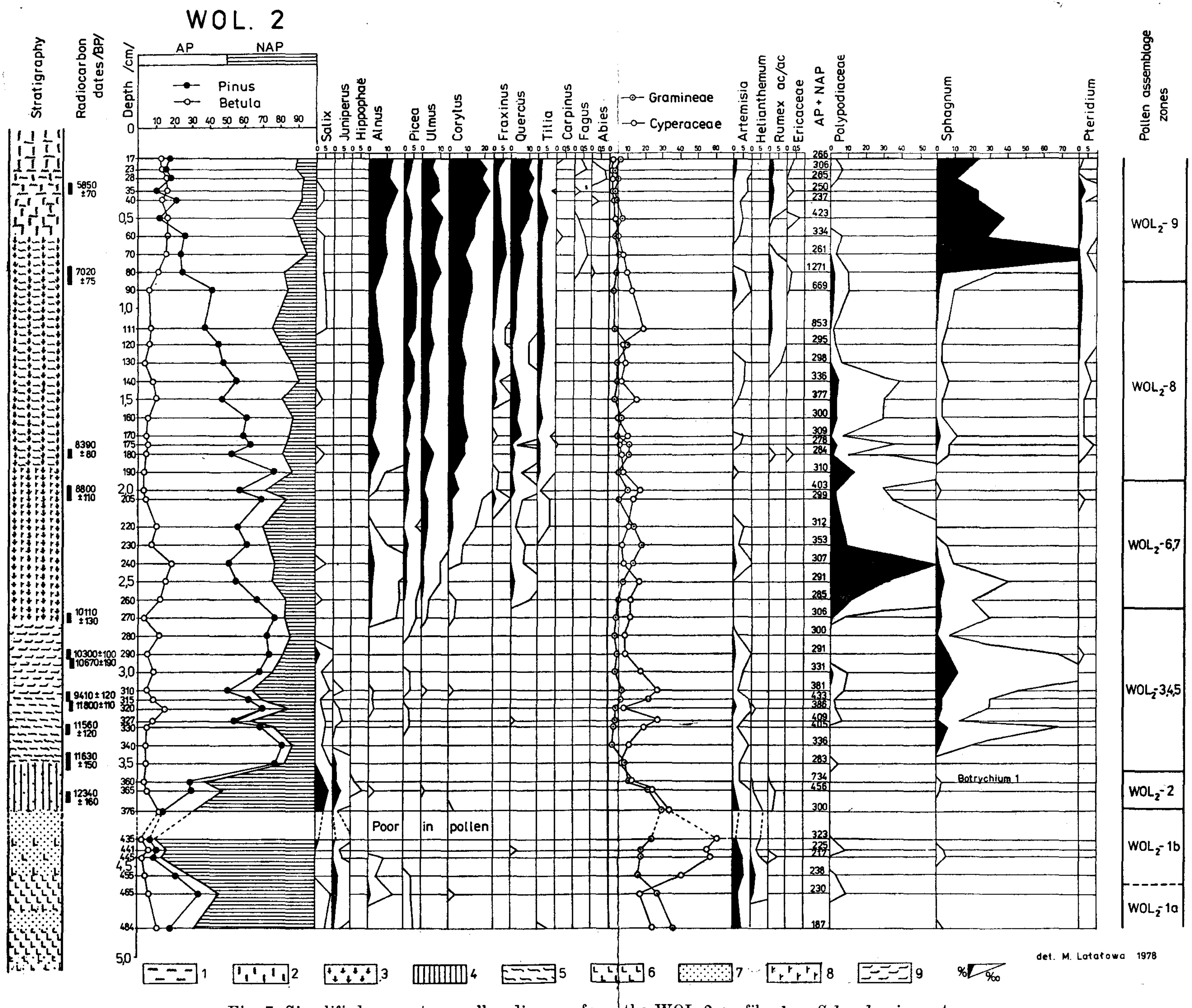


Fig. 7. Simplified percentage pollen diagram from the WOL. 2 profile. 1 — *Scheuchzeria* peat, 2 — *Eriophorum vag.* peat, 3 — *Magnocariceti* peat, 4 — *Carex* peat, 5 — moss peat, 6 — mud

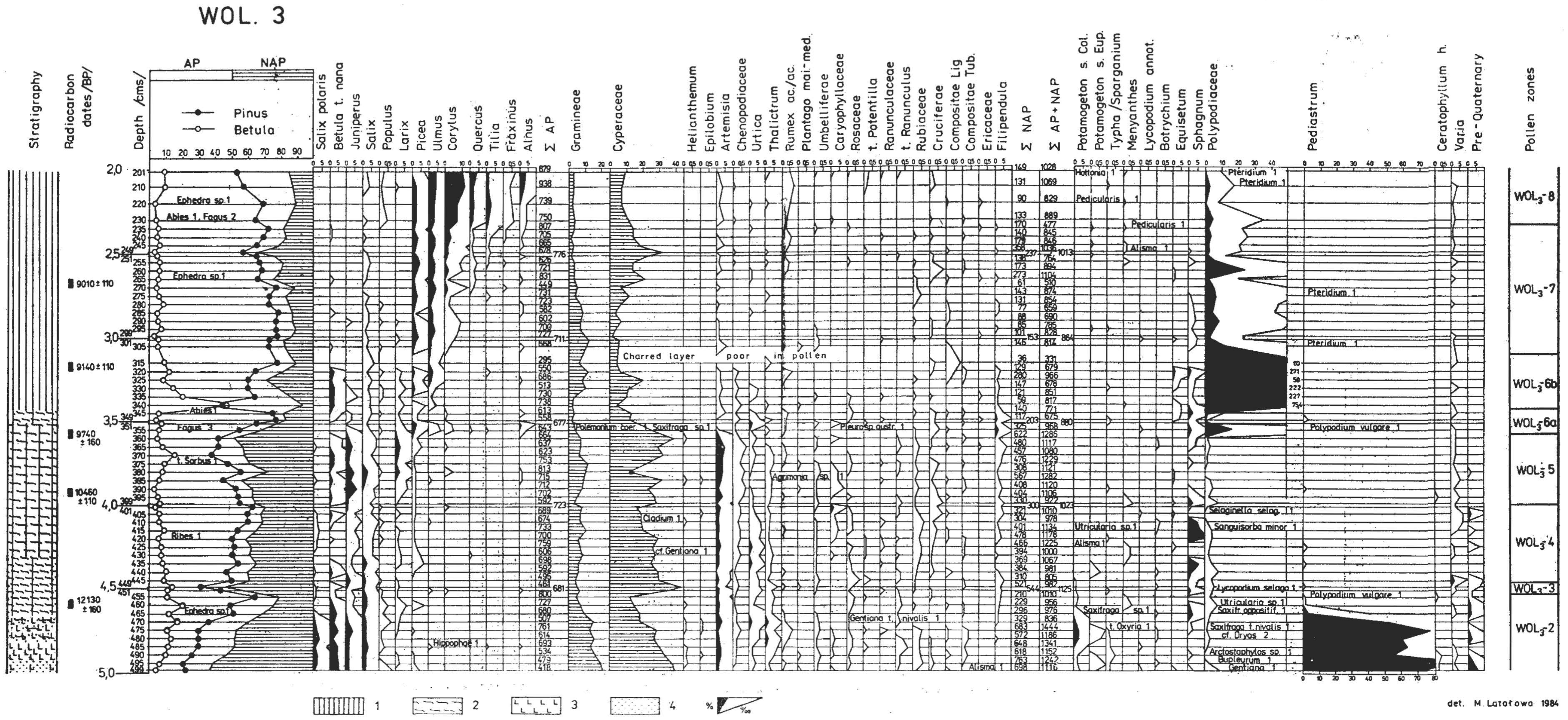


Fig. 8. Percentage pollen diagram from the WOL. 3 profile. 1 — *Carex* peat, 2 — moss and *Sphagnum* peat, 3 — mud and silt, 4 — sand

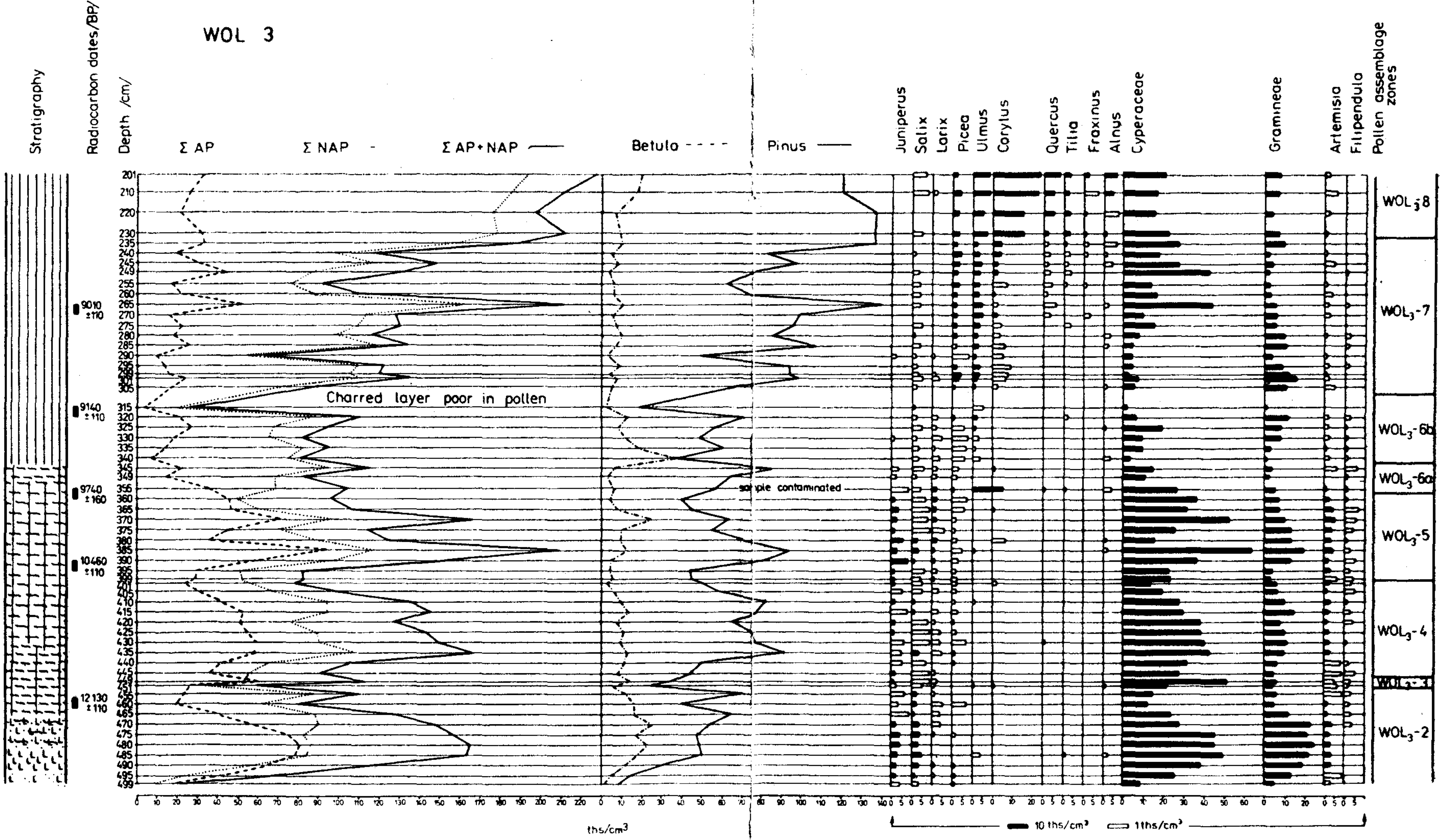


Fig. 9. Pollen concentration diagram from the WOL. 3 profile. Description of stratigraphy as for Fig. 8

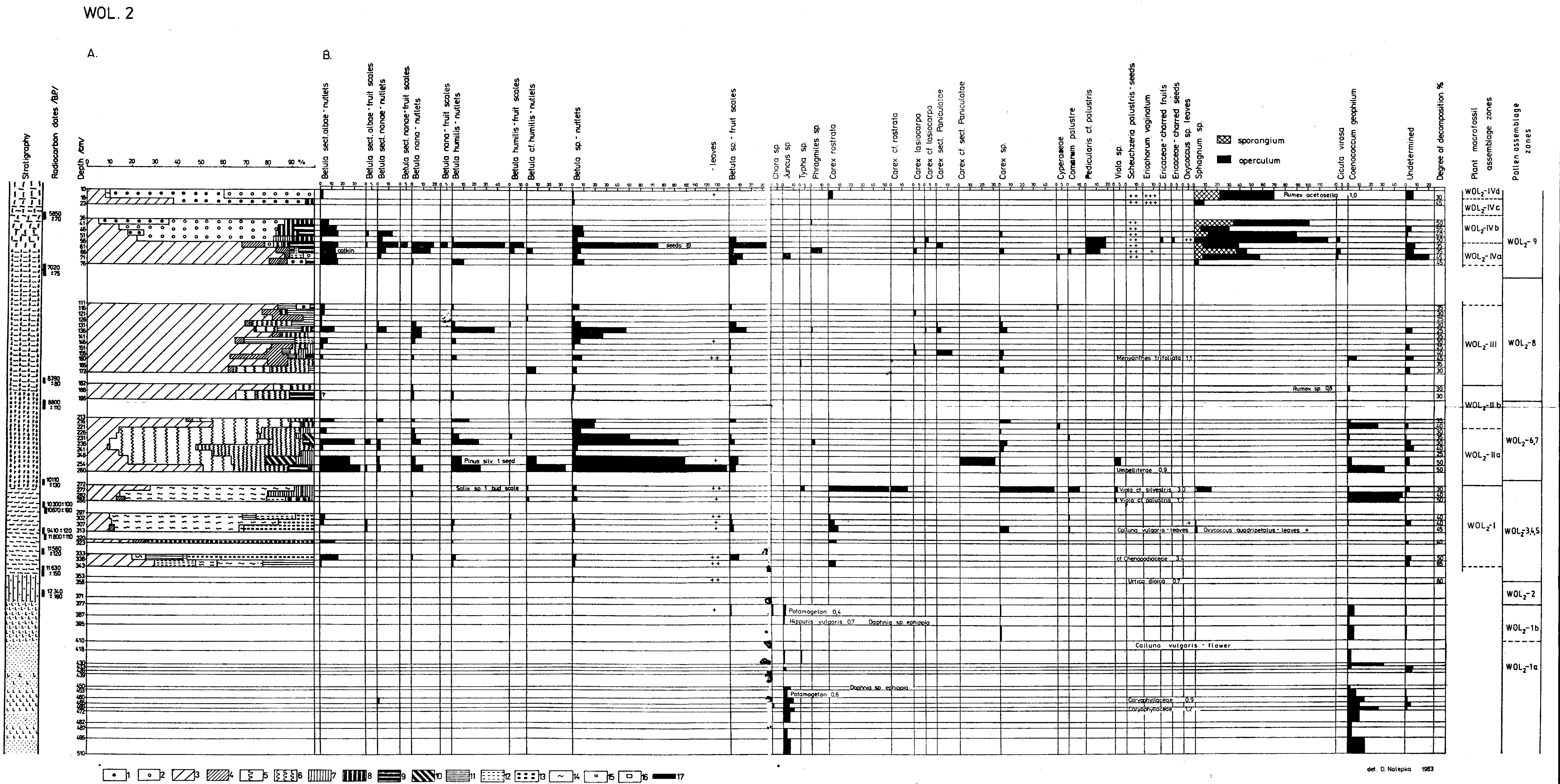


Fig. 11. Diagram of the botanical composition of the peat from the WOL. 2 profile. 1 — *Eriophorum* sp., 2 — *Scheuchzeria palustris*, 3 — *Carex* sp., 4 — *Carex limosa*, 5 — *Gramineae*, 6 — *Phragmites communis*, 7 — *Typha* sp., 8 — *Ericaceae* (periderm), 9 — *Alnus*, *Betula*, *Salix* (periderm), 10 — *Pinus* (periderm), 11 — *Bryales*, 12 — other mosses, 13 — *Drepanocladus* sp., 14 — *Sphagnum* sp., 15 — *Sphagnum teres*, 16 — *Comarum palustre*, 17 — fruits and seeds in 50 cm³. Description of stratigraphy as for Fig. 7