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Plant trash in the basal sediments of glacial lakes

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ABSTRACT. Abundant macrofossils of *Picea* and other forest plants, mixed with sand and other glacial material, occur at the base of the fine organic sediment of many lakes in Minnesota and adjacent areas at the margin of the Laurentide ice sheet in central North America. Such accumulations are interpreted as representing forest-floor litter washed into depressions from superglacial forest on stagnant ice. An example of a trash layer in Minnesota is described from Steel Lake, which contains not only macrofossils of *Picea* from the superglacial forest but also much older fragments representing forest overridden by the advancing ice. A modern analogue is on the surge moraines of the Klutlan glacier in the Canadian Rocky Mountains. Trash layers have not been described from similar dead-ice landscapes in Europe, perhaps because tundra plants rather than forest invaded the stagnant ice and left little litter. The closest example is found in Poland, where a basal peat of Allerød age is interpreted as of superglacial origin. The trash layer in the Minnesota sites is abruptly overlain by many meters of typical Holocene fine organic sediment. At the same level the *Picea* pollen zone changes to the *Pinus* zone, marking a prominent climatic change at nearly the same date as the end of the Younger Dryas cool interval, which is registered especially in areas around the North Atlantic Ocean. In Minnesota, however, the *Picea*/*Pinus* transition is time-transgressive from southwest to northeast over about 2000 years, in synchrony with the retreat of the Laurentide ice sheet.

KEY WORDS: stagnant glacial ice, superglacial *Picea* forest, macrofossils, climatic change

INTRODUCTION

Above the glacial sediments that characterize the base of the sediment in many of the 10 000 glacial lakes for which Minnesota is known, in a landscape much like that of northern Poland, is a layer up to 50 cm thick containing macrofossils of *Picea* and other plant detritus, along with sand, pebbles, and other mineral particles. These sediments are generally abruptly overlain by gyttja, which continues to the top of the sedimentary fill of the lake. Such lakes can be found in moraines or outwash plains associated with the retreat of the Laurentide ice sheet. Plant trash was first described at Kirchner Marsh in southeastern Minnesota (Fig. 1), where macrofossil analysis yielded the following taxa in addition to abundant *Picea: Larix laricina*, *Juniperus communis*, *Cornus stolonifera*, *C. canadensis*, *Rubus pubescens* type, *Fragaria virginiana*, *Viola* sp., arid, many wet-ground and aquatic plants (Watts & Winter 1966). Diatom analysis of the sediments recorded the presence of *Hantzschia amphioxus*, *Pinnularia borealis*, and other diatoms from dry mosses and other terrestrial substrates (Florin 1970). As a result of these findings an hypothesis was developed to explain the unusual occurrence of terrestrial sediment under fine-grained homogeneous deep-water lacustrine organic sediment (Florin & Wright 1969).

MANNER OF FORMATION

Terminal moraines and retreatal outwash plains commonly contain masses of glacial ice with rock debris eroded during ice advance (Fig. 2). In fact moraines characteristically

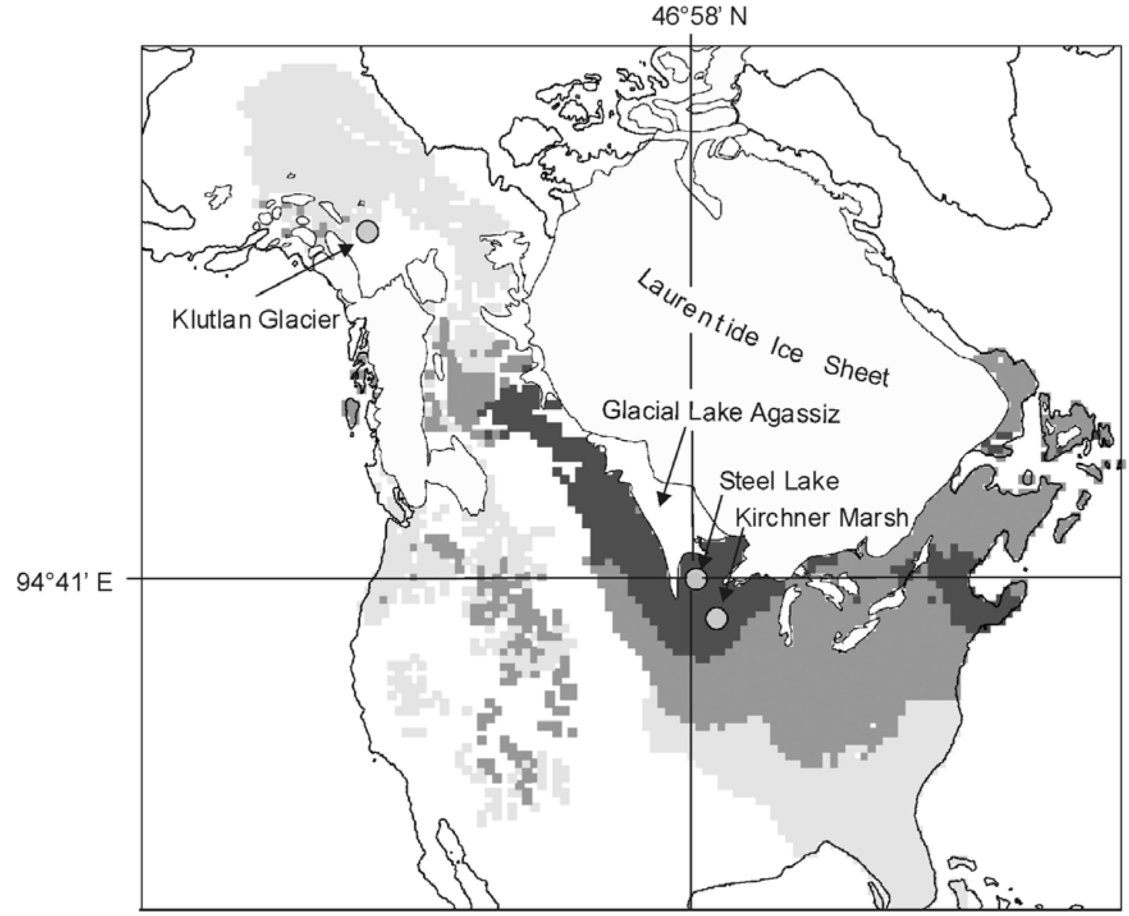

Fig. 1. Map of North America (provided by J.W. Williams) showing the inferred extent of *Picea* 12 000 cal yr BP with relation to the margin of the Laurentide ice sheet. Dark gray > 20% *Picea* pollen, medium gray 5–20%, light gray < 5%. Localities mentioned in the text are added

consist of sectors of clean glacial ice with layers or sectors containing variable amounts of rock debris. As the ice down-wastes the rock debris becomes concentrated on the surface, inhibiting further melting. As the relatively clean glacier from the moraine melts back, the moraine is left as a dead-ice feature**,** which continues to down-waste slowly, with the clean-ice sectors wasting more rapidly. The result is an irregular topography, with pools of water in some of the depressions. Meanwhile the protective mantle of rock debris on the high sectors becomes covered with vegetation. In Minnesota the *Picea* forest-floor litter is washed into the pool along with mineral matter derived from the melting ice. By the time the ice melts completely the pool is enlarged to a lake, in which fine-grained organic sediment is then deposited.

In the case of Kirchner Marsh, the trash layer contains 50% *Picea* pollen, contributed by the superglacial forest as well as by the forest that covered much of the area to the south (Fig. 1). Radiocarbon dates on *Picea* wood in the trash layer at Kirchner Marsh are 11 760 and 11 840 ^{14}C yr BP, calibrated to 13 679 and 13 938 cal yr BP. Dates on the overlying gyttja are 13 279 and 12 050 ^{14}C yr BP, calibrated to 15 933 and 14 102 cal yr BP. But these gyttja dates are probably in error because of inflow of water from glacial sediments containing fragments of Paleozoic limestone, from which the ^{14}C has been lost. Kirchner Marsh is located on the St. Croix moraine, which marks the maximum extent of the Superior lobe of the Laurentide ice sheet during the Late Wisconsin glaciation. If the wood dates are accepted as dating the down-wastage of stagnant ice in the St. Croix moraine, persistence of stagnant ice for at least 10 000 years can be postulated, for the Late Wisconsin maximum of other ice lobes are dated as at least 24 000 cal yr BP. The relations imply that the mean annual temperature during this time was a few degrees below freezing, inhibiting the down-wastage of buried ice.

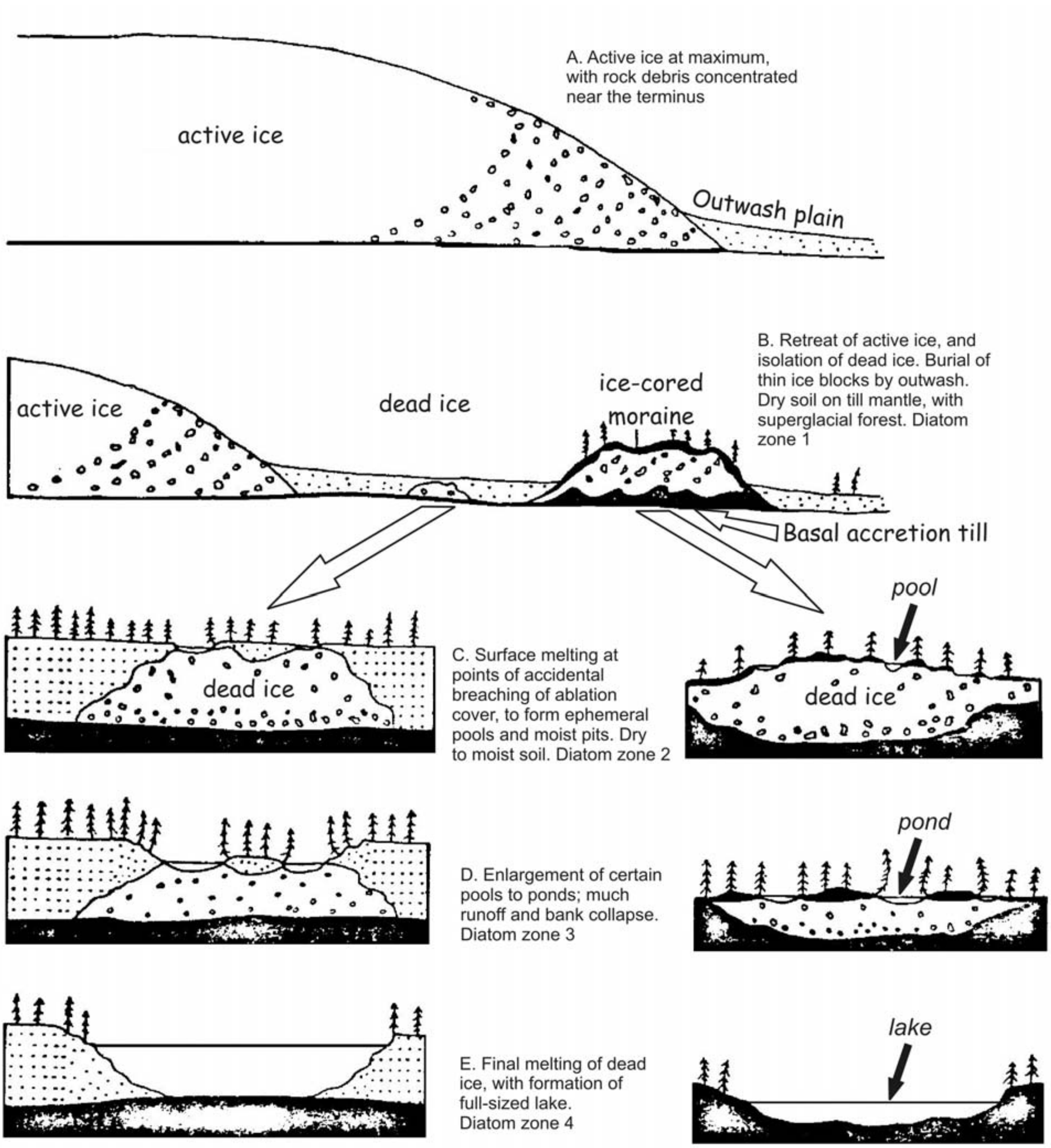

Fig. 2. Sequential diagrams illustrating the formation of trash layers at the base of fine organic lake sediments. From Florin and Wright (1969)

THE STEEL LAKE EXAMPLE

A recently investigated example of a trash layer is at Steel Lake in central Minnesota, also located in the St. Croix moraine (Wright et al. 2004). Here four *Picea* macrofossil dates in the trash layer were 12 373, 11 434, 11 371, and 11 257 cal yr BP (Fig. 3). These were interpreted as indicating debris washed into the superglacial pool from the adjacent forest floor. In addition three other much older macrofossil dates (> 41 190, > 35 290, and 18 519 cal yr BP) were probably derived from detritus of a forest overridden by the advancing glacier and melted out of the ice along with sand and stones. The 75% *Picea* pollen in the trash layer is well preserved and was presumably blown from the local contemporaneous superglacial *Picea* forest or from the forest that prevailed south of the ice sheet. The trash layer is immediately overlain by varved organic sediment with dominant *Pinus* pollen and dates of 11 207, 11 242, 10 927, 10 760, and 10 687 cal yr BP. The stagnant ice was completely

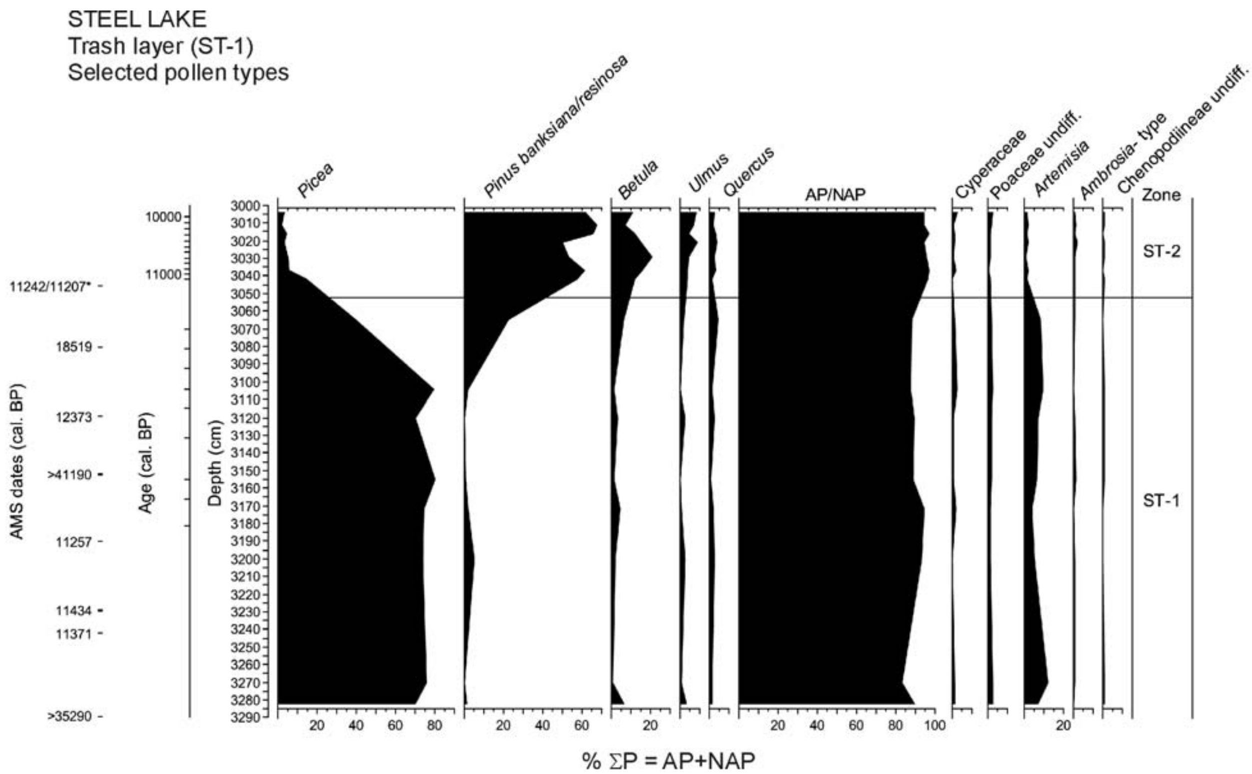

Fig. 3. Major pollen profiles for the *Picea* and *Pinus* pollen zones at Steel Lake, Minnesota, with calibrated AMS radiocarbon dates on terrestrial macrofossils. Extracted from Wright et al. (2004)

melted out by this time, just when the change in climate brought about the major shift in forest type, the deepening of the lake, and the formation of organic varves. Because Steel Lake, like Kirchner Marsh, is located on the St. Croix moraine, stagnant ice lasted there some 12 000 years.

A MODERN ANALOGUE

The debris-covered stagnant ice of the Klutlan glacier in the Canadian Rocky Mountains of the Yukon Territory in Canada offers a modern analogue for the formation of trash layers (Wright 1980). The glacier has had a long history of periodic surging, resulting in a series of progressively younger ice masses beyond the climatic limit of an equilibrium valley glacier (Fig. 4). The younger surge moraines are covered with pioneer herbs and shrubs, but the oldest has a cover of a multi-generation forest of *Picea* estimated as 600–1200 years old (Birks 1980). Occasional breaks in the forest cover expose the stagnant ice, which then melts to form small water bodies, into which are deposited detritus from the melting ice as well as from the forest floor.

THE EUROPEAN SCENE

Whereas trash layers are commonly found beneath fine organic sediment at many sites on the moraines and outwash plains of the southern edge of the Laurentide ice sheet, where *Picea* forest was so close that its colonization of debris-covered dead ice could be expected (Fig. 1), no such features have been reported from comparable locations at the margin of the Scandinavian ice sheet in Europe. Here tundra bordered the ice sheet, and if dead ice was colonized by tundra plants the amount of litter would have been very small, compared to that of a full grown forest. It is true that basal sediments commonly contain reworked pollen grains of types that have been found in underlying glacial deposits, and such an occurrence has been described in Minnesota by Cushing (1964). But this is not trash in the sense described here, in which macrofossils are involved. In the unusual case of Steel Lake some of the macrofossils are reworked, having been transported by the ice, but most are derived from the superglacial forest floor that post-dates active ice movement.

The closest example of macrofossils at the base of European lake sediments is represented by the occurrence of basal peat in

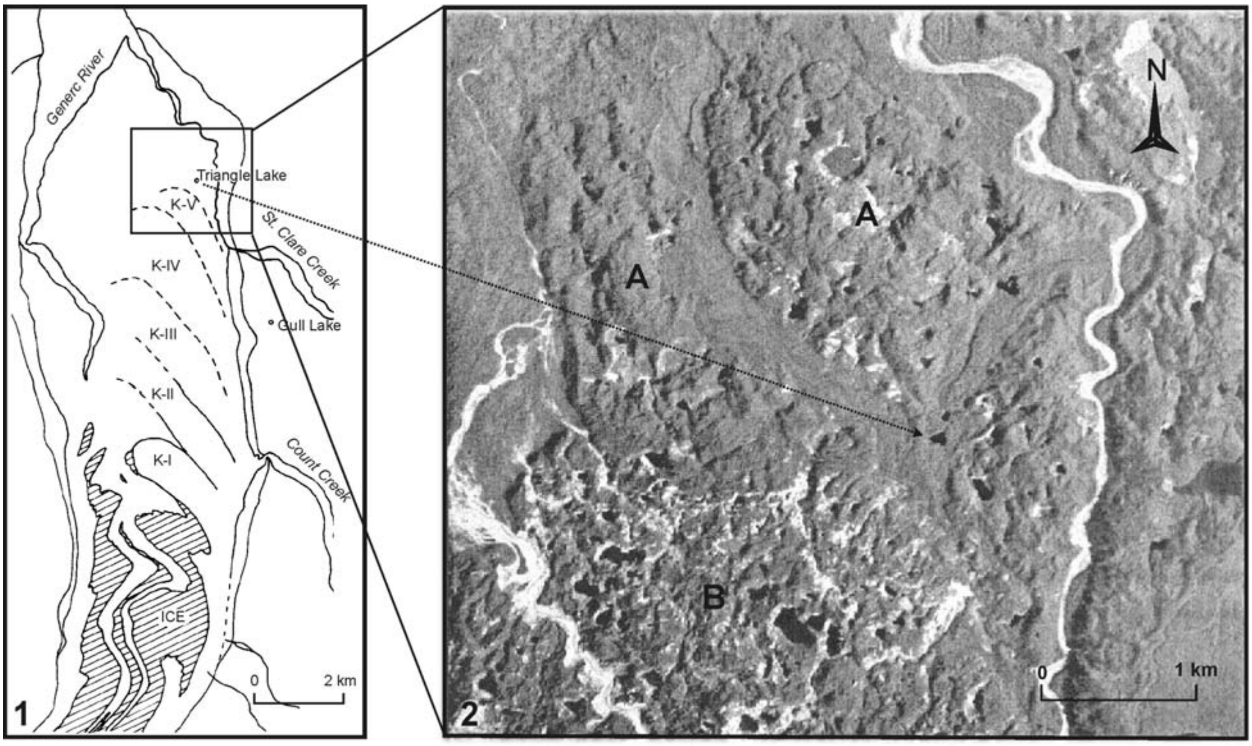

Fig. 4. **1** – General view of the Klutlan Glacier, Yukon Territory, Canada, **2** – air photograph showing as area **A** the oldest surge deposits (Harris Creek moraine) of the Klutlan Glacier, with multi-generation spruce forest on dead ice. Local melting of the dead ice produces small lakes into which litter from the superglacial forest can wash. A pollen diagram for Triangle Lake shows the succession from *Shepherdia* shrubs to *Picea* forest (Birks 1980). Area **B** is a younger (K-IV) surge lobe with a sparser forest cover and more active wastage of the dead-ice

northern Poland (Więckowski 1969), who offers the following interpretation: "Consistent with the opinion of H. Gross, commonly endorsed today, these peats have developed on top of fluvioglacial deposits which at one time were covering buried ice masses. Afterwards when the climate improved, the ice gradually melted, and the peats and deposits which covered the ice dropped to the bottom of lakes developing in the depressions, and were subsequently overlain by lacustrine deposits (Gross 1937)". Pollen analysis of the basal peat at several points in Lake Mikołajki by Ralska-Jasiewiczowa (1966) indicated an Allerød assemblage, an interpretation confirmed by radiocarbon dating.

THE LATE GLACIAL *PICEA* FOREST IN MINNESOTA

In contrast to the Polish example mentioned above, in Minnesota at Steel Lake the Allerød warm interval is not recorded in the *Picea* pollen zone, so the Younger Dryas is not identified either. The end of the Younger Dryas dated as 11 500 cal yr BP in the Greenland ice cores by ice-layer counts and in Europe by radiocarbon dating. For example, in the Swiss Alps the oxygen-isotope curves from lacustrine carbonates have been matched even in detail for the entire late-glacial with those from Greenland (Schwander et al. 2000). The end of the Younger Dryas is considered as the chronostratigraphic horizon marking the Pleistocene-Holocene boundary. At Steel Lake in Minnesota the sharp decline of *Picea* at end of the trash layer has nearly the same date (11 200 cal yr BP) as the end of the Younger Dryas in Greenland and Europe, but such a close correlation is not possible at other sites in the area. In fact a transect of well-dated pollen sites along a line about 500 km long ranges from more than 12 000 cal yr BP in the southwest to 9800 cal yr BP in northeasternmost Minnesota, suggesting that the *Picea* decline is time-transgressive over more than 2000 years, probably reflecting the contemporaneous retreat of the Laurentide ice sheet into southern Canada (Wright et al. 2004). The *Picea* forest had persisted in the periglacial area because of cool summers engendered by the bordering ice sheet, for mean July temperature exceeding 10°C inhibit

Picea regeneration. Higher summer insolation related to Milankovitch Earth/Sun orbital changes was an additional factor in reducing the *Picea* extent. The late-glacial/post-glacial boundary in this region is thus not a synchronous chronologic boundary as it is in Europe, where many paleoclimatic proxies reflect events in the North Atlantic Ocean. In the Minnesota area the time-transgressive retreat of the massive Laurentide ice sheet slowed the response of the vegetation to the rapid change that affected Europe. The demise of the *Picea* forest is such a conspicuous event that it is adopted as the late-glacial/postglacial boundary even though it is time-transgressive.

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