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KRYSTYNA WASYLIKOWA[1] and H. E. WRIGHT, Jr.[2]

LATE-GLACIAL PLANT SUCCESSION ON AN ABANDONED DRAINAGEWAY, NORTHEASTERN MINNESOTA, USA[3]

Późnoglacjalna sukcesja roślinności na obszarze opuszczonej przez lądolód rynny odpływowej (NE Minnesota, USA)

INTRODUCTION

Most glacial lakes containing fossil-bearing sediments result from the delayed melting of buried ice blocks, so the earliest stages of plant succession after ice recession generally go unrecorded (Florin and Wright 1969). Furthermore, attempts to date the time of ice recession by the radiocarbon method are frustrated for the same reason — basal organic sediments on moraine lakes generally provide the only available material by which such an event can be dated, yet the date must be considered minimal because of the lag in melting of buried ice.

The mode of formation of ice-block lakes is recorded by the common occurrence of a layer of coarse plant debris and even peat at the very base of the limnic sediment, just above the glacial outwash or till that forms the substratum (Hartz 1912, Więckowski 1967, Ralska-Jasiewiczowa 1966, Stasiak 1963). The debris consists dominantly of fragments of twigs, roots, leaves, needles, cone scales, and other terrestrial material that together most closely resembles forest duff,

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[1] Institute of Botany, Polish Academy of Sciences, Kraków, Poland.

[2] Limnological Research Center, University of Minnesota, Minneapolis, USA.

[3] Contribution No. 60, Limnological Research Center, University of Minnesota, Minneapolis, Minnesota. Research supported by funds from the Hill Family Foundation, the U. S. National Science Foundation (Grant GB-8704), and the Minnesota Geological Survey.

perhaps slightly transported. Debris of this nature is reported from several sites in Minnesota, such as Kirchner Marsh (Watts and Winter 1965), Andree Bog (Cushing 1964), and Martin, Bog D, and Terhell Ponds (McAndrews 1966). Fungal remains and corroded pollen grains in the detritus at Andree Bog indicate partial decomposition of the material before deposition, as in a forest duff. Terrestrial diatoms are dominant (Florin 1970). The forest in which this material formed may have grown directly on the buried ice. As the ice melted out, the debris collected in the bottom of small depressions. Subsequently it was buried and preserved by accumulation of limnic sediments.

Small glacial lakes or peat accumulations that are suitable for paleobotanical study (yet not of ice-block origin) are not common in Minnesota. Two general types occur. One is a beach pond of a large ice-dammed glacial lake, the shores of which can have no buried ice because of the heating effect of the adjacent lake water. Three such ponds on the beaches of Glacial Lake Agassiz in northwestern Minnesota were investigated by Shay (1965), who was able to identify the time at which one of the ponds was isolated from confluence with Lake Agassiz. The C-14 date from the isolation horizon thus records the time of recession of the lake — an important event in the glacial history — and the pollen studies indicate the nature of the contemporaneous vegetation.

The second type is peat accumulation on the floor of the large spillway of a glacial lake. The river in such a spillway may have eroded deeply into the terrain and may have cut completely through such buried ice as might have occurred in the glacial drift. The rarity of ice-block lakes in spillways indicates the effectiveness of this erosional process. Then, when the broad, flat spillway is abandoned as a result of diversion of the lake outlet following glacier retreat, a depression may be formed on the floor between the alluvial fans that are deposited by successive tributary streams. Lake Traverse, Big Stone Lake, and Lac Qui Parle were formed in such a way in the Minnesota River spillway of Glacial Lake Agassiz in western Minnesota. In more humid regions, however, the poor drainage of flatfloored abandoned spillways has allowed the accumulation of peat without the formation of definite topographic depressions. The spillways of Glacial Lake Upham in northeastern Minnesota, including the site here described, have had this history.

The present investigation was designed in part to date events in the late-Wisconsin history of Superior Lobe in northeastern Minnesota (Fig. 1). In addition, it was hoped to determine the pattern of forest invasion into the region, for investigations on incompletely dated lake-sediment sites elsewhere in northeastern Minnesota leave unsettled the question of distribution and duration of tundra in the periglacial area.

The site selected, here called Blackhoof after a nearby stream, is on an abandoned channel of the St. Louis River, which, as the spillway of

Glacial Lake Upham, was diverted southward into the drainage of the St. Croix River by the still active Superior Lobe. Final withdrawal of the Superior Lobe into the Lake Superior basin allowed the St. Louis River to empty into Glacial Lake Duluth and its successors, thereby leaving the large earlier spillways available for peat formation.

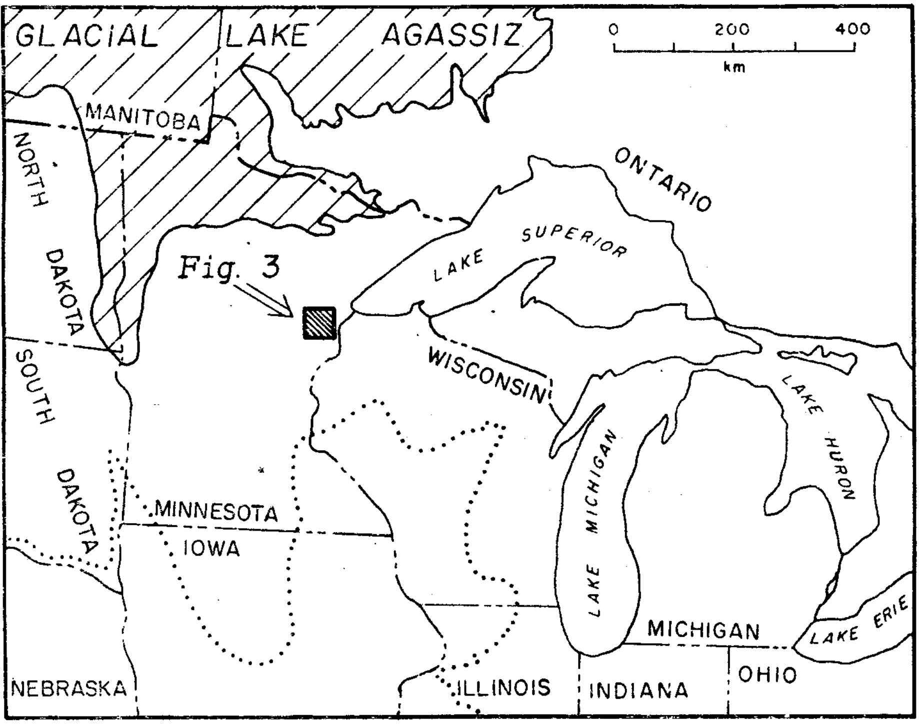


Fig. 1. Index map to show the location of the Blackhoof site with respect to the southern limit of the main Wisconsin drift (dotted line).

Ryc. 1. Położenie stanowiska Blackhoof w stosunku do przebiegu południowej granicy zlodowacenia Wisconsin (linia kropkowana).

GEOLOGIC SETTING

The glacial sequence in northeastern Minnesota (Wright and Ruhe 1965; Farnham et al. 1964, Wright and Watts 1969) postulates four phases of activity of the Superior Lobe during the Wisconsin glaciation — the St. Croix, Automba, Split Rock, and Nickerson phases — and relates these to the activity of other ice lobes and to the spillways of their proglacial lakes (Fig. 2). Whereas in the St. Croix and Automba phases the Superior Lobe expanded far out of the Lake Superior basin, in the Split Rock phase it extended only 100 km along the narrow lowland southwest of the lake, and it barely reached the low divide leading to the

Minneapolis lowland to the south. Reworking of proglacial lake beds overridden by the readvancing ice imparted a clayey texture to the till, which much resembles the Valders red clay till of eastern Wisconsin but is demonstrably older. This ice advance, and the one that followed,

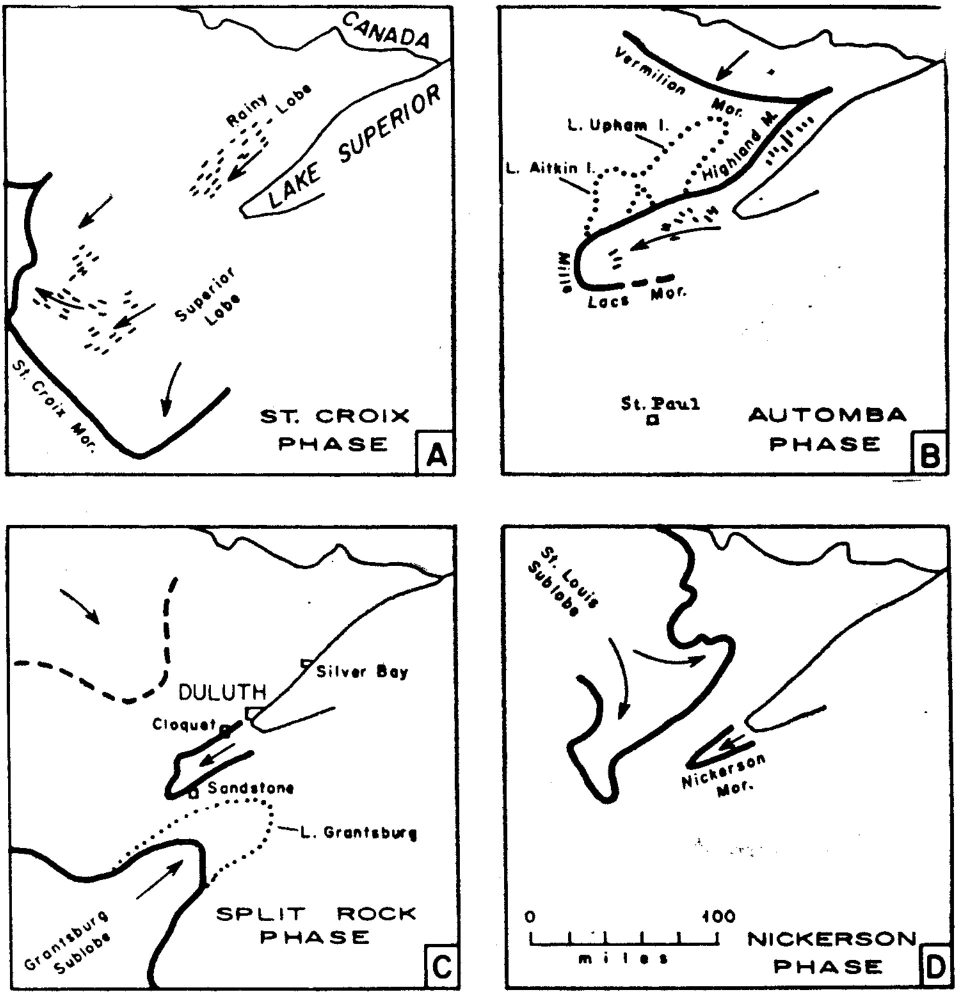


Fig. 2. Phases of main Wisconsin glaciation in eastern Minnesota, showing location of Blackhoof area.

Ryc. 2. Fazy zlodowacenia Wisconsin we wschodniej części stanu Minnesota w okolicy stanowiska Blackhoof.

have been explained as the result not of climatic change but of surging of the ice lobe, caused by changes in ice thickness and thermal gradients (Wright 1969). Outwash from the ice front spread westward from several prominent eskers that led eventually to the headwaters of the Snake River. An ice-block depression in this frontal outwash plain, Kotiranta

Lake, 10 km west of Cloquet, has C-14 dates of 16 150 ±550 (W-1973), 13 480 ±350 (W-1762), and 11 500 ±600 (W-1059) in the basal sediments, which contain macrofossils of tundra plants (Wright and Watts 1969). The St. Louis River at this time did not exist, or if it did it flowed to the west from the Superior Lobe rather than to the east, eventually reaching the Mississippi River.

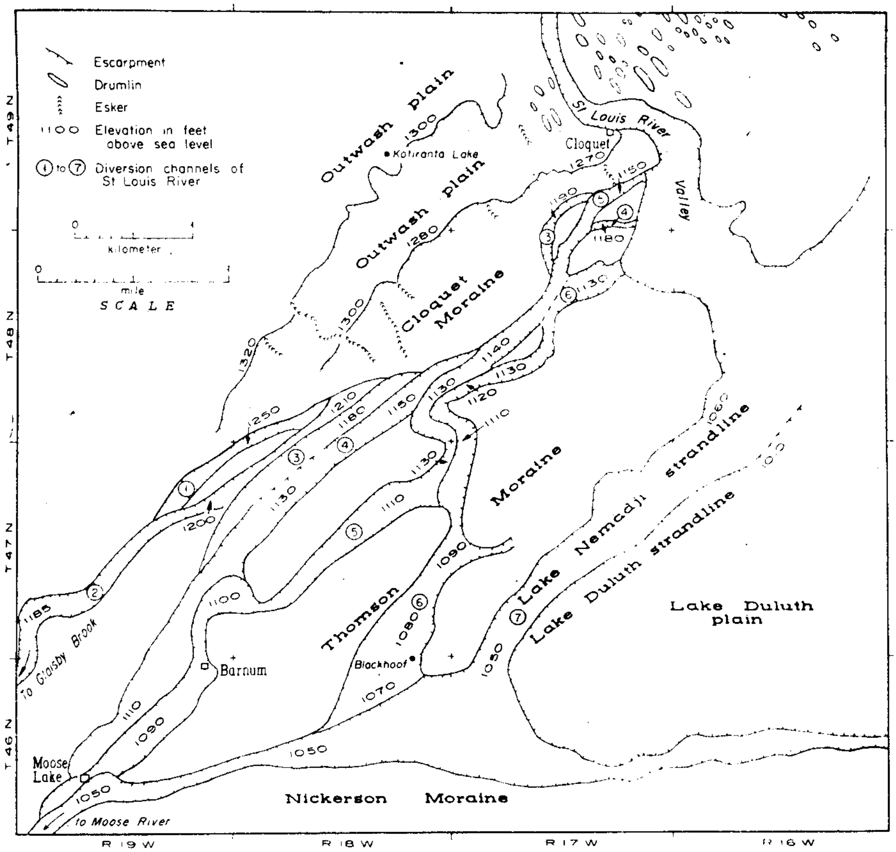


Fig. 3. Map of successive diversion channels of St. Louis River, resulting from blockage by Superior Lobe at the Thomson Moraine.

Ryc. 3. Mapa kolejnych rynien, wyciętych przez rzekę St. Louis w wyniku zatamowania jej odpływu przez lob Jeziora Górnego sięgający do moreny Thomson.

Then the Superior Lobe retreated a few kilometers, and in the Nickerson phase it advanced as a thin tongue over lake beds in a similar manner and built the conspicuous Nickerson Moraine on its left flank and the Thomson Moraine on its right flank. Meanwhile the St. Louis Sublobe advanced eastward in its Alborn phase, overriding clayey sediments of an early Glacial Lake Upham (I), and forming a terminal moraine only 25 km west of the Thomson Moraine. Its meltwater extended eastward down the St. Louis River to the contemporaneous Thomson Moraine, where it was diverted sharply to the southwest into the Moose River drainage — ultimately to the St. Croix and Mississippi Rivers. As the St. Louis Sublobe retreated, Glacial Lake Upham II formed at its front, and the spillway thereafter carried a clear, eroding St. Louis River. A series of seven channels (Fig. 3) records successively lower courses of the St. Louis River in its diversion at the Thomson Moraine (Wright et al. 1970). The increasing breadth and depth of the channels reflects the increasing discharge of the river as Lake Upham became enlarged by further retreat of the St. Louis Sublobe. The older channels are only about 300 m broad. Later channels are much more distinct as they cut the Thomson Moraine and its outwash fan. They have floors increasing in width from about 700 m as they leave the main river valley to twice that amount downstream. The Blackhoof site is located on the sixth channel of the series (Fig. 4). With further slight retreat of the Superior Lobe the St. Louis River, which still served as the Lake Upham outlet, emptied into proglacial Lake Nemadji, whose outlet was also southwestward (at 1160 feet) into the Moose River. At the same time, other small proglacial lakes formed along the southern side of the Superior Lobe, such as Lake Ontonagan in northern Michigan, which has a C-14 date of 10 220 ±500 (M-359). Finally the Superior Lobe withdrew far enough so that a lower outlet was uncovered in northwestern Wisconsin; this is Glacial Lake Duluth.

Radiocarbon control on this sequence is provided first by the minimal date at Kotiranta Lake of 16 150 B. P., in an outwash kettle on the Cloquet plain of the Split Rock phase. Outwash from the same ice went south via the Snake River into Glacial Lake Grantsburg, which is older than 13 530 ±240 B. P. (Y-1978). Closer control is provided by a pair of dates on Glacial Lake Aitkin II, which, like Lake Upham II, formed after retreat of the St. Louis Sublobe and was thus at first contemporaneous with the St. Louis River diversion channels described above (Farnham et al. 1964). A buried peat layer in these lake beds has dates of 11 710 ±325 (W-502) and 11 560 ±400 (W-1141).

These dates all imply a pre-Valders age for the red clayey till of the Split Rock and Nickerson phases of the Superior Lobe. The Blackhoof site should provide a closer control on the retreatal history of the Superior Lobe because the drainageway on which it is located was exactly contemporaneous with the ice dam immediately to the east, and because the peat presumably began to form immediately after abandonment of the channel.

THE BACKGROUND OF VEGETATIONAL HISTORY

The vegetational history for the conifer-hardwood forest region of northeastern Minnesota (Fig. 5) was established by the studies of Fries (1962) and Baker (1965), recently summarized by Wright and

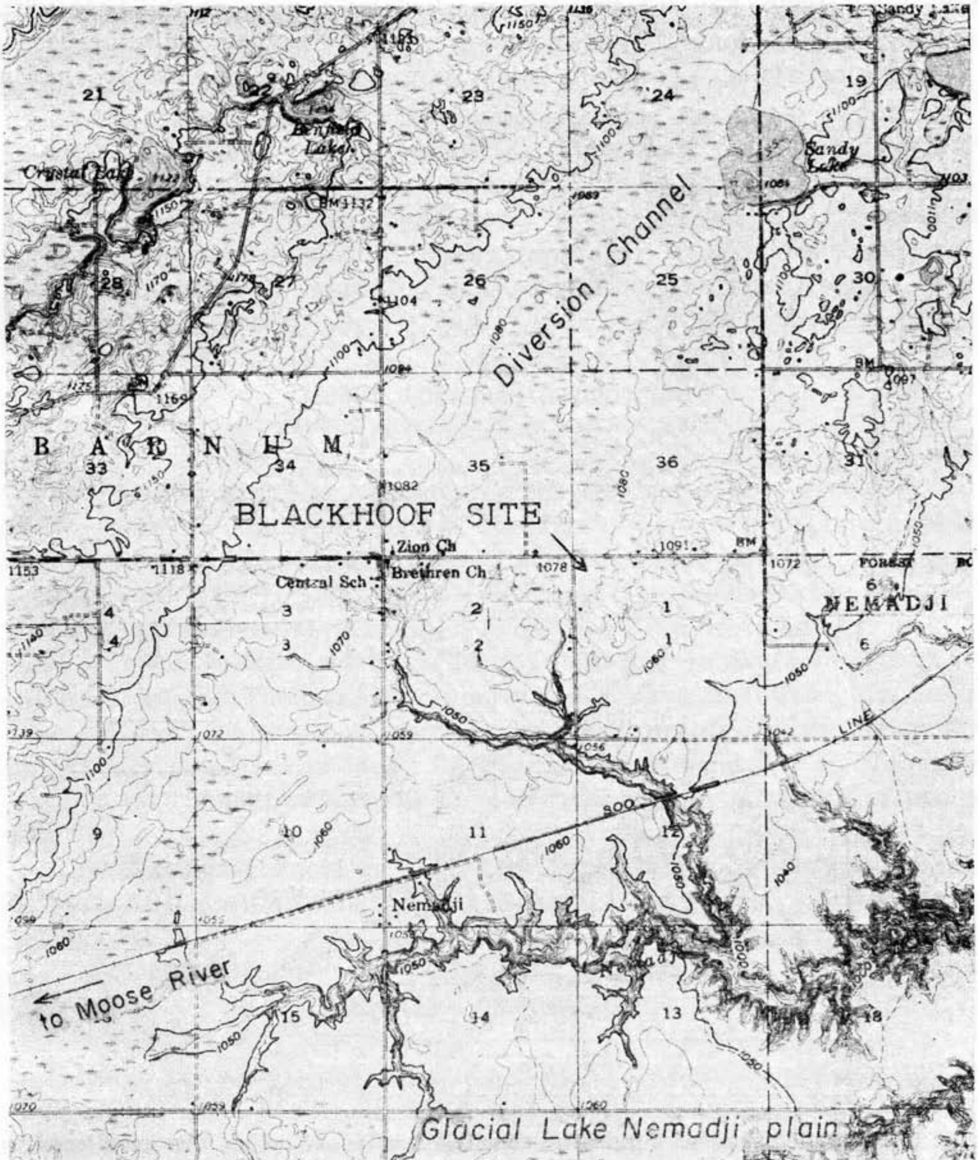


Fig. 4. Topographic map showing the location of the Blackhoof site on the diversion channel of the St. Louis River. Contour interval 10 ft. Numbered sections are 1 square mile in area. From U. S. Geol. Survey (Barnum and Bruno quadrangles).

Ryc. 4. Mapa topograficzna obrazująca położenie stanowiska Blackhoof w obrębie rynny rzeki St. Louis. Poziomice co 10 stóp. Numerowane kwadraty mają powierzchnię 1 mili kwadratowej. Z U. S. Geol. Survey (arkusze Barnum i Bruno).

Watts (1969). Several sites are marked by a zone at the base with macrofossils of plants that are common in tundra regions (*Salix herbacea, Dryas integrifolia, Vaccinium uliginosum* var. *alpinum, Rhododendron lapponicum, Betula glandulosa*), and with no macrofossils of *Picea, Larix, Betula papyrifera,* or other boreal trees. The abundant pollen of *Picea* in the same zone implies that spruce trees were not far away. Perhaps the landscape may be described as a park tundra, with groves of spruce

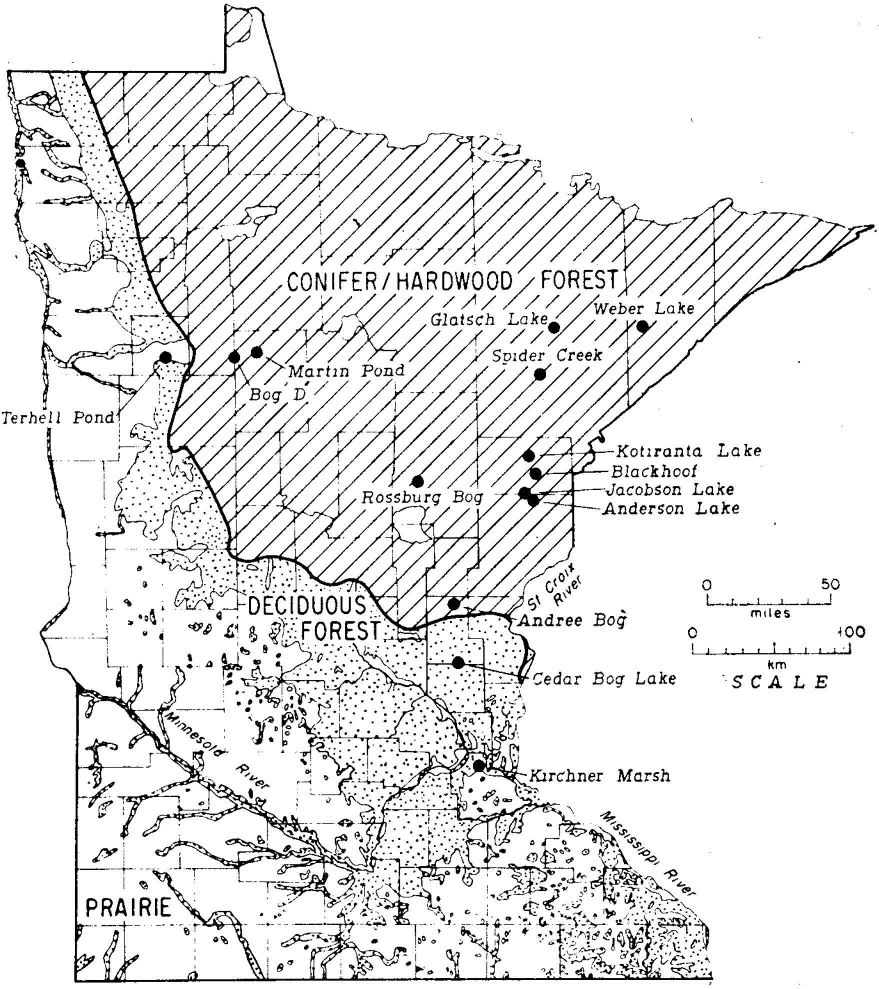


Fig. 5. Vegetation map of Minnesota, showing location of pollen sites mentioned in the text. Original map was compiled by Upham (1884) before extensive agricultural clearance.

Ryc. 5. Mapa roślinności stanu Minnesota z podaniem wymienionych w tekście stanowisk, z których opracowano diagramy pyłkowe. Oryginalna mapa zrobiona była przed okresem intensywnego wycinania lasów, związanego z rozwojem rolnictwa (Upham 1884).

on favorable habitats but not around the sites in question. But because depressions are the very places where one might expect to find the protection favorable for tree growth, it might be more reasonable to visualize a somewhat sharper tundra/forest ecotone located southwest of the sites in question, close enough to permit the importation of abundant pollen of spruce (and even a few grains of thermophilous plants). Determination of the location and nature of migration of this ecotone is a challenging problem for precise paleobotanical stratigraphy and radiocarbon chronology, combined with glacial geology. The Blackhoof site provides some detail for this history.

DESCRIPTION OF BLACKHOOF SITE

The Blackhoof site is located near the NW cor. Sec. 1, T. 46 N., R. 18 W., near the southern edge of the Barnum quadrangle topographic map of the U. S. Geological Survey, about 9 km east of Barnum, Carlton County, at 46°30·2′ N. Lat., 92°34·4′ W. Long. The drainage channel here, which trends from north to south, is more than 2 km broad and has an elevation of about 1075 feet above sea level. It cuts in a winding course through a portion of the Thomson Moraine, and it is separated from the Lake Nemadji plain to the east by the innermost portion of the Thomson Moraine. About 2 km to the south the channel is truncated by the east-west outlet channel of Glacial Lake Nemadji at an elevation of about 1050 feet.

The drainage channel is floored by sand, which is locally overlain by peat. At the sample site the peat is about 150 cm deep.

METHODS OF ANALYSIS

Several cores were taken with a 2-inch Livingstone piston sampler (Cushing and Wright 1965) at a lateral distance of about 20 cm apart. Two of them, Blackhoof A and C, were analyzed for pollen and radiocarbon age (Fig. 6). Plant macrofossils were studied only in core A (Fig. 7). The detailed description of the sediment is given in an appendix.

A carbon-14 date of 10 630 ±500 years ago (W-1677) was obtained for the sample of basal moss peat (unit 2) from cores A and C jointly. Swamp peat (unit 4) in core C was dated to 10 420 ±300 years B. P. (W-1714).

Pollen samples were prepared according to standard methods by the use of KOH, HF, and acetolysis, stained with safranin, and mounted in silicone oil (Faegri and Iversen 1964). Percentage curves in the pollen diagram are based on the total pollen, excluding aquatics and

Sphagnum. To evaluate the possible influence of local pollen of *Cyperaceae* and *Dryopteris* type on the pollen spectra, supplemental curves were drawn with these two taxa excluded from the pollen sum.

For macrofossil analysis, core segments of measured weight (proportional to volume) were heated in water with the addition of 10% KOH and washed through screens of 0·1 and 0·5 mm. The sums of macrofossils plotted on the diagram include entire or nearly entire ($> {}^3/_4$) specimens, plus large fragments (${}^1/_2$ to ${}^3/_4$ full size) counted as half. Still smaller fragments were counted only if no larger pieces were found. Conifer needles were counted in a manner explained with the description of species. Notes on the criteria for identification of especially significant or difficult macrofossils are presented in the appendix.

DESCRIPTION AND INTERPRETATION OF POLLEN ZONES

The diagrams from core A (Figs 6—7) are divided into spruce-herb, spruce, and pine pollen zones. In core C (Fig. 6) only the sediments of spruce-herb and the basal part of the spruce pollen zones were analyzed.

Spruce-herb pollen zone (1a). This zone is marked by *Cyperaceae* and *Artemisia* in high percentages. *Picea* is the dominant tree-pollen type. *Fraxinus, Populus, Juniperus* or *Thuja,* and *Betula* are present in moderate amounts, and other tree genera in small quantities. The amount of pine is very low.

The basal part of the zone (lowest three levels in core A), which has more pollen of *Fraxinus, Juniperus/Thuja,* and *Populus,* is very poor in the identifiable plant macrofossils. Of considerable interest is the occurrence of two leaves of *Dryas integrifolia.* Trees and shrubs are represented by very rare remains of *Picea* sp. and *Larix laricina,* by one fruit of *Betula* series *Humiles,* and one bract of staminate catkin of *Alnus* sp.

In the rest of the zone *Cyperaceae* pollen is very abundant, and the curves for *Fraxinus, Juniperus/Thuja,* and *Populus* decrease as *Betula* increases (particularly in core C). The maximum for the *Cyperaceae* pollen is associated with a maximum of fruits of *Carex aquatilis.* This species is often found in the Late-glacial sediments from Minnesota and is included in the category of the pioneer semi-aquatic plants (Watts 1967, Watts and Bright 1968). The *Betula* pollen peak probably results from the dwarf birch *Betula glandulosa,* as indicated by the find of one cone bract of *B.* cf. *glandulosa* and 6 fruits of *B.* series *Humiles* (which includes the temperate-bog birch *B. pumila* and its variety *glandulifera* as well as *B. glandulosa*). *B. glandulosa* today is confined to arctic-alpine Canada, alpine New England and New York, the alpine zone of the Rocky Mountains, and the Black Hills of South Dakota (Fernald 1950, Harrington 1954). At the top of the zone macroscopic remains of tamarack and spruce are abundant.

The large amount of *Artemisia* pollen, which represents heliophilous upland vegetation, and the leaves of *Dryas integrifolia* in the lower part of the spruce-herb pollen zone point to the existence of open herbaceous vegetation, which included at least some elements of tundra. *Dryas integrifolia* is common today in the tundra and alpine regions, although it has an isolated occurrence in the boreal forest north of Lake Superior (Baker 1965). It often grows as a pioneer plant on unstable soils, which must have been available at Blackhoof during the deposition of the basal sand.

The increase of the birch pollen curve above the level dated to 10 420 ±300 B. P. precedes the increase of *Picea* and *Larix* pollen and the abundant occurrence of macrofossils of these two genera. A similar picture can be seen in the diagrams from Weber Lake (Fries 1962) and Spider Creek (Baker 1965), and the interpretation given for these sites is that the thickets of *Betula glandulosa* immediately preceded the invasion of the boreal forest (Watts 1967). The explanation seems correct also for Blackhoof, which about 10 400 years ago witnessed the same kind of plant succession from the open herbaceous vegetation through the stage of *Betula glandulosa* to the local development of *Picea-Larix* forest.

During the accumulation of the sediments of spruce-herb pollen zone the Blackhoof site was probably situated in the region of the forest/tundra transition, which had a mosaic of tundra vegetation and forest groves of spruce and tamarack on favorable habitats. Sediments of about the same age in nearby localities, viz. Jacobson Lake (10 400 B. P.) and Anderson Lake (10 800—10 200 B. P.) and even older in Kotiranta Lake (11 500 B. P.), contain macrofossils of *Picea* and *Larix* (Wright and Watts 1969). At Blackhoof the spruce and tamarack were locally absent until the time corresponding to the deposition of the top sediments of this zone. Pollen of *Picea* and *Larix* was probably transported partly from the stands of trees within the transitional zone, partly, together with pollen of thermophilous trees, from forests more to the south. *Picea, Larix, Populus, Abies,* and *Betula* represent tree genera that grow today in the whole region of boreal forests in North America, while *Fraxinus, Ulmus,* and *Quercus* appear only in its southern part. These thermophilous trees probably played a more important role in the Late-glacial forests of central and southern Minnesota than they do to-day in the boreal region, and they were the source of pollen for the northern part of the state. The complex problems in the ecological interpretation of the high-herb pollen zone assemblages in the Great Lakes region are discussed elsewhere (Wright 1968).

Spruce pollen zone (1b). This zone is characterized by the dominance of *Picea* pollen, by the increasing curve for *Pinus*, and by values for *Ulmus, Abies,* and *Larix* that are higher than in the spruce-herb pollen zone. The sum of herb pollen diminishes mainly as a result of smaller amounts of *Cyperaceae.* Numerous macroscopic remains of *Picea, Larix,* and *Salix* are found in this zone. Among birches, fruits similar to *Betula papyrifera* are first to appear. Fruits of *Carex aquatilis* are less abundant than in zone 1a.

During the time of this zone the drainageway was probably covered by bog forest of *Larix laricina* and *Picea mariana* (although the *Picea* species was not determined), with enough pools of water and wet habitats to support the vegetation with *Myriophyllum* sp., *Typha* sp., *Hippuris vulgaris, Menyanthes trifoliata, Lycopus uniflorus* or *L. virginicus, Carex aquatilis,* and *Selaginella selaginoides.*

Pine pollen zone (2). In the pine zone the curve for *Pinus* pollen attains its highest values, followed by an increase of *Betula* and *Alnus. Larix* is present in considerable amount. The curve for *Picea* pollen declines to very low values. Among herbaceous plants, ferns (e. g. *Dryopteris* type) play an important part. The sediments of this zone are rich in macroscopic remains of different plants. Most common tree species is *Larix laricina;* for the first time macrofossils of *Abies balsamea* and *Pinus* sp. appear. Unfortunately the species of pine was not determined, but pollen studies at other sites in the area indicate that *Pinus banksiana* or *P. resinosa,* and not *P. strobus,* was involved (Wright 1968). Macroscopic remains of *Picea* are common even at the top, where its pollen curve is very low. Aquatic and damp-soil vegetation includes: *Potamogeton* sp., *Nymphaea* sp., *Typha latifolia, Typha angustifolia* or *Sparganium* sp., *Alisma* sp., *Menyanthes trifoliata, Lysimachia thyrsiflora, Lycopus uniflorus* or *L. virginicus,* and *Urtica* cf. *gracilis.*

At the time of the pine pollen zone, as the regional climate became drier and warmer, the boreal *Larix-Picea* forest on the drainageway apparently was largely replaced by more temperate lowland types like *Abies balsamea* and then *Alnus rugosa,* while the drier sites contained *Pinus* and then *Betula papyrifera.*

Because the analyses were not continued to the top of the sediment, identification of pollen zones younger than the pine zone was not made.

CONCLUSIONS

The Blackhoof site, in combination with other paleobotanical sites in northeastern Minnesota, indicates that the time interval 11 500 to 10 300 B. P. was marked by a shifting ecotone between tundra and boreal forest, as the Superior Lobe retreated into the Lake Superior basin. The distribution of trees and open areas was probably determined by local factors of soil and exposure in the diversified terrain freshly bared by the retreating ice. Trees of *Picea* and *Larix* had invaded the Kotiranta area by 11 500 years ago, but not the Blackhoof site (only 17 km to the east) until 1000 years later. Meanwhile, at Blackhoof, tundra herbs and shrubs characterized the vegetation, as they did also farther north at Spider Creek and especially Weber Lake.

If the assumption is correct, as presented in the introduction, that the basal peat at Blackhoof was formed as soon as the drainageway was abandoned (and not later after melting of buried ice), then it must be concluded that the Superior Lobe of glacial ice still filled the Lake Superior basin to the Thomson-Nickerson Moraines as recently as about 10 600 years ago, so that the St. Louis River was still diverted through the Blackhoof channel until this time. When the ice then withdrew from these moraines, Glacial Lake Nemadji and other small lakes along the south side of the ice were formed (Leverett 1932). One of these, Glacial Lake Ontonagan, has a radiocarbon date of 10 220 ±500 (M-359), providing a further check on the chronology.

The Blackhoof dates of 10 630 and 10 420 indicate the time just after withdrawal of the ice from the moraines. The advance to the moraines themselves, i. e. the Nickerson phase, might still have occurred as long ago as 12 000 B. P., i. e. pre-Valders, as indicated by the radiocarbon dates of Glacial Lake Aitkin II, which postdated the maximum of the Nickerson advance.

The long persistence of ice within the Lake Superior basin may help to explain why tundra vegetation was present at Blackhoof (only a few kilometers from the ice front) but had already been replaced by forest at Kotiranta. Tundra vegetation lasted until about the same time (10 300 B. P.) at Weber Lake, which was located at least 30 km from the edge of the Superior Lobe at this time but about 135 km northeast of Blackhoof. Because other sites farther away from the ice front (Glatsch, Aitkin, Rossburg, Jacobson, and Anderson as well as Kotiranta) already had been forested by this time, the persistence of tundra at Blackhoof and Weber can be attributed to periglacial effects of the Superior Lobe.

APPENDIX

Description of the sediment

The composition and the physical properties of the sediment are based on the examination of cores A and C. Symbols follow Troels-Smith (1955). The layer numbers refer to both cores. The depth of layers is given from the surface of the peat. First numbers refer to the depth in core A, numbers in parentheses to the depth in core C. The difference is due to the fact that core C was taken obliquely.

9. 50—90 cm Dark-brown very decomposed peat with abundant fragments of wood (among others *Picea* or *Larix*). Penetrated by recent herbaceous roots (*Cyperaceae* and others).
nig. 3, strf. 1, sicc. 3, elas. 0
Sh 2,5, Th^{2}1, Tl(Dl?) 0,5, Th^0+, Tb^1(+), Dh+, [anth. (+)]

8. 90—105 cm Yellowish-brown very compact swamp peat with great admixture of mosses and gyttja. Penetrated by recent herbaceous roots (among others *Cyperaceae*).
nig. 3, strf. 2, sicc. 2, elas. 3
Th^{2}2, Tb^{2}1, Ld^{1}1, Th^0(+), Dh ++, Dl(+)

7. 105—110 cm (110—118 cm). Yellowish-brown swamp peat composed of intertwined roots of herbs, with small amount of mosses. Penetrated by recent herbaceous roots.
nig. 3, strf. +, sicc. 2, elas. 1
Th^{2}4, Th^1+, Th^0(+), Dl(+), Dh+, [anth. (+)]

6. 110—114·5 cm (118—126 cm). Olive-green swamp peat with gyttja. Contains small admixture of silt (or clay), CaCO$_3$, and pyrite. Penetrated by recent herbaceous roots (among others *Cyperaceae*).
nig. 2, strf. +, sicc. 2, elas. 1
Th^{2}3, Ld^{1}1, Tb^1+, Th^0(+), Ag/As+, Dh+, Lc(+), Lf(+)

5. 114·5—123 cm (126—142 cm). Blackish-brown swamp peat with abundant leafy shoots of mosses. A layer of mosses in core A at 117·5—119 cm, in core C at 130—136 cm. Contains silt (or clay) and pyrite and is penetrated by recent herbaceous roots (among others *Cyperaceae*). Few pieces of wood and few charcoals.
nig. 3—4, strf. 1, sicc. 2, elas. 1
Th^{2}3, Tb^{2}1, Th^0(+), Dl(+), Ag/As(+), Lf(+), [anth. (+)]

4. 123—130 cm (142—148 cm). Yellowish-brown swamp peat with some woody twigs or roots and a few mosses. Few recent herbaceous roots. No identifiable macrofossils.
nig. 3, strf. +, sicc. 2, elas. 1
Th^{2}4, Th^0(+), Tb^2(+), Ag/As(+), Dl/Tl(+), [anth. (+)]

3. 130—134 cm (148—150 cm). Brownish-gray coarse-grained sand with small admixture of mosses and a few fragments of wood. Few recent roots of herbs.
nig. 2, strf. 0, sicc. 2, elas. 0
Ga4, Gs+, Th^0(+), Th^1(+), Tb^2(+), Ag/As+, Dl(+)

2. 134—137 cm (150—153 cm). Yellowish-brown peat composed of mosses and intertwined herbaceous roots. Few recent herbaceous roots. The sample was not washed for macrofossils, but 2 fruits of *Potamogeton* sp. and one *Larix* needle fragment were found in core A while the recent roots were being removed to prepare the sample for radiocarbon dating.
nig. 3, strf. 0, sicc. 2, elas. 1
$Tb^{2}2$, $Th^{2}2$, $Ld^{1}+$, Ag/As+, Ga++, Gs+, Lf(+), $Th^{0}(+)$

1. 137—160 cm Brownish-grey stratified sand with some organic material. At 142 to 160 cm, admixture of gravel to 1 cm in diameter. Few recent and fossil herbaceous roots. Very few small charcoals, at 152 to 160 cm some remains of mosses.
nig. 2, strf. 1, sicc. 2, elas. 0
Ga4, Gs+, $Th^{1}(+)$, $Th^{0}(+)$, Lc(+), $Tb^{1}(+)$, [anth. (+)]

Description of the more interesting macrofossils. Plant names follow Fernald (1950)

Corylaceae

Alnus rugosa (Du Roi) Spreng is represented by 29 whole cone-bracts with terminal lobes prolonged and slightly ascending, 9 fragments of cone-bracts, and 6 nutlets.

Alnus sp. has 45 bracts of staminate catkin, 2 male flowers with four-parted perianth, and 11 tepals of perianth.

Betula is represented by 69 fruits and by 7 scales of pistillate catkins. For identification they were compared with 5 native taxa that occur today in Minnesota (*Betula lutea* Michx., *B. nigra* L., *B. papyrifera* Marsh., *B. pumila* L., and *B. pumila* L. var. *glandulifera* Regel) and with two northern species (*B. glandulosa* Michx. and *B. nana* L. ssp. *exilis* (Sukatch.) Hultén) whose fossil remains have been reported from Minnesota. The possibility of *B. michauxii* Spach was also considered.

In the lower part of the section (96—134 cm), corresponding approximately to the lower peak of the birch pollen curve, only the remains of *B.* cf. *glandulosa* were found, with the possible presence of *B. nana* ssp. *exilis* and *B. pumila* var. *glandulifera*. In the upper part of the diagram (50—96 cm) the fruits most similar to *B. papyrifera* appeared, and this species was identified without any doubts at the depth 54—80 cm, which corresponds to the upper peak of the birch pollen curve. Fruits similar to *B. glandulosa* were present in the upper part of the diagram too.

Betula papyrifera Marsh. (Plate I) was identified on the basis of two catkin scales with narrow middle lobe and broader and divergent lateral ones.

Betula cf. *glandulosa* Michx. (Plate I). One catkin scale has the shape and size most similar to this species, but the possibility of *B. nana* ssp. *exilis* cannot be excluded, because the fossil specimen has only two lobes preserved and their ends are broken. The fossil differs from *B. papyrifera* by its broader angle between the middle and lateral lobes, and by having its middle lobe about as broad as the lateral one. It cannot belong to *B. pumila* or *B. pumila* var. *glandulifera* because its lateral lobe is more protruding upward than with these two species.

Betula series *Humiles* D. J. Koch. Fifteen fruits were identified as belonging to this group. Nutlets are oval or almost circular in outline and have a rather broad base. Seven of them possess at least partly preserved wings that are narrower than half of the breadth of the nutlet. This shape of fruits is most commonly found in *B. glandulosa* and *B. nana*, but may be also met with in *B. pumila* and *B. pumila* var. *glandulifera*.

Betula sp. Eleven fruits, oval in outline, without wings, can be identified only as belonging to the genus, along with 4 very damaged catkin scales. In addition, 42 fruits, also preserved without wings, have a narrow base, with the broadest part above the middle of the nutlet. This shape is most common in *B. papyrifera*, but it is also found in *B. pumila* and *B. pumila* var. *glandulifera*. These 42 fruits are included on the diagram as *B. papyrifera* type.

Ericaceae

Gaultheria sp. (Fig. 8). Five seeds of this genus were found. They differ from similar seeds of *Chamaedaphne calyculata* by the lack of the processus near the hilum and by less elongated cells of the testa.

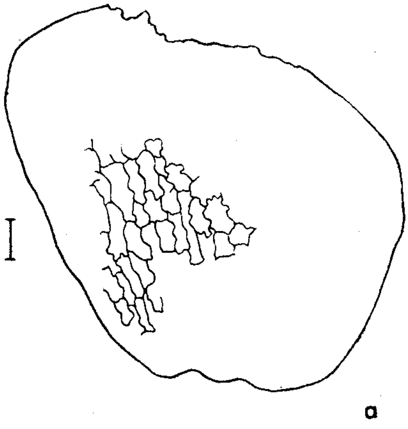
Labiatae

Lycopus uniflorus Michx. or *L. virginicus* L. Three nutlets with muricate corky ridge may belong to one of these species. Both of them have similar shape of fruits and grow at present in Minnesota. *L. virginicus* has its general distribution more to the south than *L. uniflorus*.

→

Fig. 8. Fossil seeds of *Gaultheria* sp. from the pine (1, 2) and the spruce (3) pollen zones of Blackhoof. Extant seeds of *Chamaedaphne calyculata* (L.) Moench (4) and *Gaultheria hispidula* (L.) Bigel. (5). a — whole specimens, b — fragments of their testa. Each scale unit is 0·1 mm.

Ryc. 8. Kopalne nasiona *Gaultheria* sp. z piętra sosny (1, 2) i świerka (3) w Blackhoof. Współczesne nasiona *Chamaedaphne calyculata* (L.) Moench (4) i *Gaultheria hispidula* (L.) Bigel. (5). a — całe okazy, b — fragmenty ich testy. Odcinki skali mają długość 0·1 mm.



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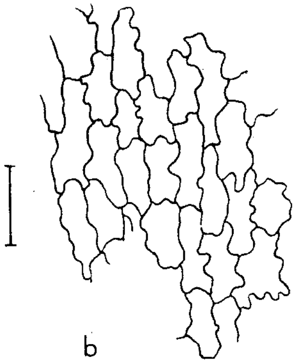

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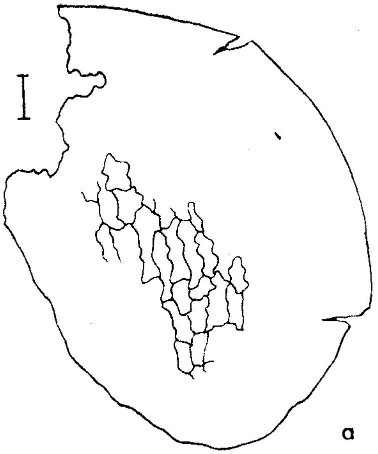
1



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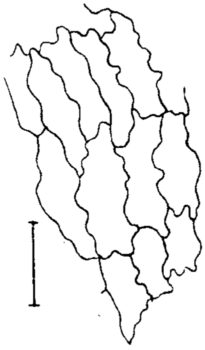

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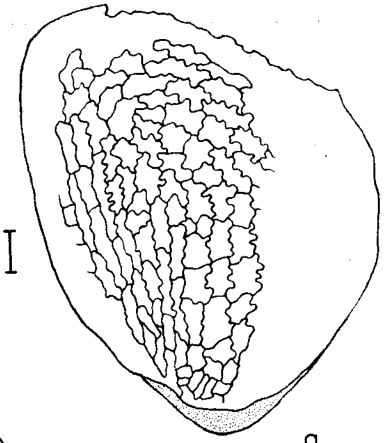

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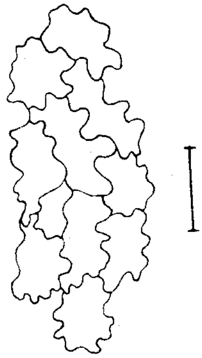

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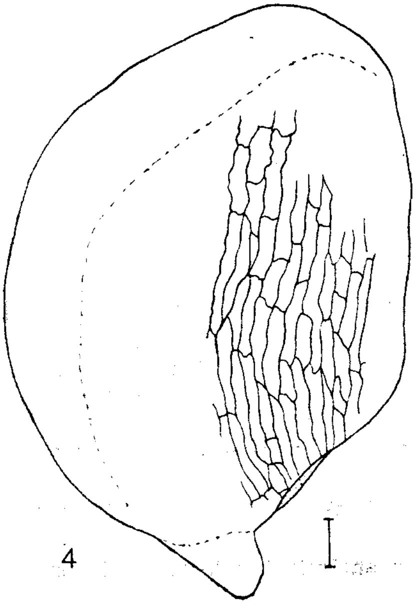

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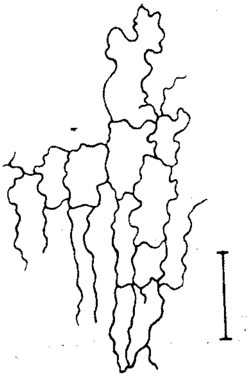

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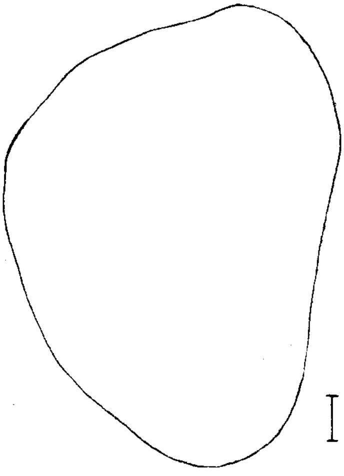


a

5

Pinaceae

Abies balsamea (L.) Mill. is represented by 55 fragments of needles with upper end blunt or notched, 2 seeds without wings, a few anthers with pollen grains, and one fragment of male catkin with anthers containing pollen.

Larix laricina (Du Roi) Koch. Tamarack represents the most common macrofossil in Blackhoof. It was identified on the basis of the following remains: 6290 needles (the sum includes whole specimens as well as the fragments preserved with the upper end), 48 seeds (some with fragments of wings), one cone and one fragment of cone, 14 basal parts of cone scales, 78 short-shoots with compact rings of leaf-scars, and one twig with 3 short-shoots. One sample contained clumps of pollen grains.

Picea sp. To this genus belong: 595 needles, 9 seeds, 4 winter buds (cf. Dallimore and Jackson 1931), 4 fragments of twigs with leaf-scars, one piece of wood of *Picea* or *Larix,* 7 fragments of seed wings, and one badly preserved fragment probably of a cone scale. The sum of needles in each sample corresponds to the number of whole needles plus the number of fragments preserved with the lower or upper end, depending on which of these end types was more abundant. No attempt at specific identification of needles was made (cf. Watts and Winter 1966).

Pinus sp. The only macroscopic remain of pine is one fragment of the basal part of a seed. It has a sharp edge, unlike *Picea,* and it has no beak typical for *Larix.*

REFERENCES

Baker R. G. 1965. Late-Glacial pollen and plant macrofossils from Spider Creek, southern St. Louis County, Minnesota. Geol. Soc. American Bull. 76 : 601—610.

Cushing E. J. 1964. Redeposited pollen in Late-Wisconsin pollen spectra from east-central Minnesota. Amer. Jour. Sci. 262 : 1075—1088.

Cushing E. J. 1965. Problems in the Quaternary phytogeography of the Great Lakes region, p. 403—416 in „The Quaternary of the United States", H. E. Wright, Jr. and D. G. Frey ed., Princeton Univ. Press, Princeton, N. J., 922 pp.

Cushing E. J. 1967. Late-Wisconsin pollen stratigraphy and the glacial sequence in Minnesota, p. 59—88 in „Quaternary paleoecology", E. J. Cushing and H. E. Wright, Jr. ed., Yale Univ. Press, New Haven, 433 pp.

Cushing E. J., Wright H. E., Jr. 1965. Hand-operated piston corers for lake sediments. Ecology 46 : 380—384.

Dallimore W., Jackson A. B. 1931. A handbook of *Coniferae.* Edward Arnold, London, 582 pp.

Faegri K., Iversen J. 1964. Textbook of pollen analysis. Munksgaard, Copenhagen, 237 pp.

Farnham R. S., McAndrews J. H., Wright H. E., Jr. 1964. A Late-Wisconsin buried soil near Aitkin, Minnesota, and its paleobotanical setting. Amer. Jour. Sci. 262 : 393—412.

Fernald M. L. 1950. Gray's manual of botany. American Book Co., 8th ed., New York, 1632 pp.

Florin M.-B. 1970. Late-glacial diatoms of Kirchner Marsh southeastern Minnesota. Beih. zur Nova Hedwigia, 31 : 667—756.

Florin M.-B., Wright H. E., Jr. 1969. Diatom evidence for the persistence of stagnant glacial ice in Minnesota. Geol. Soc. American Bull. 80 : 695—704.

Fries M. 1962. Pollen profiles of Late Pleistocene and recent sediments from Weber Lake, Minnesota. Ecology 43 : 295—308.

Hartz N. 1912. Allerød-gytje and Allerød-mull. Dansk Geol. Foren. Medd. 4 : 85—92.

Harrington H. D. 1954. Manual of the plants of Colorado. Sage Books, Denver, 666 pp.

Lawrence D. B., Schoenike R. E., Quispel A., Bond G. 1967. The role of *Dryas drummondii* in vegetation development following ice recession at Glacier Bay, Alaska, with special reference to its nitrogen fixation by root nodules. Jour. Ecol. 55 : 793—813.

Leverett F. 1932. Quaternary geology of Minnesota and parts of adjacent states. U. S. Geol. Survey Prof. Pap. 161, 149 pp.

McAndrews J. H. 1966. Postglacial history of prairie, savanna, and forest in nortwestern Minnesota. Torrey Bot. Club Mem. 22, 2 : 1—72.

Ralska-Jasiewiczowa M. 1966. Osady denne Jeziora Mikołajskiego na Pojezierzu Mazurskim w świetle badań paleobotanicznych (Bottom sediments of the Mikołajki Lake, Masurian Lake District, in the light of paleobotanical investigations) Acta Palaeobot. 7, 2 : 1—118.

Shay C. T. 1965. Postglacial vegetational development in northwestern Minnesota and its implications for prehistoric human ecology. M. S. thesis, Univ. of Minnesota.

Stasiak J. 1963. Historia jeziora Kruklin w świetle osadów strefy litoralnej (History of Kruklin Lake as revealed by the deposits of its littoral zone). Pr. Geogr. Inst. Geogr. PAN 42 : 1—94.

Troels-Smith J. 1955. Karakterisering af løse jordarter. Danmarks Geol. Unders., ser. 4, 3, 10 : 1—73.

Upham W. 1884. Catalogue of the flora of Minnesota. Geol. Nat. Hist. Surv. Minnesota, Ann. Report (1883), pt. 6 : 5—197.

Watts W. A. 1967. Late-glacial plant macrofossils from Minnesota, p. 89—97 in „Quaternary paleoecology", E. J. Cushing and H. E. Wright, Jr. ed., Yale Univ. Press, New Haven, 433 pp.

Watts W. A., Bright R. C. 1968. Pollen, seed, and mollusk analysis of a sediment core from Pickerel Lake, northeastern South Dakota. Geol. Soc. America Bull. 79 : 855—876.

Watts W. A., Winter T. C. 1966. Plant macrofossils from Kirchner Marsh, Minnesota — a paleoecological study. Geol. Soc. America Bull. 77 : 1339—1360.

Więckowski K. 1968. Geneza, wiek i ewolucja jezior północno-zachodniej Polski (Origin, age, and evolution of lakes in northeastern Poland). Folia Quaternaria 29 : 145—151.

Wright H. E., Jr. 1968. The roles of pine and spruce in the forest history of Minnesota and adjacent areas. Ecology 49 : 937—955.

Wright H. E., Jr. 1969. Glacial fluctuations and the forest succession in the Lake Superior region. Internat. Assoc. Great Lakes Res., 12th Conf. (Ann Arbor 1969). Proc. (In press).

Wright H. E., Jr., Mattson L. A., Thomas J. A. 1969. Geology of the Cloquet Quadrangle, Carlton County, Minnesota. Minnesota Geol. Survey, Spec. Publ. (In press).

Wright H. E., Jr., Ruhe R. V. 1965. Glaciation of Minnesota and Iowa, p. 29—41 in „The Quaternary of the United States", H. E. Wright, Jr. and D. G. Frey ed., Princeton Univ. Press, Princeton, N. J., 922 pp.

Wright H. E., Jr., Watts W. A. 1969. Glacial and vegetational history of northeastern Minnesota. Minnesota Geol. Survey, Spec. Publ. 11.

STRESZCZENIE

PÓŹNOGLACJALNA SUKCESJA ROŚLINNOŚCI NA OBSZARZE OPUSZCZONEJ PRZEZ LĄDOLÓD RYNNY ODPŁYWOWEJ (NE MINNESOTA, USA)

Celem badań na stanowisku Blackhoof było datowanie pewnych zjawisk związanych z działalnością lobu lodowcowego Jeziora Górnego w północno-wschodniej Minnesocie oraz dostarczenie dalszych informacji o historii rozwoju pierwszych zbiorowisk roślinnych na tym terenie u schyłku zlodowacenia Wisconsin.

W czasie zlodowacenia Wisconsin czynne były w Minnesocie cztery główne jęzory lodowcowe, które przesuwały się w różnych kierunkach i pozostawiły po sobie materiał morenowy o zróżnicowanym składzie litologicznym. Pozwoliło to na rozpoznanie faz transgresji i zastoju poszczególnych lobów, a zastosowanie datowania węglem radioaktywnym umożliwiło przynajmniej częściowe ustalenie ich wzajemnej korelacji w czasie (Wright i in. 1965, Farnham i in. 1964, Wright i Watts 1969). Dla lobu Jeziora Górnego w północno-wschodniej Minnesocie opisano cztery fazy, w czasie których nasuwał się on z basenu Jeziora Górnego w kierunku południowo-zachodnim (ryc. 2). W czasie najmłodszej z nich, zwanej fazą Nickerson i datowanej na około 12 000 lat temu, lob Jeziora Górnego utworzył moreny Thomson i Nickerson (ryc. 3). Czoło lodowca przy morenie Thomson stanowiło zaporę dla wód spływających z północnego zachodu doliną rzeki St. Louis, najpierw od odgałęzienia (sublobe) St. Louis lobu des Moines, a potem z jezior proglacjalnych Aitkin i Upham, powstałych po wycofaniu się tego odgałęzienia. Wody te z doliny rzeki St. Louis spływały do rzeki Moose wzdłuż zachodniej krawędzi moreny Thomson, wycinając w niej coraz to głębsze i szersze rynny odpływowe. W najmłodszej rynnie położone jest stanowisko Blackhoof (ryc. 4). Po pewnym cofnięciu się lobu Jeziora Górnego rzeka St. Louis znalazła ujście do wąskiego proglacjalnego jeziora Nemadji, odwadnianego także w kierunku południowo-zachodnim do rzeki Moose. W tym samym czasie wzdłuż krawędzi ustępującego lodowca utworzyły się małe jeziora, z których jedno — jezioro Ontanogan — datowane jest na 10 220 ± 500 lat temu (M-359). Ostateczne wycofanie się lobu Jeziora Górnego doprowadziło do zlania się jezior proglacjalnych w jedno glacjalne jezioro Duluth, do którego przesunęło się ujście rzeki St. Louis, a jej dawne połączenie z rzeką Moose uległo przerwaniu.

Na stanowisku Blackhoof, położonym w obrębie jednego z dawnych koryt rzeki St. Louis, na podłożu piaszczystym znajduje się warstwa torfu (około 1,5 m miąższości), którego akumulacja mogła rozpocząć się dopiero po ustąpieniu przepływu wód przez rynnę. Datowanie spągu torfu na 10 630 ±500 (W-1677) i 10 420 ±300 (W-1741) lat temu pozostaje w zgodzie z chronologią opisanych poprzednio zjawisk, uzyskaną na podstawie datowań z innych stanowisk. Wycinanie rynien przez rzekę St. Louis zaczęło się około 11 710 ±325 (W-502) i 11 560 ±400 (W-1141) lat temu, ponieważ w tym czasie utworzyło się glacjalne jezioro Aitkin (Farnham i in. 1964), a wszystkie rynny, z wyjątkiem odpływu jeziora Nemadji, były już pozbawione przepływu wód lodowcowych wcześniej niż 10 220 lat temu (wiek jeziora Ontanogan i prawdopodobnie jeziora Nemadji). Jeśli, jak przyjęto w tej pracy, torf w Blackhoof zaczął się tworzyć bezpośrednio po ustaniu przepływu wód, to daty spągowe z tego stanowiska określają czas tuż po wycofaniu się lobu Jeziora Górnego z moren Thomson-Nickerson.

Diagram pyłkowy (ryc. 6) obejmuje piętro świerka i roślin zielnych (1a), piętro świerka (1b) i piętro sosny (2). Rozwój roślinności przebiegał tu od zbiorowisk tundrowych (dolna część piętra 1a), przez fazę zarośli z *Betula glandulosa* (górna część piętra 1a), do lasów świerkowych z modrzewiem (piętro 1b), które z kolei (piętro 2) zostały częściowo wyparte przez lasy z jodłą i olszą (*Alnus rugosa*), podczas gdy siedliska suchsze zajęły sosna i brzoza (*Betula papyrifera*).

Datowanie piętra 1a za pomocą C-14 na 10 630 i 10 420 lat temu pozwala na porównanie roślinności okolic Blackhoof z roślinnością innych stanowisk tego regionu. Diagramy pyłkowe z położonych około 13 km na południe od Blackhoof jezior Anderson i Jacobson wskazują, że w tym czasie panowały tam lasy świerkowe, podobnie jak w okolicy jeziora Kotiranta, 11 km na północny zachód, gdzie przejście od tundry do lasu nastąpiło już około 11 500 lat temu. Nad jeziorem Weber natomiast, 135 km na północny wschód, tundra przetrwała do około 10 300 lat temu, przypuszczalnie dzięki panowaniu warunków peryglacjalnych związanych z bliskością (30 km) lobu Jeziora Górnego. Podobne warunki klimatyczne mogły panować przez krótki czas także w Blackhoof, oddalonym zaledwie o kilka km od krawędzi lodowca, co umożliwiało lokalny rozwój zbiorowisk tundrowych w czasie, gdy większość terenów położonych na południe i zachód opanowana już była przez lasy świerkowe.

Plate I

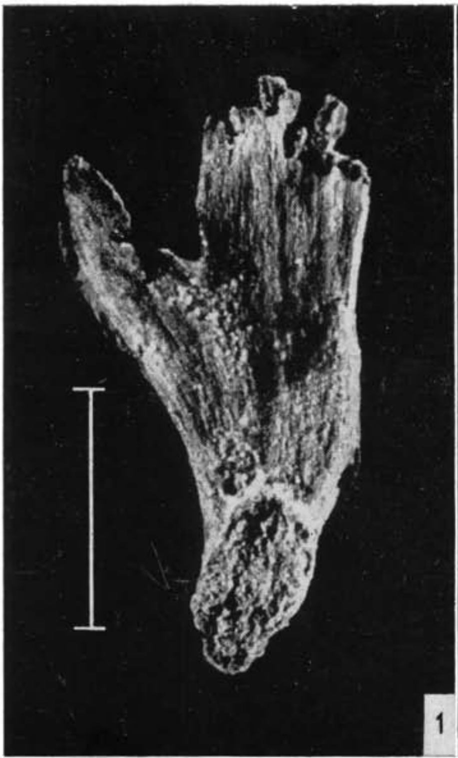
1. Catkin scale of *Betula* cf. *glandulosa* from pollen zone 1a of Blackhoof
2, 3. Catkin scales of *Betula papyrifera* from pollen zone 2 of Blackhoof
4. Seed wing of *Picea* sp. from pollen zone 1a of Blackhoof
Each scale unit is 1 mm

Tablica I

1. Łuska owocowa *Betula* cf. *glandulosa* z piętra 1a w Blackhoof
2, 3. Łuski owocowe *Betula papyrifera* z piętra 2 w Blackhoof
4. Skrzydełko nasienne *Picea* sp. z piętra 1a w Blackhoof
Odcinki skali mają długość 1 mm

Phot. *R. C. Bright* and *Roger Woo.*
Fot. *R. C. Bright* i *Roger Woo.*

Plate I
Tablica I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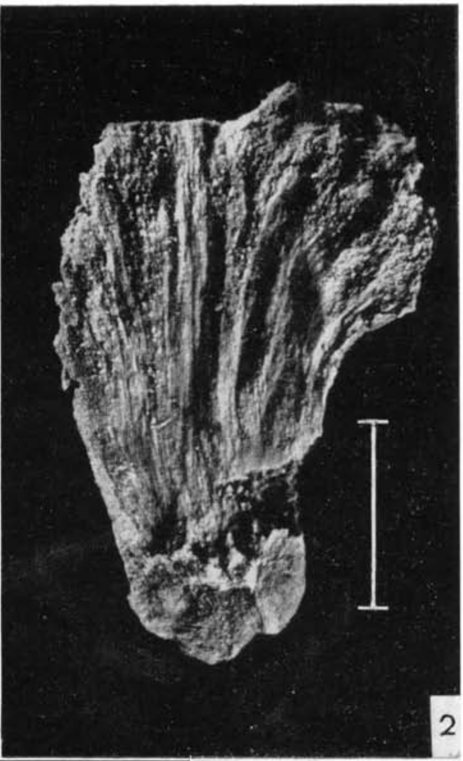
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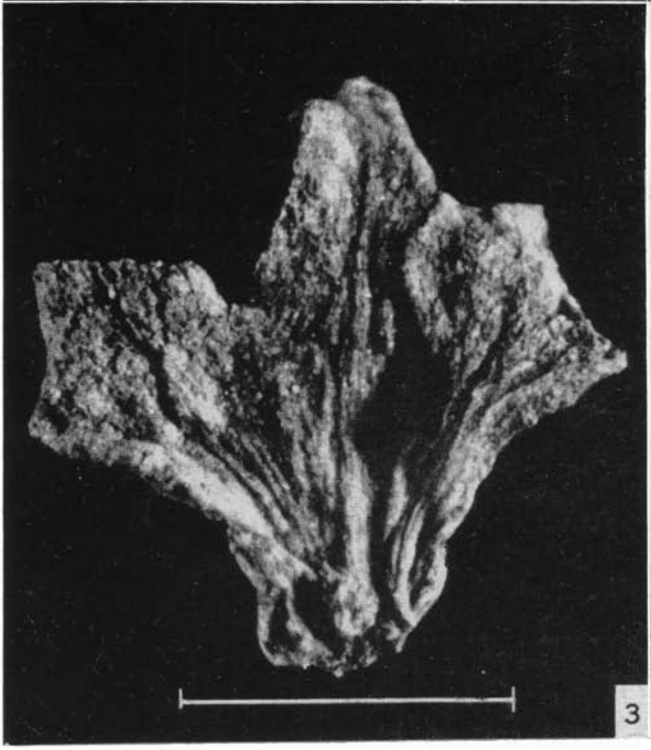
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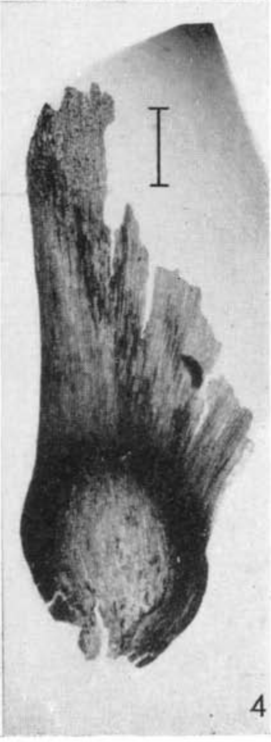
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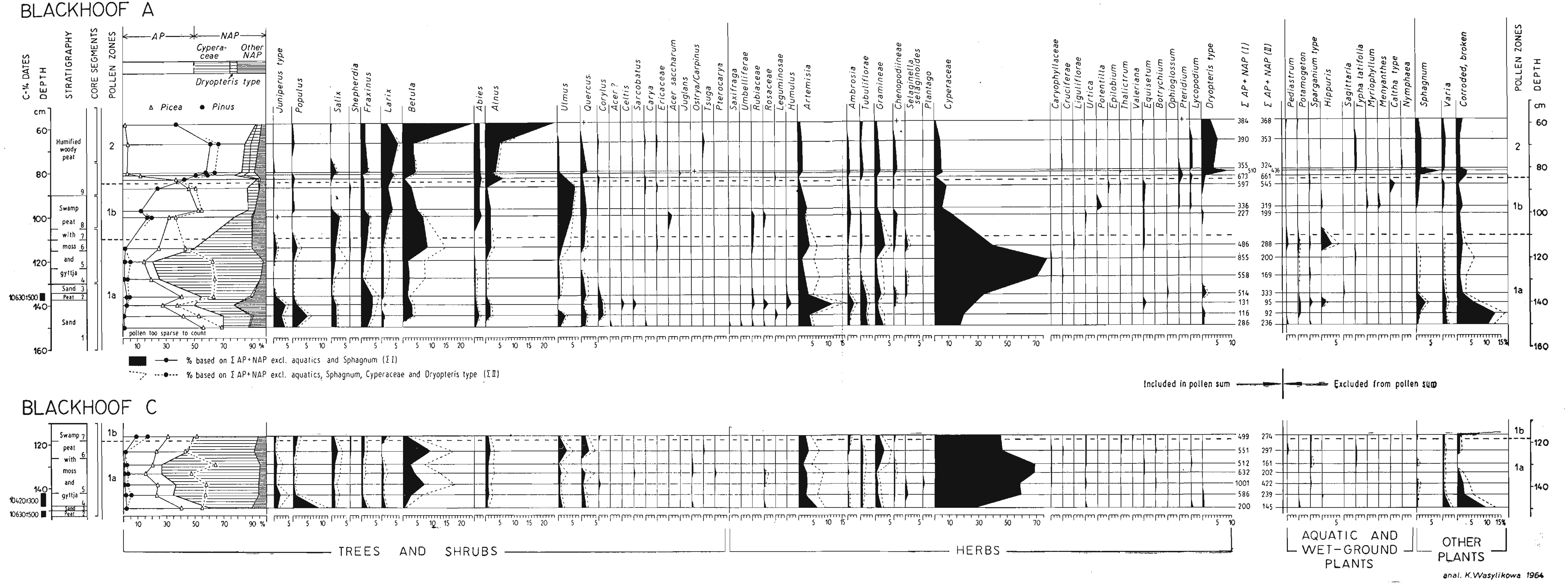

anal. K. Wasylikowa 1964

Fig. 6. Pollen diagram for the Blackhoof site, cores A and C.
Ryc. 6. Diagram pyłkowy ze stanowiska Blackhoof, rdzenie A i C.

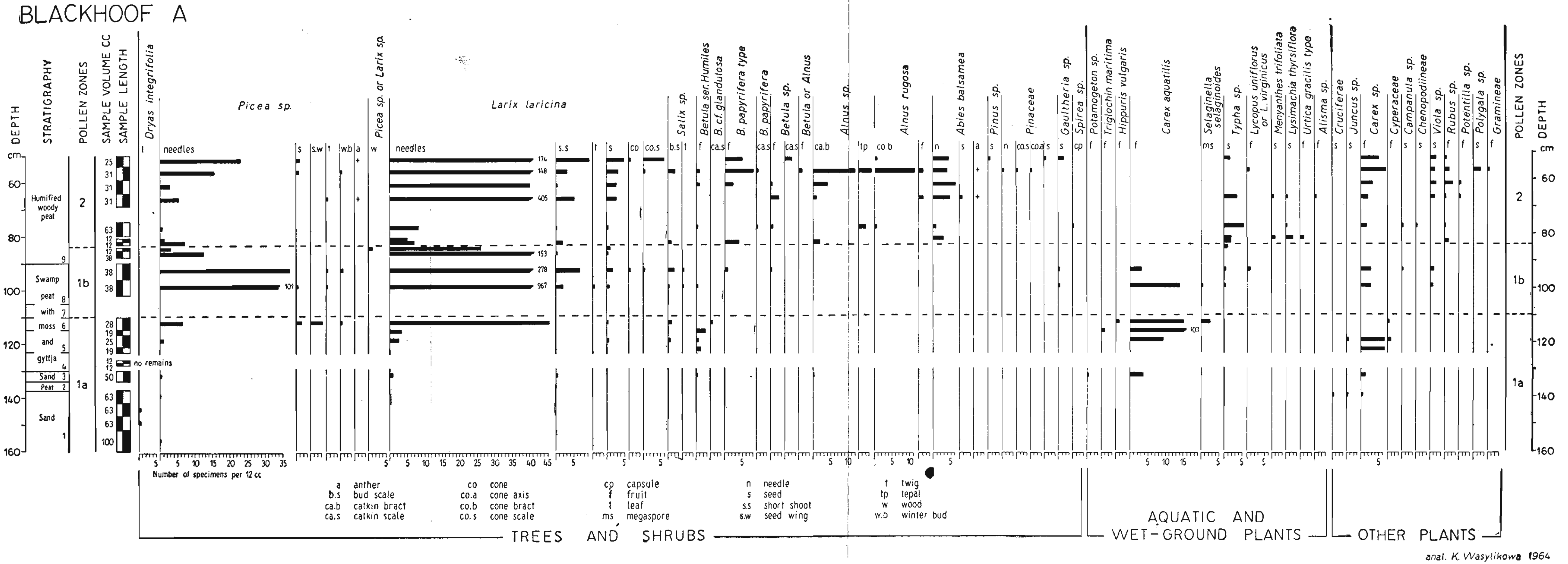

Fig. 7. Plant-macrofossil diagram for the Blackhoof site, core A.
Ryc. 7. Wykres szczątków makroskopowych roślin ze stanowiska Blackhoof, rdzeń A.