

A LATE-GLACIAL POLLEN DIAGRAM FROM MADELIA, SOUTH-CENTRAL MINNESOTA

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ABSTRACT. Late-glacial and early postglacial pollen stratigraphy is described for a gyttja and peat section overlying Mankato drift, in the center of the Des Moines glacial lobe near Madelia, Minnesota. Five pollen zones are distinguished; the oldest may represent pioneer vegetation shortly after the retreat of the ice. The transition from zone I to II is likely to be the beginning of the Two Creeks interstadial. The Two Creeks vegetation shows up in the pollen diagram as a spruce-ash forest. During zone III, the Valders stadial, a shrub forest with birch, alder, spruce, and *Artemisia* seems to have been present. The postglacial starts with a rapid decline of spruce and a strong rise of birch (zone IV) followed by elm and oak (zone V).

The diagram is controlled by two radiocarbon dates: the transition from zone I to II is dated at $12,650 \pm 350$ B.P. (W-824); the top of zone IV at 9300 ± 350 B.P. (W-825).

The locality lies less than 200 miles outside the presumed margin of the Valders ice. It is therefore worth noting that the Valders readvance did not produce tundra or park tundra at the site but merely increased the proportion of shrubs in the forest.

INTRODUCTION AND ACKNOWLEDGMENTS

Many studies have been published concerning the last part of the Wisconsin glaciation in the Great Lakes area. A generally accepted subdivision is based on the succession of moraines and tills and is controlled by many radiocarbon dates. The succession of stadials and interstadials is believed to be as follows:

- Postglacial
- Valders stadial
- Two Creeks interstadial
- Mankato stadial
- Interstadial
- Cary stadial

In Minnesota the most recent studies on this subject are by Wright (1956, in press), Zumberge and Wright (1956), and Wright and Rubin (1956). We know from these field studies many details about the extent of the ice lobes of the different substages and have a good picture of the more or less extensive coverage of the land ice during the whole late Wisconsin.

So far pollen analyses have given little support to these studies, and little or nothing is known about the vegetation history during the late Wisconsin in the ice-free parts of Minnesota. Studies of lake deposits by Potzger (1953) and Artist (1939) include diagrams that usually start at the base with a spruce or spruce-fir zone, supposedly representing the first vegetation after the retreat of the ice sheet. But as their diagrams do not give the amount of the non-arboreal pollen (NAP), we have no idea whether this zone really represents a forest or a parklike landscape. We also do not know whether this first zone is late-glacial or postglacial.

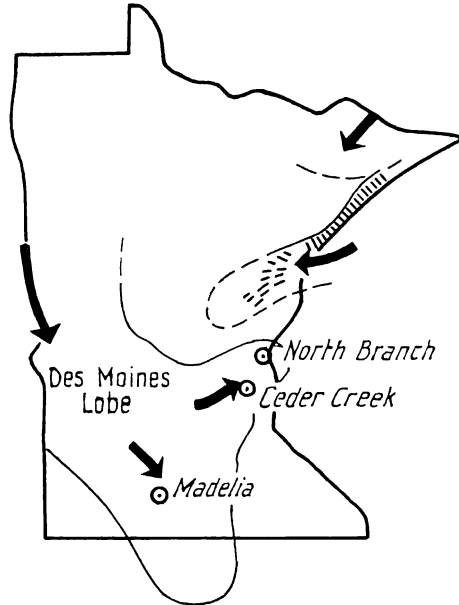


Fig. 1. Map with Mankato moraines in Minnesota (after Wright, 1957).

If we want to know something more about the vegetation during the late-glacial in the Great Lakes area we have to go to Wisconsin and Michigan. In the famous Two Creeks site in Wisconsin, remains of spruce trees are found overlain by Valdres till. In a pollen study in southern Michigan Andersen (1954) suggests that the spruce forest of the Two Creeks interstadial was changed to a park tundra with spruce during the Valdres stadial. So in this part of the Great Lakes area spruce seems to be an important tree in the late-glacial vegetation.

The Madelia site is a gyttja and clay-gyttja deposit found in an excavation 1.5 miles north of the town of Madelia, Minnesota (fig. 1). The excavation is situated in a little depression in the ground moraine one mile north of and inside of Leverett's Marshall moraine. The Marshall moraine, according to Leverett (1932), was deposited during retreat of the Des Moines lobe of the Mankato substage of the Wisconsin. At the time of formation of this moraine, the ice consisted of a narrow tongue 15 to 30 miles wide, with its axis along the Minnesota River valley, and terminating near the present town of Mankato. The Madelia site was therefore not uncovered until after further withdrawal of this ice lobe in the late Mankato.

The excavation was about 160 feet long (NS) and 15 feet deep; the gyttja-clay layer was found at the bottom. At the north side of the excavation the gyttja is covered by sand containing lenses of coarse sand, granules, and layers of clayey sand; this deposit could be interpreted as poorly sorted slope wash. The succession of layers is as follows:

Depth below surface in cm	Sediment description
-0.72	Black sandy clay with lenses of white sand (disturbed?)
72-121	Yellow clayey sand and sandy clay
121-162	Granules and laminated sand and clay with detrital organic fragments
162-180	Medium sand with granules
180-214	Fine sandy silt, gray-green
216-230	Gyttja with some plant fragments and some little pieces of wood
230-247.5	Gyttja containing some clay
247.5-265	Clay-gyttja
265-280	Clay-gyttja; slightly sandy
280-300	Clay, sandy with ostracods and gastropods
300-320	Gravel

Samples for pollen analyses were collected from 180 to 300 cm by M. Fries (University of Uppsala) and H. E. Wright, Jr. (University of Minnesota) in November, 1958 with the assistance of Alex Robertson, Soil Conservation Service. The samples were prepared and studied by the present author during her stay at the pollen laboratory of the Geology Department, University of Minnesota in 1959-1960. The work was supported by grants from the Hill Family Foundation, St. Paul, Minnesota. I thank H. E. Wright, Jr. for information about the glacial deposits in Minnesota; and R. G. West (University of Cambridge) for reading and discussing the manuscript. The manuscript was submitted in September 1960.

The clay and clay-gyttja samples were all treated with potassium hydroxide, hydrofluoric acid, and acetolysis solution, the gyttja samples only with potassium hydroxide and acetolysis solution. All samples were stained with safranin.

POLLEN-ANALYTICAL RESULTS

The results of the pollen analyses are reproduced in the diagram (fig. 2), according to the method proposed by Iversen (1942). The pollen sum that serves as the base for the percentages includes all arboreal pollen (AP) and the sum of wind-pollinated herbs (NAP). The Quercetum-Mixtum curve (QM) is composed of the sum of *Quercus*, *Ulmus*, *Fraxinus*, *Tilia*, *Acer*, *Carya*, and *Juglans*. The diagram is subdivided into five zones:

Zone	Description
V	QM dominant. <i>Ulmus</i> higher than <i>Quercus</i> . <i>Acer</i> , <i>Carya</i> , <i>Juglans</i> , <i>Ostrya-Carpinus</i> , and <i>Tilia</i> show relatively high percentages. <i>Betula</i> , <i>Alnus</i> , and NAP low.
IV	QM curve starts to rise (going upward). <i>Betula</i> has its maximum and <i>Alnus</i> and <i>Picea</i> are declining. NAP low.
III	<i>Alnus</i> , <i>Betula</i> , and <i>Picea</i> high. The NAP has a second but small maximum. QM curve is irregular.
II	<i>Picea</i> dominant. QM low, mostly <i>Fraxinus</i> . NAP very low.
I	NAP very high, mainly consisting of Cyperaceae. <i>Picea</i> and <i>Salix</i> .

Zone I.—The most striking point in zone I is the very high amount of NAP that has its maximum at the bottom (70 to 90 percent) and decreases upwards. The AP consists mainly of *Picea*, some *Quercus*, and a little *Fraxinus*. Two samples show relatively high amounts of *Salix*, so *Salix* must have taken part in the vegetation but it is always under-represented in pollen diagrams because it is insect-pollinated (Iversen, 1942).

The hatched area in the diagram, constituting the total of herbs in the pollen sum, represents in zone I almost entirely Cyperaceae. The Gramineae curve is low, and that for *Artemisia* starts and rises near the top of zone I but it is relatively low. More important and striking is the occurrence in small amounts of *Elaeagnus commutata*, *Shepherdia canadensis*, *Juniperus*, *Thalictrum*, *Saxifraga* sp., and *Saxifraga oppositifolia*. The last-mentioned species is now found mostly in arctic-alpine areas and indicates cold conditions. *Elaeagnus commutata* is a common plant in the Rocky Mountains and, according to Andersen (1954), it also occurs in a few isolated places in Manitoba, Ontario, Quebec, and the Gaspé Peninsula. Andersen describes this species as a typical pioneer on dry unstable soils and compares its occurrence with *Hippophae* in the European Late-Glacial.

The occurrence of the above-mentioned pollen can help us trace the kind of vegetation during the time of zone I. It indicates probably cold climate and open vegetation. The ratio between AP and NAP gives an indication that the vegetation of the base of zone I must have been nearly treeless and in the top of zone I had the character of a park landscape with *Picea* and *Salix*. Martin (1958) compares such pollen spectra as we have in the base and top of zone I with a tundra and a taiga respectively. In my opinion all of zone I could be seen as representing successional development of a pioneer vegetation shortly after the retreat of the ice.

But how shall we explain the small amounts of deciduous tree pollen (*Quercus* and a little *Fraxinus* and *Ulmus*) in zone I? These trees do not seem to fit very well in the above-mentioned vegetation. If these pollen types are not locally derived there are two possibilities to explain their presence: either they have been redeposited from other sediments or they have blown in from a long distance. The variable percentages of these types in zone I might suggest the operation of either of the two factors. In zone II, however, we see that the QM curve is mainly of *Fraxinus* and that *Quercus* is much lower. This high percentage of *Fraxinus* fits very well in our knowledge of the recent boreal forest in Canada. The base maps by Munns (1938) show that of the deciduous trees *Fraxinus* reaches the highest latitude; the northern limit of *Ulmus* is farther south, and that of *Quercus* is still farther south. So the high *Quercus* percentages from zone I do not fit very well with the high *Fraxinus* and low *Quercus* of the overlying zone II; the only deciduous tree to be expected in zone I would be *Fraxinus*. It seems possible that at least the *Quercus* and the *Ulmus* are here either blown in from a long distance or washed in from the surrounding sediments as so-called "secondary pollen". No analyses of the surrounding sediments were made.

The NAP of zone I has a decreasing tendency towards the top. Zone II starts when the NAP suddenly drops down to 10 percent.

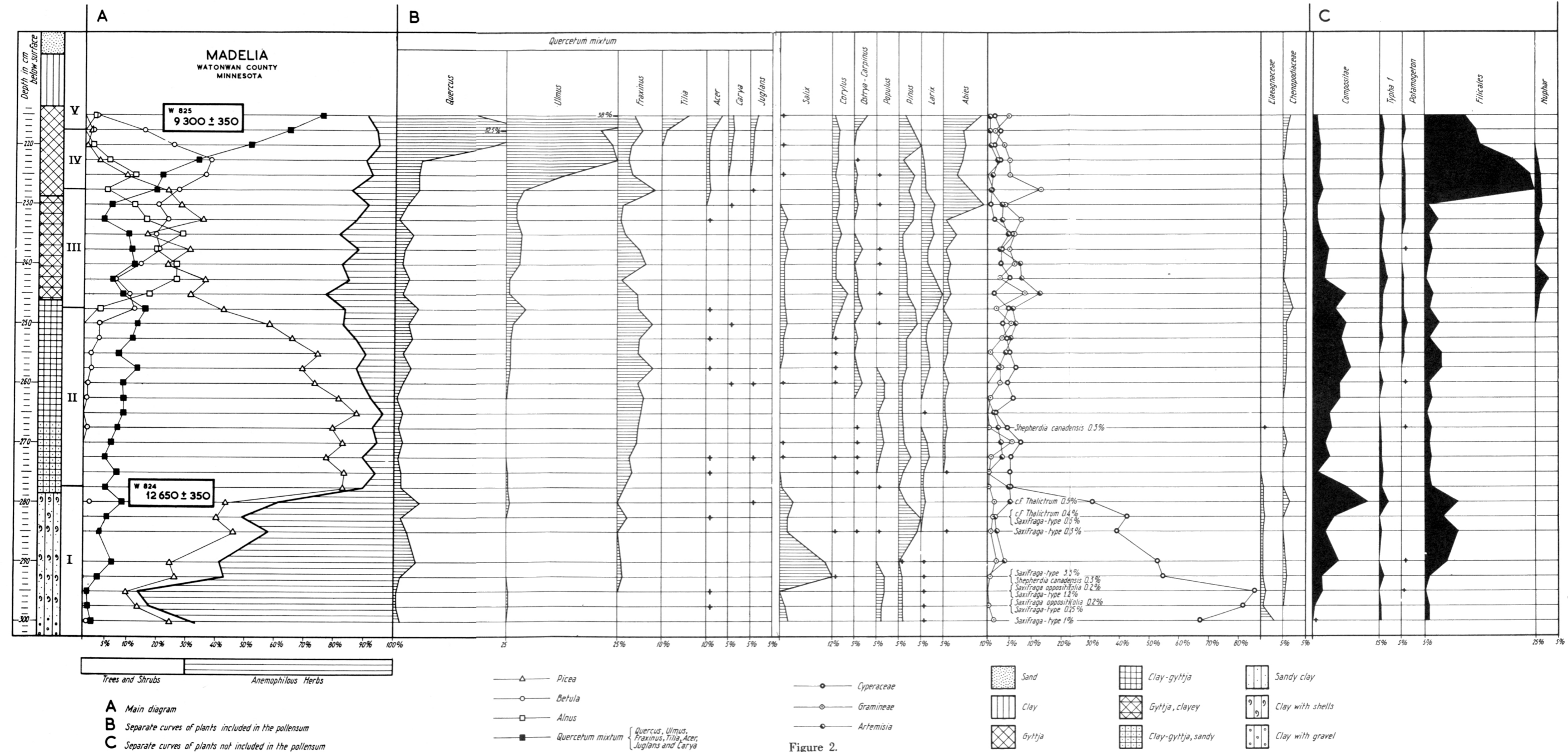


Figure 2.

Zone II.—In zone II *Picea* is dominant, the QM proportion is 6 to 10 percent, and *Betula*, *Pinus*, *Populus*, and *Larix* occur in small amounts. It is clear that after the open vegetation of zone I a *Picea* forest invaded the area. Whether this *Picea* forest consisted of *P. mariana* or *P. glauca*, or both species, is not certain. It may be possible to distinguish the pollen grains of both species by size differences. Two kinds of spruce pollen, a larger and a smaller type, were found, but it is at this moment not possible to determine their relationship to the two species. Near the top of zone II *Picea* declines. NAP rises, and the *Salix* and *Corylus* curves start. Zone III starts at the level where the *Alnus* and *Betula* curves rise.

Zone III.—The most important pollen types of this zone are *Picea*, *Betula*, and *Alnus*. The QM curve is in general lower than in zone II. A subdivision of this zone into three subzones is possible on the basis of the *Betula* and *Alnus* curves. In the lowest subzone *Alnus* and *Picea* are nearly equal in percentages, and *Betula* is less abundant. The middle subzone shows high *Betula*, *Alnus*, and *Picea*. In the top subzone *Alnus* and QM are decreasing and *Betula* and *Picea* are dominant. The vegetation of zone III seems to be less dense than the spruce forest of zone II, for the NAP is slightly higher (mainly *Artemisia*) and the AP consists mostly of small trees or shrubs. This could be an indication of a wetter and colder climate than in zone II.

Special studies of the *Betula* and *Alnus* pollen were not undertaken, so we do not know to what species they belong. Their association with spruce, however, makes it possible that we deal here with the shrub *Betula pumila* and the tall shrub *Alnus rugosa* or allied forms.

Zone IV.—The beginning of zone IV is characterized by a rapid decline of *Picea* and *Alnus* and the rise of the QM curve. *Betula* reaches its maximum in this zone but declines rapidly to lower percentages, indicating the shifting to zone V. The NAP curve decreases after its maximum in zone II, and the continuous curve of *Salix* stops. The high QM curve, the first appearance of *Acer*, *Carya*, and *Juglans* in continuous curves, and the rising *Abies* indicate a warmer and perhaps drier climate than in zone III.

Zone V.—In zone V the QM is dominant, and *Betula*, *Alnus*, *Picea*, *Abies*, and *Pinus* are scarcely present. Of the QM *Ulmus* is dominant and *Quercus* high. The curves of *Tilia*, *Ostrya-Carpinus*, *Acer*, *Juglans*, and *Carya* are typical of this zone, which probably represents warmer conditions than zone IV.

The zones discussed above indicate a vegetation shifting from a tundra(?) to a deciduous forest by way of a park landscape, boreal spruce forest, mixed spruce-shrub forest, and a birch-deciduous tree forest.

INTERPRETATION AND CORRELATION

As was pointed out before, zone I must in our opinion represent a pioneer vegetation shortly after the retreat of the ice. The radiocarbon date of the transition of zones I/II gives the age of $12,650 \pm 350$ B.P. (W-824, Rubin and Alexander, 1960). This date fits fairly well with the radiocarbon dates of the Mankato stadial in the Great Lakes area as summarized by Wright (in press): range of dates 11,540-12,710 B.P., average 12,350 B.P. The Des Moines lobe of the Mankato substage therefore probably retreated from the Madelia site shortly before 12,650 B.P. The North Branch site in the Anoka sandplain

northeast of Minneapolis (W-389, 12,700 and W-354, 12,030 B.P.) had been uncovered a little earlier when the Des Moines lobe was still expanded eastward as the Grantsburg sublobe. Cedar Creek Bog, also on the Anoka sandplain, was open as a kettle lake before 11,830 B.P. (W-466, Rubin and Alexander, 1958).

The spruce forest of zone II probably represents the Two Creeks interstadial between Mankato and Valders in Minnesota. During this interstadial the ice lobes retreated rapidly northward, leaving nearly all of Minnesota ice-free.

According to the radiocarbon date of the transition of zone I/II, the Two Creeks interstadial must have started here rather early. The average of many samples taken at the type of the Two Creeks is 11,200 B.P. This age is generally believed to represent the end of the interstadial, for all the datings are done on the spruce trees that were killed and overridden by the Valders ice advance. So the beginning of the Two Creeks interstadial in the Great Lakes area must be older than 11,200 B.P., and it is possible that our date of $12,650 \pm 350$ (W-824) represents the very beginning of this interstadial. In Europe the beginning of the Allerød oscillation, according to van der Hammen (1957), is ca. 11,900 B.P. and the end ca. 11,000 B.P., so the date of the type locality of the Two Creeks would fit the end of the Allerød.

In New England the late- and postglacial pollen diagrams by Deevey (1951), Leopold (1956), and Davis (1958) are divided into C, B, A, and T zones. The T zone with high NAP is replaced higher in the diagrams by the A zone, the so-called Durham spruce zone that has low NAP and is subdivided into several subzones (A1, A2, A3, etc.) indicating more or less spruce, deciduous trees, and pine. The latest radiocarbon dates (Deevey, Gralensky, and Hoffren, 1959; see also Deevey, 1958) of the upper part of the T zone, T3, shows an age of $12,350 \pm 400$ B.P. (Y-505), and the lower part of the Durham spruce zone, A2, $11,590 \pm 200$ B.P. (Y-503). The lower part of the Durham spruce zone is correlated with the early Two Creeks. All these dates of early Two Creeks seem to be slightly younger than the Madelia date, and it is not certain that the beginning of our zone II can be correlated with the beginning of the Two Creeks elsewhere. The radiocarbon date of the top of the diagram, 9300 ± 350 B.P. (W-825, Rubin and Alexander, 1960), gives us the proof that this part of the section represents the postglacial. This is in good agreement with the pollen diagram, which shows a predominance of deciduous tree pollen.

The radiocarbon dates indicate that the time of the Valders stadial must be represented in the diagram. It is clear, however, that this time does not show up in the diagram by a change from spruce forest to a park landscape with spruce, as Andersen (1954) suggested in southern Michigan. The only effect of the Valders can be seen in zone III, where *Picea* declines, the NAP slightly increases, and shrubs of small trees like *Betula*, *Alnus*, *Salix*, and *Corylus* are important. This kind of vegetation is more open than that of zone II and implies a colder and wetter tendency. The deciduous forest pollen (QM) is lower than in the preceding zone II, indicating a slightly cooler climate than in zone III. With some caution, this zone III can be correlated with the Valders stadial, whose ice advance left traces in north and northeast Min-

nesota (Wright, in press). The connection between the Valders stadial and a vegetation outside that area showing a shrub maximum is in good agreement with the A4 zone (Valders) in the eastern part of the United States. On the other hand it seems to contradict Andersen's interpretation of the southern Michigan diagram, but in the latter case the Valders correlation is not confirmed by radiocarbon dates.

It is striking that the Valders ice advance in the United States did not seem to change the vegetation into a park landscape or a tundra as did the contemporary Fennoscandian advance in Europe, even at rather great distances from the continental ice. The Madelia site is situated less than 200 miles from the oldest moraine interpreted as Valders, so it must have been relatively near this ice sheet. In contrast with the broad, nearly treeless belt that surrounded the land ice in Europe, the treeless belt in the United States must have been relatively small and narrow. Martin (1958) published a map of vegetation zones during the Valders ice advance, indicating in the Great Lakes area a broad taiga and tundra belt surrounding the ice lobes. But we do not find this tundra and taiga in our diagram, and it seems therefore to have been less extensive than indicated in the map.

The beginning of the postglacial period, in our opinion, lies at the base of zone IV, where the QM curve starts to rise and the continuous curves of *Carya*, *Juglans*, and *Acer* are starting. *Betula* is still high, however, so this

TABLE 1

Suggested correlation of late-glacial and early postglacial pollen zones in Minnesota with those in Europe and eastern United States, based in part on radiocarbon dates

Years B.P.		Northwestern Europe		Northeastern United States		South-central Minnesota (Madelia)		Northeastern Minnesota
9,000	V	Boreal				V Elm, oak, ash, maple, hickory, walnut		Spruce, pine forest
	IV	Pre-Boreal birch, pine forest	B	Pine		IV Spruce, birch		Spruce, birch forest
10,000	III	Younger Dryas park tundra birch	A4	Spruce and shrubs; less oak		III Spruce, willow, birch, alder, hazel		Spruce park tundra
	II	Allerød pine forest	A3 A2 A1	Spruce, fir, pine, oak		II Spruce forest with oak, ash, elm		
11,000	Ic	Older Dryas tundra	T3	Younger Herb park tundra				
12,000	Ib	Bølling park tundra birch	T2	Pre-Durham spruce		I Park tundra with spruce and willow		
	Ia	Oldest Dryas tundra birch, willow	T1	Older Herb				

level presumably may represent the end of the Valdres stadial. but the radiocarbon date at a slightly higher level (9300 ± 350) indicates that zone V is not the first. but the second postglacial zone. Zone V is represented by only one spectrum in the top of the main diagram. A few meters away from the main section a calcareous clay-gyttja was found that nicely shows the pollen content of zone V. The deposition of clay at this place also indicates moist conditions. in agreement with the pollen-analytical results.

In table 1 we have tried to make a correlation between our pollen zones and those of the east coast and of Europe. It is clear that this table needs some qualifications. and when more dated diagrams from several places in the northern part of the United States are obtained the correlation may undergo important changes. The column for northeastern Minnesota depends on two unpublished diagrams. one by Fries and one by the present author.

(After completing the paper a radiocarbon date of the beginning of zone III was made: 11.250 ± 400 . W-1058. This dating is in excellent agreement with the pollen-analytical results).

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