

## Early and Middle Wisconsinan Environments of Eastern Beringia: Stratigraphic and Paleoecological Implications of the Old Crow Tephra

### Les conditions environnementales au cours du Wisconsinien inférieur et moyen en Béringie orientale : les conséquences de la présence du tephra de Old Crow des points de vue stratigraphique et paléoécologique

### Die Umweltbedingungen in Ost-Beringia im frühen und mittleren Wisconsin: stratigraphische und paläoökologische Bedeutung des Tephra Vorkommens von Old Crow

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Résumé de l'article

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# EARLY AND MIDDLE WISCONSINAN ENVIRONMENTS OF EASTERN BERINGIA: STRATIGRAPHIC AND PALEOECOLOGICAL IMPLICATIONS OF THE OLD CROW TEPHRA

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**ABSTRACT** The widespread Beringian Old Crow tephra occurs in Imuruk Lake (Alaska) core V, above the Blake paleomagnetic event and below Radiocarbon dates, which provide an extrapolated tephra age between 87 000 — 105 000 BP. Exposure KY-11 (Alaska), where the tephra occurs in a dated lacustrine sequence, provides corroboration. Fossil pollen records show that O.C.T. was deposited across northern Beringia on birch-shrub tundra vegetation during an interval of colder climate. A series of climatic oscillations followed tephra deposition. A prolonged period of cold-arid climate (= marine isotope Stage 4) preceded an interval of warmer than present climate starting ca. 60 000 BP (beginning Stage 3). During this interval, designated the Koy-Yukon thermal event, an exposed Bering land bridge promoted an interglacial type climate that led to significant biotic changes and permafrost degradation. O.C.T. occurs on drift of the Mirror Creek Glaciation which is equivalent to other presumed Early Wisconsinan glaciations in Alaska and Yukon. These glaciations could not have occurred later than marine Stage 5. Stage 4 was fully as cold as Stage 2 (Late Wisconsinan), yet seems not to have been a time of extensive glaciation. The Middle Wisconsinan, 30 000 to more than 80 000 BP, was a nonglacial interval with several climate fluctuations, one of which, the Koy-Yukon thermal event, was warmer than at present.

**RÉSUMÉ** Les conditions environnementales au cours du Wisconsinien inférieur et moyen en Béringie orientale: les conséquences de la présence du tephra de Old Crow des points de vue stratigraphique et paléocologique. Le tephra de Old Crow, se manifeste, entre autres, au trou de forage V à Imuruk Lake, en Alaska. Puisqu'il se situe après l'inversion magnétique de Blake, mais au-delà de la portée des datations au radiocarbone, la date approximative de son dépôt doit se situer entre 87 000 et 105 000 BP. La coupe KY-11 (Alaska), où l'on trouve le tephra dans une séquence lacustre, appuie cette hypothèse. Les registres de pollen fossile démontrent que le tephra de Old Crow s'est déposé dans le nord de la Béringie dans un milieu de toundra arbustive à bouleau, au cours d'une période froide. Plusieurs oscillations climatiques se sont succédé par la suite. Une longue période de climat aride froid (phase isotopique océanique 4) a précédé un épisode au climat plus chaud que maintenant et qui a commencé vers 60 000 BP environ. Durant cet épisode (que l'on nomme ici Koy-Yukon), l'émergence du pont terrestre de Bering a contribué à l'avènement d'un climat de type interglaciaire, qui a provoqué des changements de type biotique importants et la dégradation du pergélisol. Le tephra de Old Crow surmonte des dépôts de la glaciation de Mirror Creek, qui correspond aux glaciations qui se sont produites en Alaska et au Yukon au cours du Wisconsinien inférieur. Ces glaciations n'ont pu avoir lieu après la phase isotopique 5. Pendant la phase 4, le climat était aussi froid que durant la phase 2 (Wisconsinien supérieur), mais il semble que cette période n'ait connu qu'un englacement limité. Il n'y a pas eu de déglaciation pendant le Wisconsinien moyen (de 30 000 à plus de 80 000 BP), mais les fluctuations climatiques ont été nombreuses, dont l'épisode de Koy-Yukon.

**ZUSAMMENFASSUNG** Die Umweltbedingungen in Ost-Beringia im frühen und mittleren Wisconsin: stratigraphische und paläoökologische Bedeutung des Tephra Vorkommens von Old Crow. Das weitverbreitete Tephra von Old Crow, Beringia, findet man auch am Bohrloch V von Imuruk Lake (Alaska). Da es nach der Inversion von Blake und vor Radiokarbondatierungen liegt, muß die annähernde Zeit der Tephra-Ablagerung zwischen 87 000 - 105 000 v.u.Z. liegen. Der Schnitt KY-11 (Alaska), wo das Tephra in einer datierten Seesediment-Folge vorkommt, bestätigt diese Datierung. Belege von fossilem Pollen zeigen, daß Old Crow Tephra in Nord-Beringia in einem Milieu von Birken-Busch-Tundra während einer Periode kälteren Klimas abgelagert wurde. Auf die Tephra-Ablagerung folgte eine Serie von Klima-Schwankungen. Eine längere Periode von kalt-trockenem Klima (= marine isotopische Phase 4) ging einer Phase, die wärmer als das heutige Klima war und die etwa 60 000 v.u.Z. begann (Beginn der Phase 3) voraus. Während dieser Zeitphase, die das thermische Koy-Yukon genannt wird, bewirkte eine ausgesetzte Bering Land-Brücke ein Klima des interglazialen Typus, welches zu bedeutenden biotischen Veränderungen und Permafrost Abtragungen führte. Old Crow Tephra findet sich über den Ablagerungen der Mirror Creek Vereisung, welche anderen mutmaßlich frühen Wisconsin Vereisungen in Alaska und Yukon entspricht. Diese Vereisungen können nicht später als in der marinen Phase 5 stattgefunden haben. Die Phase 4 war so kalt wie die Phase 2 (spätes Wisconsin), scheint jedoch keine Zeit extensiver Vereisung gewesen zu sein. Das mittlere Wisconsin, von 30 000 bis mehr als 80 000 v.u.Z., war eine nicht glaziale Zeitspanne mit gewissen Klima-Schwankungen, deren eine, das thermische Koy-Yukon, wärmer als die Jetztzeit war.

## INTRODUCTION

Distal tephra occur at a number of Quaternary exposures in Northwestern North America. Their study can provide many new insights on Quaternary stratigraphy, and when associated with fossils and organic deposits, they also make possible the reconstruction of coeval biotic patterns over large areas (SCHWEGER and MATTHEWS, 1984). This paper deals with the paleoenvironmental implications of the Old Crow tephra of Yukon and Alaska (eastern Beringia) (NAESER *et al.*, 1982; WESTGATE, 1982; WESTGATE *et al.*, 1985). The unusually wide distribution of this tephra (Fig. 1) and its occurrence at a variety of sites with different depositional environments makes it a valuable datum for east Beringia, during a geological instant of Early Wisconsinan time, which is well beyond the range of radiocarbon dating (WESTGATE, 1982; WESTGATE *et al.*, 1985).

The published Wisconsinan age stratigraphy and paleoenvironmental record for many of these sites are reviewed and in some cases reinterpreted. New fossil pollen data from Koyukuk River locality KY-11 and from Porcupine River locality Twelvemile Bluff are presented. Together, these data allow refinement of our understanding of the course of environmental change during the Wisconsinan (MATTHEWS and SCHWEGER, 1985). One outcome is the recognition of a climatic event, herein informally termed the "Koy-Yukon thermal

event", which is recorded in sediments scattered across east Beringia and represents a period of remarkably strong climatic amelioration at the start of isotope Stage 3.

## FIELD AND LABORATORY METHODS

Field work at locality KY-11, Koyukuk River, Alaska, was undertaken by one of the authors (C.E.S.) and T. D. Hamilton (U.S. Geological Survey, Anchorage). Sediment samples were collected at 10 cm intervals through the thickest portion of the lacustrine sequence. Fossil pollen extraction was accomplished using a  $ZnBr_2$  heavy liquid technique (SCHWEGER, 1976). Two hundred grain counts were made on each sample and these data were used to construct an abbreviated relative percent pollen diagram.

Porcupine River, Yukon, locality Twelvemile Bluff has been studied by both authors. Pollen samples from this site along with modern pollen surface samples were processed following a standard laboratory procedure (FAEGRI and IVERSEN, 1974). Unpublished pollen counts by S. Lichti-Federovich (Geological Survey of Canada, Ottawa) were made on samples collected by Owen Hughes (Geological Survey of Canada, Calgary). Their methods have been described elsewhere (LICHTI-FEDEROVICH, 1973, 1974). Macrofossils (seeds and insects) were recovered from selected Twelvemile Bluff sediment samples through wet sieving and flotation (MATTHEWS,

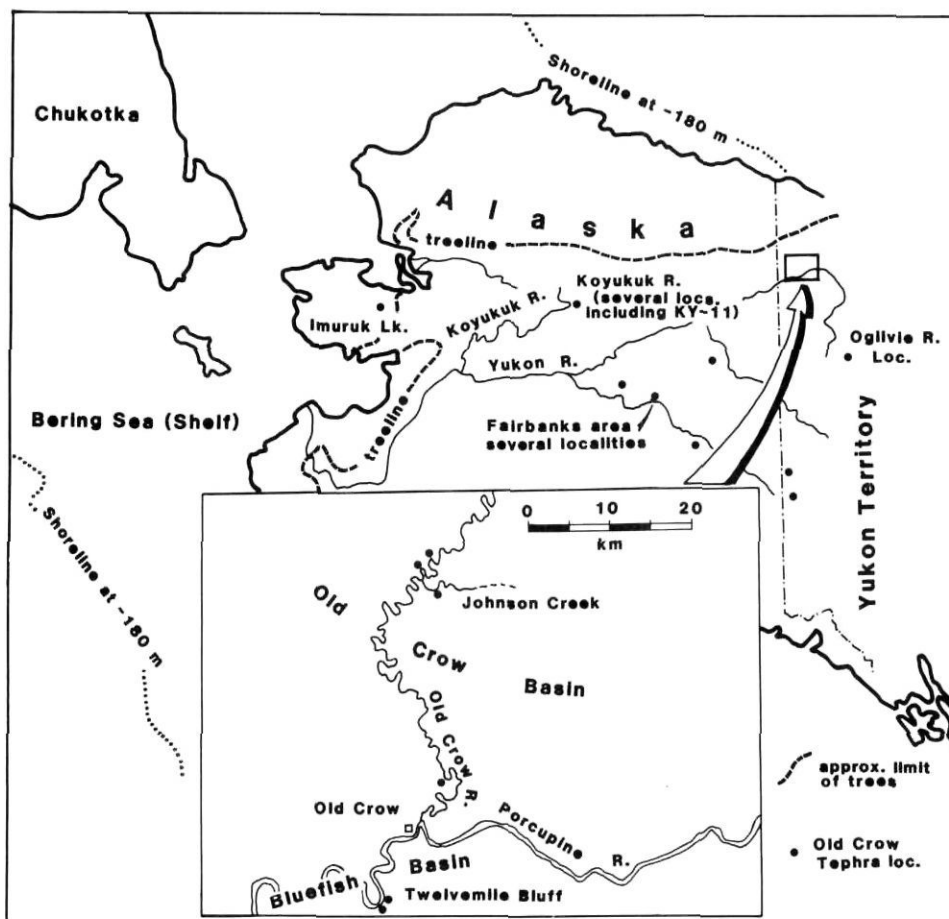


FIGURE 1. Distribution of Old Crow tephra in east Beringia (WESTGATE *et al.*, 1985). Dashed line indicates approximate current position of treeline.

Répartition du tephra de Old Crow en Beringie orientale (WESTGATE *et al.*, 1985). Les tirets montrent la limite approximative des arbres.

1975). All macrofossil identifications were made by one of the authors (J.V.M.).

### OLD CROW TEPHRA LOCALITIES IN ALASKA-YUKON

Old Crow tephra was first collected by O. L. Hughes (Geological Survey of Canada, Calgary) in 1968 during a study of the Twelvemile Bluff exposure (equivalent to Hughes' locality HH228), 19 km down the Porcupine River from Old Crow, northern Yukon. The paleoecological data associated with the Old Crow tephra at this and four other sites are examined in the following section.

#### IMURUK LAKE (ALASKA)

COLINVAUX's benchmark study (1964) dealt with pollen from Imuruk Lake core I. Subsequent analyses of this core and other Imuruk Lake cores have refined the radiocarbon chronology (COLBAUGH, 1968) and resulted in discovery in core V (located approximately 3 km NW of core I) of Old Crow tephra (SHACKLETON, 1982; WESTGATE, 1982) (Fig. 2). The tephra was deposited near the end of a long interval (pollen Zone G) characterized by relatively high percentage values for *Betula*, Cyperaceae and Gramineae and (in the upper part) *Artemisia* (Fig. 2). A paleomagnetic excursion correlated with the Blake Event occurs within zone G<sub>2</sub> (SCHACKLETON, 1982; WESTGATE *et al.*, 1985).

Much lower values of *Betula* and somewhat higher frequencies of Cyperaceae and Gramineae characterize overlying Zone H. In Zone i, *Picea*, *Alnus* and *Betula* rise to maximum values, only to decline again higher in the sequence. Cyperaceae and Gramineae pollen frequencies dominate pollen Zone J at the top of this attenuated core. Core IV, collected 1 m from core V, completes the record with zones K and L, both characterized by high values of *Betula* and *Picea*, respectively (COLBAUGH, 1968). Surface pollen spectra from the area (*cf.* NELSON, 1979 for a compilation) contain significant quantities of alder (up to 20%) and spruce, and high percentages of birch. Alders now grow 40 km to the north, the nearest spruce outliers are 25 km to the east (Fig. 1), and shrub birch is part of the local tundra vegetation (SHACKLETON, 1982).

Pollen core V subzones G<sub>2</sub>, G<sub>4</sub>, and H<sub>2</sub> feature slightly higher values of *Betula*, *Alnus*, and *Picea* relative to adjacent subzones. SHACKLETON (1982) concludes that Zone G "suggests temperatures similar to the present" while Subzone H<sub>2</sub> "seems to be a short period of climatic warming". *Alnus* is only a minor component throughout Zone G, but its absence in Zone G<sub>3</sub> (Fig. 2) may indicate somewhat colder and drier conditions than at present.

High values for *Picea*, *Alnus*, and *Betula* characterize Subzone i<sub>1</sub>. The *Picea* frequencies of up to 44% are higher than in any other Imuruk zone including Holocene Zone L of cores I and IV. These values are also markedly higher than spruce pollen percentages in modern surface samples from the lake (COLINVAUX, 1964) and nearby coastal sites (MATTHEWS, 1974a; NELSON, 1979). *Sphagnum* maintains high values through Subzone i<sub>1</sub> in all of the Imuruk cores. According to

SHACKLETON (1982), "Zone i<sub>1</sub> suggests a period of time when the climate was at least as warm or possibly warmer than today." This zone was previously interpreted as representing the Sangamon Interglacial (COLINVAUX, 1964; COLBAUGH, 1968), a conclusion now invalidated by data from core V (see below).

#### KOYUKUK REGION (ALASKA)

The Koyukuk region is located in northcentral Alaska south of the Brooks Range (Fig. 1). The climate is continental. Valleys and lower slopes are forested with spruce, tree birch, alder, balsam poplar, and quaking aspen. Regional treeline occurs at elevations of 600-800 m, approximately 400 m or more above the valleys where exposures containing the Old Crow tephra are found (HAMILTON, 1982; WESTGATE *et al.*, 1983).

The Pleistocene stratigraphy of the region has recently been documented (HAMILTON, 1982). Several of the exposures contain the Old Crow tephra. At localities KY-10 and KY-12 (WESTGATE *et al.*, 1983; Fig. 7) the discontinuous tephra layer was deposited along with loess on the former floodplain of the Koyukuk River. Wood from peat overlying the tephra at both localities has been dated at 59 000 ± 3200/–5400 (QL-1284) and 52 800 ± 1300 BP (QL-1283), respectively. Koyukuk locality 11 (66°32.5'N 152°05'W; herein designated KY-11), a 55 m high bluff on the west side of the Koyukuk River, features the tephra near the base of a thick sequence of lacustrine silt overlain by a peat containing *Picea* wood dated >56 000 BP (QL-1282). WESTGATE *et al.* (1983) conclude that the Old Crow tephra was deposited during the Iktalik Glaciation (HAMILTON, 1982) and was followed at approximately 50-60 000 BP by development of a forest bed representing interstadial conditions.

At KY-11 fifteen metres of organic silt and peat overlie 29 m of glacial drift composed of sand, gravel, and till (WESTGATE *et al.*, 1983; Fig. 7). This sequence represents the evolution of a small lake basin in which organic silt was first deposited, and followed, as the basin filled and became a fen or bog, by formation of a woody peat. The peat is 6-7 m above a well developed horizon of Old Crow tephra. Toward the upstream end of the exposure the underlying gravels rise and define one margin of the former lake and the tephra pinches out in near-shore sandy silts and gravels. The lacustrine sequence is thickest at a station (Table I) 75 m downstream from the pond margin.

The 0-80 cm interval is barren, but pollen is abundant and well preserved in every sample above 80 cm. The arboreal (AP) component is dominated by *Picea* which initially rises to 14% then drops off to less than 5%, until the 300 cm level, immediately above the Old Crow tephra, where *Picea* rises to 10%. After falling again to less than 5%, *Picea* reaches a third maximum of nearly 18% between 440 cm and 480 cm. Above 520 cm *Picea* is rare until the spruce rich woody peat at the top of the section (uppermost sample, Fig. 3) where pollen values attain a maximum of 22%. *Alnus* frequencies are low throughout. However, at 100 cm they reach 3% and at the top of the section they peak at 33%. *Betula* percentages range from 8-12% over 80-100 cm and display a second

# IMURUK LAKE CORE V

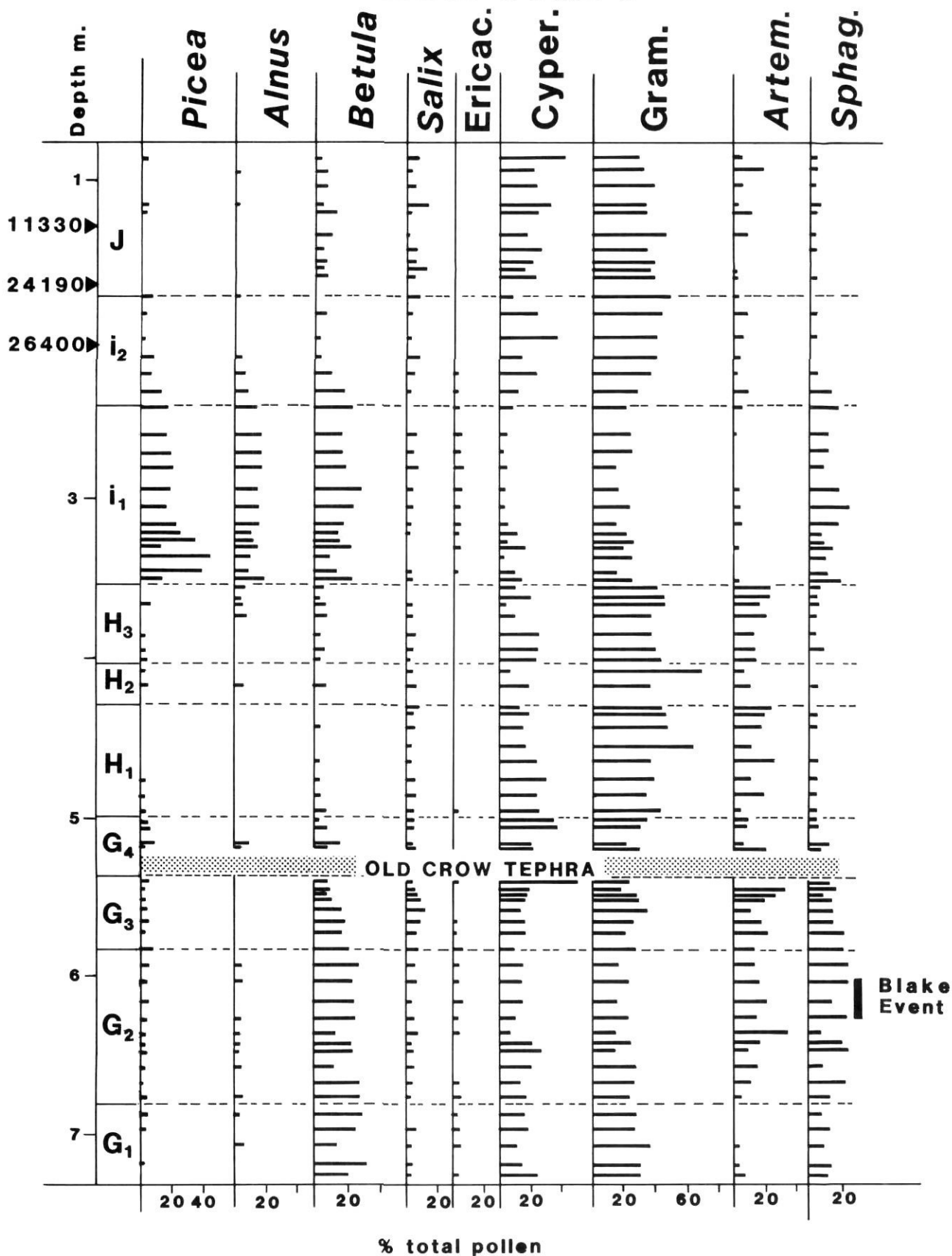


FIGURE 2. Imuruk Lake core V pollen diagram, modified from SHACKELTON (1982). Note that the diagram includes only the main pollen types but percentages represent percent of total pollen (excluding spores such as *Sphagnum*). Values less than 2% are not plotted. Eric.: Ericaceae; Cyper.: Cyperaceae; Gram.: Gramineae; Artem.: Artemisia; Sphag.: *Sphagnum*.

Diagramme pollinique du trou de forage V de Imuruk Lake (modifié de SHACKELTON, 1982). Le diagramme ne comprend que les principaux types de pollen, mais les pourcentages comprennent l'ensemble du pollen (sauf les spores comme ceux de *Sphagnum*). Les taux inférieurs à 2% ne sont pas inclus. Eric.: Ericaceae; Cyper.: Cyperaceae; Gram.: Gramineae; Artem.: Artemisia; Sphag.:

TABLE I  
Sediment description of the Koyukuk Location KY-11  
lacustrine sequence

|  |  |
|--|--|
| <p>1460-1810 cm: Silts, disturbed and slumped slope material to top of section.</p> <p>1130-1400 cm: Silt, gray brown (5Y5/1), mottled red brown (10YR4/4). Non-bedded, compact. Organic content very fine grained, 2 cm thick peat bed at 1250 cm. Above 1290 cm it becomes very organic but then changes (1290-1460cm) to a gray silt, mottled, red-brown.</p> <p>840-1130 cm: Peat and peaty silt with beds of gray (5Y4/1) silt. Largely bryophytic peat up to 930 cm, mostly sedge peat above this, some woody stems, some willow leaf fragments. Peat exhibits a platy parting. Upper metre becomes very woody, <i>Picea</i> cones present. Upper contact is sharp.</p> <p>300-840 cm: Silt, dark gray (5Y4/1) to grayish dark brown (2.5Y3/2), interbedded with yellowish brown (10YR5/8) silt.</p> <p>285-300 cm: Volcanic tephra (10YR8/1). Lower and upper 5 cm evenly bedded, approximately 45 laminae 2-3 mm thick. Middle 5 cm massive.</p> | <p>245-285 cm: Silty fine sand, gray (5Y5/1) to olive gray (5Y5/2). Lower contact gradational. Bedding mostly indistinct, but well bedded over upper 10 cm. Non-organic, between 255-267 cm abundant organic carbonate fragments, small gastropods and <i>Chara</i> stem fragments. Sharp contact with overlying unit.</p> <p>105-245 cm: Silty fine sand, gray brown (2.5Y5/2), interbedded with gray (5Y5.5/) silty fine sand. Beds average 2 cm thick, over lower 10 cm they are deformed and involutions occur at 138 cm and 168 cm. Elsewhere bedding is horizontal. Fine grained organic matter found throughout. Allochthonous organic matter including twigs. Forms distinct bed at 208 cm.</p> <p>80-105 cm: Silt, light olive brown (2.5Y5/2), massive, looks like single depositional event.</p> <p>0-80 cm: Silt and very fine sand, light olive brown (2.5Y5/4), interbedded over lower 300 cm with beds 1-2 cm thick of gray silt. Bedding disturbed and broken by cracks. Upper 50 cm olive gray (5Y5/2), with highly involuted and distorted bedding. Detrital wood present.</p> |
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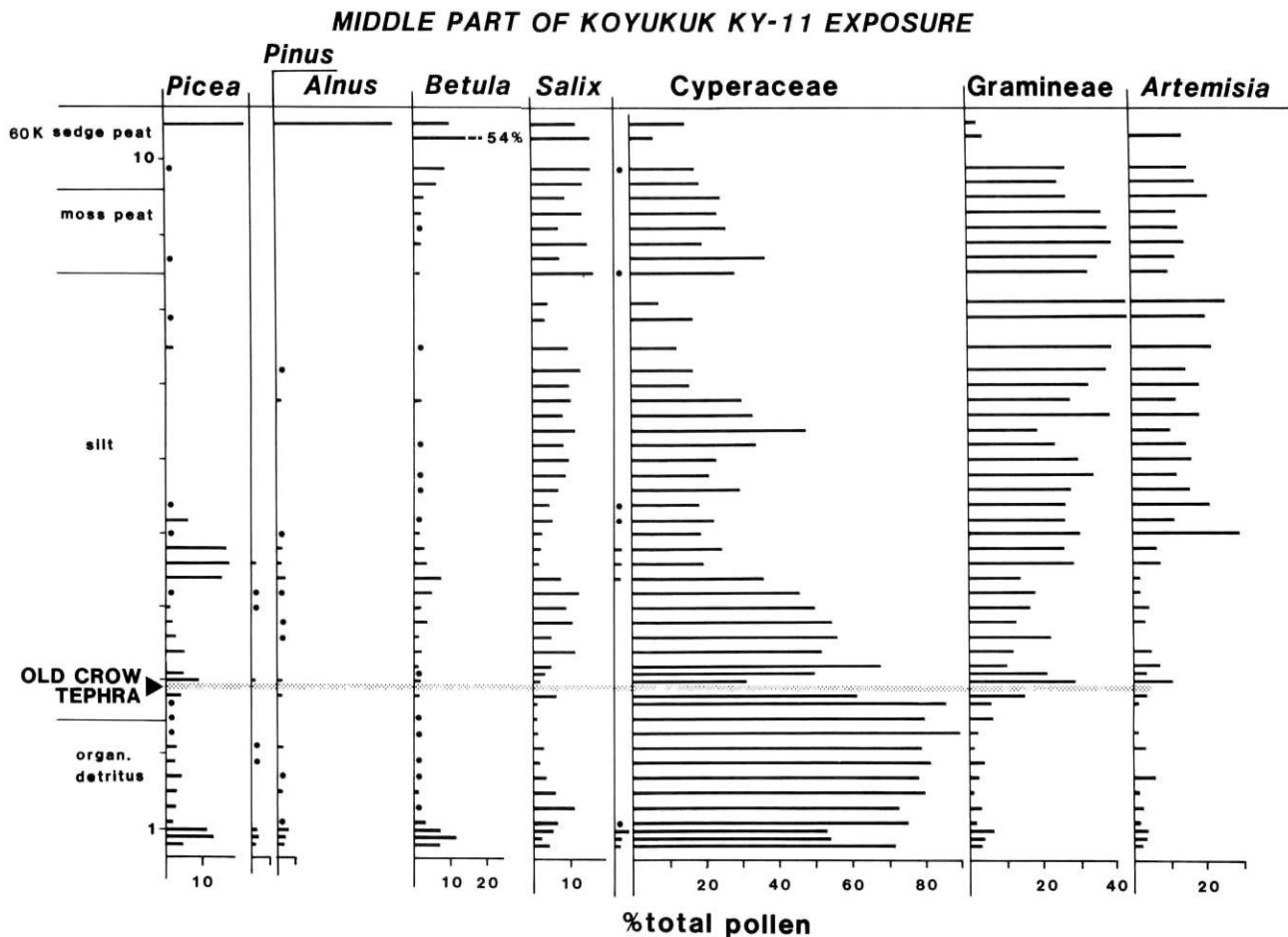


FIGURE 3. Partial pollen diagram from the Koyukuk K-11 exposure. Pollen spectra are from the middle part of the section, the stratigraphy of which is described in Table I. A complete pollen diagram for the KY-11 will be published at a later date. Note that the diagram includes only the main pollen types but percentages represent percent of total pollen.

Diagramme pollinique partiel de la coupe K-11 de Koyukuk. Le spectre pollinique provient de la partie centrale de la coupe stratigraphique décrite au tableau I. Le diagramme complet sera publié ultérieurement. Le diagramme ne comprend que les principaux types de pollen, mais les pourcentages comprennent l'ensemble du pollen.

broad rise to a maximum of 8% between 380 cm and 460 cm. Above 900 cm *Betula* values rise steadily, reaching 54% at 1030 cm but falling to 10% in the overlying woody peat. *Salix* percentages vary, with maxima of 16% at 850 cm and 1030 cm. Most of the KY-11 pollen record is dominated by non-arboreal (NAP) pollen, Cyperaceae (sedge) in particular. Between 80 cm and 270 cm sedge is very abundant, ranging from 53% to a maximum of 90%. However, values drop off to less than 50% over the remainder of the section. Gramineae frequencies rise to 30% above the tephra and remain relatively high, peaking at 46% between 790 cm and 810 cm.

Above the Old Crow tephra (285-300 cm) sandy shallow water sediments change to deeper water silts (Table I). Above the tephra the very high Cyperaceae percentages decline and those of algal colonies (*Pediastrum* and *Botryococcus*) rise (not shown in Fig. 3). Together these changes indicate a shallow lake or fen deepening near the time of Old Crow tephra deposition. In terms of regional vegetation, the combination of relatively high frequencies of *Picea* and *Betula* and a rise of *Alnus* above background suggest that boreal woodland (RITCHIE and LICHTI-FEDEROVICH, 1967; RITCHIE, 1976) characterized the site during times represented by the 75-100 cm and 440-480 cm intervals. The slight increase in *Picea* frequencies immediately above the level of the Old Crow tephra may also signify approaching treeline. Maximum values of *Picea*, *Alnus*, and *Betula* above 1030 cm clearly indicate a well developed boreal forest. This sample comes from near the base of a woody peat bed exposed over most of the exposure. *Picea glauca* cones and spruce logs are found throughout this unit providing further evidence of forest development. There is also an abundance of beaver chewed wood. In other parts of the section, especially over the intervals 350-440 cm and 520-1000 cm, high values of Gramineae and *Artemisia* combined with the near absence of *Picea*, *Betula*, and *Alnus* call for open tundra vegetation.

In summary, the 10.5 m pollen record from the middle of the KY-11 section reveals three probable times when open boreal forest existed at the site or spruce treeline stood nearby, and one phase when boreal forest was well developed locally. During the last one, *Alnus* percentages are higher than at any other time in the record and higher than in most modern pollen surface samples from boreal woodland regions (NELSON, 1979). This may signify warmer climatic conditions than at present. Separating the high spruce phases are episodes characterized by tundra-like spectra, including what must have been an extended period of severely cold and arid climate during the time represented by the 550-1000 cm interval.

The forest peat at the top of the section has been correlated with the woody peats from locations KY-10 and KY-12 (WESTGATE *et al.*, 1983); therefore, the radiocarbon dates from those two sections suggest that the top of the KY-11 profile, as shown in Figure 3, is between 53 000 and 59 000 years in age. For the remainder of this report we use a rounded estimate of 60 000 BP for the peat, although admittedly, the finite radiocarbon dates from KY-10 and KY-12 may only represent minimum estimates (T. D. Hamilton, pers. comm., 1983), and the peat itself may represent 10 000 or more years of time.

#### FAIRBANKS REGION (ALASKA)

The Fairbanks region of central Alaska contains a number of localities that expose one or more Late Pleistocene Tephra in stratigraphic context (Fig. 1) (PÉWÉ, 1975a, b).

Gold Hill Loess (Fig. 4) is the main unit in the basal part of many exposures. Although the sediments of this unit are perennially frozen, they are relatively inorganic compared to the silts of the overlying Eva Formation and Goldstream Formation (Fig. 4). Gold Hill loess is separated from these units by an angular unconformity (Fig. 4), representing a long period of thawing and slumping that occurred prior to 56 900 years ago (Hv-1328) (PÉWÉ, 1975a). The Eva Formation, a wood-rich silt that occurs immediately above the unconformity at the Eva Creek locality (PÉWÉ, 1975a; Fig. 6), may represent part of this warm interval. PÉWÉ (1975b) refers this interval of apparent warmer-than-present climate to the last (Sangamon) interglaciation, but we conclude that it represents an abnormally warm Wisconsinan interstadial (see below).

At most of the silt exposures in the Fairbanks area the Eva Formation is missing and Gold Hill Loess is capped by the Goldstream Formation, a fetid highly organic, perennially frozen silt unit with inactive (incompletely thawed) ice-wedges and abundant well preserved remains of vertebrates and plants (Fig. 4). PÉWÉ (1975b) has suggested that the Goldstream Formation is of Wisconsinan age. It probably includes several climatic oscillations (MATTHEWS, 1974b; SELLMANN, 1967); however, it appears never to have undergone a period of deep thawing like Gold Hill Loess. Thus, regional climate during Goldstream time was never much warmer than at present, and for much of that interval it was undoubtedly much colder, since treeline was often considerably lower than at present (MATTHEWS, 1968, 1970).

Old Crow tephra occurs within the Gold Hill Loess unit, hence stratigraphically below a radiocarbon date of >56 900 BP (Fig. 4). At the nearby Halfway House exposure, Old Crow tephra is underlain by sediments containing a paleomagnetic excursion thought to represent the Blake Event (WESTGATE *et al.*, 1985).

Scattered fossil insect and pollen evidence from the Gold Hill Loess shows that at least the upper part accumulated in a mesic tundra environment (MATTHEWS, 1968, 1970), but to date there is no paleoecological evidence from Fairbanks sediments that are directly associated with the tephra.

#### BLUEFISH BASIN (NORTHERN YUKON)

Old Crow tephra is known from several exposures in the Old Crow region of northern Yukon (Fig. 1). In the Bluefish Basin, one of several lowland areas drained by the Porcupine River and its tributaries, it occurs at the Twelvemile Bluff section (locality HH228), a 4 km long and 45 m high exposure on the Porcupine River downstream from the village of Old Crow. Twelvemile Bluff is the exposure discussed by HUGHES (1972) in his first iteration of the Pleistocene history of the region, and was also one of the sites (Porcupine 1) studied for pollen by LICHTI-FEDEROVICH (1974). The most recent examination of the site by the authors (1983) has helped to

clarify the lateral extent of the tephra and the stratigraphy of the unit in which it occurs.

The complex stratigraphy of Twelvemile Bluff may be divided into six major units. Unit 4, which consists of alluvial silt, sand, and gravel in addition to fine-grained lacustrine sediments, is both underlain and overlain by lacustrine clays, Units 3 and 5 respectively (Fig. 5b). Old Crow tephra occurs inter-

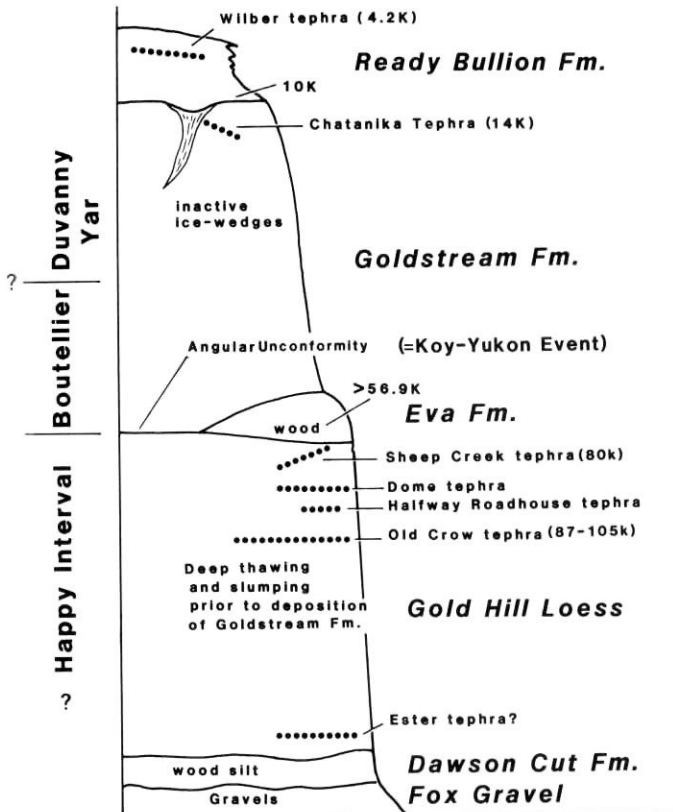


FIGURE 4. Generalized stratigraphy of frozen silt sections in the Fairbanks area (modified from PEWÉ, 1975a). Sheep Creek tephra has not been found at same exposures as Old Crow tephra, but recent Uranium-series dates (HAMILTON and BISCHOFF, 1984) suggest that it is approximately 80,000 years in age, supporting its placement above Old Crow tephra in the diagram. Another unnamed tephra is known to occur below the Old Crow tephra and above Ester tephra (WESTGATE *et al.*, 1982). Regional intervals on left margin are those established by HOPKINS (1982), but the interpretation shown there of the way in which they correlate with the Fairbanks stratigraphy differs slightly from that of Hopkins. The Koy-Yukon thermal event is defined in the text of this paper.

*Stratigraphie généralisée de coupes de limon gelé dans la région de Fairbanks (modifié de PEWÉ, 1975a). Le tephra de Sheep Creek n'a pas été trouvé dans les mêmes coupes que celui de Old Crow, mais des datations à l'uranium récentes (HAMILTON et BISCHOFF, 1984) semblent indiquer que le tephra de Sheep Creek date de 80 000 ans, ce qui justifie sa position au-dessus du tephra de Old Crow sur le diagramme. On sait aussi qu'un autre tephra s'est déposé entre le tephra de Old Crow et celui d'Ester (WESTGATE *et al.*, 1982). Les intervalles qui apparaissent à gauche ont été établis par HOPKINS (1982), mais l'interprétation donnée ici quant à leur corrélation avec la stratigraphie de Fairbanks est quelque peu différente de celle de Hopkins. L'épisode de Koy-Yukon est expliqué dans le texte.*

mittently in the upstream and middle parts of the exposure within Unit 4b. The tephra is usually 4-6 cm in thickness but locally forms pods up to 20 cm thick. At some stations it is undulating, possibly due to post-depositional cryoturbation; whereas, elsewhere it is finely laminated and horizontally bedded.

The sediments from part of the Twelvemile Bluff section have been analyzed for their paleomagnetic signature (PEARCE *et al.*, 1982). Additional paleomagnetic samples were collected in 1983 and preliminary study reveals a short (40 cm) interval of reversed polarity starting about 1.7 m below the tephra that is believed to be the Blake Event (WESTGATE *et al.*, 1985).

A pollen study has been carried out at Twelvemile Bluff (LICHTI-FEDEROVICH, 1974), but at the time the samples were collected, the details of the stratigraphy of Unit 4 (Fig. 5b) were obscure. All but the upper three samples in Figure 5a come from the downstream end of the exposure (Fig. 5b). It is known that a channel cuts into unit 4b in the middle part of the section, accounting for the absence of the tephra there, but it is not yet clear whether this channel also exists at the site where pollen samples were taken. In any case, the tephra has not been observed at the downstream part of the section, making uncertain any attempt to relate the pollen sequence to the tephra. What can be said with some certainty is that the upper part of Lichti-Federovich's pollen Zone C (Fig. 5a) probably postdates the tephra as does all of Pollen Zone D (Fig. 5a). In addition it is clear that the pronounced peak of spruce pollen in Zone D predates 37 000 (GSC-2783) (Fig. 5b).

Unpublished pollen spectra (Lichti-Federovich, pers. comm., 1982) directly associated with Old Crow tephra come from the upstream part of the section (Table II). They show that the tephra was deposited in a shrub-birch tundra environment. *Picea* pollen frequencies decline from 11%, 39 cm below the tephra, to 4%, 3 cm below the tephra where *Betula* reaches a value of 42%. Above the tephra Cyperaceae dominates (45-50%) the pollen assemblages while *Picea* and *Betula* change only slightly.

Analyses of macrofossils by J.V.M. from immediately above and below the tephra show them to be dominated by seeds of aquatic plants yet they contain mostly fossils of terrestrial (rather than aquatic) insects. This discrepancy remains to be explained, but it is possible that the aquatic fossils are allochthonous, e.g., floated in during the early spring when shallow water covered the site, and that the insects and plants, such as willows (*Salix* wood occurs in the tephra: R. J. Mott, unpublished GSC wood identification report 84-18), represent a time later in the summer when the site had drained. Similar seasonal water level changes occur today in the Bluefish Basin.

Although Lichti-Federovich's pollen spectra above and below the tephra show significant percentages of *Betula*, birch macrofossils have not as yet been observed in samples directly associated with the tephra. This discrepancy probably reflects the fact that although birch shrubs (*Betula glandulosa*) are common in several widespread habitat types in the area today (RITCHIE and CWYNAR, 1976; RITCHIE, 1984) their distri-



bution can often be patchy. The site from which the pollen samples come is 2 km from the spot where macrofossil samples were collected. The macrofossil assemblage from one sample contains a single spruce needle. This may be a rebedded "old" spruce fossil; however, spruce pollen percentages in the samples directly associated with the tephra are high enough

to warrant the conclusion that a few spruce trees grew in the region at the time of the ash fall.

Two major horizons of ice-wedge pseudomorphs occur within Unit 4 (Fig. 5b). Both probably represent periods of regional thawing. The upper horizon is associated with a peat

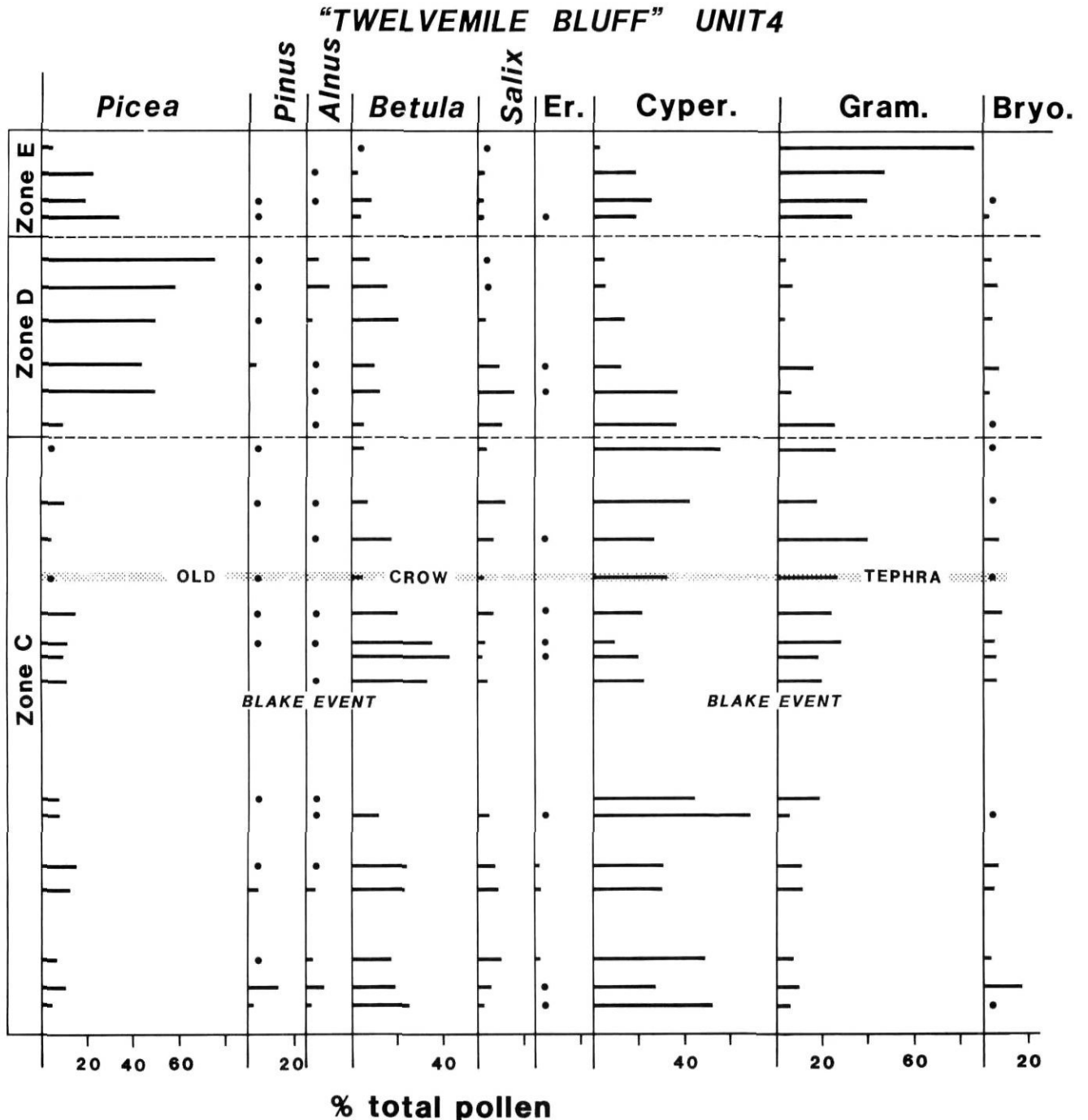


FIGURE 5a. Recast of pollen data from Unit 4 of the Twelvemile Bluff exposure (from LICHTI-FEDEROVICH, 1974 and unpublished data supplied from Lichti-Federovich). Zones are those used by Lichti-Federovich. Er.: Ericaceae; Cyper.: Cyperaceae; Gram.: Gramineae; Bryo.: Bryophytes; Black circle: less than 2%.

Refonte des données polliniques de l'unité n°4 de la coupe de la falaise de Twelvemile (de LICHTI-FEDEROVICH, 1974, et des données inédites du même auteur). La division zonale est celle de Lichti-Federovich. Er.: Ericaceae; Cyper.: Cyperaceae; Gram.: Gramineae; Bryo.: Bryophytes; cercle noir: moins de 2%.

dated at >37 000 BP (GSC-2783) which contains pollen and macrofossils indicative of forested conditions similar to the present (Table II). Old Crow tephra is intruded by the lower set of ice-wedge pseudomorphs. An exposure which illustrates this relationship is shown in Figure 5 of WESTGATE *et al.* (1983). The peat shown in that illustration is dated at >53 000 BP (GSC-2676) and located a few tens of centimetres below the tephra. It has yielded pollen (Table II: "Ice-wedge peat") and a large assemblage of insect and plant macrofossils. Shrub birch macrofossils are abundant even though *Betula* accounts for only 6% of the pollen. Taken together the pollen and macrofossils from the peat call for a shrub-tundra environment.

Zone D of Lichti-Federovich's sequence is notable for its extremely high percentages of *Picea* (up to a maximum of 76%) and as much as 11% *Alnus*. LICHTI-FEDEROVICH (1973, 1974), ruling out redeposition of spruce pollen, classified Zone D spectra as representing "Pollen Assemblage Type II", which is interpreted as a nonanalog "Forest-tundra type" vegetation. However, since spruce values within this zone are significantly higher than in modern surface samples (Table II), we believe Zone D represents boreal forest. The peak of spruce values probably coincides with the base of Unit 4c and may represent the same phase of climatic amelioration that caused thaw of the ice-wedges in Unit 4b.

In Zone E (Fig. 5a) *Picea* drops to less than 5% near the top of Unit 4 and the spectrum immediately beneath Unit 5 has a herb-tundra aspect. The climatic deterioration registered by the pollen samples from this zone reflects in a general way the climatic decline that ultimately culminated with deposition of glaciolacustrine clay of Unit 5.

In summary, present information on the fossils and stratigraphy at Twelvemile Bluff indicate that Old Crow tephra was deposited in a shrub-tundra environment. Since the region is partly forested today, a colder climate than at present is implied. At least two periods of regional permafrost degradation, took place in the interval between deposition of the Old Crow tephra and 37 000 BP. During one of these (probably coinciding with development of the lower pseudomorph horizon), boreal forest existed in a region that is only open forest today. Macrofossils of plants and insects that now have northern limits well south of Bluefish Basin (J. V. Matthews, Jr., unpublished GSC Fossil Arthropod Report 84 — 36 and Plant Macrofossil Report 84 — 36) imply summer climate that was warmer than at present during initial deposition of Unit 4c.

OLD CROW BASIN (NORTHERN YUKON)

Old Crow Basin, is located immediately north of Bluefish Basin. Here Old Crow tephra occurs at several exposures along the Old Crow River (Fig. 1) where it is typically found

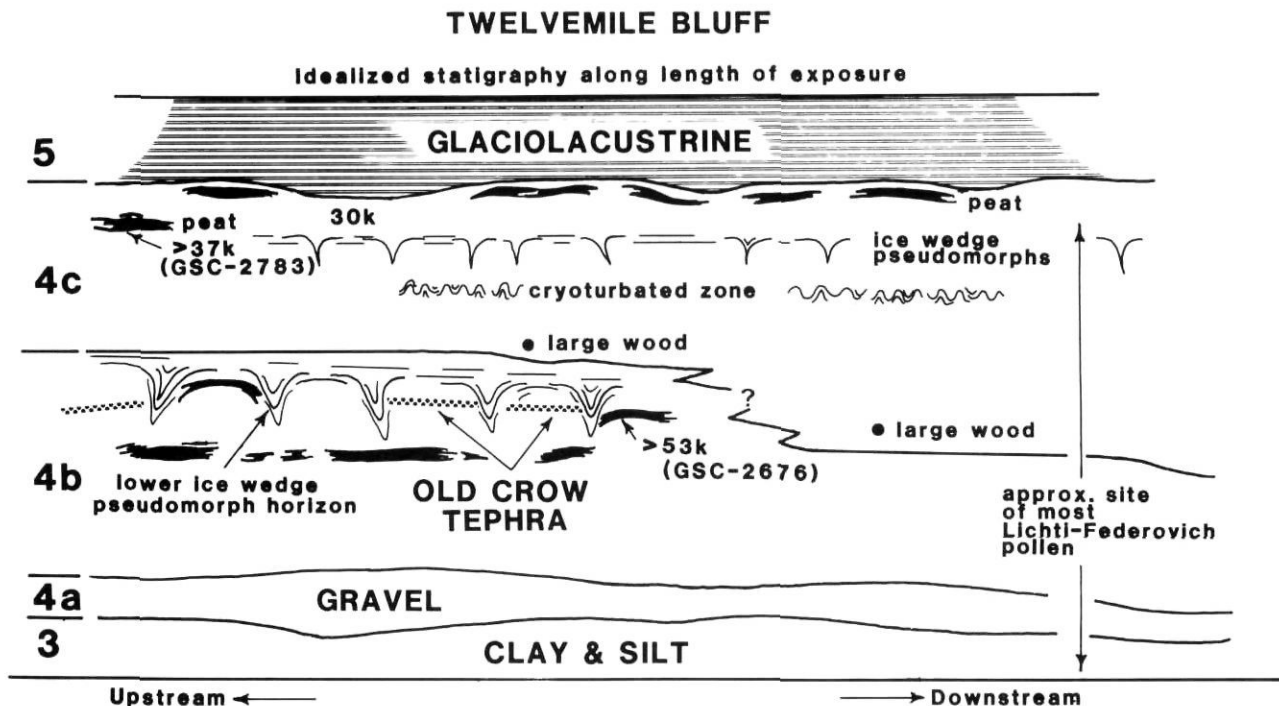


FIGURE 5b. Stratigraphy and the approximate position of pollen sample series in relation to Old Crow tephra. Note that the part of Unit 4 containing the tephra is not present in the downstream part of the section. It has either been removed prior to deposition, or the lower part of 4C may be a downstream facies of upper 4b. See Table II for pollen samples directly associated with tephra and pollen data on Peat dated by GSC-2783.

*Stratigraphie de la falaise de Twelvemile et localisation approximative du lieu d'échantillonnage de la série pollinique donnée en relation avec celle du tephra de Old Crow. La partie de l'unité n°4 où se situe le tephra n'apparaît pas dans la portion aval de la coupe. Cette partie a été éliminée avant le dépôt de l'unité n°4, ou alors elle constituait un faciès aval de la partie supérieure de l'unité n°4b. Voir le tableau II pour connaître les échantillons de pollen directement associés au tephra et les données polliniques de la tourbe datée (GSC-2783).*

TABLE II

Miscellaneous Twelvemile Bluff pollen samples and surface samples

| Taxon                          | Samples directly associated with Old Crow tephra |      |      |      | Ice-wedge peat | Peat 3 | Modern surface samples Old Crow Region |      |      |      |      |
|--------------------------------|--|------|------|------|----------------|--------|--|------|------|------|------|
|                                | +64  | +12  | -3   | -39  |                |        | 1                                      | 2    | 3    | 4    | 5    |
| <i>Picea</i>                   | 7.9  | 6.7  | 4.0  | 10.7 | ....           | 32.0   | 23.7                                   | 23.9 | 14.3 | 2.9  | 20.6 |
| <i>Pinus</i>                   | 1.2  | 1.2  | .... | 0.4  | ....           | 0.2    | 0.2                                    | .... | .... | .... | .... |
| <i>Alnus</i>                   | 0.8  | .... | 0.9  | .... | 0.2            | 7.7    | 26.7                                   | 10.7 | 32.8 | 20.8 | 20.6 |
| <i>Betula</i>                  | 3.7  | 6.7  | 42.2 | 39.8 | 6.1            | 12.7   | 31.3                                   | 35.7 | 34.8 | 57.0 | 22.0 |
| <i>Salix</i>                   | 3.3  | 11.1 | 8.3  | 8.0  | 2.3            | 4.6    | 0.9                                    | 3.1  | 2.4  | 2.9  | 12.4 |
| <i>Populus</i>                 | ....   | .... | .... | .... | ....           | 0.6    | 0.4                                    | .... | 1.1  | .... | .... |
| <i>Juniperus</i>               | ....   | .... | .... | .... | ....           | ....   | ....                                   | .... | 0.4  | .... | 1.8  |
| <i>Abies</i>                   | ....   | .... | 0.9  | .... | ....           | ....   | ....                                   | .... | .... | .... | .... |
| <i>Quercus</i>                 | ....   | 0.4  | .... | .... | ....           | ....   | ....                                   | .... | .... | .... | .... |
| <i>Larix</i>                   | ....   | .... | .... | .... | ....           | 0.2    | ....                                   | .... | .... | .... | .... |
| Cyperaceae                     | 45.0   | 50.2 | 11.8 | 17.2 | 77.4           | 27.6   | 2.3                                    | 15.0 | 2.4  | 10.5 | 22.0 |
| Gramineae                      | 26.9   | 14.2 | 29.0 | 13.8 | 8.1            | 6.2    | 1.3                                    | 2.5  | 1.1  | 1.9  | 1.8  |
| Ericaceae                      | 0.8  | 0.8  | 0.9  | 0.8  | ....           | 5.2    | 9.8                                    | 5.3  | 6.3  | 1.6  | 4.6  |
| <i>Artemisia</i>               | 1.2  | 0.4  | .... | .... | 0.2            | 0.2    | 0.4                                    | 1.1  | 2.4  | 1.3  | .... |
| Tubuliflorae                   | 2.9  | 1.2  | 0.9  | 2.7  | 2.1            | ....   | ....                                   | .... | .... | .... | 0.5  |
| Caryophyllaceae                | 0.4  | 1.2  | 0.3  | .... | 0.4            | ....   | ....                                   | 0.4  | .... | .... | .... |
| Rosaceae undif.                | ....   | .... | .... | 3.4  | 0.4            | 1.0    | ....                                   | 0.9  | .... | .... | 0.9  |
| <i>Rubus chamaemorus</i>       | ....   | .... | .... | .... | ....           | 1.0    | 3.0                                    | 0.7  | 1.4  | 0.3  | 0.5  |
| <i>Potentilla</i> typ.         | ....   | .... | .... | .... | ....           | 0.6    | ....                                   | 0.2  | .... | 0.3  | 0.5  |
| <i>Chenopod.-Amaranthus</i>    | 0.4  | 2.8  | .... | .... | 2.1            | ....   | ....                                   | .... | .... | .... | .... |
| <i>Ranunculus</i> typ.         | ....   | 0.4  | 0.6  | 1.5  | ....           | ....   | ....                                   | .... | .... | .... | .... |
| Cruciferae                     | 1.2  | .... | .... | .... | ....           | ....   | ....                                   | 0.2  | 0.7  | 0.7  | 1.4  |
| <i>Polemonium</i>              | ....   | .... | .... | 0.4  | 0.2            | ....   | ....                                   | .... | .... | .... | .... |
| <i>Phlox</i>                   | 1.2  | 1.2  | .... | .... | 0.2            | ....   | ....                                   | .... | .... | .... | .... |
| <i>Thalictrum</i>              | ....   | 0.4  | 0.3  | .... | ....           | ....   | ....                                   | .... | .... | .... | .... |
| Liguliflorae                   | 1.2  | .... | .... | .... | ....           | ....   | ....                                   | .... | .... | .... | .... |
| <i>Dryas</i>                   | ....   | 0.8  | .... | .... | ....           | ....   | ....                                   | .... | .... | .... | .... |
| <i>Papaver</i>                 | 0.8  | .... | .... | .... | ....           | ....   | ....                                   | .... | .... | .... | .... |
| <i>Rubus</i> typ.              | 0.8  | .... | .... | .... | ....           | ....   | ....                                   | .... | .... | .... | .... |
| <i>Saxifraga</i>               | ....   | .... | .... | 0.8  | ....           | ....   | ....                                   | .... | .... | .... | .... |
| Ranunculaceae                  | ....   | .... | .... | .... | ....           | ....   | ....                                   | .... | .... | 0.6  | .... |
| Umbelliferae                   | ....   | .... | .... | .... | ....           | 0.6    | ....                                   | .... | .... | .... | .... |
| <i>Circaea</i>                 | ....   | .... | .... | .... | ....           | ....   | ....                                   | .... | .... | .... | 0.5  |
| <i>Mitella</i> typ.            | ....   | .... | .... | .... | ....           | ....   | ....                                   | .... | .... | .... | 0.5  |
| <i>Penstemon</i> typ.          | ....   | .... | .... | .... | ....           | ....   | ....                                   | .... | .... | .... | 0.5  |
| <i>Shepherdia canadensis</i>   | ....   | .... | .... | .... | ....           | ....   | ....                                   | .... | .... | .... | 0.5  |
| <i>Valeriana</i>               | ....   | .... | .... | .... | ....           | ....   | ....                                   | .... | .... | .... | 0.5  |
| <i>Epilobium</i>               | ....   | .... | .... | 0.4  | ....           | ....   | ....                                   | .... | .... | .... | .... |
| <i>Gaura</i>                   | ....   | 0.4  | .... | .... | ....           | ....   | ....                                   | .... | .... | .... | .... |
| <i>Myrica</i>                  | ....   | .... | .... | .... | ....           | ....   | ....                                   | 0.4  | .... | .... | .... |
| <i>Myriophyllum</i>            | ....   | 0.4  | .... | .... | ....           | ....   | ....                                   | .... | .... | .... | .... |
| <i>Polygonum bistorta</i> typ. | ....   | .... | .... | .... | ....           | ....   | ....                                   | .... | .... | .... | .... |
| Indeterminant pollen           | ....   | .... | .... | .... | 19.0           | 2.5    | 1.7                                    | 5.1  | .... | 3.2  | 13.8 |
| Unknown pollen                 | 0.8  | 0.4  | 0.3  | 1.1  | ....           | ....   | ....                                   | .... | .... | .... | .... |
| ** POLLEN SUM **               | 242  | 253  | 348  | 261  | 479            | 518    | 460                                    | 448  | 287  | 313  | 218  |
| Pteridophytes                  | 0.4  | 0.8  | 4.0  | 20.3 | ....           | ....   | ....                                   | .... | .... | .... | .... |
| <i>Lycopodium</i>              | ....   | 0.8  | .... | 0.4  | ....           | 0.6    | 0.4                                    | 0.9  | .... | .... | .... |
| <i>Isoetes</i>                 | ....   | .... | .... | .... | ....           | ....   | ....                                   | 0.4  | .... | .... | .... |
| <i>Selaginella</i>             | ....   | .... | .... | .... | ....           | ....   | ....                                   | .... | .... | .... | 2.8  |
| <i>Equisetum</i>               | ....   | .... | 0.3  | 0.4  | ....           | ....   | ....                                   | .... | .... | .... | .... |
| Musci                          | 1.7  | 3.2  | 6.6  | 23.0 | 0.8            | 2.1    | 8.3                                    | 27.7 | 6.0  | 1.6  | 3.7  |
| Old Palynomorphs               | 0.8  | 0.4  | .... | .... | ....           | 0.4    | ....                                   | 10.7 | .... | .... | .... |

NOTES: Pollen assemblages associated with Old Crow Tephra come from Twelvemile Bluff, Porcupine River, Y.T. Peat 3 = peat dated at >37 000 BP (GSC-2783) (see Fig. 5b). Ice-Wedge Peat refers to peat shown in Fig. 5 of WESTGATE *et al.* (1983) and in Fig. 5b (>53 000 BP; GSC-2676) of this paper. Modern surface samples from Old Crow Basin: (1) Moss polster near unnamed lake ("Square Lake"); (2) Center of "Square Lake"; (3) Moss polster from tundra site at location CRH-32; (4) Small pond at location CRH-44; (5) Moss polster near last spruce stand on Timber Creek on north side of Old Crow Basin. All numbers = percent of total pollen.

in cryoturbated clayey silts within the upper part of a thick alluvial unit bounded above and below by units of lacustrine clay. The age of the lower clay unit is unknown but is at least as old as early Wisconsinan, *i.e.* marine isotope Stage 5. The upper clay is the equivalent of Unit 5 at Twelvemile Bluff; hence, it began to accumulate in a meltwater lake between 25 000 and 30 000 years ago (MORLAN, 1985). Where Old Crow tephra occurs, it is usually located 5-7 m below the lower contact of the upper glaciolacustrine clay unit. At some sites it is intruded by (and slumped into) ice-wedge pseudomorphs that probably represent a subsequent period of regional warming. Because ice wedges are currently forming in the region, the degree of climatic amelioration represented by the pseudomorphs seems to be greater than today.

LICHTI-FEDEROVICH (1973) studied pollen samples from several of the Old Crow exposures where tephra has subsequently been found, but comparison of the unpublished stratigraphic notes associated with her collections shows that none of her samples include the upper part of the unit in which the tephra occurs. Thus at present there is little available pollen data that apply directly to the tephra. However, stratigraphic evidence does show that the tephra fell at a time when climate was cold enough for the formation of ice wedges (*i.e.*, a permafrost environment as cold as the present), and we can also say with relative certainty that tephra deposition was followed sometime prior to  $41\,100 \pm 1650$  BP (GSC-2574) (BLAKE, 1984) by at least one period when climate was as warm or warmer than at present.

#### CENTRAL AND SOUTHERN YUKON

Two Old Crow tephra localities are found in central and southern Yukon. One of these is located in the upper Ogilvie River drainage (Fig. 1) where small wisps of the tephra occur in a terrace sequence stratigraphically above sediments containing an inactive (incompletely thawed) ice wedge (V. N. Rampton, pers. comm., 1982). Two other sites are located near Kluane Lake and the Alaska-Yukon border (WESTGATE, 1982) (Fig. 1). Although neither of these has yielded paleoecological information, they show conclusively that the Mirror Creek Glaciation (RAMPTON, 1971) in that region predates deposition of Old Crow tephra. The Mirror Creek Glaciation and its central Yukon equivalent, the Reid Glaciation, are generally considered to be no younger than Early Wisconsinan.

In summary the Old Crow tephra occurs within Imuruk Lake pollen zone G<sub>4</sub>, Ky-11 interval 285-300 cm, the Gold Hill Loess of Fairbanks, Unit 3 of Old Crow Basin, and pollen zone C and Unit 4b of the Twelvemile Bluff locality (Fig. 6). The Blake paleomagnetic reversal occurs below the tephra at Imuruk Lake and Twelvemile Bluff while evidence of a paleoclimate warmer than at present occurs above the tephra at all study localities.

#### AGE OF THE OLD CROW TEPHRA

The best previous estimate of the age of the Old Crow tephra is that it fell within the interval 60 000-120 000 BP (WESTGATE *et al.* 1983). The minimum value comes from the fact that at the KY-11 exposure in the Koyukuk valley the

tephra occurs well below a level dated at 60 000 BP. The higher value is derived from a fission-track date on the glass of the tephra (NAESER *et al.*, 1982). Other estimates have appeared in the literature (*e.g.*, 70 000 and 80 000 years in WESTGATE, 1982), but these appear to be no more than educated guesses.

Occurrence of Old Crow tephra in Imuruk core V offers the opportunity for derivation of a more objective and precise age estimate. In the core, the tephra occurs stratigraphically between a paleomagnetic reversal identified as the Blake Event (SHACKLETON, 1982) and a radiocarbon dated level (DIC-910, Fig. 7). Although, it has been suggested that the reversed zone in core V is a local anomaly (MARINO and ELWOOD, 1978), this now seems unlikely in view of the occurrence of a similar magnetic perturbation beneath Old Crow tephra at the Twelvemile Bluff exposure in the Yukon (see above). We follow SHACKLETON (1982) and assume that it represents the Blake Event, which is dated at between approximately 100 000 and 125 000 BP (SMITH and FOSTER, 1969). If a relatively constant mean deposition rate is assumed for core V, the two chronologic datum points (DIC-910 and the Blake Event) allow an extrapolated age estimate of 87 000-105 000 BP for Old Crow tephra (Fig. 7).

Independent confirmation for this estimate comes from comparison of pollen sequences. It is argued below that the top of the KY-11 section, dated at 60 000 BP, correlates with the level of Imuruk Subzone *i*<sub>1</sub> where spruce values peak. If so, that level of Subzone *i*<sub>1</sub> is also 60 000 in age. A line joining the point so defined with the mean value for DIC-910 falls within the stippled zone in Figure 7, and yields an estimate of about 100 000 years for the age of the tephra.

Although the new estimate for the age of the tephra does not define the "instant" of the ash fall, it nearly halves the range of the former estimate. Most important it shows, as the previous fission-track based estimate does not, that the tephra was deposited during marine isotope Stage 5. Furthermore the tephra is almost certainly younger than isotope Stage 5e, which is generally accepted to represent the last interglacial, *e.g.*, the last time when world ice volume was as low as at present, world sealevel as high or higher, and climate warmer (MANGERUD *et al.*, 1979) (Fig. 8).

#### ENVIRONMENT AT THE TIME OF THE OLD CROW TEPHRA

Old Crow tephra is found at the base of Imuruk Lake Subzone G<sub>4</sub>, a period of slightly higher *Picea*, *Alnus*, and *Betula* values (11%, 11%, and 18%, respectively). Surface samples from Imuruk Lake (COLINVAUX, 1964; COLBAUGH, 1968; SHACKLETON, 1982) show similar amounts of *Picea* pollen although distinctly higher values of *Alnus* and *Betula*. On the other hand, Subzone G<sub>4</sub> values of Gramineae (20-30%) and *Artemisia* (10-20%) are considerably higher than in the modern pollen rain. Birch-dominated shrub tundra is the probable vegetation at Imuruk Lake during deposition of the tephra, but this tundra was probably more xeric than that of the present. Although spruce treeline may have been closer

THE LAST GLACIATION AND CLIMATE IN ALASKA-YUKON

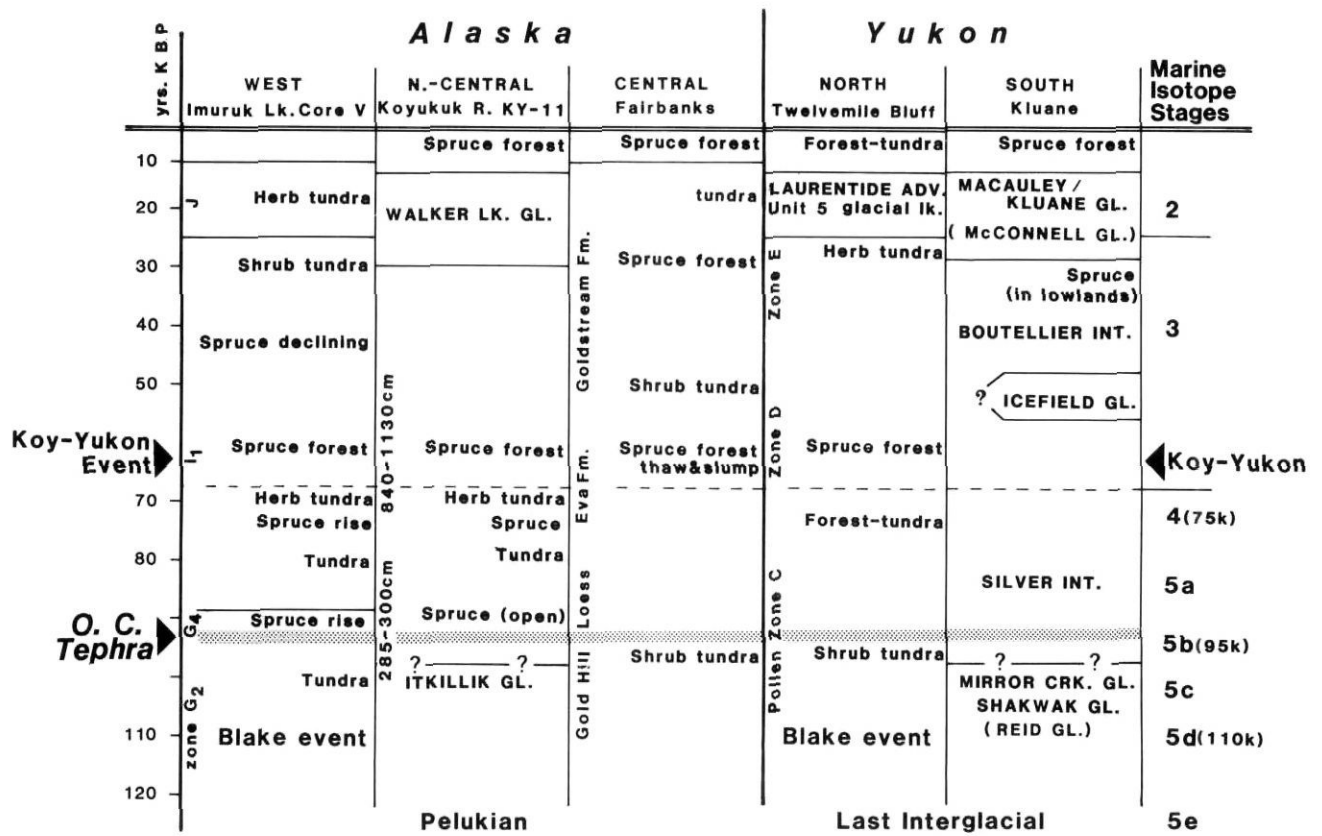


FIGURE 6. Summary diagram of events, zones and units associated with the Old Crow tephra and Koy-Yukon thermal event cited in text. For greater detail consult the appropriate section of text.

Diagramme abrégé comprenant les différents phénomènes, les zones et les unités associés au tephra de Old Crow et à l'épisode de Koy-Yukon dont on parle dans le texte.

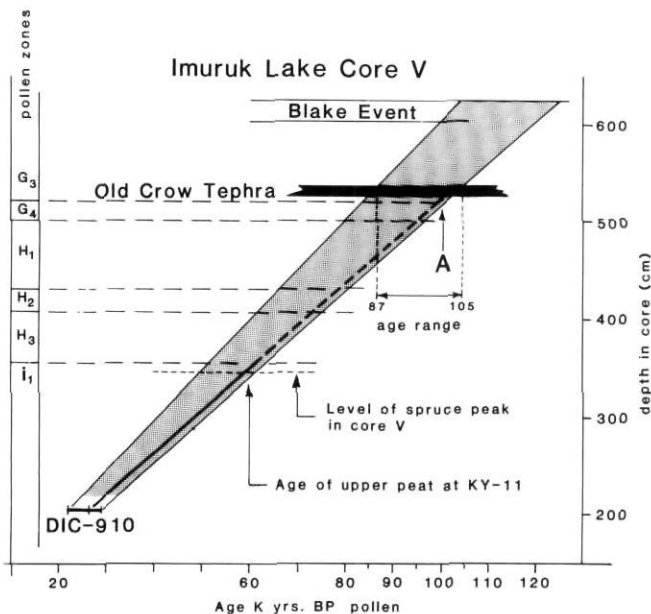


FIGURE 7. Extrapolated age of the Old Crow Tephra (based on data presented in SHACKLETON, 1982). Stippled band is the sedimentation rate derived using the max-min. age range for DIC-910 and the Blake Paleomagnetic Event and assuming constant average sedimentation rate between these two levels. Pollen zones are those of Imuruk Core V. Since the deposition of the tephra is an instantaneous event, the maximum and minimum estimates for its age coincide with the intersection of the field boundaries with the lowest occurrence of the tephra. Solid and dashed heavy line within the stippled field represents the extrapolated age (intersection A) for the tephra using DIC-910 and a 60 000 yr age for the spruce peak in Subzone i<sub>1</sub> (see text).

Extrapolation de l'âge du tephra de Old Crow (à partir des données de SHACKELTON, 1982). La zone en gris correspond au taux de sédimentation calculé à partir de l'écart maximal et minimal de la datation du niveau DIC-910 et de l'inversion magnétique de Blake, en supposant un taux de sédimentation constant entre les deux niveaux. Les zones polliniques sont celles du trou de forage Imuruk V. Le dépôt du tephra étant un événement instantané, l'estimation de son âge (minimal et maximal) doit correspondre avec l'intersection des limites de la zone en gris et de la base du tephra. La ligne continue qui se poursuit par un tireté gras dans la zone en gris correspond, à l'intersection A, à l'âge extrapolé pour le tephra à partir du niveau DIC-910 et la date de 60 000 ans pour le maximum de l'épinette dans la sous-zone i<sub>1</sub> (voir le texte).

to Imuruk Lake shortly after deposition of the tephra, at the "instant" of deposition it was probably further from the site than it is at present.

At Koyukuk locality KY-11 the tephra was also deposited during or just before an interval of slightly elevated *Picea* values. The local abundance of Cyperaceae and the lack of modern surface samples from lakes in interior Alaska hinders vegetation reconstruction. Nevertheless, it is likely, judging from surface samples at other boreal sites, that spruce percentages at the level of the tephra and immediately above it are lower than in the present Koyukuk Basin pollen rain. The tundra environment at KY-11 at the time of the ash fall was probably also more xeric than is true of present lowland tundra in western Alaska.

In the Bluefish Basin at Twelvemile Bluff, Old Crow tephra was deposited at a time of low amounts (4%) of *Picea*, and high frequencies of Cyperaceae, Gramineae, *Salix*, and *Betula* (Table II). Spruce percentages rise slightly 60 cm above the tephra. Macrofossils from an autochthonous peat positioned near the level of the tephra indicate a local environment of sedge-dominated wetlands interspersed with drier sites containing shrub-birch and willows. Modern surface samples from small ponds in the Old Crow Basin, 60 km north of Twelvemile Bluff, record 3-15% *Picea* but, in contrast to the tephra-associated spectra, 20-30% *Alnus* and 20-60% *Betula* (Table II). It would appear then that in the Old Crow-Bluefish Basin area, Old Crow tephra was deposited in a xeric shrub tundra environment characterized by shrub-birch and willow, but with little or no *Alnus*. Spruce was rare to absent locally, but spruce treeline probably existed near-by, perhaps much closer than it was to Imuruk Lake and KY-11 on the Koyukuk River.

As paleoecological data become available from other Old Crow tephra exposures and those elsewhere in the Yukon, they will help to map the former regional position of treeline at the time of the tephra fall. Based on the evidence at hand, it is likely that at least open spruce forest existed somewhere in central and southern Alaska. While it is clear that the tephra was deposited when climate was colder than at present, the tephra nevertheless occurs inside the limit of the preceding glaciation. Thus, at the time of the tephra all glaciers in Alaska-Yukon were on the wane (Fig. 6), and the subarctic biota probably in the initial stages of a northward movement.

#### THE KOY-YUKON THERMAL EVENT

The primary lacustrine pollen records from Koyukuk location KY-11 and Imuruk Lake core V can be correlated solely on the basis of their respective pollen sequences and their position with respect to Old Crow tephra (Fig. 6). Paleomagnetic studies at KY-11 indicate normal field conditions through the entire 10 m of lacustrine silt (WESTGATE *et al.*, 1983), showing that this record starts after the upper part of Imuruk Lake Subzone G<sub>2</sub> in which the Blake Event is registered. KY-11 interval 75-125 cm shows a distinct *Picea* peak that is not as evident at Imuruk Lake. However, Subzone G<sub>3</sub> and KY-11 interval 125-275 cm are both dominated by non-arboreal (NAP) pollen with little *Picea* or *Alnus*. Imuruk Subzone G<sub>4</sub> is equivalent to the 230-320 cm interval at KY-11 because

both are bounded by Old Crow tephra. The sequence of fluctuations above the tephra is remarkably similar at both sites (compare Figs. 2 and 3). Zones H<sub>1</sub> and H<sub>3</sub> at Imuruk and the 350-425 cm and the 525-1030 cm intervals at KY-11 are characterized by high frequencies of Cyperaceae, Gramineae, and *Artemisia*, with rare or no *Picea*, *Alnus*, or *Betula* pollen. The pollen spectra imply herb-tundra and severely cold climate. Zone H at Imuruk and the 425-525 cm interval at KY-11 display higher values of *Picea* and *Betula* pollen, while pollen Subzone i and the KY-11 woody peat above 1030 cm have maximum values of *Picea* and *Betula* in addition to high frequencies of *Alnus*. The last named taxon does not again become significant in east Beringian records until the Holocene. Thus both Imuruk core V and KY-11 record three periods of warming following deposition of the Old Crow tephra.

The age of the lower one is fixed by our estimate for the age of the Old Crow tephra. The middle one (= Imuruk Subzone H<sub>2</sub>) appears to have occurred sometime between 62 000-80 000 BP (Fig. 7). This means that Subzone H<sub>2</sub> and its presumed KY-11 equivalent (425-525 cm level) may represent a northwestern manifestation of the St. Pierre interstade of eastern Canada (dated at 72 700-77 400: QL-198, STUIVER *et al.*, 1978, but see also OCCHIETTI, 1983, p. 11). The European Amersfort interstade (LUNDQVIST and MOOK, 1981) is another possible equivalent of Imuruk Subzone H<sub>2</sub>.

The uppermost peak of spruce percentages (Subzone i<sub>1</sub> at Imuruk Lake and the top of the KY-11 sequence) is presumed on the basis of radiocarbon dates to be approximately 60 000 years in age. If so, it corresponds to the start of marine isotope Stage 3 (Fig. 8). But in the marine record Stage 3 does not portray warmer climate than at present. The Imuruk and KY-11 records do. One way to resolve this contradiction would be to reject previous correlation arguments and assign Imuruk Subzone i<sub>1</sub> to marine isotope Stage 5a. Stage 5a in the marine record does represent a world climate more like that of the present than Stage 3 (Fig. 8). We reject this solution because: 1) it would mean that the close resemblance between the Imuruk and Koyukuk records is purely fortuitous; and 2) it would require that Zone H at Imuruk have been deposited at the improbably high rate of 0.5 m/1000 years (assuming a median estimate of 93 000 BP for the age of Old Crow tephra). Thus it appears likely that isotope Stage 3 is the most likely correlative for Subzone i<sub>1</sub> and the upper peat at KY-11.

The warming phase that occurred during Imuruk Subzone i<sub>1</sub> and uppermost KY-11 represents a significant Wisconsinan climatic event in east Beringia. Recognizing this, we here informally name it the "Koy-Yukon thermal event". An indication of its regional importance is that it is apparently represented at other sites in Alaska-Yukon (Fig. 6). For example, in the Fairbanks area it likely corresponds to the period of deep thawing that followed deposition of the Gold Hill Loess (Fig. 4). At Twelvemile Bluff in the Bluefish Basin of the Northern Yukon, the Koy-Yukon thermal event is probably portrayed by the lower ice-wedge pseudomorph horizon, the organic sediments at the base of Unit 4c, and the peak of spruce pollen in Lichti-Federovich's Zone D (Fig. 5a). At least one other period of deep thawing, accompanied by development

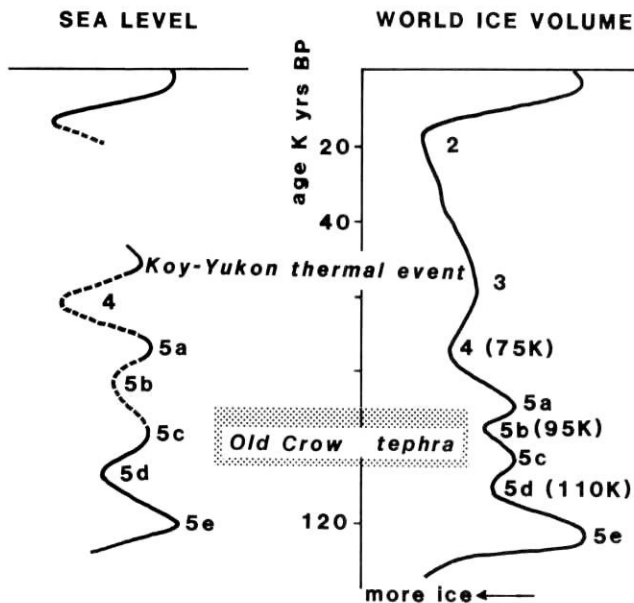


FIGURE 8. Comparison of marine isotopic stages (after DANS-GAARD and DUPLESSY, 1981) with the extrapolated age for the Old Crow tephra and the Koy-Yukon thermal event. See text for discussion. The isotopic curve suggests that the last period of world climate as warm as at present occurred during isotope Stage 5e, i.e., before deposition of Old Crow tephra.

Comparaison entre les phases isotopiques océaniques (selon DANSGAARD et DUPLESSY, 1981) et l'âge extrapolé du tephra de Old Crow et de l'épisode de Koy-Yukon (voir le texte). La courbe isotopique suggère que la dernière période pendant laquelle le climat était aussi doux que maintenant correspond à la phase isotopique 5e, c'est-à-dire avant le dépôt du tephra de Old Crow.

of boreal forest, occurred somewhat later but still prior to 37 000 BP.

In the Old Crow Basin the Koy-Yukon thermal event may be represented by a period of regional thawing post dating the tephra and predating 41 000 BP.

The Koy-Yukon thermal event probably lasted a minimum of several thousand years. If its start was approximately 60 000 years, as concluded above, then it falls within the Boutellier Interval of HOPKINS (1982). As used here and by HOPKINS (1982); Fig. 2), the Boutellier Interval is different from DENTON and STUIVER's (1967) "Boutellier nonglacial interval". Hopkins' Boutellier Interval is the period of time between approximately 65 000 BP (HOPKINS, 1982; Fig. 2) and the start of marine isotope Stage 2 at 25 000 BP. The preceding Happy Interval (HOPKINS, 1982) is defined as including the Gold Hill Loess (Fairbanks), which we now know contains Old Crow tephra (WESTGATE *et al.*, 1983) and the Blake Paleomagnetic Excursion (WESTGATE *et al.*, 1985).

The Koy-Yukon thermal event is probably correlative with the earliest and warmest part of the Karginsk "interglacial" of eastern Siberia and the early Port Talbot Interstade of the North American mid-Continent (DREIMANIS and RAUKAS, 1975). ANDREWS and BARRY (1978) also record a period of significant warming (Quajon Interstade) at about 60 000 BP on Baffin Island. The Fennoscandian ice sheet apparently

retreated sharply at about the same time (BOULTON, 1979), corresponding to the Odderade of Brörup Interstade (LUNDQVIST and MOOK, 1981).

The outstanding characteristic of the Koy-Yukon thermal event is that it represents climatic conditions ordinarily associated with an interglacial (MATTHEWS, 1980; MATTHEWS and SCHWEGER, 1985; SCHWEGER and MATTHEWS, 1984). DREIMANIS and RAUKAS (1975) have shown that the early part of isotope Stage 3 had an interglacial character in several parts of the world, one of which was eastern Siberia. Our findings suggest that this was the case throughout the Beringian area. The anomalous interglacial signal of the Koy-Yukon thermal event probably results from the unique paleogeography of the region at that time. For example, there is probable cause for assuming that Middle Wisconsinan sea level was lower than at present (HOPKINS, 1982); and if it was as low as -100 m (CRONIN, 1983), most of the Beringian land bridge would have been emergent. The climatic continentality implied by such a circumstance (BARRY, 1982) would have enhanced the effect of isotope Stage 3 climatic warming in east Beringia. The resulting warm, dry summers would have favored expansion of spruce (HOPKINS, 1959; BLACK and BLISS, 1980) and alder in western Alaska. Better drainage combined with warmer climate would also have promoted the occurrence of more closed boreal forest in the Old Crow-Bluefish basins, and may even have allowed spruce to expand onto the Yukon coastal plain. In this regard it is notable that aspen and cottonwood occurred on the Alaskan coastal plain around 52 000 BP (HOPKINS *et al.*, 1981).

Although floral records from Siberia and North America show that spruce did not cross the land bridge during the Koy-Yukon thermal event, it is possible that this was the time when some typical North American taiga plants (*e.g.*, *Populus balsamifera* and *Viburnum edule* (high bush cranberry) (YURTSEV, 1982), gained a foothold in Chukotka, where they remain today as very rare elements of the Siberian flora. Similarly North American boreal mammals such as the red squirrel (*Tamiasciurus hudsonicus*) that are now extinct in Siberia may have moved into that area during the Koy-Yukon thermal event (AGADJANIAN, 1979).

Drought resulting from the continental influence of the emergent landbridge might have fostered the development of parkland or savanna-like environments in lowland areas of interior Alaska and the Yukon during the Koy-Yukon thermal event. This was probably the time when now disjunct or locally extinct Asian and North American steppe plants and animals such as *Artemisia frigida* and saiga antelope gained continuous distributions across Beringia (YURTSEV, 1982). Emerging evidence also suggests that the Middle Wisconsinan was the optimal time for development of the complex Mammoth-Steppe ungulate fauna recently discussed in detail by GUTHRIE (1982). It has been thought that this unique fauna, dominated by grazers was best developed during the Late Wisconsinan (isotope Stage 2) (MATTHEWS, 1982). Instead, the Late Wisconsinan may have been a time when the Mammoth-Steppe fauna had a precarious existence, perhaps even suffering the loss of some of its minor component taxa.

## DISCUSSION

Pollen and macrofossil data from three widely separated sites in east Beringia represent a west-east transect of paleoenvironmental conditions at the time of Old Crow Tephra deposition. The tephra fell during a period of climate colder and drier than at present, and was followed by a slight warming trend. Old Crow Tephra occurs at a number of sites in Alaska-Yukon, and, according to its mapped distribution, will probably be found in cores from the Beaufort Sea, Bering Sea (WESTGATE, 1982), and possibly even in Chukotka. The tephra promises to broaden our knowledge of Middle Wisconsinan environments. It also allows us to define the Koy-Yukon thermal event, a period of abnormal warmth which we believe occurred approximately 60 000 years ago at the start of the Boutellier interval and marine isotope Stage 3 (Fig. 8). The Koy-Yukon thermal event has all the characteristics of an interglacial. In fact sediments that we refer to it were formerly thought to be of Sangamon interglacial age (COLINVAUX, 1964; PÉWÉ, 1975b).

The occurrence of Old Crow Tephra in a number of stratigraphic contexts points up another intriguing aspect of the Wisconsinan climatic historic of Northwestern North America. In the southern Yukon the tephra overlies glacial drift that is presumed to be no younger than Early Wisconsinan (RAMP-TON, 1971). In the Koyukuk region it is interstratified with drifts of the Early Wisconsinan Iktalik Glaciation (WESTGATE *et al.*, 1983). The next major glaciation in Alaska-Yukon, including the intrusion of Laurentide ice in the eastern Yukon (HUGHES *et al.*, 1981), dates to around 25 000 BP (isotope Stage 2). If Old Crow tephra is as old as isotope Stage 5, then the Middle Wisconsinan non-glacial interval in Alaska-Yukon was extraordinarily long. Furthermore, it includes episodes that on the basis of several lines of biotic evidence, appear to have been fully as cold as the preceding and following glacial periods. In Alaska-Yukon (east Beringia) marine isotope Stage 4 seems to have been characterized by little glacial activity; whereas, on a world scale, it was unquestionably a time of major ice build-up.

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