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NAME OF AUTHOR/*NOM DE L'AUTEUR* Charles E. Schweger

TITLE OF THESIS/*TITRE DE LA THÈSE* Late Quaternary Paleoecology of the Onion Portage Region, Northwestern Alaska.

UNIVERSITY/*UNIVERSITÉ* Univ. of Alberta

DEGREE FOR WHICH THESIS WAS PRESENTED/*GRADE POUR LEQUEL CETTE THÈSE FUT PRÉSENTÉE* Ph D

YEAR THIS DEGREE CONFERRED/*ANNÉE D'OBTENTION DE CE GRADE* 1976

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THE UNIVERSITY OF ALBERTA

LATE QUATERNARY PALEOECOLOGY OF THE ONION PORTAGE REGION, NORTHWESTERN ALASKA

by

CHARLES E. SCHWEGER ©

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY

EDMONTON, ALBERTA

SPRING 1976

THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR ....CHARLES E. SCHWEGER

TITLE OF THESIS ....LATE QUATERNARY PALEOECOLOGY OF THE ONION PORTAGE REGION, NORTHWESTERN ALASKA

DEGREE FOR WHICH THESIS WAS PRESENTED ....Ph.D.

YEAR THIS DEGREE GRANTED 1976

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled LATE QUATERNARY PALEOECOLOGY OF THE ONION PORTAGE REGION, NORTHWESTERN ALASKA submitted by Charles E. Schweger in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

John Westgate
Supervisor

Alan L. Bryan

C N Stelck

Wilson N. Stewart

Date April 26, 1976

Abstract

The Onion Portage region of the Kobuk River Valley, northeastern Alaska, lies within a broad forest-tundra mosaic or ecotone. Here a number of typically boreal species reach their western limits. Many of the forest stands are dominated by deciduous species, Populus balsamifera, P. tremuloides and Betula papyrifera. The diverse topography influences the vegetation pattern since it controls climatic and edaphic factors that interact in a series of complex interrelationships. Permafrost depth seems to be one of the most important environmental factors.

This region was greatly affected by late Quaternary glaciations. The Kobuk Glaciation (early Wisconsin) and the Ambler Stade of the Itkillik Glaciation (late Wisconsin) had frontal positions within the central Kobuk Valley. The stratigraphic history of the Epiguruk exposure indicates periods of extensive alluviation dated greater than 40,000 years ago and from 24,000 to 17,700 B.P. These correlate with the Kobuk Glaciation and Ambler Stade. Organic rich sediments at Epiguruk represent the mid-Wisconsin interstadial; they have yielded a fossil pollen record dominated by grass, sedge and Artemisia. This record indicates a steppe-tundra vegetation and a cold, arid climate. Between 17,700 and 10,000 years B.P. downcutting brought the river to very near its present level.

Late glacial-Holocene sections from Epiguruk were examined

for fossil pollen content. These data indicate that an open, high arctic tundra existed in the region from about 12,000 to 10,000 years ago at which time birch shrubs invaded. By about 7,000 B.P. alder appeared resulting in a vegetation similar to that now present across the Alaskan north slope. Spruce finally arrived in this region 5,500 B.P. and has since spread resulting in the modern forest-tundra vegetation. This pollen record indicates an initial cold and possibly arid climate that gave way in the early to mid Holocene to a warmer, moister climate. No climatic reversals are observed in this record.

Excavations at the Onion Portage archaeological site revealed additional paleoenvironmental data. Changes in paleosol type, cryoturbation and plant macrofossils indicate that tundra vegetation and a shallow permafrost table changed to boreal vegetation and deeper permafrost levels. This change occurred about 5,600 years B.P. and corroborates the pollen records.

This paleoecological record compares closely to other published studies revealing a picture of Alaskan vegetation development during the Holocene. However, these data indicate that paleoclimatic inferences are difficult and often confusing.

The Onion Portage archaeological record can be successfully compared to this paleoecological record. In this way culture history reveals human adaptations to a changing arctic environment.

ACKNOWLEDGMENTS

A great number of people have aided me throughout this research; I should like to acknowledge their generous assistance and cooperation. D.A. Anderson and Mrs. J.L. Giddings, Anthropology Department, Brown University, provided archaeological assistance and support. T.D. Hamilton, Geology Department, University of Alaska, generously shared his data and opinions on geological matters. D.M. Hopkins, U.S. Geological Survey, Menlo Park, stimulated my curiosity and encouraged my efforts. J.V. Matthews, Geological Survey of Canada, Ottawa, and J. Westgate, Geology Department, University of Alberta, visited me in the field and provided stimulating and challenging discussion and opinion. S. Pawluk, Pedology Institute, University of Alberta, provided assistance with soil analysis.

Very special acknowledgment must be made of the generous assistance received from the late R. Fryxell, Anthropology Department, Washington State University. His help with soils and stratigraphy greatly aided my work. V. Harms, Botany Department, University of Saskatchewan, provided valuable time and expertise in checking my plant identifications and correcting my mistakes. Barbara Schweger, my wife and field companion, provided her help and patience under often less than ideal conditions. Finally, but not least, I must acknowledge the help and friendship provided by the Kobuk River Eskimos, whom I shall always remember.

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INTRODUCTION

Project Purpose

The Onion Portage region of northwestern Alaska has become a focus for Quaternary research. In 1941 Louis Giddings, an archaeologist, discovered the Onion Portage archaeological site. However, it was not until 20 years later, in 1961, when extensive excavations began, that the significance of this deeply stratified prehistoric cultural record was realized. Excavations in 1961 and 1964 by Giddings, and after his death by Douglas A. Anderson, from 1965 to 1968, recovered thousands of artifacts representing nine major cultural horizons. This record spans at least 10,000 years and makes Onion Portage one of the most important archaeological sites in northwestern North America.

Because of the significance of this archaeological record, research was initiated into other aspects of the paleoenvironment and Onion Portage became the focus of an interdisciplinary research project aimed at reconstruction of the late Quaternary cultural, geological and ecological history. Archaeological studies were undertaken by Douglas A. Anderson, Brown University, the geology by Thomas D. Hamilton, University of Alaska and the paleoecology by myself. This research was designed to investigate three important areas: Firstly, the adaptive role of culture to arctic environments and environmental change. Secondly, the development of a glacial and geomorphic history for the Kobuk-Ambler River Valley system. Thirdly, the documentation of the paleoecological history of the Onion Portage region and its paleoclimatic interpretation. The research carried out to satisfy the third goal, is the subject of this dissertation.

Whereas the work of Hamilton provides a regional view of the Quaternary geology and chronology, these studies were designed to provide a more detailed paleoecological record for the Onion Portage area. The organization of this dissertation reflects the basic organization of this research. The classic principle of Uniformitarinism operates in paleoecology so that interpretations are predicated on a basic understanding of the modern environment. Quaternary paleoecological research becomes more valuable as more of the modern environment is considered. Since little is known of the modern ecology of northwestern Alaska, these data were assembled for the Onion Portage region and are presented here. The present day flora was collected as an inventory of what is present in the region today, and a minimum amount of plant ecological data was gathered in order to provide an understanding of the plant communities and environmental controls. The recovery and analysis of fossil pollen from dated stratigraphic sections provided the basic paleoecological method. Additional information came from interpretation of the depositional history at the Onion Portage archaeological site. Field work was carried out during the summers of 1967, 1968 and 1969 with the laboratory analyses being performed during the subsequent winters. These studies were funded under National Science

Foundation (United States Government) grants to Douglas A. Anderson and grants from the University of Alberta, Boreal Institute, to the author.

Physiographic Setting

From its source in the Endicott Mountains, Brooks Range, the Kobuk River (Figure 1) flows south and then westward to Kotzebue Sound, traversing the southern edge of the Brooks Range. A number of major tributaries such as the Ambler, Hunt and Squirrel Rivers enter the Kobuk from the mountains to the north. The geography and topography of this region is dominated by the major east-west structural features of the Brooks Range which form the Waring and Jade Mountains (Warhaftig, 1965). These foothill ranges rise to 610 m. and 1,020 m. respectively, and form the south and north boundaries of the Kobuk Valley in the region of Onion Portage.

Onion Portage (67° 6' N lat., 150° 17' W long.), on the Kobuk River (Figures 2 and 3), is on the upstream side of a meander loop which swings back into itself to form a narrow neck of floodplain, used as a prehistoric portage. Onion Portage sits at about the midway point in the Kobuk Valley, approximately 160 km. from the coast. The valley floor is a broad, low depression which lies mainly between 15 and 60 m. (above S.L.) and then rises steeply in the north to mountains over 1,000 m. in elevation.

The various surficial materials include lacustrine silts, alluvium, coarse outwash, dune sand and glacial till (Figures 2 and 3). Bedrock exposed in the nearby Jade and Waring Mountains and in places

Figure 1

Map of Alaska and surrounding regions showing major topographic features and localities mentioned in the text.

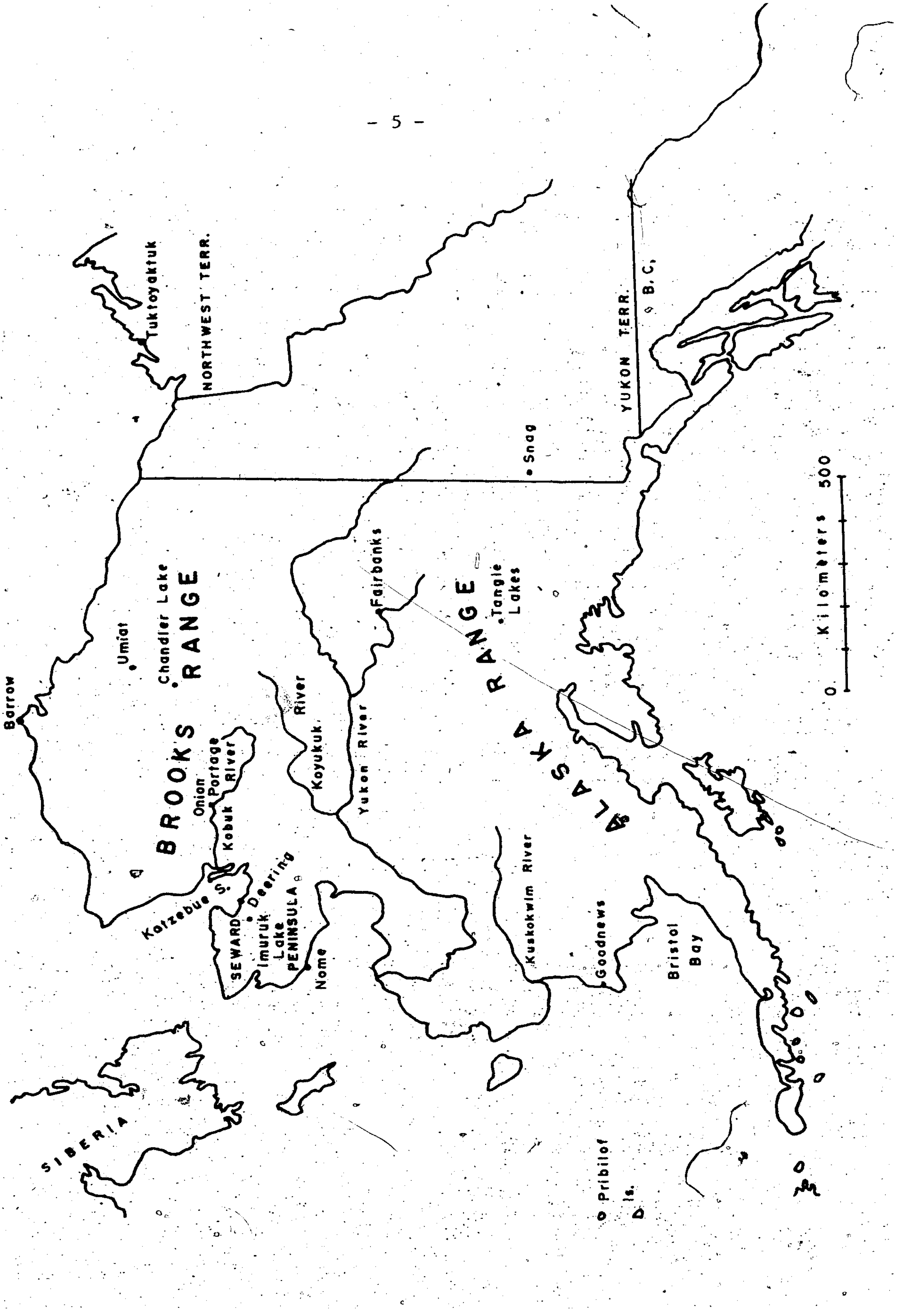
Tuktoyaktuk
NORTHWEST TERR.
YUKON TERR.
B.C.
Snag
Barrow
Umiat
Chandler Lake
BROOK'S RANGE
Onion Portage
Kobuk River
Koyukuk River
Yukon River
Fairbanks
Tangle Lakes
ALASKA RANGE
Kotzebue S.
Deering
SEWARD PENINSULA
Imuruk Lake
Nome
Kuskokwim River
Goodnews
Bristol Bay
Pribilof Is.
SIBERIA
0
Kilometers
500

Figure 2

Airphoto mosaic of Onion Portage region, central Kobuk Valley. Transparent overlay shows localities and outlines major geomorphic surfaces, after Hamilton (1973, unpublished manuscript). Feature A is Israkalik Lake. The short dimension, center of photo mosaic, is 50 kilometers long.

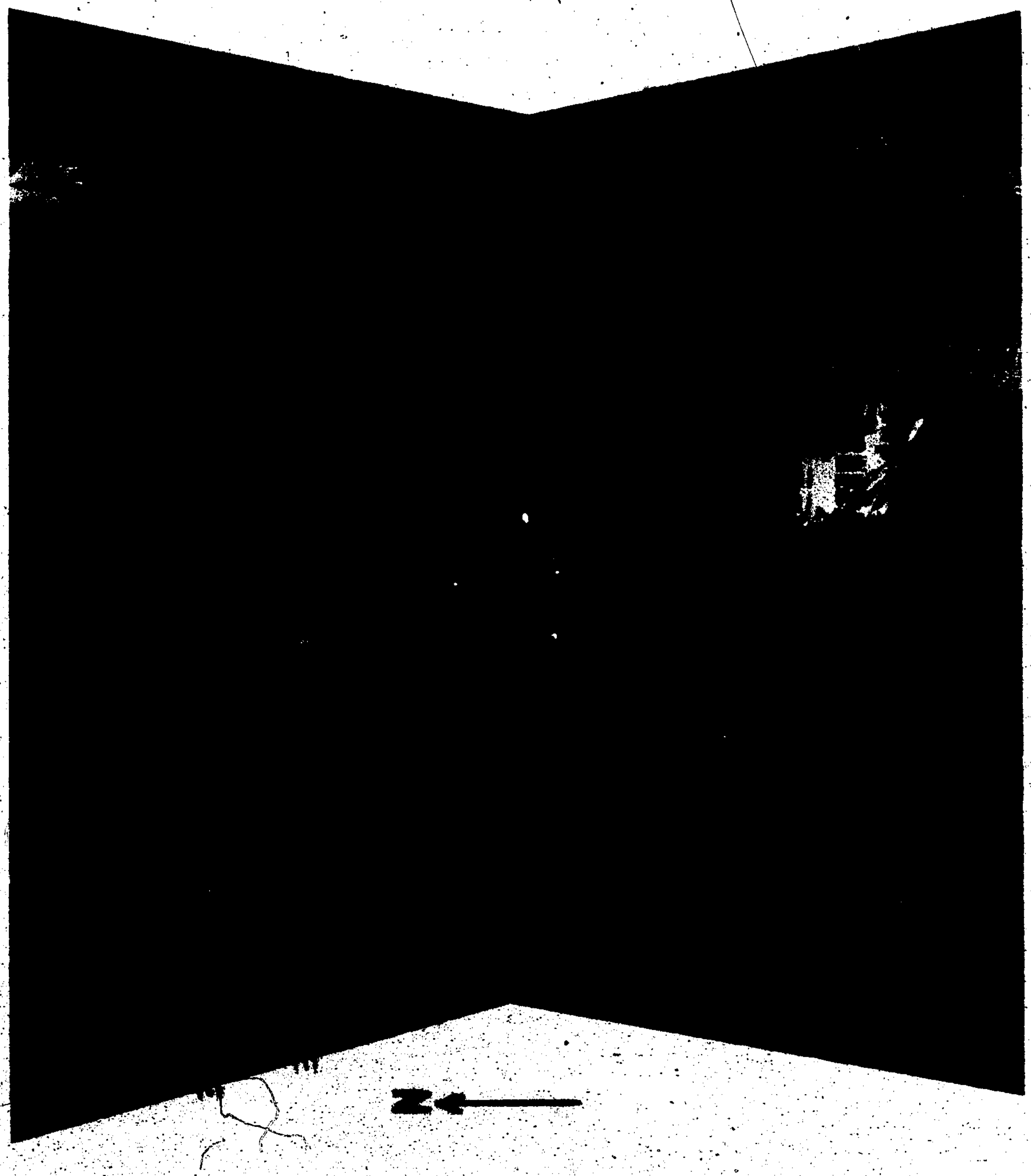
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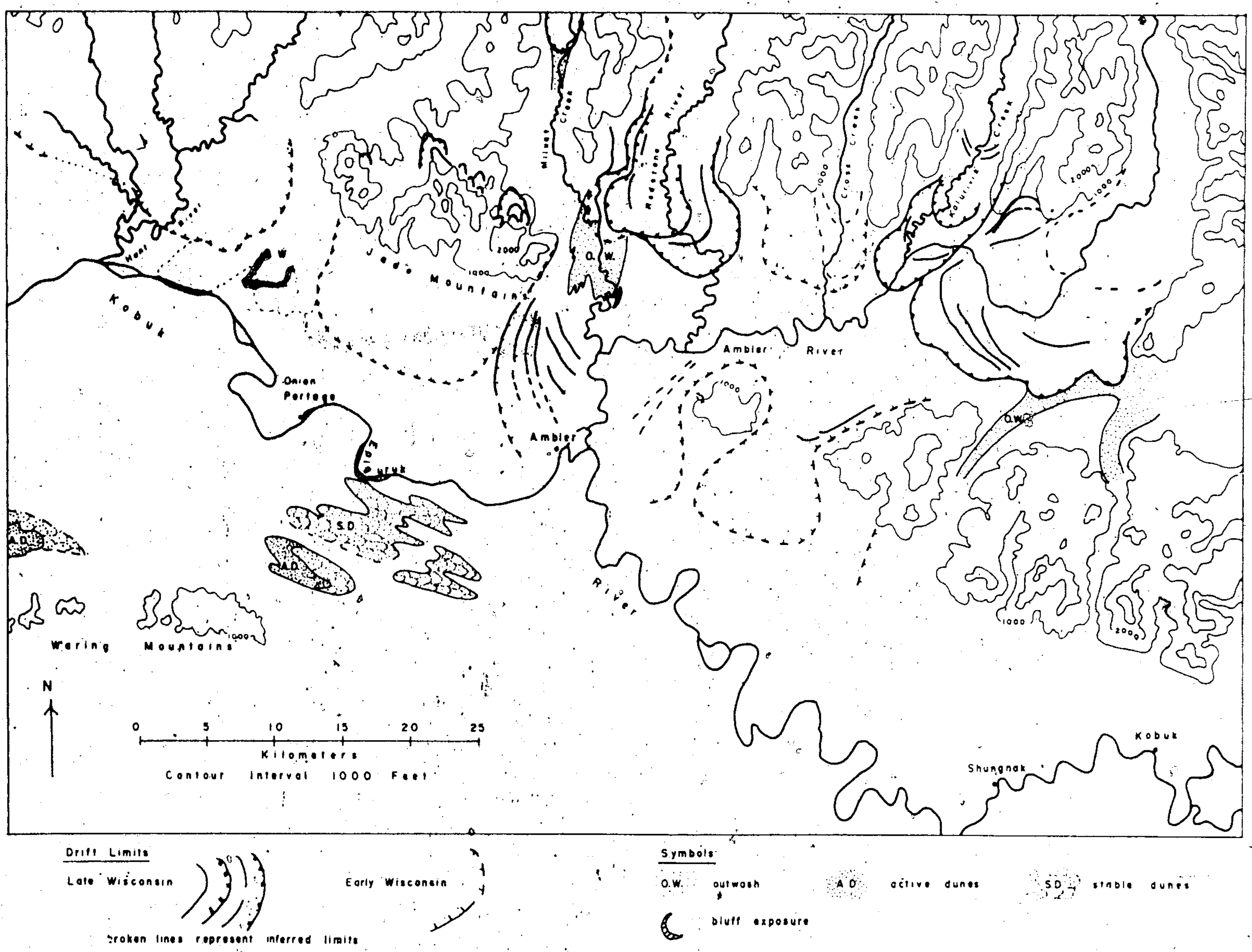
Figure 3

Glacial map of central Kobuk River Valley. Drift limits are taken from Hamilton (1973, unpublished manuscript).


Kobuk
Hunt River
Jade Mountains
Milluet Creek
Redstone River
Cross Creek
Kaluich Creek
O.W.
Ambler River
Ambler
Onion Portage
Episruk
S.D.
A.D.
River
Shungnak
Kobuk
1000
2000
Waring Mountains
N
0
5
10
15
20
25
Kilometers
Contour Interval 1000 Feet
Drift Limits
Late Wisconsin
Early Wisconsin
Broken lines represent inferred limits
Symbols
O.W. outwash
A.D. active dunes
S.D. stable dunes
bluff exposure

along the river is of Cretaceous clastics and Paleozoic metasediments and volcanics (Patton, Muller and Tailleur, 1968). The active Great Kobuk and Little Kobuk Sand Dunes as well as large areas of stabilized dunes are found south of the Kobuk River near Onion Portage.

This is a region that has been strongly affected by Pleistocene glaciation. During Illinoian time ice completely filled the Kobuk Valley all the way to the coast, but Wisconsin glacial ice was mainly confined to tributary valleys extending from the Brooks Range (Coulter, et al., 1965).

No glaciers are found in this section of the Brooks Range at present, but rock glaciers appear to be active in cirques of the Jade Mountains. Permafrost is continuous over this region but its depth beneath the surface varies depending upon a variety of environmental factors. This has had a great influence on the pattern of surface drainage and the vegetational mosaic (see Figure 2), as well as on the variety of periglacial or cryoturbation features that are present.

Previous Work.- Archaeology

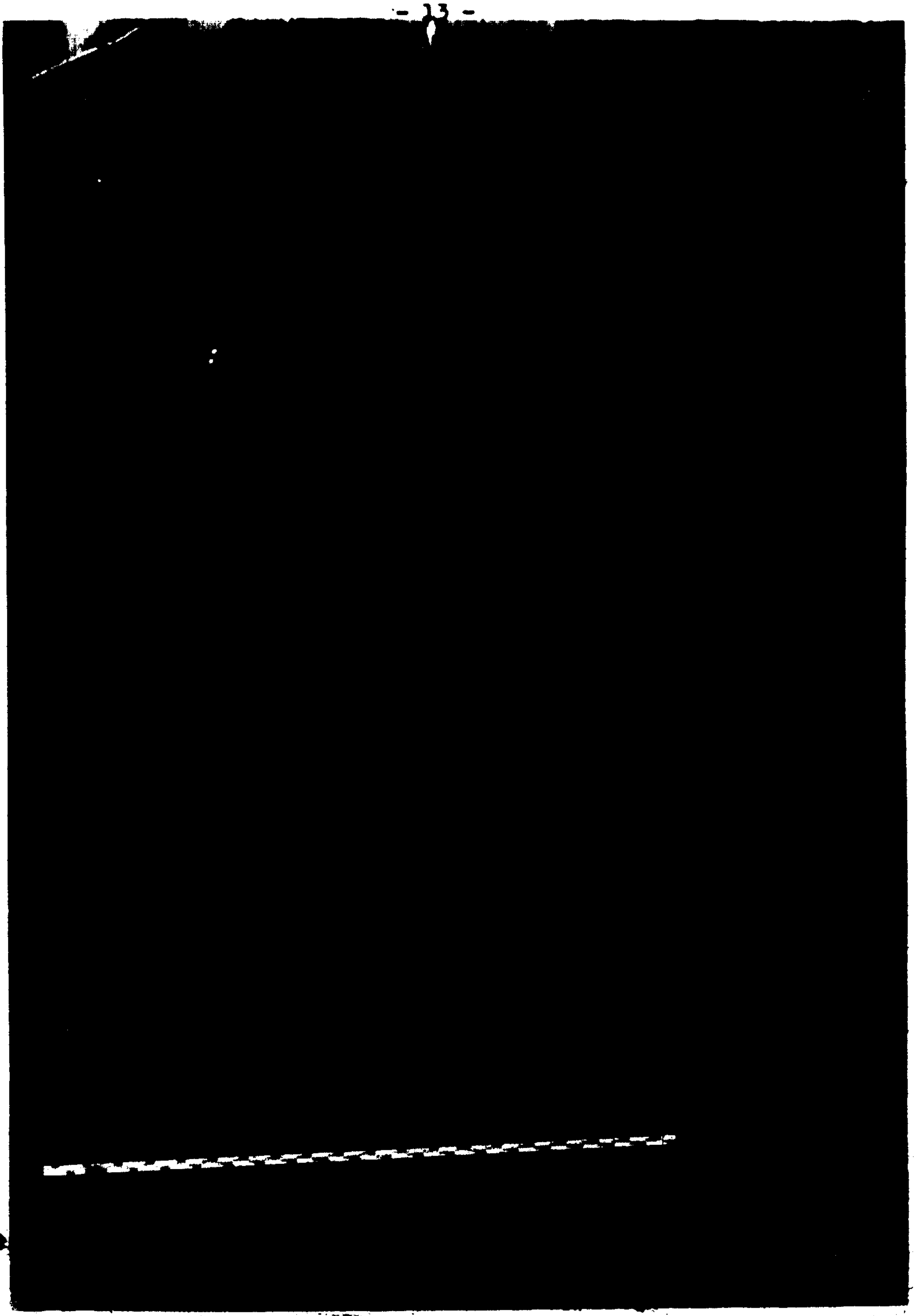
The Onion Portage archaeological site was discovered in 1941 by J.L. Giddings. These original excavations were limited to surface features and it was not until 1961 that excavation was resumed. The 1961 work demonstrated natural and cultural stratigraphy and prompted full-scale excavations during the summer of 1964. Following Giddings' death in 1964, D.A. Anderson took over and excavations continued during 1966, 1967 and 1968. The cultural sequence has been described by Giddings (1962, 1966 and 1967) and by Anderson (1968, 1970a, 1970b and 1970c) and the geological framework by Hamilton (1970 and 1973, unpublished manuscript).

The archaeological site is located at the base of a south-facing bluff formed during river incisement. As the Kobuk River eroded, the channel migrated southward away from the bluff and a point-bar was formed away from the bluff. The former channel positions are easily seen on air photographs (Figure 2). Frequent flooding has resulted in the deposition of thin sedimentary units of alluvial silt that alternate with bands of white eolian sand to form a detailed floodplain record. This record has been punctuated by gully erosion which cut into the bluff and deposited wedge-shaped fans of sand over the alluvium and eolian deposits (Figure 4).

Archaeological excavations covered an area of approximately one hectare along the levee and floodplain at the base of the bluff (see Hamilton, 1970). Further testing indicated that additional cultural materials are present downstream along the levee. The stratigraphic sequence at the archaeological site is a vertical record of buried ground surfaces occupied for intervals from about 100 to 1,000 years to produce a cultural record extending back 10,000 years. The archaeological materials were deposited on these ground surfaces. These materials can be grouped into eight distinct cultural bands numbered one to eight, the youngest being near the surface, the oldest near the base. An earlier cultural component has been recognized below Band 8 although the main artifact

Figure 4

Sedimentary section from Onion Portage archaeological site, gully sand wedges are from the left, alluvial beds from the left. Stadia rod is scaled in decimeters.



concentration was along the bluff edge above the site. Each band may be represented by a series of occupations designated as levels. These terms are used to describe the cultural stratigraphy and not the geological stratigraphy although many geological units fall within a band designation. Forty-four radiocarbon dates, mainly charcoal samples from hearths, date the eight cultural bands and by interpolation the geological units. Figure 5 summarizes the cultural stratigraphy and radiocarbon chronology.

Although nine archaeological cultures were defined, these can be grouped into "traditions" to describe the persistence of cultural traits over considerable time (Figure 5). Anderson (1968) recognized three cultural traditions: American Paleo-Arctic, Northern Archaic and Arctic Small-Tool. Each of these is characterized by a distinct assemblage of lithic tool types and manufacturing technology and they suggest distinct environmental adaptations.

The American Paleo-Arctic Tradition includes the Kobuk (Band 8) and the Akmak Complexes (pre Band 8). The former dates from 8200 - 8000 B.P. and the latter has been dated at 9900 B.P. These are microblade core and burin industries. The Akmak assemblage has, in addition, large core bifaces and large blades (Anderson, 1970a, 1970b). Both complexes, and especially the Akmak, show strong affinities with arctic Upper Paleolithic cultures of northeastern Asia (Anderson, 1970a).

The Northern Archaic Tradition is represented by the Palisades II (Bands 7 and 6) and the Portage Complexes (lower Band 5). These

Figure 5

Correlation of Onion Portage archaeological sequence with radiocarbon chronology and cultural traditions, after Anderson (1968).

BAND	DATES B. P.	CULTURE	TRADITION
1	950-250	ARCTIC WOODLAND ESKIMO	ESKIMO
2	1550-1150	NORTHERN INDIAN	
		NORTON/IPIUTAK	ARCTIC SMALL-TOOL
3	3500-2500	CHORIS COMPLEX	
4	4200-3800	DENBIGH FLINT COMPLEX	ARCTIC SMALL-TOOL
5			
	4600-4200	PORTAGE COMPLEX	NORTHERN ARCHAIC
6	5900-4600	PALISADE II COMPLEX	
7	6000-5900		
8	8200-8000	KOBUK COMPLEX	AMERICAN PALEO-ARCTIC
pre 8	?15000-8500	AKMAK COMPLEX	

CULTURAL RECORD—ONION PORTAGE SITE

bands date 6000 - 5900 B.P., 5900 - 4600 B.P. and 4600 - 4200 B.P. respectively. The assemblages are characterized by such diverse artifacts as knotched projectile points, large lunar-shaped bifaces, net sinkers and needle-sharpening stones. This tradition is significant in showing affinities with Archaic archaeological assemblages far to the southeast in forested environments (Anderson, 1968).

The Arctic Small-Tool Tradition is represented by the Denbigh Flint (upper Band 5 and Band 4), Choris (Band 3) and Norton/Ipiutak complexes (lower Band 2). These Complexes date 4200 - 3800 B.P., 3500 - 2500 B.P., and 1600 to near 1200 B.P. respectively. These again are microblade industries but with stemmed projectile points, blade insets, beaked tools and adze blades (Anderson, 1968, 1970b). These complexes represent arctic cultures with inland as well as coastal affinities. Finally, over the past 1,000 years both northern Indian as well as arctic woodland Eskimo cultures occupied Onion Portage. One of the major goals of the Onion Portage research project is to interpret these different cultural traditions in terms of environment, climate and adaptation.

Previous Work - Quaternary Geology

Glaciers are known to have extended south from the Brooks Range, through the foothills, filling the Kobuk Valley down valley to the Baldwin Peninsula in Kotzebue Sound. This period of maximum glaciation has been correlated with the Illinoian Glaciation Stage of the United States mid-continent region (Hopkins, McCulloch and Janda, 1962; Coulter, *et al.*, 1965).

Fernald's reconnaissance study (1964) was the first mapping of surficial geology in the central Kobuk Valley. He mapped broad surfaces of till and outwash near the base of the foothills as representing a pre-Wisconsin glaciation he called the Kobuk Glaciation (Table 1). His younger drift, representing the Wisconsin age Ambler Glaciation, is seen as moraines and outwash deposits along the larger tributary valleys to the Ambler River near the mountain front. Still younger moraines near the headwaters of the Kobuk River are associated with the Walker Lake Glaciation.

Hamilton (1969, 1970 and 1973, unpublished manuscript) has conducted detailed surficial mapping and stratigraphic studies in the Kobuk Valley and valleys of its major tributaries. He recognizes an earlier Pre-Kobuk glaciation marked by high-altitude faceted bedrock spurs and glacial divides that transect the Jade Mountains at 500 to 600 m. altitude; this may represent the more extensive Illinoian Glaciation. In the western Brooks Range lower elevations and smaller accumulation areas may have inhibited the later ice advances. According to Hamilton, the Jade Mountains and Cosmos Hills south of the Ambler River (Figure 3) confined the ice so that it reached the Kobuk Valley floor only near the mouths of the principal tributaries. Meltwater streams caused extensive aggradation of the floor of the central Kobuk Valley and the lower portions of its tributaries. During the Kobuk Glaciation ice from the Ambler Valley and its principal tributaries coalesced and extended to a terminal position about 3 km. southwest of the village of Ambler (Figure 3). A series of recessional moraines lead back to near the mouth of the Ambler River.

Table 1

Glacial Chronologies and Correlations for the Central Kobuk Valley

Time-Stratigraphic Units	Fernald, 1964	Hamilton, 1969 and 1973 unpublished manuscript		Schweger, this study Epigurik Units
Holocene				
Late Wisconsin	Walker Lake Glaciation	Itkillik Glaciation	Walker Lake Stade Ambler Stade	C
Mid-Wisconsin	Ambler Glaciation	28,000 Interstade 40,000		B
Early Wisconsin		Kobuk Glaciation		A
Sangamon	Bluff 4, Epiguruk here			
Pre-Wisconsin	Kobuk Glaciation	Pre-Kobuk Glaciation		

To the west of Onion Portage, glaciers extended down the Hunt River drainage system to a terminus probably near the present course of the Kobuk Valley. Evidence of this lobe has been removed or is buried beneath later alluvium. What remains are exposures of outwash gravels (Fernald, 1964, p. 7) that form an outwash terrace extending east to Onion Portage and south toward the Kobuk River where it meets younger alluvium to the south (Figure 2). This younger alluvial surface, 30 - 50 m. in elevation, extends from the eroded flank of the outwash terrace to bluffs along the Kobuk River near Onion Portage. The composition and age of this alluvium will be discussed later in the section on the Epiguruk exposure.

Hamilton (1973, unpublished manuscript) has dated a post-Kobuk interstadial with four radiocarbon dates, two greater than 40,000 B.P., 33,000 B.P. and 28,000 B.P. The dated materials come from coarse-grained terrace deposits in the Ambler and Redstone Valleys where alluviation began during the late Kobuk Glaciation, persisted through a subsequent recessional stade and continued until at least 28,000 B.P., after which renewed glaciation began. These dates suggest an early-Wisconsin or pre-Wisconsin age for the Kobuk Glaciation. Hamilton concluded that an interstade, not an interglaciation, followed the Kobuk Glaciation and therefore it should be correlated with the early-Wisconsin. This being so, the later Ambler Glaciation (Fernald, 1964) may be correlated with the late-Wisconsin Glaciation of the standard North American mid-continent chronology. Hamilton (1969) has extended the glacial chronology of the southcentral Brooks Range into the central Kobuk Valley; Fernald's

Ambler and Walker Lake Glaciations now represent stades within the late-Wisconsin Itkillik Glaciation (Table 1).

The extent of the Itkillik glaciers in the central Kobuk region was controlled, as with the Kobuk Glaciation, by the lower snow source areas across the western portion of the Brooks Range. Glacial ice was therefore confined to the Ambler River Valley and its tributaries. Massive end moraine complexes were mapped near the mountain front along the Ambler Valley and its adjacent tributary (Figure 3). Glacial ice from the Redstone Valley flowed south to within 6 km. of its mouth where it formed a large end moraine belt of irregular topography. Exposures along the Redstone River indicate mixing of Ambler Valley river alluvium with outwash from the expanding Redstone glacier sometime after 30,000 B.P. A small glacier lobe extended part way down the Miluet Valley and smaller glaciers formed in the north-facing cirques of the Jade Mountains. In most valleys the Itkillik Glaciation is represented by a series of recessional moraines. Hamilton does not believe there is sufficient time separation to designate any of them as stadial significance.

During the Itkillik glacial maximum extensive alluviation from glacial streams produced floodplains at heights 30 - 35 m. above the modern river levels. Outwash aprons of sand and gravel were deposited near glacier termini and fluvial sands and silts were deposited down valley and throughout the central Kobuk Valley. These sediments are now exposed in high level terraces along the Ambler and Redstone Valleys, near the mouth of the Ambler River and in the Kobuk Valley near Onion Portage.

MODERN ECOLOGY OF ONION PORTAGE REGION

Climate

Weather records have never been kept at Onion Portage; the nearest climatic data are from Shungnak, 80 km. to the west, and from Kotzebue on the coast. The following data have been extrapolated for Onion Portage from Warhaftig (1965), United States Geological Survey National Atlas (1965, published separates) and Johnson and Hartman (1969) and should be viewed as a regional approximation.

Mean Annual Temperature, -5.3^{o}C.

Month	Daily Average (C^{o})	Daily Average Minimum (C^{o})	Daily Average Maximum (C^{o})
January	-23	-26	-17
April	-9	-15	-4
July	10	9	-20
October	-7	-9	-4

Mean annual precipitation is only 203 mm, mean annual snowfall is between 1270 mm and 1900 mm. There are less than 40 wet days per year (a wet day has 2.54 mm or more of water precipitation), [illegible] the average over most of Alaska. For Kotzebue the average freeze free growing season is less than 90 days; at Shungnak only 65 d[illegible] the figure for Onion Portage is closer to the latter. The [illegible]onal temperature variation (half the difference between mean July and mean January temperature) is over 19°; this, according to Johnson and Hartman (1969) puts this region into a continental climatic zone. Watson (1959) would place it into an arctic climate, but near the boundary of the continental climatic zone. The mean annual evapo-transpiration is 14 inches, leaving a negative water balance of 6 inches. Using Thornthwaite's index system, this area is classified as a semiarid climate (Newman and Branton, 1972).

From my observations the summers are highly variable, periods of unusually warm, dry weather, with temperatures in the 20's are often quickly replaced by cool, cloudy weather that may bring rain or snow and freezing temperatures as early as mid-August. Another important climatic factor, especially from the standpoint of vegetation and sedimentation, is the very strong winds that most frequently blow to the south out of the mountain valleys. These have often been strong enough to topple trees and remove great quantities of sand from the river bars and floodplains, and are important in the distribution of winter snowfall.

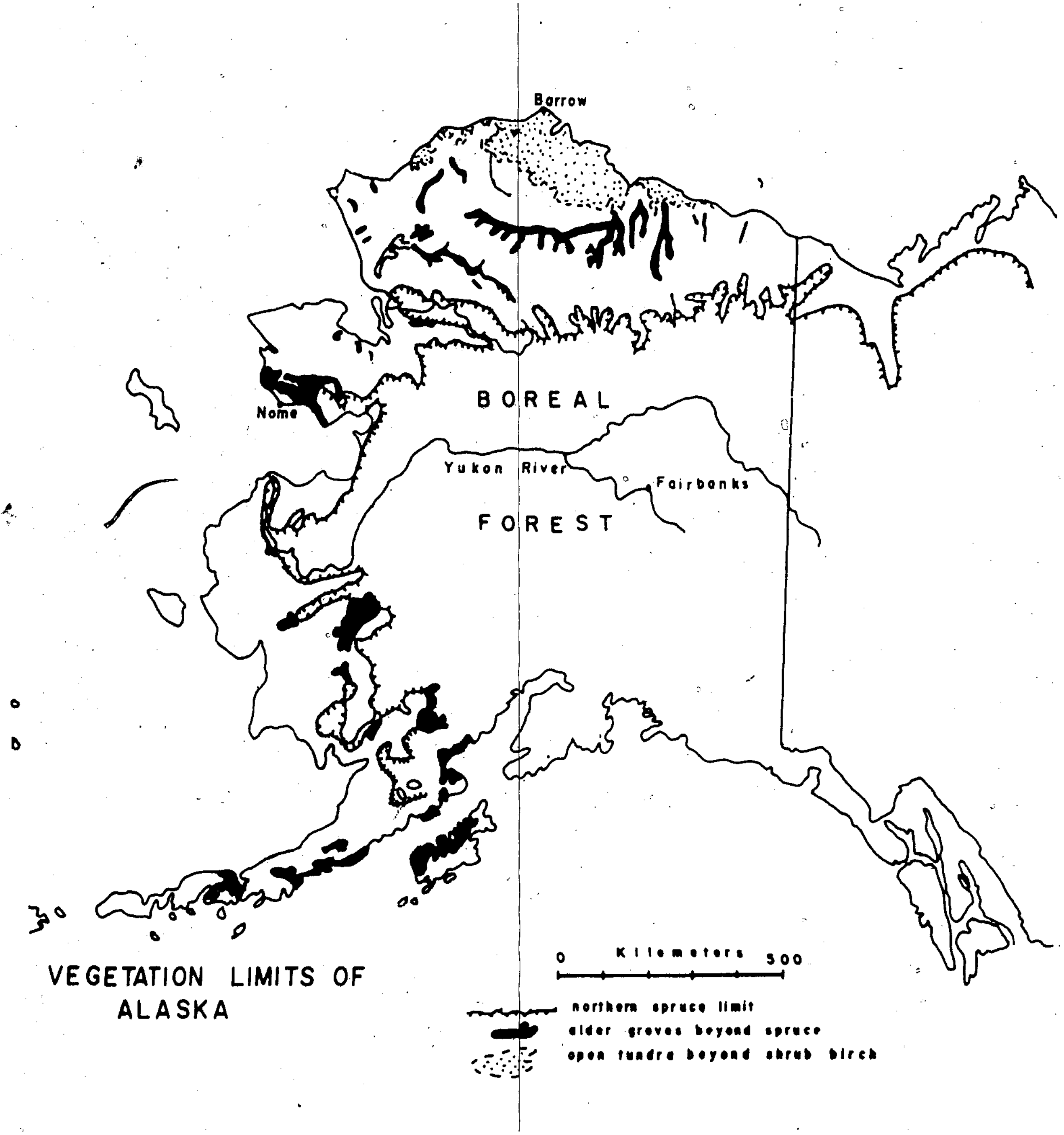
Regional Vegetation

The interior of Alaska can be described as boreal forest or taiga, while the northern and western coastal regions are tundra vegetation (Figure 6). However, a variety of factors, most importantly topography and local climatic differences, complicates this simple pattern so that the forest-tundra boundary interdigitates and becomes diffuse to form a broad ecotone (Sigafoos, 1958; Kuchler, 1966; Viereck and Little, 1972).

Onion Portage lies within a tongue of spruce forest that extends westward from the forests of interior Alaska along the Kobuk

<u>Figure 6</u>

Map of Alaska showing the limits of plant taxa important in the vegetation cover.



VEGETATION LIMITS OF
ALASKA

Valley to the coast at Hotham Inlet, Kotzebue Sound. At the coast and scattered across the broad delta of the Kobuk River, stunted Picea glauca and Populus balsamifera trees and Alnus crispa and Salix sp. shrubs form narrow bands of forest along channel margins and old ox-bow sloughs where permafrost is absent. Inland, this restricted assemblage zone becomes progressively broader and more complex as it occupies more diverse habitats until a gallery forest is formed and eventually merges with the boreal forest of the interior.

Forest meets alpine and arctic tundra south and north of the Kobuk Valley and to the west lies coastal tundra. As a result, a broad complex ecotone of forest, woodland and tundra communities has developed. This vegetation mosaic is highly dependent upon microenvironment, substrate conditions, climate and succession (Hopkins and Sigafoos, 1951; Hansen, 1953; Spetzman, 1959; Johnson, et al., 1965; Britton, 1967).

The boreal forest zone of the Kobuk Valley is entirely comparable in composition and dynamics to the forest of the Alaskan interior (Lutz, 1956; La Roi, 1967; Hulten, 1968). Forest fires (Lutz, 1956), permafrost development (Viereck, 1970) and nutrient supply (Heilman, 1966, 1968) are the important factors in determining the successional relationships and maintaining the forest diversity and mosaic dominated by spruce.

Alnus crispa shrubs are common in the forest and tundra vegetation of the Kobuk Valley. Beyond the tree-line it dominates many regions of shrub tundra; it also forms dense sub-alpine zones on slopes and riparian thickets along valley bottoms that penetrate the Brooks Range (Figure 6; also Sigafoos, 1958; Spetzman, 1959; Viereck and Little, 1972).

An open shrub tundra dominated by low shrubs of Betula glandulosa, B. nana and Salix (various species) and species of Cyperaceae, Compositae, Ranunculaceae, Saxifragaceae, Rosaceae and Scrophulariaceae is found north of the Brooks Range and at higher elevations. Near Point Barrow and along the northern coast the tundra is dominated by Cyperaceae and Gramineae species; Betula sp. is not found here and Salix species are the dominant shrub forms (Spetzman, 1959; Britton, 1967).

The four major vegetation zones briefly described here as the boreal forest, alder-birch shrub tundra, birch shrub tundra and open sedge tundra appear to have regional climatic significance. Hopkins (1959) has shown that the spruce tree-line in northern Alaska is determined largely by the summer temperature; the tundra climate is marked by less than 130 degree-days above 50°F. Summer temperatures, which are most important to plant growth and reproduction, reach their lowest values at Point Barrow and along the northern coast but increase inland to the south. Clebsch and Shanks (1968) demonstrated the effect of this summer temperature gradient on the vegetation gradient near Barrow, where tundra shrubs increase in abundance and graminoid species decrease away from the coast. Matthews (1970) believes that the northern distribution of Betula nana parallels the -12°C. mean annual isotherm.

Young (1971) has provided the most complete treatment of arctic floristic zonation and climatic controls. He recognizes four major floristic zones beyond the spruce tree-line. Most of northern Alaska is in zone 4, which contains both Alnus ssp. and Betula glandulosa. A thin strip along the northern coast where alder and B. glandulosa are not found is in zone 3. Only the Point Barrow region of mainland Alaska, where Betula nana is not found, is in zone 2, as is the greatest part of the Canadian Arctic Archipelago. Floristic zone 1 represents the coldest regions surrounding the Arctic Basin. Young's analysis of the controlling ecological factors demonstrates the significance of the summer temperature. By computing an "a" value from the sum of mean temperatures of all months having a mean temperature above 0°C., he showed that zone 1 stations characteristically have an "a" between 0 and 6, zone 2 between 6 and 12, zone 3 between 12 and 20, zone 4 between 20 and 35 and zone 5, timbered regions, over 35. Young (1971) hypothesized that, "the reproductive phase of the life cycle of a plant is the most sensitive to critically low amounts of warmth, either in the production of propagules or their germination."

In addition to any climatic significance, the four vegetation zones outlined for northern Alaska (Figure 6) is each characterized by a dominant plant taxon; spruce, alder, birch and sedge dominate respectively, the forest, alder-birch tundra, birch shrub tundra and open tundra. This greatly aids the interpretation of the paleoecological record based on pollen analysis in northwestern Alaska.

Flora of the Onion Portage Region

The first step in describing the plant ecology of the Onion Portage region was determination of the local flora. Since botanical data from the Kobuk Valley are sparse, it was necessary to collect the flora from this region. Only in this way was it possible to determine what species were present. The resulting plant collection also served as the basis of an important pollen reference collection.

Most of the collection was made within a 10-kilometer radius of Onion Portage and represents both forest and shrub tundra. Over 1,000 specimen sheets were collected; a complete set of voucher specimens was deposited in the herbarium of the University of Alaska. Other sets were deposited in the herbariums of the University of Arizona, Brown University, Haffenreffer Museum and University of Alberta. All my identifications were checked by Dr. Vernon Harms, Botany Department, University of Saskatchewan; he also saw to it that certain groups were examined by specialists. Hulten (1968) was used as final authority for nomenclature.

Appendix I lists the 171 vascular species that were collected. No doubt more intensive collecting would increase this flora, particularly the grasses, sedges and aquatics. For example, over 300 species were collected from the Ogotoruk Creek drainage near Cape Thompson on the northwest coast of Alaska (Johnson, et al., 1966). The Onion Portage flora demonstrates very well the degree to which boreal forest and arctic tundra are mixed in this ecotonal region. A typical Alaskan boreal forest can be assembled as well as a typical arctic tundra.

Most noticeable, however, is the large number of taxa that reach or extend their western range limits here, based on the distribution maps from Hulten (1968). *Picea mariana*, *Populus tremuloides*, *Betula glandulosa* and *Betula papyrifera* attest to the development of typical boreal forest vegetation at Onion Portage along with the following: *Lycopodium annotinum* ssp. *annotinum*, *Agrostis scabra*, *Carex canescens*, [illegible]. *brunnescens*, *Juncus alpinus*, *Iris setosa* ssp. *interior*, *Habenaria hyperborea*, *Spiranthes romanzoffiana*, *Goodyera repens*, *Geocaulon lividum*, *Nuphar polysepalum*, *Aquilegia brevistyla*, *Delphinium glaucum*, *Anemone multifida*, *Corydalis sempervirens*, *Draba stenoloba*, *Capsella bursa-pastoris*, *Potentilla norvegica* ssp. *monspeliensis*, *Pyrola secunda*, *Moneses uniflora*, *Ledum palustre* ssp. *groenlandicum*, *Viburnum edule*, and *Arnica alpina* ssp. *attenuata*. The Onion Portage flora indicates a far westward extension and development of the boreal forest typical of the interior of Alaska.

Three other taxa display marked range extensions. *Pyrola chlorantha*, previously, was not known from north of the Yukon River. *Poa leptocoma* is a rare species with a southern maritime distribution; its discovery here on wet tundra is a significant range extension. *Corispermum hyssopifolium* has only been recorded from four other scattered localities in Alaska. This is only the second time that *Oxytropis kobukensis* has been collected; this species found on sand dunes near the mouth of the Hunt River, is apparently endemic to this region.

Composition and Structure of Forest and Tundra Communities of the Onion Portage Region

The distribution of forest and tundra in the central Kobuk River Valley creates a mosaic of vegetation types. In order to interpret the sequence of late Quaternary vegetation development it is necessary to determine what factors interact to control the modern plant communities and their distributions. This again is only the application of Uniformitarianism to paleoecology.

The environmental factors that interact to determine the nature of the vegetation mosaic near Onion Portage are slope, aspect, site age, substrate composition, drainage, stand history, succession, snow cover and permafrost. The latter is one of the most significant factors, since it interacts directly with all the other factors in a complex relationship. In order to describe more fully the vegetation mosaic near Onion Portage, four forest and two tundra communities were selected for detailed study. These six stands were selected on the basis of topographic position and soil type along an environmental transect that intersected a variety of vegetation types. These vegetation types are typical members of the regional mosaic. They cover a region of approximately one square kilometer north and west of the archaeological site.

In order to sample the various strata within the forest stands, a point-quarter method, as outlined by Cottam and Curtis (1956), was employed. In addition, one square meter quadrats were used for surface and open vegetation. The tree strata were represented by individuals with a breast-height basal area greater than 31 cm.^{2}; saplings and high-shrubs had basal diameters greater than 2.5 cm. and seedlings and shrubs had smaller stems. Twenty random points and quadrats were used to sample each stand. From these data percentages of species density, frequency and dominance were calculated. The sum of these three measures is the species Importance Value (I.V.). These calculations followed the method outlined by Cottam and Curtis (1956) and Curtis and Cottam (1964). For the herbaceous species in each quadrat only presence was noted and tabulated for each stand. Forest stand results are given in Table 2 and Table 3 lists presence values for species encountered in quadrats from each stand.

Although this is a boreal forest, Populus balsamifera and Betula papyrifera dominate stand I and stands II and III respectively. Spruce, Picea glauca, is, however, the only other important tree species in these stands and Picea mariana dominates stand IV along with P. glauca. Spruce dominates the sapling and high-shrub stratum in all stands to a greater degree, but here Salix glauca, Salix bebbiana and Alnus crispa also become important. Considerable variation is seen in the seedling and shrub stratum with the shrub birches Betula glandulosa and Betula nana becoming important and dominating the dense shrub layer of stand IV.

The herbaceous data (Table 3) combine quadrat data from the four forest and two adjacent tundra stands. There is a marked variation in the herb layer in the six stands. Vaccinium vitis-idaea, V. uliginosum and Empetrum nigrum occur in all stands, while a number of

Table 2

Forest Stand Composition Data

Species	Trees			Importance
	% Frequency	% Density	% Dominance	Value
STAND I				
Picea glauca	34.1	35	31.8	100.9
Betula papyrifera	22	16.3	13.2	51.5
Populus balsamifera	31.7	42.5	52.4	126.6
Populus tremuloides	4.9	2.5	1.3	8.7
Salix glauca	7.3	3.8	0.9	12.0
927 trees/hectare				
STAND II				
Picea glauca	45.5	42.5	56	144
Betula papyrifera	54.5	57.5	44	156
416 trees/hectare				
STAND III				
Picea glauca	16.7	10	9.7	36.4
Betula papyrifera	83.3	90	90.3	263.6
312 trees/hectare				
STAND IV				
Picea glauca	43.8	32.9	46.9	123.6
Picea mariana	56.3	67	53.1	176.4
156 trees/hectare				

Species	Saplings-High Shrubs		Seedlings-Shrubs	
	% Frequency	% Density	% Frequency	% Density
STAND I				
Picea glauca	31.4	43.8	13.9	21.2
Populus balsamifera	28.5	26.3	20.9	23.8
Populus tremuloides	2.9	1.4	6.9	6.3
Betula papyrifera	2.9	1.4	4.6	2.5
Salix glauca	31.4	26.3	30.1	18.8
Alnus crispa	2.9	1.4		
Betula glandulosa			23.2	27.8
	927 stems/hectare		4.156 stems/hectare	

..... continued

Table 2 -- Continued

	Saplings-High Shrubs		Seedlings-Shrubs	
Species	% Frequency	% Density	% Frequency	% Density
STAND II				
Picea glauca	38.5	41.3	33.4	41.3
Picea mariana	2.6	1.2		
Betula papyrifera	38.5	47.5	22.2	23.8
Salix bebbiana	12.6	6.2	24.4	16.3
Salix glauca	7.7	3.7		
Betula glandulosa			11.1	11.5
Populus tremuloides			8.9	7.5
	494 stems/hectare		1,041 stems/hectare	
STAND III				
Picea glauca	38.3	39.3	35.3	35
Betula papyrifera	34.1	41.6	15.7	12.5
Betula glandulosa	10.6	8.8	11.5	18.7
Salix glauca	12.5	7.6	19.6	16.3
Salix bebbiana	4.3	2.6	11.5	13.7
Populus tremuloides			5.9	3.7
	129 stems/hectare		331 stems/hectare	
STAND IV				
Picea mariana	41.9	61.2	25	17.5
Picea glauca	11.6	7.5	2.5	1.2
Alnus crispa	25.6	18.7	2.5	1.2
Salix glauca	20.9	12.5	15.0	15.0
Betula glandulosa			32.5	32.5
Betula nana			22.5	32.5
	657 stems/hectare		17,313 stems/hectare	

Table 3

Stand Quadrat Data as Present in 20 One-Meter Square Quadrats

Species	QUADRATS					
	I	II	III	V	VI	IV
Rubus arcticus	2					
Polemonium acutiflorum	2					
Populus balsamifera	3					
Moehringia laterifolium	6					
Aconitum delphinifolium	7					
Galium boreale	7					
Viburnum edule	8					
Calamagrostis lapponica	13					
Epilobium angustifolium	14					
Rosa acicularis	14	1				
Lineae borealis	15	6				
Betula papyrifera	1	2	1			
Equisetum pratense	12	2	1			1
Picea glauca	2	3	1	1		
Empetrum nigrum	2	2	1	7	1	2
Vaccinium vitis-idaea	13	20	20	20	14	18
Vaccinium uliginosum	10	13	6	19	17	20
Ledum decumbens	7		1	19	11	16
Spiraea beauverdiana	4					1
Salix glauca	3				11	3
Pedicularis labradorica		10	8	1	3	2
Betula glandulosa		1			1	9
Salix bebbiana		3				
Lycopodium complanatum		1				
Festuca altaica			4			
Carex sp.				19	20	19
Betula nana				10	19	9
Pyrola secunda obtusata				6	1	
Pedicularis sudetica				5	2	
Arctostaphylos alpina				1	13	7
Loiseleuria procumbens				1		
Andromeda polifolia					19	8
Rubus chamaemorus					10	12
Equisetum scirpoides					9	3
Oxycoccus microcarpus					7	6
Picea sp.					5	4
Eriophorum vaginatum					5	1
Poa leptocoma					3	
Arctagrostis latifolia					3	3
Tofieldia pusilla					2	1
Petasites frigidus						6
Chamaedaphne calyculata						1
Valeriana capitata						1
Spiranthes romanzoffiana						1
Cryptogams	17	16	20	7	20	20
Cladonia sp. presence and % cover	5,<1%	18,16%	20,47%	20,34%	10<1%	5,<1%

species such as Epilobium angustifolium and Chamaedaphne calyculata are restricted to only one stand. Forest stand IV is unique in that its herb assemblage most closely resembles the tundra stand IV.

Environmental Controls in the Onion Portage Region

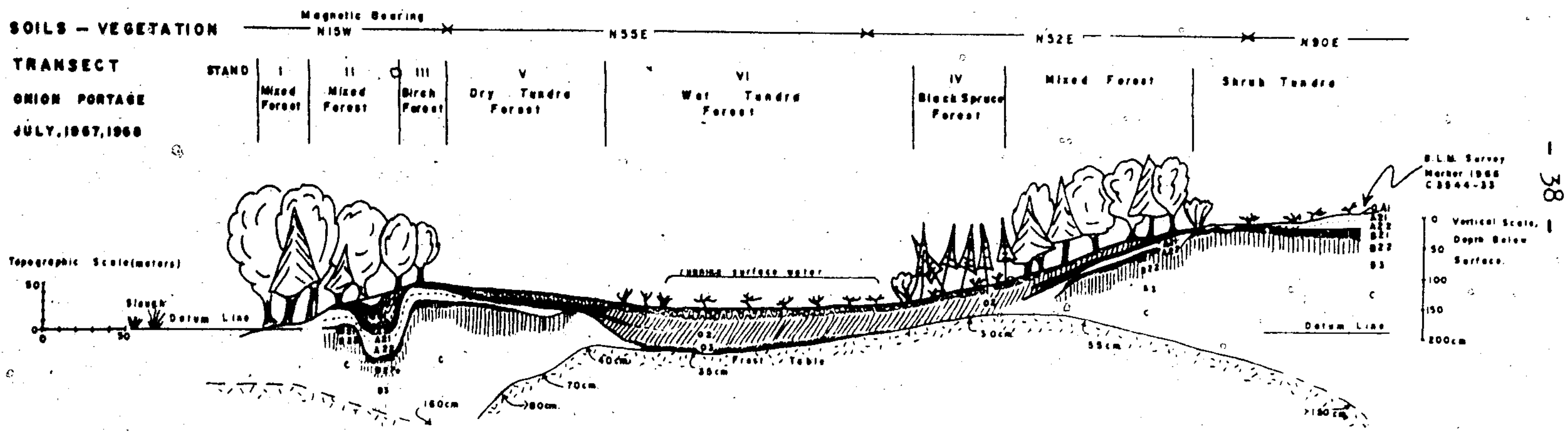
The six stands just discussed display considerable variability even though they are contiguous. In order to demonstrate the relationships and explain the differences between the stands and the substrate environment, a transect across the study area was examined; topography, soil development, drainage, permafrost and vegetation were noted. A cross-section summary of this transect is shown in Figure 7. The soil parent material across this transect is a uniform fine-grained sandy silt and is, therefore, not an important variable. The frost table depths were measured in mid-July and are probably not maximum depths although they no doubt are close to the permafrost table.

The slough, just west of the archaeological site, is on the present floodplain; it floods during the spring and dries out by fall. The permafrost depth was approximately 50 cm. The soil is a gleyed azonal profile built up by alluvial deposition with virtually no organic matter added to the profile. Equisetum palustre L. and mosses are the only vegetation in the open wet portion of the slough; Salix glauca and Carex sp. are important near the edge.

Stands I, II and III are situated on a series of terrace remnants formed as the Kobuk down-cut during late-glacial time.

Figure 7

Cross-section of soils-vegetation transect at Onion Portage. Survey Marker, B.L.M. 1966, C 3544-33, locates the north end of the transect.



SOILS — VEGETATION TRANSECT

ONION PORTAGE

JULY, 1967, 1968

Depth to permafrost is 80 cm. under stand I, 100 to 120 cm. under stand II and up to 160 cm. under stand III. The soil of these three forest stands and tundra stand V is a very well-developed podzol, the variable O and A horizons (U.S. soil terminology) thicken on the poorly drained sites and thin on slopes and ridge crests. The B horizons, differentiated on the basis of color, show no textural variation. Frost cracking and churning are evident in soil profiles from stands III and IV. Across the transect Cladonia sp. surface cover increases from less than 1% in stand I to 47% in stand III, but drops to 34% in stand V and is less than 1% in stands VI and IV. Stem density for trees, saplings, high shrubs and seedling shrubs decreases from a total of 6,010 in stand I to 772 in stand III. Stands V and VI are open tundra, but stem density reaches a maximum total of 18,126 in stand IV.

Populus balsamifera is found only along the first terrace adjacent to the slough. River or slough margins with immature soils subject to occasional flooding is typical of the habitat of this species. Stand II on the second terrace represents the mesic condition whereas stand III on the upper terrace represents a dry site. Although Picea glauca is important in both stands I and II, it is less so in stand III where Betula papyrifera dominates an open forest. The edge of stand III marks a local tree-line.

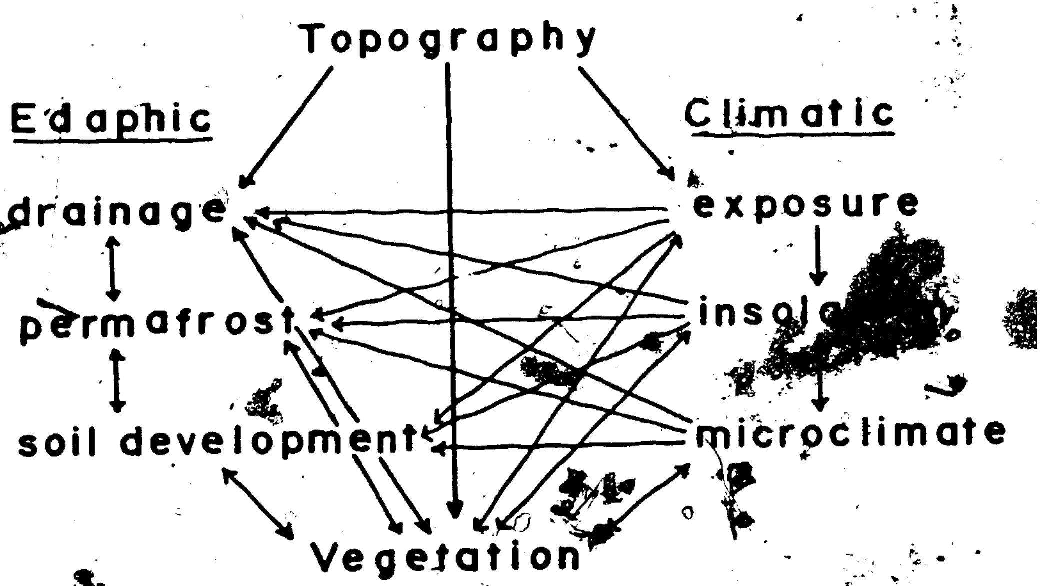
Tundra stands V and VI are located across a broad swale rising to a ridge. Permafrost rises under stand V from over 100 cm. to 40 cm. and is only 35 cm. beneath the surface in stand VI. The soils change from podzolic profiles in V to azonal tundra-bog soil in VI, and frost churning was evident in most of the profiles examined. Soil drainage is very poor in stand VI and surface water was common.

Beneath forest stand IV the permafrost table is reached in only 30 cm., as a result the soil drainage is generally poor. The soil is an azonal tundra-bog profile but upslope the permafrost table drops, drainage improves and a podzolic profile develops. The tree stratum dominated by Picea mariana is very open since most of the mature stems are stunted and too small for trees. The high numbers of sapling-high shrubs and seedling-shrubs makes this a very dense stand. Stand IV is typical of the stunted black spruce "drunken" forests common in the interior of Alaska, where permafrost is shallow and bog soils predominate. Continuing upslope, Picea mariana is rapidly replaced by Picea glauca, and Betula papyrifera and Populus tremuloides appear to form a mixed hill side community. At the upper edge of the hill, forest gives way to a shrub tundra vegetation dominated by Betula glandulosa, B. nana, Salix sp., Ledum decumbens and a variety of graminoid species.

This transect demonstrates a number of important interrelationships between the regional vegetation and the environment. The general factors and interrelationships are outlined in Figure 8. Topography is the primary influence since it determines the edaphic as well as climatic factors that ultimately operate on the vegetation. Drainage affects permafrost, wet soils have different thermal properties than dry soils, and it affects soil development. Both permafrost and

Figure 8

Outline of major edaphic and climatic factors influencing vegetation mosaic in Onion Portage region. Arrows indicate interrelationships.


Topography
Edaphic
Climatic
drainage
exposure
permafrost
insolation
soil development
microclimate
Vegetation

drainage in turn affect the vegetation. Exposure (slope and aspect) affects both the insolation and microclimate and each of these operates on the vegetation. But these interrelationships are more complex in that the type of vegetation cover operates to change each of the above factors and the climatic factors operate directly or indirectly to influence the edaphic factors. Examples from the Onion Portage transect will help to illustrate these interrelationships.

Across this transect the permafrost table drops deeper beneath the surface under ridges and is generally shallow elsewhere. This is the result of higher insolation and better subsurface drainage on the ridges. Wind blown ridges, however, are free of snow and may have greater soil movement (cryoturbation) as a result of insulation loss and the more rapid heat exchange. This is seen in the frost cracks and boils along tundra ridges near Onion Portage. Wet depressions have a thick moss-sedge layer which effectively insulates the soil during summer, maintaining a shallow permafrost table which further impedes drainage. Cool, wet soils have incomplete organic decomposition with the production of humic acids, and low pH increases the competitive advantage of mosses. Drainage affects soil development, for azonal tundra and bog soils develop where drainage is poor, while podzolic profiles are found on better drained sites. These factors and interactions have been effectively demonstrated and discussed for Alaska by Hopkins and Sigafoos (1951), Brown and Johnson (1965), Holowaychuk et al. (1966), Heilman (1966, 1968) and Viereck (1970) and in Canada by Brown (1969).

An additional factor in soil development at Onion Portage is the role of soil lichen Cladonia sp., which is the important or dominant ground cover on well-drained podzolic soils. Lichens supply abundant plant acids and chelators to the soil profile that greatly aid the leaching process, resulting in the formation of an A2 horizon (Ae - Canadian equivalent) and a podzolic profile. Cladonia from stand III was collected and mixed with river water, of near neutral pH; the pH of the water dropped to 3.5, indicating that abundant soluble acids had been leached from the lichens. This is no doubt another factor in the development of the podzols at Onion Portage, and another example of the way in which vegetation affects soil development.

Permafrost further affects the vegetation of this region by controlling the distribution of the deep-rooted tree species such as Populus tremuloides and Betula papyrifera which occupy ridges and exposed knolls on the tundra as well as large areas of stabilized dune sand south of the Kobuk River. Frozen ground prevents deep root penetration and so these trees are restricted to well-drained sites where the depth to permafrost is great. B. papyrifera, and to a lesser extent P. tremuloides, is common at local tree lines such as stand III, and it is not uncommon to see an isolated clump of B. papyrifera on a small hill surrounded by treeless tundra. These deciduous species have a definite advantage in these locations. Frequent strong winds characterize this region. During the early spring when tree roots and soil are still frozen and the trees cannot transpire winds put maximum water-loss stress on the evergreen spruce and less stress on the deciduous trees, which are leafless at this time.

Other evidence of the effect of strong winds on vegetation is seen in frequent winter burn damage and tip-overs. Most exposed spruce trees show evidence of ice and snow abrasion and wind damage; isolated spruce in stands V and VI are damaged at a height of 50 to 60 cm., just above the mean snow depth, many stems are dead and krumholtz are formed. A dense, well-developed spruce forest is found in a valley north of the Jade Mountains. This is a narrow, sheltered valley protected from strong winds. Wind must be considered an important factor in the establishment of local tree lines in this region of the Kobuk Valley. Extensive areas of [illegible] and vegetated sand dunes further attest to its significance [illegible] plant ecology of this region (Figure 2).

In summary, the [illegible] of the Onion Portage region represents a mixture of tundra and boreal forest elements, the latter are frequently near their western limits. Forest communities show considerable variety in their composition and structure, with deciduous tree species often dominating over wide areas of this region. Topography and permafrost appear to be dominant factors in influencing this pattern of forest and tundra vegetation.

PALEOECOLOGICAL RECONSTRUCTION: PHYSICAL CRITERIA

Epiguruk Exposure

A large cut-bank exposure (Figure 9) approximately 7 km. up river from Onion Portage displays much of the alluvial history of the central Kobuk Valley, and has provided the basic stratigraphic framework for much of the late Quaternary paleoecological history of the Onion Portage region. This exposure, Fernald's bluff locality 4 (1964, p. 23), is here called by its local Eskimo place name, Epiguruk. Fig[illegible] 10 represents a detailed cross-section of the first 900 m. upstream direction. This section was assembled from detailed measured sections every 50 m. and from observations over a period of three field seasons, since slumping continually modified the exposure.

Sedimentary Units

Five sedimentary units (A to E) were recognized; they are described in detail below and shown in Figures 9, 11 and 12.

Unit A is a coarse-grained sand, moderately well sorted, and gray to buff in color (Figure 9); cross-bedding and current ripple marks are common. This lithology is remarkably uniform over the entire Epiguruk exposure; no gravel or cobbles were observed. The upper contact, between 50 and 350 m. along the river (Figure 10), is a sharp, commonly unconformable break to a dark gray silt or sand. Ripple marks and small peat balls were observed at this contact.

Figure 9

View of Epiguruk from Kobuk River, Unit A represented by bedded sands in lower two-thirds of exposure; Unit B is dark horizon approximately two-thirds above base; Unit C is light colored silts in upper one-third of exposure. Here exposure is approximately 40 meters high.

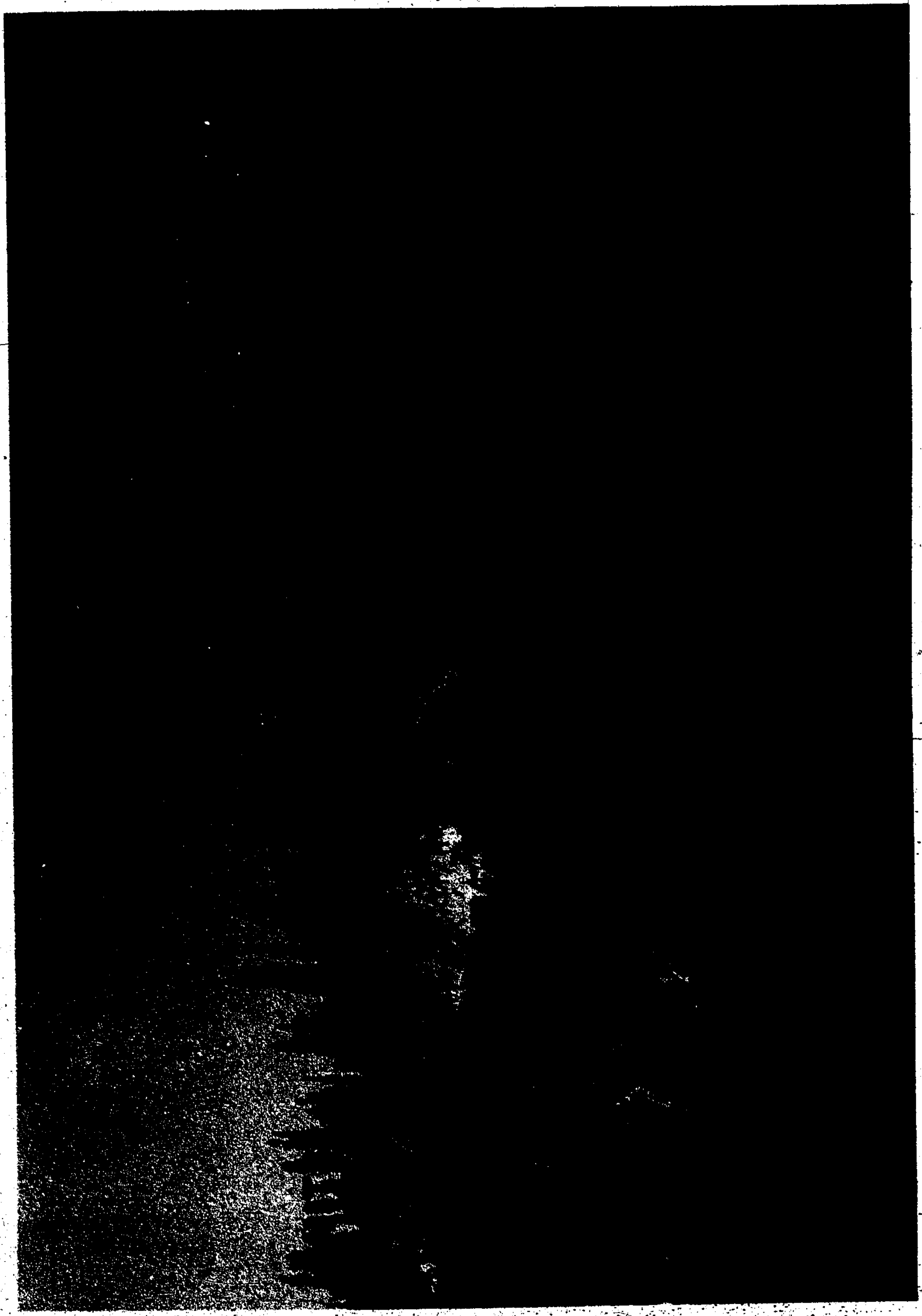
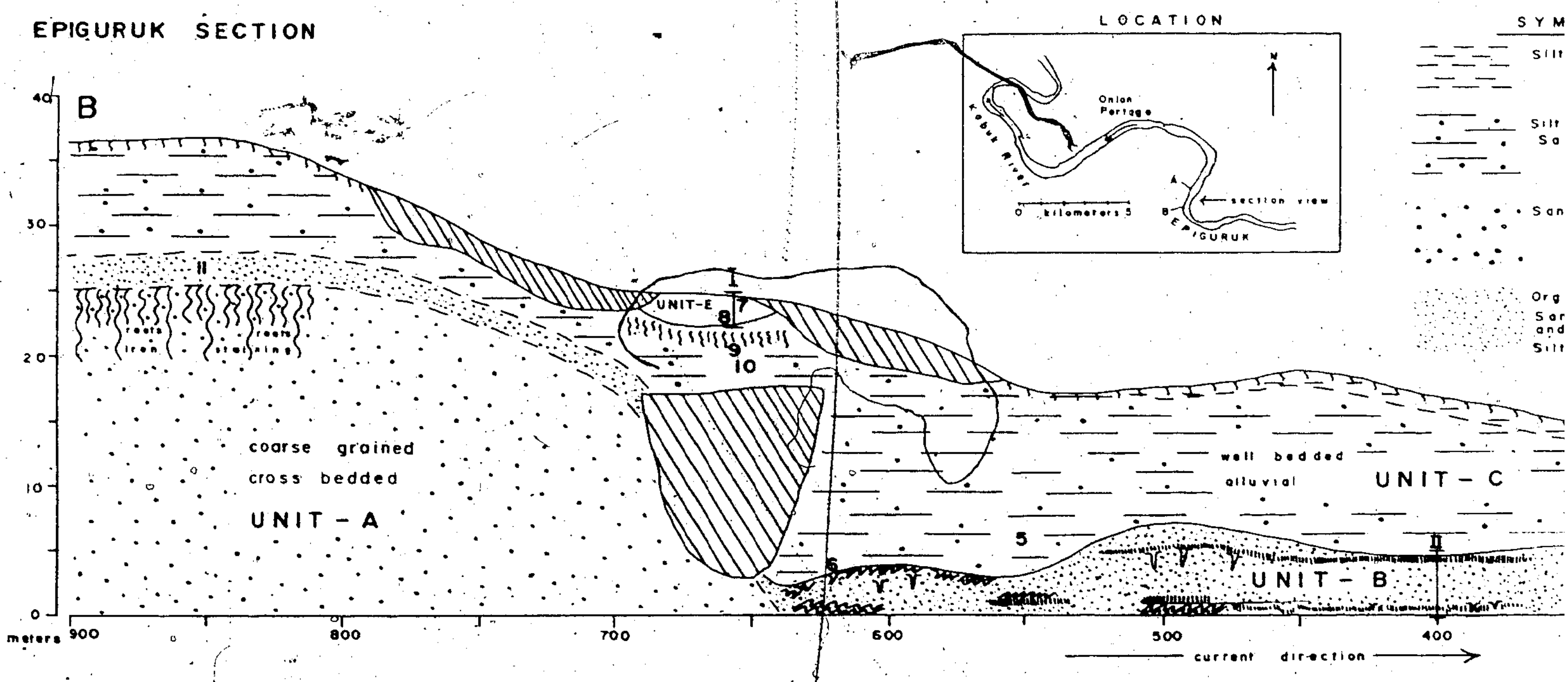
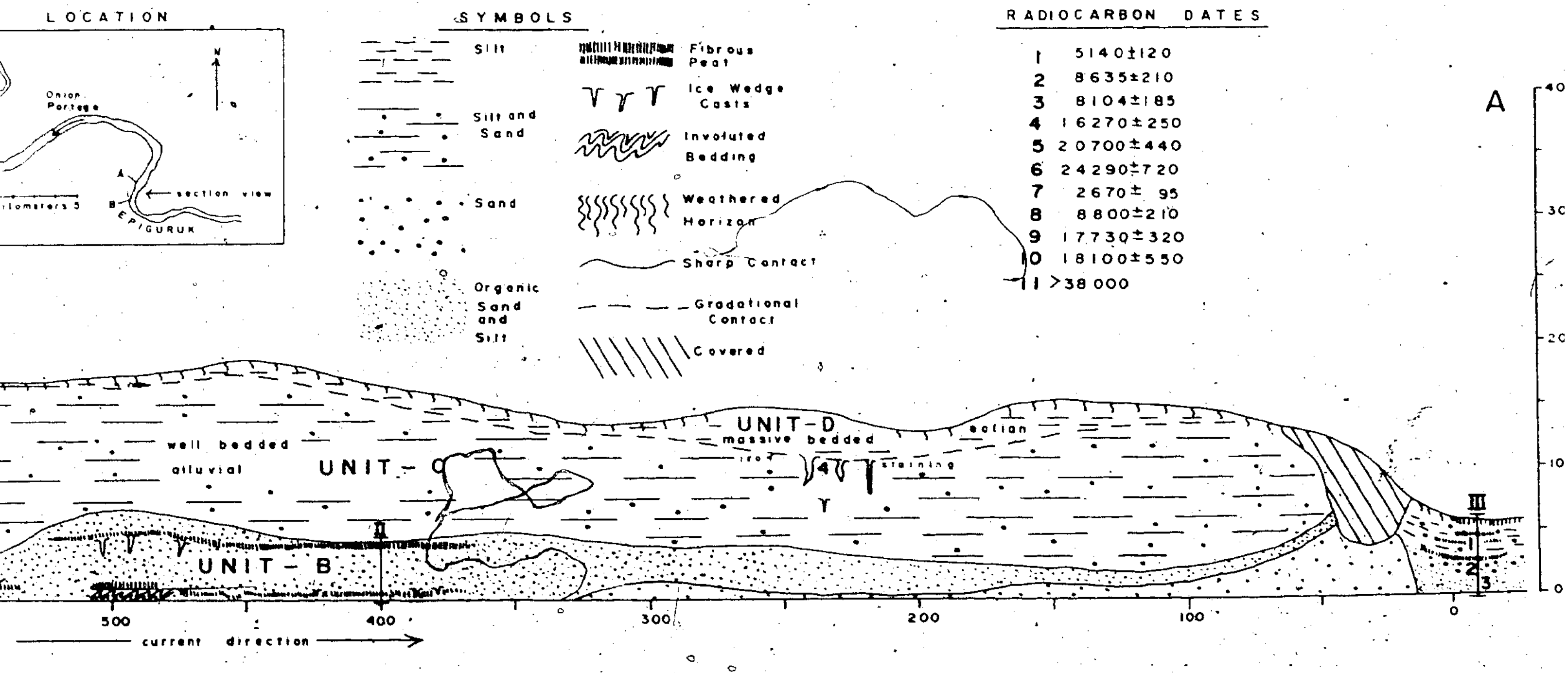


Figure 10

Cross-section of Epiguruk, first 900 m. upstream direction represented. Stratigraphic relationships are from detailed measured sections; pollen sections and radiocarbon dates are shown.

EPIGURUK SECTION




LOCATION
Onion Portage
N
A
B
section view
ilometers 5
EPIGURUK
SYMBOLS
Silt
Silt and Sand
Sand
Organic Sand and Silt
Fibrous Peat
Ice Wedge Casts
Involuted Bedding
Weathered Horizon
Sharp Contact
Gradational Contact
Covered
RADIOCARBON DATES
1 5140±120
2 8635±210
3 8104±185
4 16270±250
5 20700±440
6 24290±720
7 2670± 95
8 8800±210
9 17730±320
10 18100±550
11 >38 000
A
40
30
20
10
0
UNIT-D
massive bedded
eolian
iron staining
4
UNIT-C
well bedded
alluvial
UNIT-B
II
III
1
2
3
500
400
300
200
100
0
current direction

Unit A and this upper contact are beneath the river level over much of this section. When they reappear, near 650 m., the contact is transitional, over 1.5 m. to a dark brown, organic sand. Between 800 and 900 m. an iron-stained, weathering zone with rootlets marks the upper part of Unit A. This unit is interpreted as a fluvial sand.

Unit B is a highly variable deposit of dark brown organic silts and sands, peats and (gray) lacustrine silts. At a point 50 m. along the river (Figure 10) it is a dark gray silt and fine-grained sand but it becomes brown in color and gives off a fetid odor at 325 m. where the organic content increases markedly. Up river from this point, lacustrine silts with mollusca are observed along with prominent bryophytic peats and interbedded organic sands and silts (Figure 11). Small ice-wedge casts of organic silt are associated with the bryophytic peats and between 570 and 635 m. the bedding is highly involuted and deformed (Figures 11 and 12). Unit B from 700 to 900 m. is a dark brown, organic rich, silty sand. The upper contact, a marked unconformity, provides a sharp break between Units B and C over most of the section. Vertebrate remains recovered from Unit B include an elephant (probably mammoth), bison, caribou, dire wolf and giant beaver. (Personal communication, G. Lammers, Manitoba Museum of Natural History.) This unit is interpreted as an inter-stadial organic deposit.

Unit C is a well-bedded, tan to gray, fine-grained sand and silt (Figure 12). It is very uniform over the exposure; no coarse-grained material was observed. The horizontal beds are one to three cm.

Figure 11

River view of Epiguruk Unit B and lower portion of Unit C at locality of Pollen Section II. Note involutions in Unit B bedding.

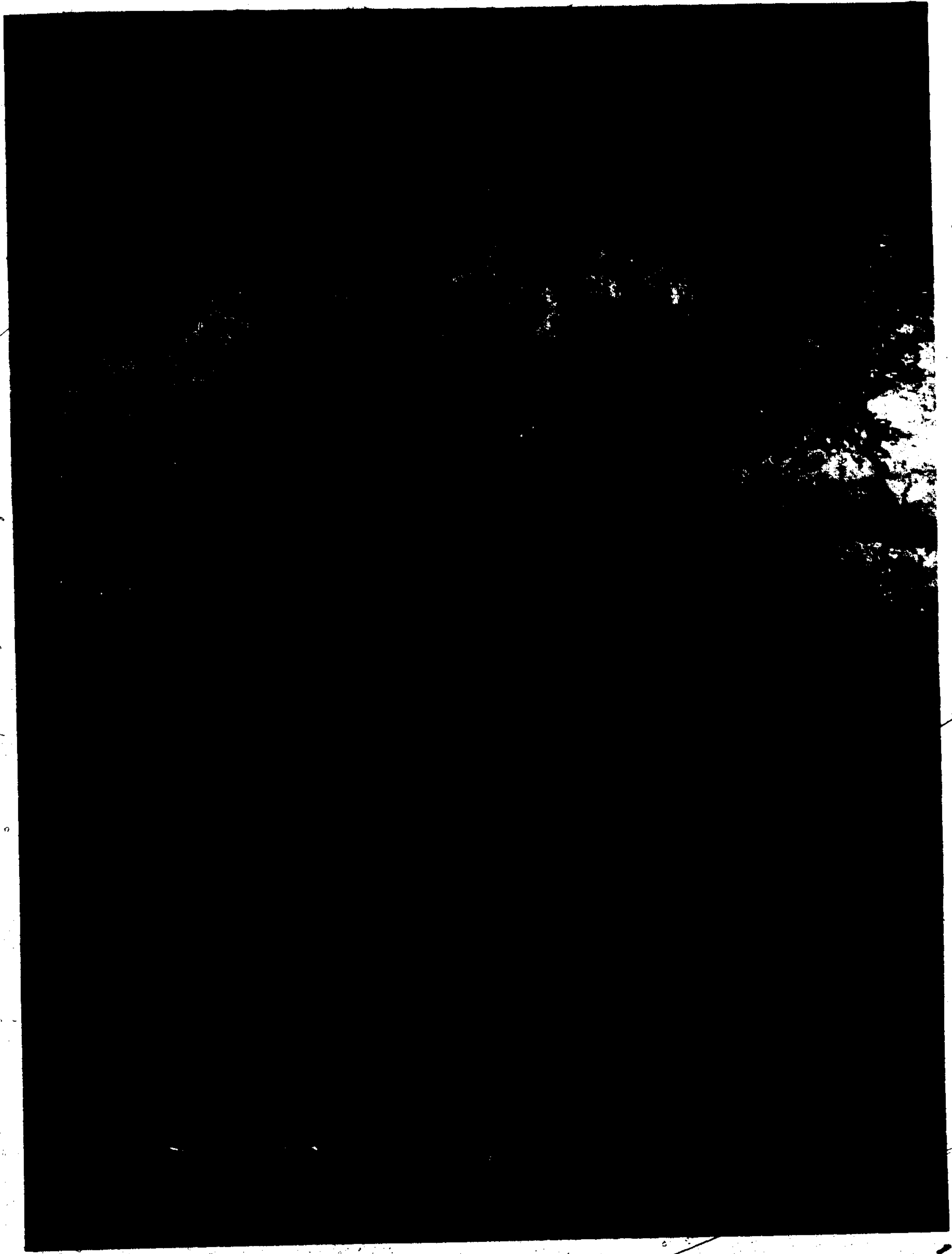
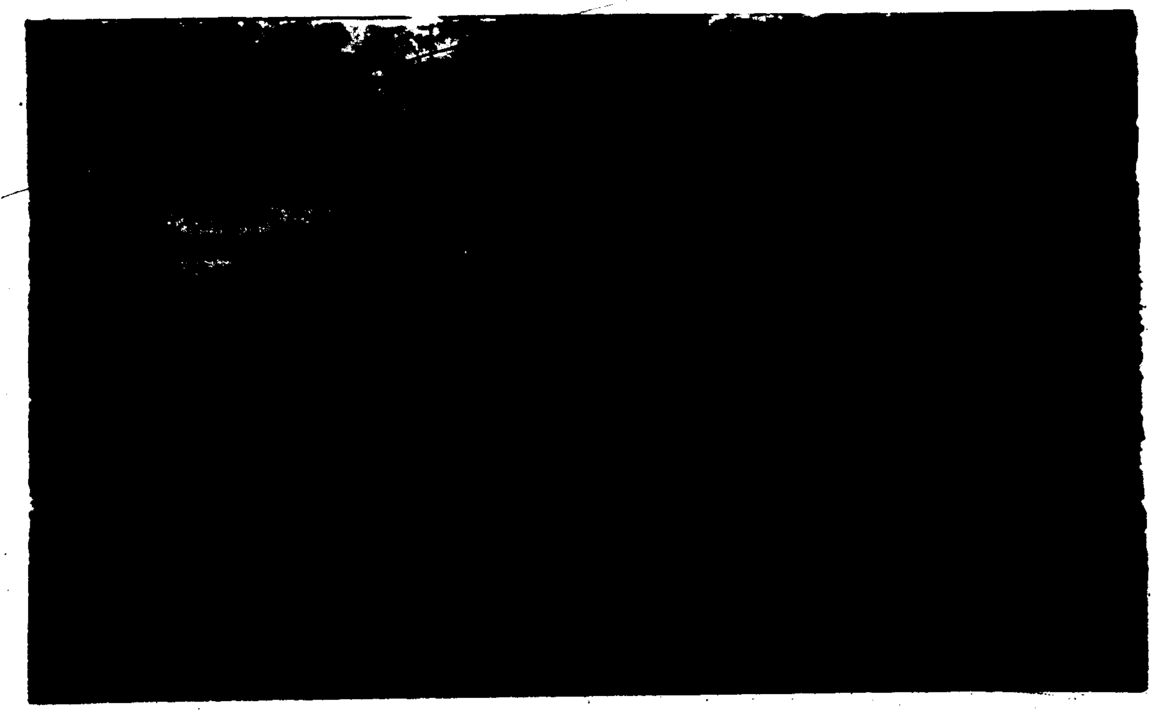


Figure 12

A. River view of Epiguruk Unit B and Unit C near river point 600 m. Note even bedding in Unit C and ice-wedge casts in Unit B.

B. Close-up view of Unit B ice-wedge casts.



thick and ripple marks, clay partings and small cut and fill structures were also observed. Although mostly sterile of organic material, scattered twigs were observed between points 50 and 250 m. (Figure 10). Several ice-wedge casts were seen near point 225 m. along the upper contact of this unit. The upper contact is a rapid gradation to a non-bedded, fine grained sand and silt. Between points 625 and 700 m. a red, iron-stained weathering horizon appears to mark this contact; this zone and the ice-wedge casts suggest an unconformity along the upper contact. This unit is interpreted as an alluvial flood plain deposit.

Unit D is a discontinuous, tan, fine-grained sand and silt. No bedding was observed and the sediment is sterile except where it grades up into the modern forest soil developed in this unit, which is interpreted as an eolian deposit.

Unit E is a local, thinly laminated, dark gray silt. Fine organic matter becomes abundant towards the top where this unit grades into the modern soil. A section through this lacustrine unit is more fully described in the section on pollen studies.

Paleoenvironmental Reconstruction

Eleven radicarbon dates were used to establish a chronology and correlation scheme. The dated organic samples were from key localities at the Epiguruk exposure, shown in Figure 10. Table 4 presents the dates and comments on the material and associations.

Fernald's bluff locality 5 (1964, p. 7), 3 km. up stream from

Table 4

Radiocarbon Dates from Epiguruk Exposure*

---

1. 5,140 ± 120 (GX-1443). Fine grained non-fibrous peat, from peat band 8 cm. thick, 1.10 - 1.18 m. below surface. River point 0.m.

2. 8,635 ± 210 (GX-1442). Angiosperm wood fragments, from coarse sand, 2.82 m. below surface. River point 0.m.

3. 8,105 ± 185 (GX-1441). Angiosperm wood fragments, from bedded silt, 4.60 m. below surface. River point 0.m.

4. 16,270 ± 250 (I-4778). Angiosperm wood fragments, from top of Unit C immediately below unconformity and adjacent to ice-wedge cast. Wood appears to have been buried stem or root in growth position. River point 230 m.

5. 20,700 ± 440 (I-4779). Angiosperm wood fragments, collected over 20 cm. interval from 5.00 to 5.20 m. above river level. River point 550 m.

6. 24,290 ± 720 (GX-1446). Angiosperm wood fragments, collected over 50 cm. interval from 4.70 to 5.20 m. above river level. This is the base of Unit C, sample is above the B/C contact. River point 625 m.

7. 2,670 ± 95 (GX-1444). Compact woody peat, from near the top of Unit E, 0.44 m. below surface. River point 650 m.

8. 8,800 ± 210 (GX-1445). Twigs, scattered along bedding planes, collected over 10 cm. interval from 1.25 to 1.35 m. below top of Unit E. River point 650 m.

9. 17,730 ± 320 (I-4777). Twigs, scattered along bedding planes, collected over 20 cm. interval from 3.95 to 4.15 below surface. The sample is from light gray silt and fine sand, even bedded, below a non-bedded reddish brown silt and fine sand that represents a weathered zone. River point 650 m.

10. 18,100 ± 550 (I-4776). Twigs, scattered along bedding plane at 5.15 m. below surface. River point 650 m.

11. > 38,000 (GX-1447). Organic-rich silt, from 10 m. below surface in middle of Unit B. River point 850 m.

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*These dates are uncorrected and based on a half-life of 5570 years. Locations are shown in Figure 10.

the mouth of the Ambler River (Figure 3), is the type locality of Kobuk Glaciation. At the down stream end of the bluff Fernald describes 9 m. of till overlain by 15 m. of yellowish-gray outwash sand. Hamilton (1973, unpublished manuscript) has also described this section and sees it as part "of a formerly continuous surface 50 m. above modern river levels, which extends southward across adjacent parts of the Kobuk's valley floor." Several till units and outwash sands and silts are described. Hamilton's unit 2 is a cross-bedded fluvial sand with locally abundant pebbles and is contemporaneous with the Kobuk Glaciation. Although this unit is not continuous through the central Kobuk Valley, Hamilton has correlated it with Unit A at Epiguruk. I agree with this tentative correlation even though more complete data are needed. The overlying organic deposits (Unit B) at Epiguruk, representing lowland and upland environments, were deposited during a non-glacial period. Unit C, in turn, can be correlated with Hamilton's Itkillik Glaciation (see Table 1). The overlying eolian and lacustrine silts were deposited during the late glacial and Holocene periods.

Fernald (1964) reported two dates of greater than 33,000 and greater than 38,000 B.P. from organic sediments exposed at the eastern edge of Epiguruk, and on the strength of these dates correlated this stratum with the Sangamon Interglacial. These organic sediments were no doubt Unit B which has here been dated at greater than 38,000 B.P. (GX-1447) (Table 4). Unit B appears to have been deposited in an open, non-forested, environment. Elsewhere in Alaska, the Sangamon is seen not only as a return to forested conditions, following the Illinoian Glacial, but as an expansion of the forests beyond its present limits (Hopkins, 1972). A pollen diagram from Unit B (Figure 22), to be discussed in detail later, indicates a steppe-tundra environment, with the forest a considerable distance from this region. Pollen cores from Imuruk Lake on Seward Peninsula (Colinvaux, 1964, 1967a; and Colbaugh, 1968) indicate an expansion of the boreal forest during pollen zone I interpreted as the Sangamon Interglacial. Pollen zone J2, representing a Wisconsin interstadial dated as starting prior to greater than 34,000 B.P., has pollen spectra very similar to the pollen assemblages of Unit B, suggesting a correlation. Matthews (1974) presented a Wisconsin age pollen record from Fairbanks; the mid-Wisconsin interstadial dated between 34,000 to 32,000 B.P. saw lower than present tree lines.

The pollen record from Epiguruk Unit B indicates that it was deposited during the colder climates of the mid-Wisconsin interstadial. But the erosional upper contact and infinite radiocarbon dates indicate that Unit B represents only a lower portion of the interstadial period. Since so much of the upper portion has been disturbed by cryoturbation, the erosional interval may have been associated with a colder climate representing the return to late Wisconsin glacial conditions. This possibility is supported by pollen evidence to be discussed later.

Unit C is dated by five radiocarbon age determinations (Table 4): 24,290± 720 (GX-1446); 20,700 ± 440 (I-4779); 18,100 ± 550 (I-4776); 17,730 ± 320 (I-4777) and 16,270 ± 250 (I-4778). These place Unit C within the late Wisconsin Itkillik Glaciation. Although the Itkillik

Glaciation is represented in the field by complex terminal and recessional moraines, depositional breaks are not evident in the alluvial record of Unit C. This supports Hamilton's (1973, unpublished manuscript) view that these moraine sequences have little stadial-interstadial significance.

Three ice-wedge casts were observed at the top of Unit C, near point 225 m. (Figure 10). These were developed in the bedded alluvial silts of Unit C and filled with massive silt. Their maximum length was 200 cm., maximum width 50 - 80 cm. and they displayed the general wedge-shaped morphology with non-parallel, often slumped, sides that taper down to a single thin fracture. The normally flat-bedded host sediments were bent upwards near the wedge and the host sediments showed strong iron staining and cementation in the area of the wedge casts. This description is typical of casts that represent ice-wedge development at surfaces of non-deposition (Pewe, _et al_., 1969).

A one meter long parallel-sided fracture was found 330 cm. below the Unit C contact at the same location. This fracture was about 10 cm. wide with abruptly taped ends and filled with massive tapered silt. Ice-wedge casts of this morphology have been described from Siberia where they have been interpreted as syngenetic wedges (Shumski, 1964; Popov, 1969). In this case ice-wedge development is synchronous with alluvial deposition and the wedge grows upward as the alluvium is deposited rather than outward as it might below a surface of non-deposition. This type of ice-wedge development would be anticipated as Unit C is interpreted as representing an aggrading floodplain.

It indicates permafrost in this area of the floodplain.

Unit C was deposited to a height of 20 m. above present river levels by 17,730 ± 320 B.P. (I-2777); it ultimately reached a height of 35 m. sometime after this date (see Figure 10). By 16,270 ± 250 B.P. (I-2778) 15 m. of downcutting had taken place leaving the high level terraces observed by Hamilton (1973, unpublished manuscript). This latter date is from organics deposited in alluvial silts at the top of Unit C. Vertical orientation of this material suggests roots. The occurrence of ice-wedge casts at the top of Unit C indicates an unconformity of sufficient time for ice-wedge development. Weathering noted by the iron staining at the top of Unit C must have occurred during the time represented by the unconformity. Sometime after 16,300 B.P. the local climate probably warmed sufficiently to have melted the ground ice. The open cracks filled with eolian silts as eolian activity reworked the exposed alluvium, forming the loess of Unit D. These events could represent minor climatic fluctuations in the Itkillik Glaciation which may have a counterpart in the glacial record. However, resolution is not such that a correlation can be made as yet.

Aggradation in the central Kobuk Valley region was apparently greatest from 24,000 to nearly 17,000 B.P.; this was probably the period of maximum glaciation in the central Brooks Range when discharge and sediment yield would have also been at a maximum. Sediments from this period of alluviation are spread from the eroded outwash terrace of the Kobuk Glaciation near the front of the Jade Mountains southward across the Kobuk River for an undetermined distance (Figure 3). The bluff face at Onion Portage exposes a basal unit of coarse outwash gravel and cobbles overlain by bedded silts and sands and capped by eolian silt and sand (Hamilton, 1970). These represent the older outwash of the Kobuk Glaciation and the later Itkillik alluvium (Table 1). Sediments belonging to an interstadial interval have not been observed here.

The postglacial alluvial history must have been fairly uniform throughout the central Kobuk-Ambler Valley regions (Hamilton, unpublished manuscript, 1973). The rivers began to incise their floodplains which were developed 30 - 35 m. above present river levels. This process continued without significant reversals to a mid-Holocene level somewhat higher than at present. This pause, marked by terraces of 5 to 9 m. height in the Redstone and Ambler Valleys, is dated between 7,000 to 5,000 B.P. (Hamilton, unpublished manuscript, 1973). Still lower terrace remnants are found along the Kobuk River between Ambler and Onion Portage.

Downcutting in the Kobuk Valley began sometime after 17,700 B.P. and continued to 9,857 ± 155 (Anderson, 1970a, p. 70), at which time the river was within a few meters above its present height. The latter date comes from gulley sediments eroded from the bluff face at Onion Portage that was formed during downcutting.

To summarize, the stratigraphy of the Epiguruk exposure pro- [illegible]cord of the alluvial history of the Kobuk-Ambler River system. [illegible] and gravels (Unit A) are correlated to the Early Wisconsin, [illegible]uk Glaciation. The overlying organic silts and sands (Unit B) represent a treeless mid-Wisconsin interstade. Because of an erosional hiatus, the latter portion of this interstade is not represented. Instead, the overlying silts and sands (Unit C) record the onset of rapid aggradation, lasting from 24,000 B.P. until after 17,700 B.P. This phase of alluvial deposition correlates with the late Wisconsin, Ikillik Glaciation. Downcutting began sometime after 17,700 B.P. but ceased about 16,000 B.P. at which time ice-wedge formation took place. During the late glacial, downcutting continued while eolian activity redeposited the silty alluvium as a local loess (Unit D). By 10,000 years B.P. the Kobuk River had downcut to within a few meters above its present level. Through this record the climate oscillated from a glacial, through an interstade, back to a glacial and finally into the Holocene warm climate.

Onion Portage Archaeological Site

Sedimentary History

During the late-glacial the Kobuk River deeply incised its channel into the floodplain, creating a series of steep-sided bluffs. The Onion Portage archaeological site is situated at the base of such a bluff (Hamilton, 1970). Hamilton has outlined the subsequent geological history of Onion Portage. He notes that as the Kobuk River downcut at least 35 meters the channel migrated laterally = 1 km. This created a series of short terrace segments that sweep back along the bluff face down valley from the archaeological site. An excavated gravel pavement at the base of the bluff marks the former position of the river. With lateral migration and pointbar development this former channel became part of the floodplain and began receiving alluvial sediments. Deep gully incision began to occur along the bluff and steepened flank of the point bar. This created a series of gully fan deposits along the base of the bluff that interfingered with the river alluvium. Stratigraphic sections through the site from the bluff face to the river's edge (Anderson, unpublished diagram) show this interfingering very well. Near the bluff face the sediments are predominantly the gully fan wedges but nearer the river there is a multiplication of the thin units of fluvial silt (see Figure 4). A levee consisting exclusively of fluvial silt and eolian sand has developed at and downstream from the archaeological site.

Paleosols

The deposition rate of alluvial or eolian sediments varies greatly. A flood or strong wind can deposit several centimeters of sediment in a very short time. This is followed by a period of non-deposition during which pedogenesis can occur. At Onion Portage the time interval between the units of alluvial silt and eolian sand is small, as a result of which soil development is very weak. Gully fan deposition was less frequent and so the time interval between fan units is much longer. Therefore, soil development is stronger here and a series of distinct paleosols were produced across the archaeological site near the lower slope of the bluff (see Hamilton, 1970). These paleosols are described below, using the procedures of the United States Soil Service (1951).

Paleosols have been recognized for Band 8, levels 2 and 3;

these are actually nothing more than azonal gleyed horizons averaging 4 cm. thick with a 10 BG. 7/1 Munsell color (Figure 13). No humus material is associated with these soils although some plant fragments were recovered by sieving. There is no structural or textural development (see section - sedimentary analyses) but dark brown manganese oxide stains, fine manganese oxide nodules and red ferric hydroxide stains are often seen scattered through the solum making a weak color B horizon.

Band 7 paleosol (Figure 14), at the base of the bluff slope, has weakly developed A1 and A2 horizons and a color B about 45 cm. thick. Downslope in the slight depression behind the levee, this soil grades into a bright blue-gray (7B 7/1) gleyed horizon approximately 5 cm. thick with a bright red (7.5 R 4/8) iron stained B horizon 2 to 10 cm. thick. This soil developed on a gulley fan surface and was in turn buried by another fan of sand.

Band 6 paleosol (Figure 14) developed on this next fan surface, is the best developed of the paleosols in the archaeological site and is described in detail (see Table 5). This is a podzolic profile as are the two overlying paleosols representing Bands 5 and 3; they also have well developed A1, A2 and color B horizons. The modern soil on this slope is also a podsol as are most of the soils in this area which are developed on the older sandy alluvium under white spruce, aspen, and birch cover.

In order to determine the vegetation cover that may have been associated with each of the paleosols, bulk soil samples were collected

Figure 13

Paleosols--developed on Band 8, levels 2 and 3. Note degree of involution. Scale rule is in centimeters.

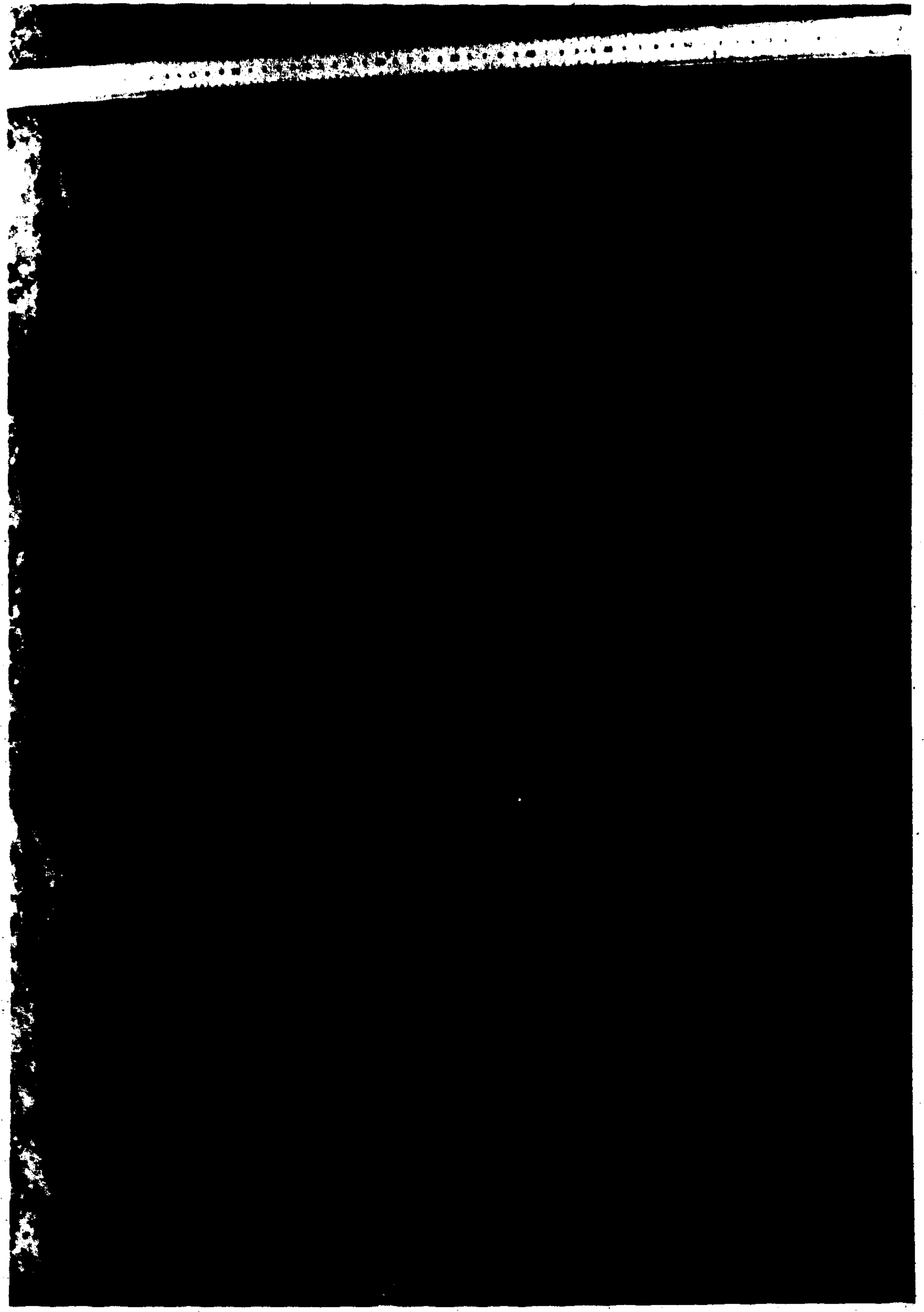


Figure 14

Paleosols developed on Bands 7, 6, and 5. Trowel is approximately 20 cm. long.

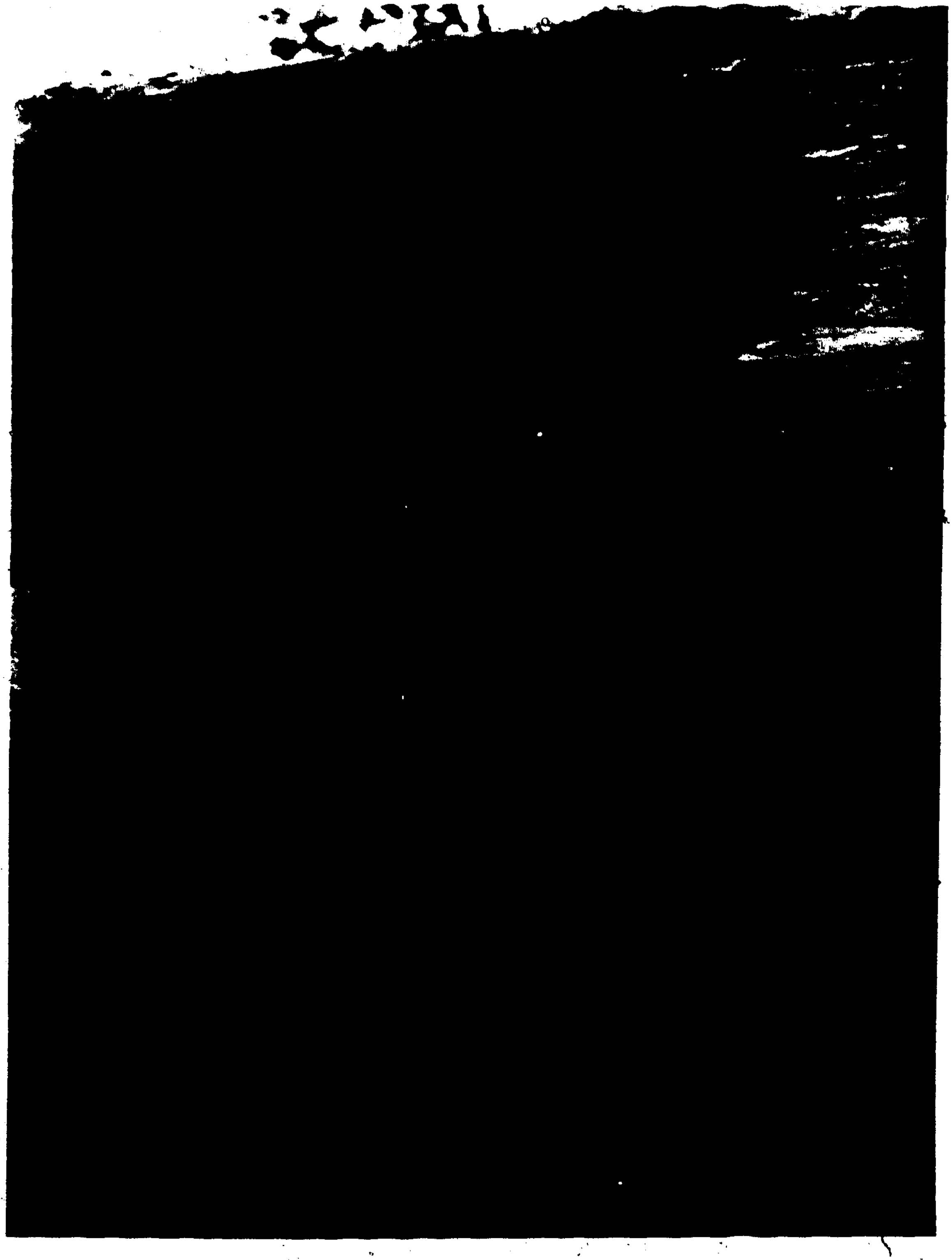


Table 5

Description of Band 6 Paleosol

A1 horizon, 10 YR 2/2 -- loamy sand, slightly platy structure, friable, 3 - 7 cm. thick, lower contact sharp.

A2/1 horizon, 5 Y 5/1 -- fine sand, structureless, friable, lower contact gradational.

A2/2 horizon, 5Y 5/1 -- fine sand, structureless, friable, slightly mottled, 5 cm. thick, lower contact gradational.

B2 horizon, 10 YR 4/4 -- fine sand, structureless, friable, 8 cm. thick, lower contact gradational.

B3 horizon, 10 YR 4.5/4 -- fine sand, structureless, friable, slightly mottled, root traces present, 60 cm. thick, lower contact is the Band 7 paleosol.

and sieved. The organic residue recovered was examined under the microscope. Soils 8/2 and 8/3 did yield some non-woody fibrous plant fragments that may have been grass or sedge remains. Material from Soil 7 consisted mainly of charcoal and carbonized twig fragments. Soil 6 organic remains proved to be of greatest interest since spruce needles, needle bases and twig fragments were recognized. Remains of spruce were found in all the other younger soils. In addition, small (1 - 2 mm.), hard, black spherical bodies were found in Soil 7 and the younger soils. These have been identified as the resting bodies or sclerotia of septate fungi. They have been recorded elsewhere in fossil peats from Alaska (Matthews, 1973), but they have no paleoenvironmental significance.

Differences in the degree of soil development, soil type and in the abundance and kind of soil organic matter suggest local paleoenvironmental change. Paleosols that are associated with Bands 8/2 and 8/3 are very similar to the poorly-drained tundra mineral soils where permafrost is very near to the surface. In the Onion Portage region these soils most often support a vegetation of Eriophorum tussocks. Band 6 soil is a forest soil type similar to the podsols associated with well-drained substrates and mixed spruce forest. These are typically localities, in this region, where the permafrost layer is absent or very deep. Band 7 soil is almost transitional between the soils of Bands 8 and 6. These data indicate changing vegetation cover and suggest a climatic change. This change occurred between Band 7 and Lower Band 6, or between 6000 and 5500 years B.P. (see Figure 5).

Permafrost Features

Paleosols associated with Band 8, levels 2 and 3, and the Band 8/1 surface are highly deformed. Cryoturbation features such as involutions (Johnsson, 1956, Jahn, 1962) characterize these units throughout most of the archaeological site (Figure 13).

Frost cracks, although not necessarily a permafrost feature, were observed over most of the site but most commonly along the crest of the levee. Although frost cracking is active in the recent alluvium, the degree of cracking is much greater in sediments associated with Bands 8 and 7 (Figure 15). Most of the cracks that were estab[illegible] at this early date continue into the recent sediments indicating modern frost cracking. The number of cracks and their pattern appears to have remained the same over the depositional history of the site. These long, continuous cracks extend from the surface down into lower Band 8/3; they generally show an offset of one or two cm. and a downward deformation of the host sediments. The cracks are generally filled with ferruginous sand; iron staining is also common in the adjacent host sediments.

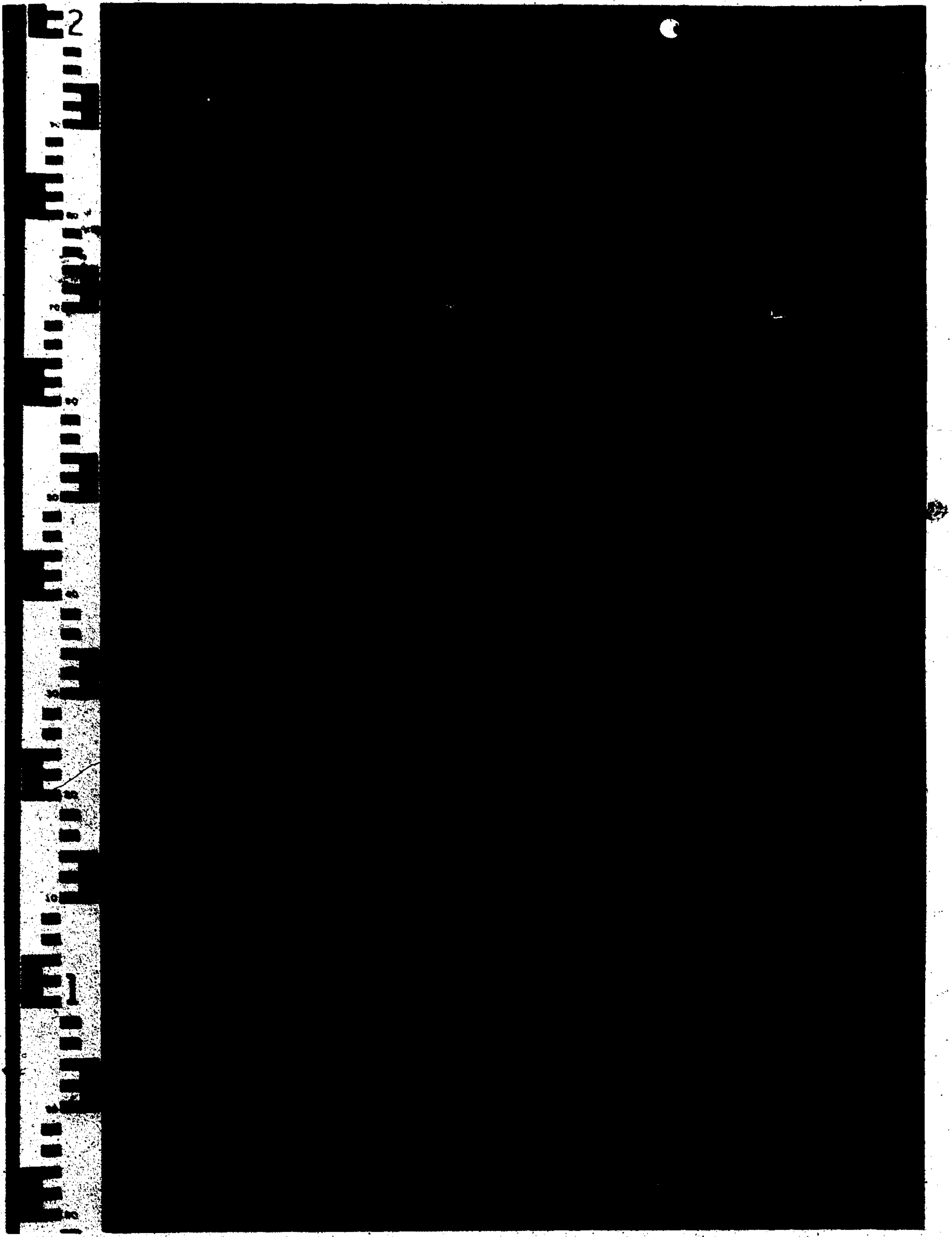
A second type of crack consists of narrow fractures approximately 30 to 40 cm. apart, penetrating to depths of 20 to 40 cm.; the host sediments are turned sharply downwards (Figure 16). These fractures are associated commonly with Band 8/2 surface, where, in plan, they form an irregular net pattern. Similar frost cracks have been observed in western Alaska by Guthrie and Matthews (1971) and in Belgium by Paepe and Vanhoorne (1967) and Paepe and Pissart (1969) where they have been

Figure 15

View of frost cracks from levee at Onion Portage archaeological site. Note that cracking has continued until the present but that the numbers of cracks and associated deformation is greatest in the oldest sediments. This exposure is 180 cm. in height.

Figure 16

Small scale frost cracks associated with Band 8 level 2. Stadia rod is scaled in decimeters.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interpreted as indicating cold permafrost conditions, but not ice-wedges. Washburn (1969) and Matthews (1973), however, considered the possibility of desiccation as the origin. Obviously frost cracking and desiccation cracking can both occur in permafrost terrain and may operate on the same cracks as they represent planes of weakness. At Onion Portage these cracks are intimately related to involutions (Figure 18A), suggesting that, here, they may be related to frost cracking.

Frost hummocks were observed on the surface of Band 8/1 (Figure 17A); these were seen as a network of mounds approximately 50 cm. in diameter bordered by downfolded layers of sediment. In section, they do not resemble the frost cracks since no crack surrounds the hummock and the infolded margins suggest an upward force at the center of the hummock. To elucidate further the origin of these features, a patch of exposed hummocky tundra near the site was excavated in plan and section. The pattern (Figure 17B) of soil deformation was identical to the fossil features. Since the excavated tundra patch is an exposed knoll probably often blown free of snow cover, it presents a very cold microenvironment in the present forest-tundra mosaic.

Solifluction activity (Figure 18A) has affected Band 8/3 to Band 7 sediments along the base of the hillside. This zone of disturbance grades vertically upward from involuted to highly disturbed and then to less disturbed sediments within 120 cm. In some cases the downslope movement has overridden a 40 cm. long lobe of soil in

Figure 17

A. Frost hummocks developed on the surface of Band 8 level 1. Stadia rod is scaled in decimeters.

B. Modern hummocky tundra surface with turf layer removed. Trowel is approximately 20 cm. tall.

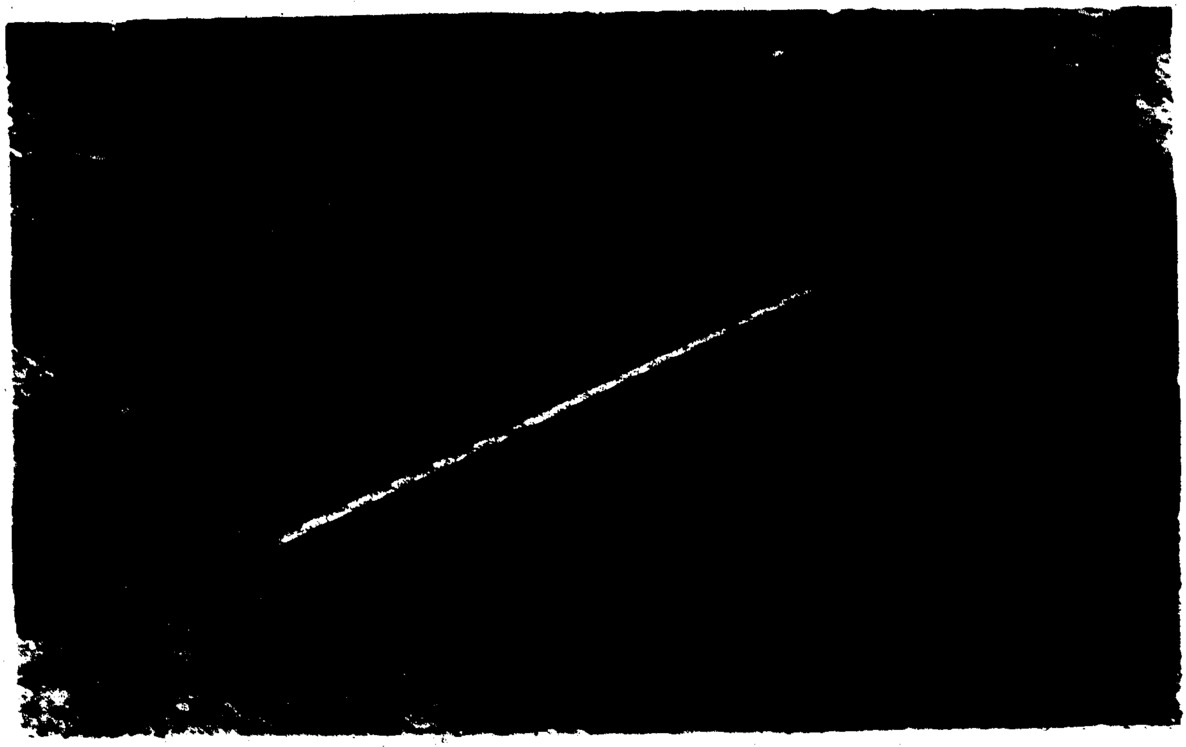
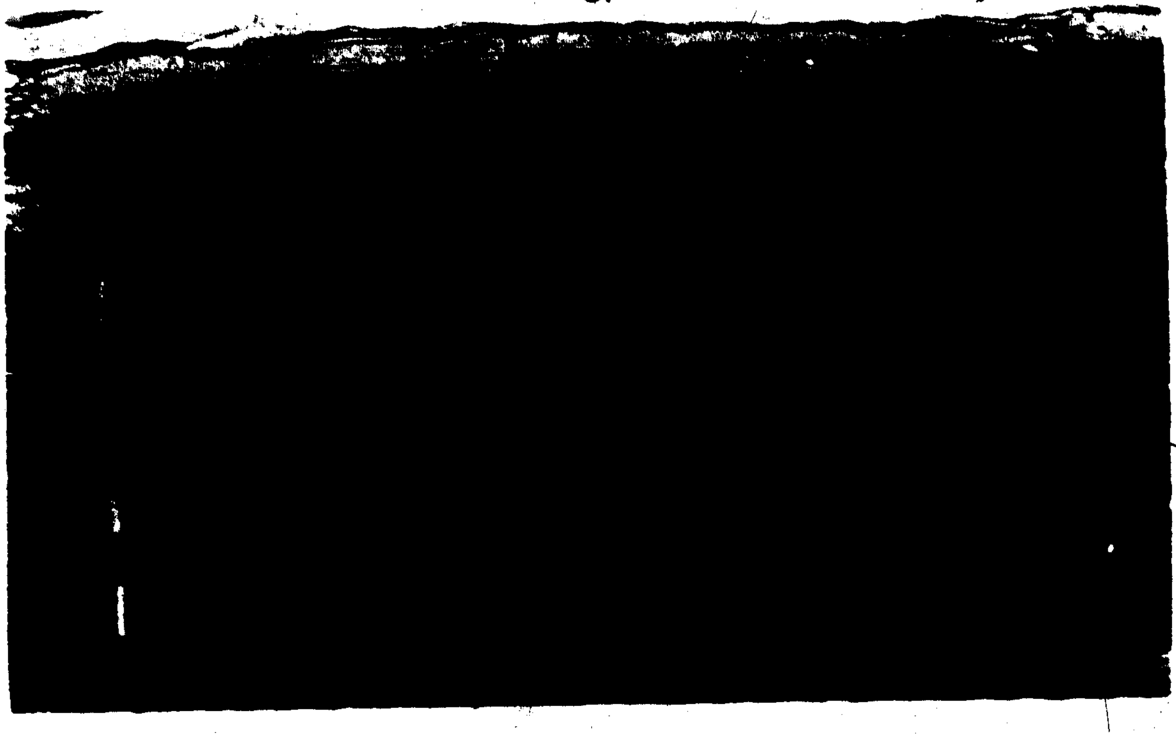
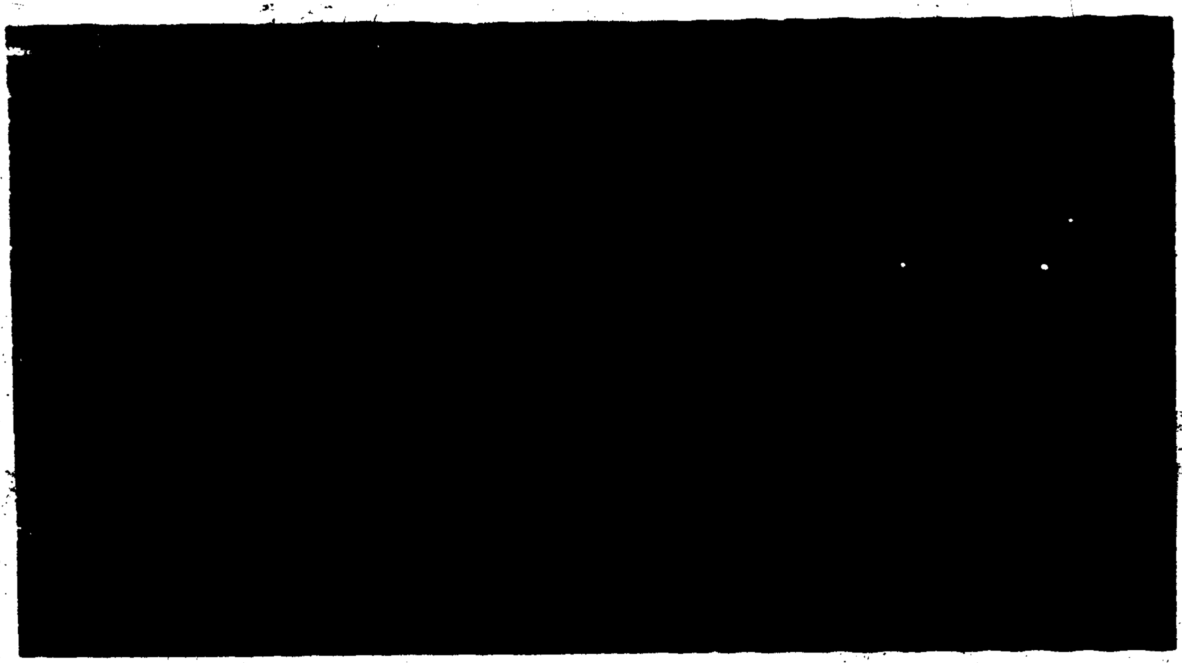


Figure 18

A. Solifluction affecting Bands 8 and 7. Rod is scaled in centimeters.

B. Solifluction affecting Bands 8 and 7. Note overriding of Band 7 paleosol at right.





a way similar to what Benedict (1966) has described (Figure 18B). Younger sediments on the hillside show some shallow soil creep but no solifluction. Solifluction lobes are now observed along the Kobuk River but only on north-facing slopes.

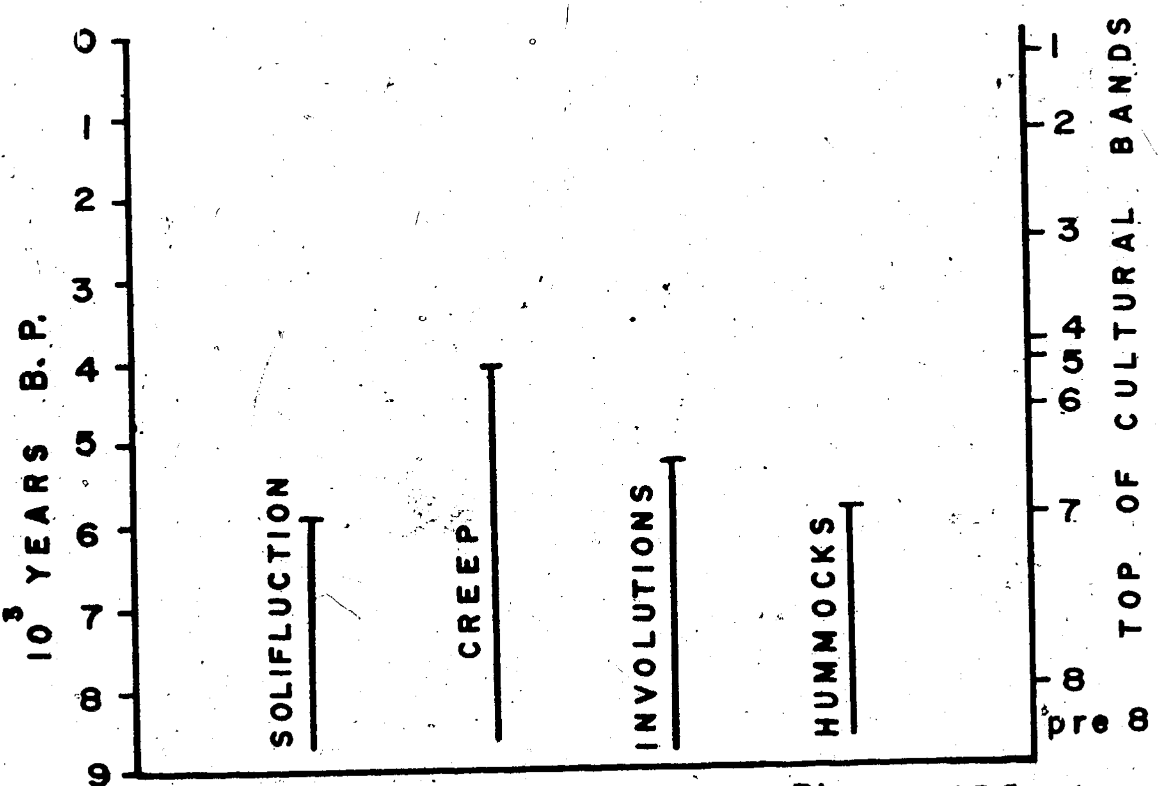
Figure 19 illustrates the temporal range of these cryoturbation features. Involutions, solifluction and creep activity began sometime before Band 8/3 (86000 B.P.) and all, except for creep, terminate after the burial of Band 7 by fan or alluvial deposits approximately 5,800 radiocarbon dates B.P. (see Figure 5). Soil creep activity persisted at the base of the bluff until after the deposition of Band 6.

The paleoclimatic significance of these features can be interpreted in terms of local or regional changes. In the case of the former while the river was near the base of the bluff the nearby alluvium would have been free of permafrost. But as the channel migrated away permafrost could have moved into the sediments, initiating cryoturbation. As alluvium and fan deposits built up this surface cryoturbation would continue until soil drainage was greatly improved and deformation in the upper layers ceased. Here only changes in local surface morphology and its influence on the permafrost condition is needed.

A second interpretation calls for a more severe climatic regime during the period from 10,000 to 6,000 B.P. This climate would have had to have been severe enough to have caused cryoturbation on this south-facing slope. Here, at the present time, solifluction

Figure 19

Diagram illustrating temporal range of cryoturbation features at Onion Portage archaeological site.



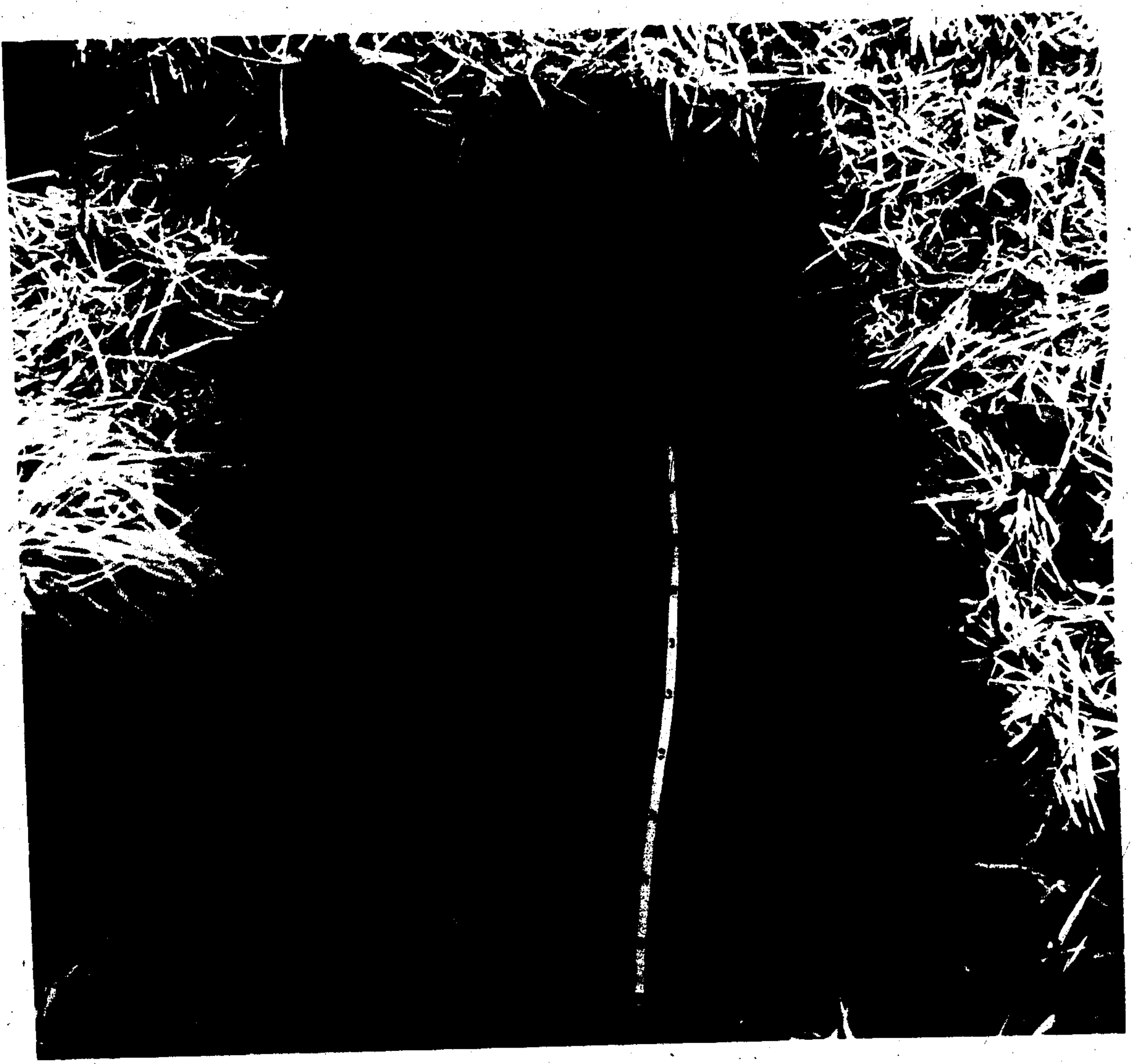
Time Range of Cryoturbation Phenomena

and active cryoturbation occur only on north-facing slopes and cold exposed tundra localities.

If the first interpretation is correct, then frost deformation should still be occurring in wet alluvial sediments away from the river. To check this, a series of pits were dug into sediments in a low-lying, seasonally wet slough approximately 150 m. west of the archaeological site. This slough is probably very similar in morphology and sedimentary environment to the archaeological site 9,000 - 7,000 years ago, that is, before the site was built up by alluvium and fan deposition. Each of the pits was dug during mid-June to the seasonal frost table, 55 cm. below the surface. The same stratigraphy was found in each pit, 30 cm. of horizontally-bedded alluvial silt and eolian sand and then a massive silt unit displaying involutions and frost boils on its upper surface (Figure 20). This lower massive silt unit probably represents alluvial deposition when the river was very nearby and possibly at a slightly higher elevation. As the channel moved away the units of alluvium became thinner and much less frequent. The upper sediments do not display frost deformation; cryoturbation is not active at the present, but was active at the time the earlier sediments were deposited. In view of this, one must conclude that the fossil cryoturbation features exposed in the archaeological site, and in the slough pits, must be the result of a past climatic regime and not the result of unique edaphic conditions that are operative under the present climate. This climate was colder than the present climate and permafrost must have been present near the surface. The resulting poorer drainage would have produced saturated

Figure 20

Cryoturbation features in soils-pit from slough adjacent to archaeological site. Note that overlying recent units are undisturbed. Tape is scaled in centimeters.



soils and therefore greater cryostatic pressures during fall freeze-up. Greater cryoturbation in the active layer would produce the kinds of features observed at Onion Portage.

Sedimentary Analyses

Samples of the alluvial units from the archaeological site were collected in order to describe the parent material and to determine the degree of pedogenetic development. The grain size distribution was determined using the standard soil particle classes (0.002 mm. = clay, 0.002 to 0.05 mm. = silt, 0.05 to 2.0 mm. = sand). The nitrogen and organic carbon percentage of the total dry weight of the soil was determined by the Kjeldahl and dry combustion methods respectively at the University of Alberta, Soils Department laboratory. The samples were taken from paleosol horizons in order to determine the degree of pedogenic weathering and organic content of some of the paleosols. Since only units of alluvium were sampled this analysis may also reflect possible changes in the tractive capacity and competence of the Kobuk River through time. However, these data (Table 6) show that a rather uniform sediment was deposited through the history of the site. Samples (OP68 - 168 and 169) of modern alluvium match closely the grain size composition of the older horizons. The sediment load and discharge of the Kobuk has not varied greatly in the time range represented at Onion Portage. This sediment uniformity also attests to the lack of pedogenic clay formation and soil development seen in the paleosols.

The organic carbon content is very low with only the younger units and modern alluvium showing a percentage over 0.70 and C:N ratios

Table 6

Grain Size Analyses and Carbon-Nitrogen Composition of Sediments from Archaeological Site

Band	% Clay	% Silt	% Sand	Organic Carbon, % Dry Wt.	Nitrogen Nitrogen % Dry Wt.	C:N Ratio
Modern	5	35	60	0.86	0.08	10:1
Modern	8	46	46	1.19	0.11	10:1
2/2	10	37	53	0.73	0.07	10:1
3/2	5	20	75	1.22	0.09	13:1
4/6	5	24	71	1.71	0.11	15:1
6/6	4	19	77	1.83	0.13	14:1
7	5	23	72	0.64	0.06	10:1
7	8	31	61	0.39	0.04	10:1
7	5	46	49	0.28	0.04	7:1
8/1	8	35	57	0.24	0.03	8:1
8/2	3	50	47	0.26	0.04	6:1
8/2	5	46	49	0.25	0.04	6:1
8/2	8	44	48	0.31	0.04	8:1
8/2	7	40	53	0.26	0.04	6:1
8/3	2	47	51	0.29	0.05	6:1
8/3	4	53	43	0.31	0.05	6:1
8/3	2	49	49	0.29	0.05	6:1
8/3	9	51	38	0.26	0.04	6:1
8/3	9	45	46	0.23	0.04	6:1
8/3	8	40	52	0.36	0.04	9:1
8/3	7	41	52	0.38	0.05	8:1
8/4	1	47	52	0.21	0.04	5:1

of 10:1 or greater. The low organic content of the older soils is in keeping with the generally low organic content of tundra mineral soils and to the short time period represented by each A-C paleosol. However, C:N ratios of fungal hyphae and bacteria range from 5-10:1, suggesting that the low organic content could be due to microbial decomposition. As further evidence of this, pollen samples prepared from the older sediments characteristically had badly preserved pollen grains and abundant fungal hyphae. These pollen assemblages were completely dominated by the spores of Polypodiaceae, Lycopodium and Sphagnum, three types which have been determined as being extremely resistant to fungal attack (Havinga, 1967). Unpublished pollen diagrams, prepared from the sediment at the archaeological site by S. Florin (1967), Uppsala, Sweden, show very high percentages of these three resistant spore types in sediments below Band 6. Pollen preservation improves markedly near Band 6, which is when the organic carbon content and C:N ratio of the sediments increases significantly. No doubt these data represent several operating factors, the initial low organic production of tundra vegetation, the poor humus development, mixing of tundra mineral soil and microbial decomposition.

Paleoecological Conclusions

Data presented above gives evidence of an early cold climate at Onion Portage. Paleosol development and soil type, macrofossil remains and cryoturbation features indicate an open tundra environment through the early history of the site representing pre Band 8 to Band 7, a time range of 10,000 to 6,000 years ago. During this time the permafrost table was shallow and cryostatic pressures were of sufficient intensity to cause marked cryoturbation. This phenomenon is primarily a feature of the fall freeze-up when wet sediments are confined between the permafrost table and an advancing seasonal freezing front. Sometime after 6,000 B.P. the climate warmed sufficiently so that the permafrost table dropped, soil drainage improved and frost deformation ceased. Spruce trees and probably aspen, poplar and arboreal birch invaded and replaced the tundra vegetation in the area of the site. The improved soil drainage, higher soil temperatures, and additional organic acids and chelators led to the development of podzolic soils.

This cold climate period coincides with the Range Front - Walker Lake Stades of the Brooks Range Wisconsin Glacial sequence, dated from 11,000 to 7,000 B.P. (Hamilton, 1973, unpublished manuscript). However, it is also coincident with the early postglacial warm interval described from the Kotzebue Sound region by McCulloch and Hopkins (1966). This discrepancy will be discussed later when additional data are reviewed.

It is very difficult to say how much colder than present the climate may have been between 10,000 and 6,000 years ago. At the present time the north-facing bank of the Kobuk River down from Onion Portage generally has tundra vegetation and often displays solifluction features while the south-facing bank is forested and apparently stable. The difference between the present climate and that about 8,000 years ago may be roughly the same as that between the present-day north-facing and south-facing slopes. Unfortunately, these or comparable data from the Arctic are not available and so comparison will have to wait until some future date.

PALEOECOLOGICAL RECONSTRUCTION: BIOLOGICAL CRITERIA

Previous Work

The first efforts to establish a fossil pollen record at Onion Portage were undertaken in 1965 by Dr. Sten Florin, Uppsala University, Sweden. His winter coring project recovered two, 2 m. long, sedimentary cores from Israkaklik, a large lake 12 km. north of Onion Portage (Figure 2). Another core 2.6 m. long was recovered from a small lake (Onion-Kobuk Lake) on the lower flood plain near Onion Portage. The unpublished pollen diagrams show very little change in the pollen spectra. Cyperaceae percentages are high (up to 40%) in the lower half of the cores from Israkaklik and drop to 20% in the upper half. Alnus rises from 5 - 10% in the lower half to 15 - 18% in the upper half. This change was dated at 6,378 ± 82 years B.P. (P1094). Pollen fluctuations in the Onion-Kobuk Lake appear to be related more to hydrarch succession of the lake than to any regional vegetation changes. A date of 4,357 ± 93 years B.P. (P1093) was determined from the middle of the core.

Florin also examined pollen recovered from alluvial sediments at the Onion Portage archaeological site. His unpublished diagrams show a very marked fluctuation near Band 6. Lycopodium, Sphagnum and Polypodiaceae spores were recovered below Band 6 while the pollen content increased greatly above Band 6. These changes are of questionable regional value as they suggest serious differential destruction of the pollen below Band 6. The factor of fungal destruction of the pollen in the alluvial sediments was discussed earlier.

Although there is an abundance of small lake basins in the central Kobuk region, these potential study sites are not without problems. Those found on the lower floodplains are relatively young and would not provide a very long or continuous pollen record. Lakes on the uplands and upper terraces have developed in permafrost. Thermal characteristics of a body of water affects the permafrost in the surrounding materials and melting occurs. With shore line melting, peats and organic sediments will slump into the lake, contaminating the lacustrine sediments with rebedded pollen. It seems almost certain that Florin's pollen diagram from Israkaklik records some rebedded pollen, thus reducing its value as a paleoecological record.

Methods

Sediment samples for pollen analysis were collected at 5 to 10 cm. intervals through the chosen stratigraphic sections. Since many of the samples had very low pollen concentrations, considerable experimentation was done before a successful processing method was evolved. Most of the samples consisted predominantly of mineral matter, and so fractions of about 50 grams (or more) were processed.

First, dilute HCl was used to remove carbonates, then the samples were swirled in water and allowed to settle for 30 seconds in order to let the sand-size material settle out. The remaining suspended sediment was concentrated and then treated with a zinc bromide solution of specific gravity 1.9, in order to separate the organic fraction. After centrifuging for 15 minutes at 1,600 r.p.m., the heavy liquid was filtered through a fiberglass micropore filter in order to remove all the pollen. Hydrofluoric acid was used to digest the filter paper and concentrated hydrochloric acid to remove the remaining silica colloids. The organic sediment was treated with NaOH (5%), and finally dried in ethyl alcohol before mounting.

The organic rich or peaty samples were processed using a more standardized procedure of NaOH, HF and acetolysis (Faegri and Iversen, 1964). Ethyl alcohol was used prior to mounting.

All samples were mounted in glycerine for counting. Counting was done using a Leitz Laborlux microscope with Periplan eyepieces and 40 X and 1 00 X oil Planachromat objectives. Pollen determinations were made with the aid of the pollen reference collection of the University of Alberta, Anthropology Department. For each sample 200 pollen grains, excluding unknown and indeterminant pollen and spores, were counted. If there was insufficient pollen additional microscope slides, up to a maximum of four, were counted. For many samples, more than one slide was needed. On many slides clumps of pollen were encountered, since they represented an unusual concentration they were arbitrarily counted as only two grains. Half conifer grains were counted, the total was divided by two and added to the total pollen sum. The total counts from all samples are given in Appendix II.

Modern surface pollen samples were collected from selected communities. A single sample consisted of a series of ten random pinches of forest duff and moss polster. The composite sample was processed following the usual chemical procedure of NOH, screening, HF and acetolysis treatments (Faegri and Iversen, 1964). Glycerine was used as a mounting medium and 200 grains, excluding unknown and indeterminant pollen and spores, were counted from each sample. In some samples, *Populus* pollen was identified but since *Populus* is rare in fossil material due to high degree of degradation, a second count was made in which *Populus* pollen was excluded. This makes the modern pollen percentages more comparable to the fossil pollen spectra.

Modern Pollen Rain

In order to establish a complete record of the paleoecological history of the Onion Portage region, the pollen-analytical method was employed. This method of vegetation reconstruction, based on the composition of the fossil pollen assemblage, relies heavily upon the relationships between modern vegetation types, modern pollen rain and regional climate. The significance of modern surface pollen samples to paleoecological interpretations is well known (Davis, 1963, 1967; Wright, 1967) and has become quite sophisticated (Webb and Bryson, 1972). A number of regional modern pollen rain studies have recently been published (Janssen, 1966; Whitehead and Tan, 1969; Livingstone, 1968; McAndrews and Wright, 1969); similar studies in arctic and boreal regions were non-existent until the regional analysis of pollen rain by Ritchie and Lichti-Federovich (1967) and Lichti-Federovich and Ritchie (1968) from central and western Canada. Bartley (1967) has provided data for the Sugluk region of northern Ungava, Quebec. Similar data from Alaska are, however, rare; modern surface pollen samples are available from Chandler Lake, Brooks Range (Livingstone, 1955); Imuruk Lake, Seward Peninsula (Colinvaux, 1964 and Colbaugh, 1968) and from the Fairbanks region (Matthews, 1970). Modern pollen rain from a series of environments in southwestern Yukon have been published by Rampton (1971). In all of these boreal or arctic studies the surface samples were only qualitatively correlated with the immediate vegetation. Because of this scarcity of published data on the modern pollen rain of Alaska, a detailed examination of pollen dispersion in the Onion Portage region was undertaken as an initial step in paleoecological reconstruction.

Surface pollen samples from the Onion Portage region were collected from forest stands I to IV (see Table 7), open shrub tundra, vegetation zones within a slough adjacent to stand I and vegetation zones up the north side of the Jade Mountains. Additional samples were collected at Cascade Lake (lat. 68°20', long. [illegible]), Brooks Range, from Mackenzie King Island (lat. 77°40'N, long. 112°W, collected by E.A. Babcock, University of Alberta, Geology Department), Canadian Arctic, and from Tangle Lake (63° [illegible]'N, [illegible]°[illegible]'W), Alaska. Table 7 gives the results of these analyses.

Modern pollen frequencies are most meaningful when they are compared with the composition of the local vegetation. Davis and Goodlett (1960), Livingstone (1968), Whitehead and Tan (1969) and Anderson (1971) have compared forest composition with pollen rain composition using a variety of quantitative measures. They were able to calculate the degree to which a tree species over- or under-represents itself in pollen production. Understanding the factor of differential pollen production is very important in the interpretation of fossil

Table 7

Modern Pollen Surface Samples

Surface Samples	*Picea*	*Pinus*	*Populus*	*Betula*	*Alnus*	*Salix*	Cyperaceae	Gramineae	Ericaceae	Compositae	*Artemisia*	Rosaceae	*Rubus chamaemorus*	Ranunculaceae	*Thalictrum*	Caryophyllaceae	*Galium boreale*	Castilleja
I Forest stand	28			115	15		16	12	1	1	1	1	1	3			1	
II Forest stand	20			145	11		7	1	7		1							
III Forest stand	45	1		110	12		22	2	8									
IV Forest stand	34			89	46	2	6	3	20									
V Tundra	23			71	64	2	19	5	16									
VI Tundra	16			63	54		37	3	21		2		4	1				
VII Tundra	24	1		53	67	1	32	1	18	1	1							
VIII Forest zone	26(6)	2	30	20(3)	115(21)	3	1	1	1									
IX Alder zone	7			17	148	2	5	7	9		4							
X Tundra zone	50(2)		12	19	94(9)	5	11(1)	3	4									
XI Open slough	17			61	92	4	17	7	2									
XII Sedge zone	34		1	30	33	7	73*	6			14			2				
XIII Salix zone	8(1)		13	20(1)	33(2)	48(4)*	61(4)	11(1)								3		
XIV Tundra	10			43	40	11	86	9						1				
XV Tundra	20		2	13	22	24	112(2)	7										
XVI Tundra	2	3		5	18	2	68	91*				1		3	1	4		
XVII Boreal woodland	90	1		43	26	9	12	12			1	3		1		1		

( ) — Additional pollen after *Populus* removed from total.

* — Pollen in aggregates.

Pollen sum = 200 grains, excluding indeterminant pollen and spores.

Table 7

Modern Pollen Surface Samples

	Gramineae	Ericaceae	Compositae	*Artemisia*	Rosaceae	*Rubus chamaemorus*	Ranunculaceae	*Thalictrum*	Caryophyllaceae	*Galium boreale*	*Castilleja* Type	Cruciferae	*Epilobium*	*Valeriana*	Indeterminant Pollen	*Lycopodium*	*Equisetum*	Polypodiaceae	*Sphagnum*	Trilete Spores	*Pediastrum*
	12	1	1	1	1	1	3			1	2	1			1	7			1	1	
	1	7		1											2	2	2		2	1	
	2	8													6	2	1	1		1	
	3	20															4	1	7	3	
	5	16														1	2		5	3	
	3	21		2		4	1									4	2		9	1	
	1	18	1	1																1	
	1	1														10		17			
	7	9		4								1				5		2	2	1	
1)	3	4													3	6(1)		3	16	5	
	7	2															60	1	6		3
*	6			14			2										9		2	1	
)	11(1)								3				1		6		2		2		
	9						1												2	1	
2)	7														5				2		
	91*				1		3	1	4			2			11					4	
	12			1	3		1		1					1	7				2		

removed from total.

rminant pollen and spores.

Sample	Localities
I-VII, XI-XIII	Onion Portage area (67°07'N, 158°22'W) forest turf.
VIII-X	Jade Mountain transect (67°15'N, 157°55'W) forest turf.
XIV-XV	Cascade Lake, Brooks Range (68°15'N, 157°55'W) moss polster.
XVI	Mackenzie King Island (77°40'N, 112°W) moss polster.
XVII	Tangle Lakes, Alaska Range (63°03'N, 146°03'W) forest turf.

pollen spectra.

In the boreal communities near Onion Portage many of the important pollen producers are shrubs and Betula is represented by both shrubs (B. glandulosa - B. nana) and trees (B. papyrifera). In order to permit comparisons between the various forest strata, species Importance Values (see p. 30), sum of dominance, density and frequency percentages, determined for the four forest stands, were employed. The Importance Values were reduced from a percentage base of 300 (trees) or 200 (shrubs) to a percentage base of 100 percent for each of the tree and shrub species compared. In this way trees and shrubs could be compared separately or together. These comparisons are shown in Figure 21.

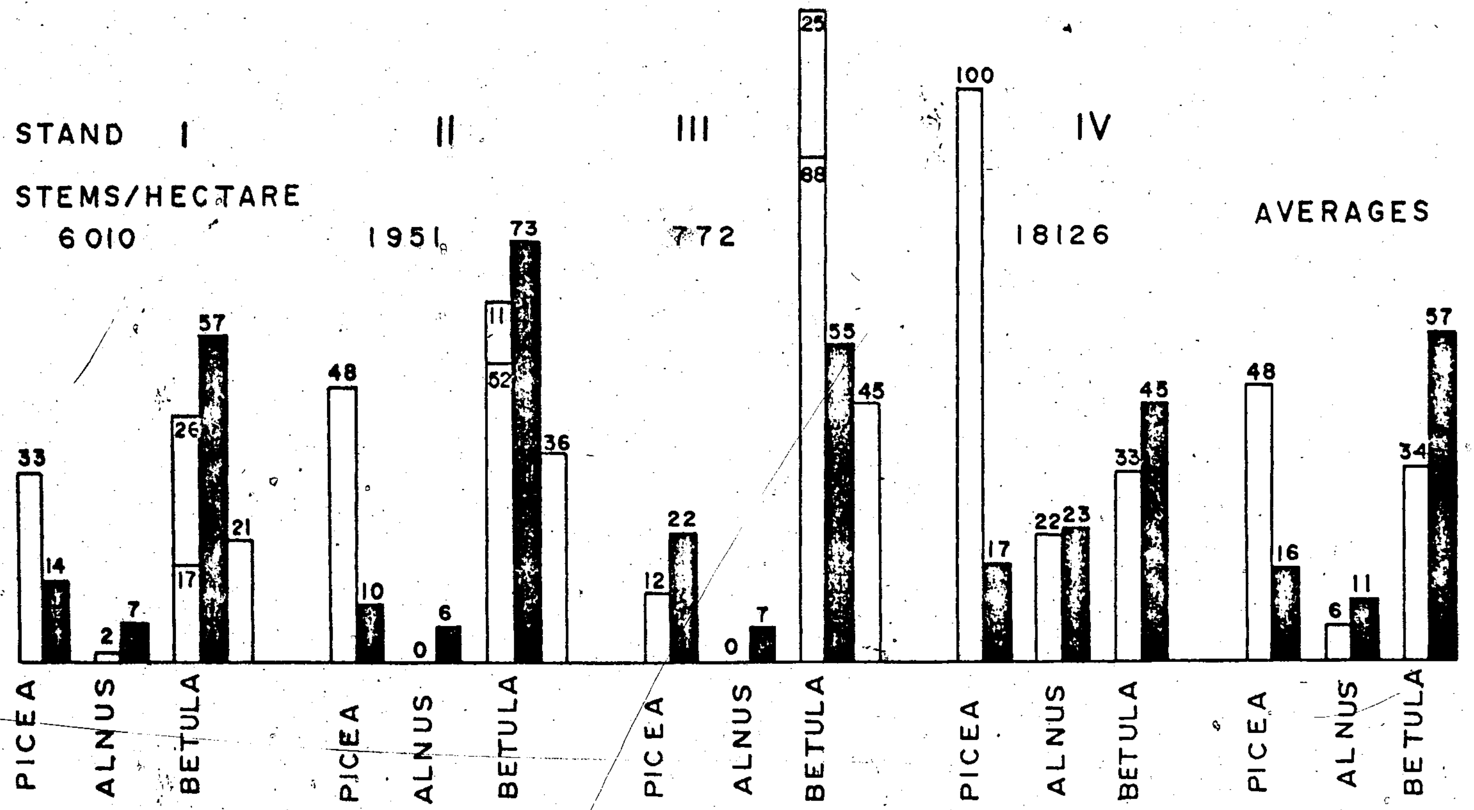
Not every taxon shows the same relationship between its pollen frequency and its I.V., and this relationship also varies from stand to stand. Picea has higher I.V. percentage than its pollen percentage, with the greatest difference found in stand IV. Picea pollen is therefore under-represented. Stand III, however, is an exception, for here it is over-represented. Alnus reached significance only in stand IV where it had about the same frequency and composition values, elsewhere it was recorded as pollen but rarely as a stem. Arboreal Betula appears to produce more pollen than its shrub species; only shrubs were recorded in stand IV. Betula clearly is over-represented in its pollen frequency.

Differential pollen production may not be the only factor influencing these comparisons, stand density and how it affects pollen

Figure 21

Comparison of modern pollen rain surface samples and Importance Values from forest stands.

POLLEN FREQUENCY AND STAND COMPOSITION



White bar = Importance Value Black bar = Pollen Frequency For Betula lower left bar = tree I.V., upper left bar = shrub I.V., right bar = combined tree and shrub. Importance Values reduced to percentage base of 100.

dispersion may also be an important factor in explaining the differences in pollen and stem frequency. Tauber (1965) has demonstrated that pollen can be filtered out of the air passing through a stand, by leaves and stems. Dense stands would trap more pollen and less would reach sites of deposition such as lakes or the forest floor. Larger and heavier pollen grains are also preferentially trapped. In very dense vegetation such as stand IV pollen entrapment should be high, while in a more open vegetation such as stand III pollen entrapment should be low. The different pollen frequencies for Picea in these two stands may reflect differential entrapment due to the differences in stem density. However, this does not explain the differences in Betula pollen frequencies, unless Betula pollen behaves aerodynamically very differently than Picea. Morphologically they are significantly different and one may anticipate a difference in dispersion ability as a result. A further factor in the fluctuations of Picea pollen may be the greater stem frequency of Picea mariana in stand IV; this species is known often to reproduce vegetatively, which would produce ~~more~~ stems and less pollen.

Surface samples V, VI and VII (Table 7) come from shrub tundra communities near Onion Portage. These communities have abundant birch and alder shrubs. The pollen spectra are very similar to those of forest stands, the differences being the slightly lower percentages of Picea and Betula and the higher percentages of Alnus and Cyperaceae. These differences are, however, so slight that they cannot serve confidently to separate shrub tundra and forest in a fossil context if they were distributed in a mosaic pattern such as in the Kobuk Valley today.

Surface samples VIII, IX and X (Table 7) represent respectively the spruce forest, alder shrub and tundra life zones on the Jade Mountains. Sample VIII was collected within a forest stand with a dense substrate of Cystopteris, yet Polypodiaceae spores are only nine percent of the total. Again the tundra zone pollen spectrum is similar to that of the forest zone. This similarity is due to the local influence of a high pollen producing forest community, near a low pollen producing tundra community. Sample IX from the intermediate dense alder shrub zone is, however, dominated by Alnus (74%). This is a situation that involves a local high pollen producer (Alnus) and a dense canopy that acts as a filter trapping pollen blown in from adjacent communities, thus preventing it from reaching the surface.

The significance of local vegetation on the pollen rain is further seen in the surface sample series XI, XII and XIII (Table 7), taken from an ephemeral slough near the Onion Portage archaeological site. These samples respectively represent the open center of the slough that is dominated by Equisetum, the surrounding dense sedge zone and the outer ring of dense willow shrubs. These three zones are clearly reflected in the pollen spectra. Although Betula (31%) and Alnus (46%) dominate, Equisetum (30%) spores are also well represented in the first zone. The sedge zone spectrum is dominated by Cyperaceae (36%) and the willow zone spectra by Salix (26%) and Cyperaceae (33%). Picea is unusually low (5%) in this last zone where again we see the filtration effect of a dense canopy of willow shrubs that have prevented spruce pollen from reaching ground surface.

Populus species are important in the forest stands of this region, yet Populus pollen is only rarely recovered in surface pollen samples (Table 7). The high susceptibility of Populus pollen to fungal decay and oxidation (Sangster and Dale, 1961 and Havinga, 1967) is no doubt responsible for its poor preservation. This imposes one of the most serious limitations in the application of pollen-analysis to boreal regions.

Three additional pollen spectra (Table 7) represent arctic tundra and the last, alpine tundra. Samples XIV and XV, from shrub tundra near Cascade Lake in the northern foothills of the Brooks Range, are dominated by Cyperaceae (43%, 57%) and Alnus, Betula and Salix. The latter two are shrubs in the area but Alnus and Picea (5%, 10%) represent long distance transport from source areas to the south or possibly further north in the case of the Alnus. Cascade Lake is approximately 60 km. beyond the limits of spruce. Sample XVI, from Mackenzie King Island in the Canadian High Arctic, is well beyond the limits of spruce, alder and birch. This pollen spectrum is dominated by Gramineae (46%) and Cyperaceae (34%). Alnus is still 9% while Picea drops to 1%. The last sample XVII represents alpine shrub tundra in the Alaska Range, just above the spruce woodland. Here Picea reaches a maximum of 45%, Betula22% and Alnus 13%; Cyperaceae and Gramineae both remain low at 6%.

These seventeen surface samples illustrate clearly the high degree of pollen rain variation in the subarctic-arctic regions. This variation should greatly aid interpretation of fossil pollen spectra. But there is also a high degree of variation in the modern pollen rain from within a restricted area, and this variation greatly complicates the paleo-interpretation. Factors such as differential pollen production, long distance transport, differential pollen preservation, local over-representation and pollen filtration are significant factors in producing such variation.

Epiguruk Pollen Sections

In order to establish a late Quaternary paleoecological record, sedimentary sections from Epiguruk were investigated in detail. This exposure afforded good stratigraphic control, time-depth and material for radiocarbon dating. The poor pollen preservation in the sediments at the Onion Portage site and the dubious value of the lake cores made the cutbank exposure a necessary choice.

Several Epiguruk sections were sampled in detail but only three were finally used for pollen-analysis (Figure 10). Unfortunately, unit A proved to be sterile of pollen and units C and D yielded only a few poorly preserved, unidentifiable pollen grains.

Pollen section I (650 m., Figure 10) presents a sedimentary record from a small, drained pond or swamp above the alluvial silts of Unit D. Slumping has obscured the margins of this basin but the exposed portion is about 30 m. long. Unit E sediments are described in Table 8. Radiocarbon samples from Units E and C, collected at 0.42 m. (peat), 1.25 - 1.35 m. (twigs), 1.95 - 4.15 m. (twigs) and 5.15 m. (twigs) have been dated at 2,670 ± 95, 8,800 ± 210, 17,730 ± 820 and 18,100 ± 550 radiocarbon years B.P. respectively (Figure 10 and Table 4). The zone of

Table 8

Sediment Description of Epiguruk Pollen Section I

Sediment Description	Depth*
Forest litter, noncompacted, silty	0 - 0.30 m.
Peat, dark brown, compacted woody; partially oxidized	0.30 - 0.44 m.
Silts, gray, laminated; sterile silts with organic partings and twigs near base grade upward to dark gray organic rich silts near top	0.44 - 1.35 m.
Silts, gray, laminated; sterile; this is base of unit E	1.35 - 2.10 m.
Silts, reddish brown non-bedded; iron staining, root casts and concretions	2.10 - 2.80 m.
Silt and fine sand, light gray; often mottled dark gray; bedding even to wavy; scattered small twigs or roots; this is the top of unit C	2.80 - 5.45 m.

*Measurements are from top of the expo[illegible]re.

secondary iron deposition and root casts represents an unconformity between the top of unit C and the base of unit E. The sediments of unit E represent basin infilling with sterile lacustrine silts at the base grading upward to organic rich lacustrine silts, peat and finally forest litter. Fossil pollen was found only above 2.10 m.; below this the sediments were sterile.

Pollen section II (400 m., Figure 10) was collected through one of the thickest and least disturbed parts of unit B. This section is described in detail in Table 9. The lower portion of unit B exposed from 50 to 650 m. along the river (Figure 10) is composed of alternating organic and inorganic sediments and represents a variety of wet land environments. Ripple marks and clay-peat balls along the contact with unit A attest to initial open water conditions. As the basin filled, organic-rich sediments and peats were deposited. Above 15.50 m. the mottled calcareous silts with snails suggest a return to open, deeper water conditions; above this the sediments again become organic-rich, indicating shallower water and the growth and deposition of organic material. As discussed above, the contact between units B and C represents an erosional unconformity.

Pollen section III (0 m., Figure 10) represents the sediment fill of a river channel or slough that was cut along the north end of the Epiguruk bank. It was probably cut or used at the same time that the Kobuk River was cutting at the base of the bluff at Onion Portage. This is confirmed by the radiocarbon dates which indicate an overlap of the two records. As the channel migrated away from the

Table 9

Sediment Description of Epiguruk Pollen Section II

Sediment Description	Depth*
Forest turf and peat	0 - 0.30 m.
Silt and fine sand, gray to buff, evenly bedded; highly micaceous; this is unit C; becomes organic rich near lower contact	0.30 - 12.0 m.
Peat, bryophyte-sedge, very compact, fibrous	12.0 - 12.65 m.
Silt and fine sand, dark brown, organic rich; non-bedded	12.65 - 13.10 m.
Sand, coarse grained, dark brown, organic rich; laminated	13.10 - 13.75 m.
Silt, dark gray to brown mottled; calcareous, partly cemented	13.75 - 14.40 m.
Silt, light brown to gray mottled; abundant snails, calcareous; red, iron stained sand at lower contact	14.40 - 15.00 m.
Silt and coarse sand, alternating, tan; poorly bedded	15.00 - 15.50 m.
Peat, bryophyte-sedge, brown, fibrous	15.50 - 15.57 m.
Sand, coarse grained, gray, well sorted, mixed with contorted units of dark brown, organic rich fine sand	15.57 - 15.75 m.
Peat, bryophyte, brown, fibrous	15.75 - 16.00 m.
Silt and medium sand, interbedded, silt is dark brown, sand is tan	16.00 - 16.44 m.

*Measurements are from top of the exposure.

Table 10

Sediment Description of Epiguruk Pollen Section III

Sediment Description	Depth*
Forest turf, uncompacted, humified	0.10 - 0 m.
Silt, gray; grades up to dark gray organic rich at top; non-bedded	0 - 1.10 m.
Peat, black, fine grained, nonfibrous	1.10 - 1.18 m.
Silt, gray, weakly bedded	1.18 - 1.60 m.
Peat, black, fine grained, nonfibrous	1.60 - 1.70 m.
Silt, blue gray, weakly bedded	1.70 - 2.05 m.
Peat, black, fine grained, nonfibrous	2.05 - 2.12 m.
Silt, blue gray, weakly bedded	2.12 - 2.20 m.
Peat, black, fine grained, nonfibrous	2.20 - 2.24 m.
Silt, blue gray, nonbedded	2.24 - 2.35 m.
Peat, brown, fibrous, bryophytic	2.35 - 2.40 m.
Silt, mottled tan and gray silt, weakly bedded	2.40 - 2.65 m.
Peat, brown, fibrous, bryophytic	2.65 - 2.70 m.
Sand, medium to coarse grain, tan; cross bedded; scattered wood fragments	2.70 - 3.37 m.
Silt and medium sand, interbedded, tan sand and gray silt, laminated with brown detrital organic debris	3.37 - 4.25 m.
Silt, blue gray, laminated, snails present near the top	4.25 - 5.25 m.

*Measurements are from top of the section.

bluff and [illegible] slough on the new lower floodplain. The sediments are described in Table 10.

Section III radiocarbon samples were collected at 1.[illegible] m. (peat), [illegible].82 m. (wood) and [illegible] m. (twigs); these were dated at [illegible] ± 128, 8,635 ± 210 and 8,135 ±[illegible] radiocarbon years B.P. respectively (Figure 10, Table 4). The inverted date at [illegible].8[illegible] m. is probably the result of redeposition of older wood fragments with the alluvial cross-bedded sands and is therefore rejected as being too old. This section represents the in-filling of an open slough; [illegible] m. of sand and silt were deposited in [illegible],000 years by alluvial deposition. Fibrous and detrital peat bands and organic rich silts near the top represent the final phase of infilling with primarily organic deposition.

Pollen sections I and III span most of late-glacial and post-glacial time and overlap with the paleoenvironmental record from the archaeological site. Since they represent a small upland pond and a floodplain slough they should provide, when compared, a record of the regional pollen rain history free of local influences.

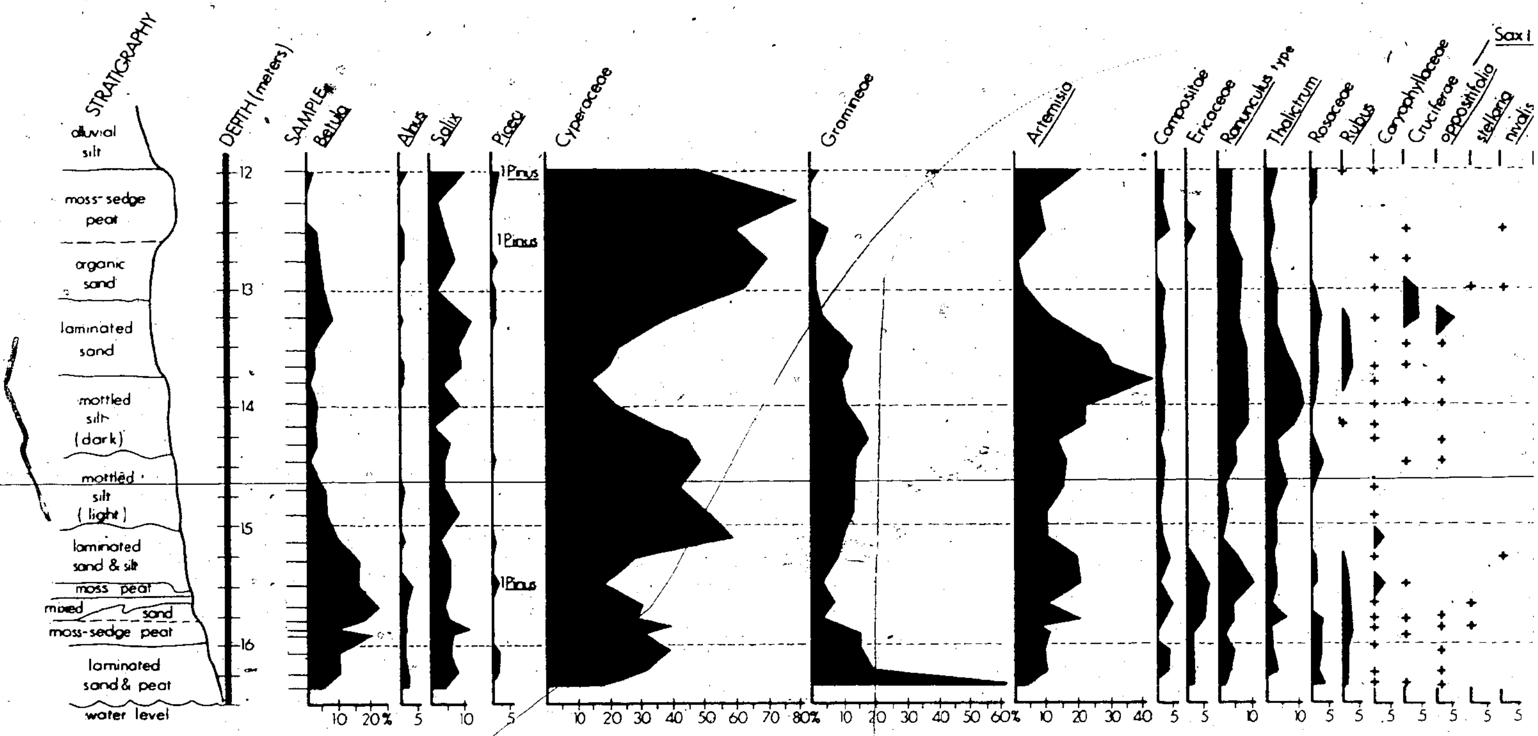
Pollen Diagram from Epiguruk II

Since pollen section II, through unit B, is considerably older than sediments of pollen sections I and III, it will be discussed first. This pollen diagram (Figure 22) shows a pollen flora dominated by Cyperaceae (20 to 80%), Gramineae (5 to 20%, and over 60% in the basal sample), Artemisia (10 to 45%) and other herbaceous types. Betula and Salix are the shrubby taxa that are significantly abundant;

Figure 22

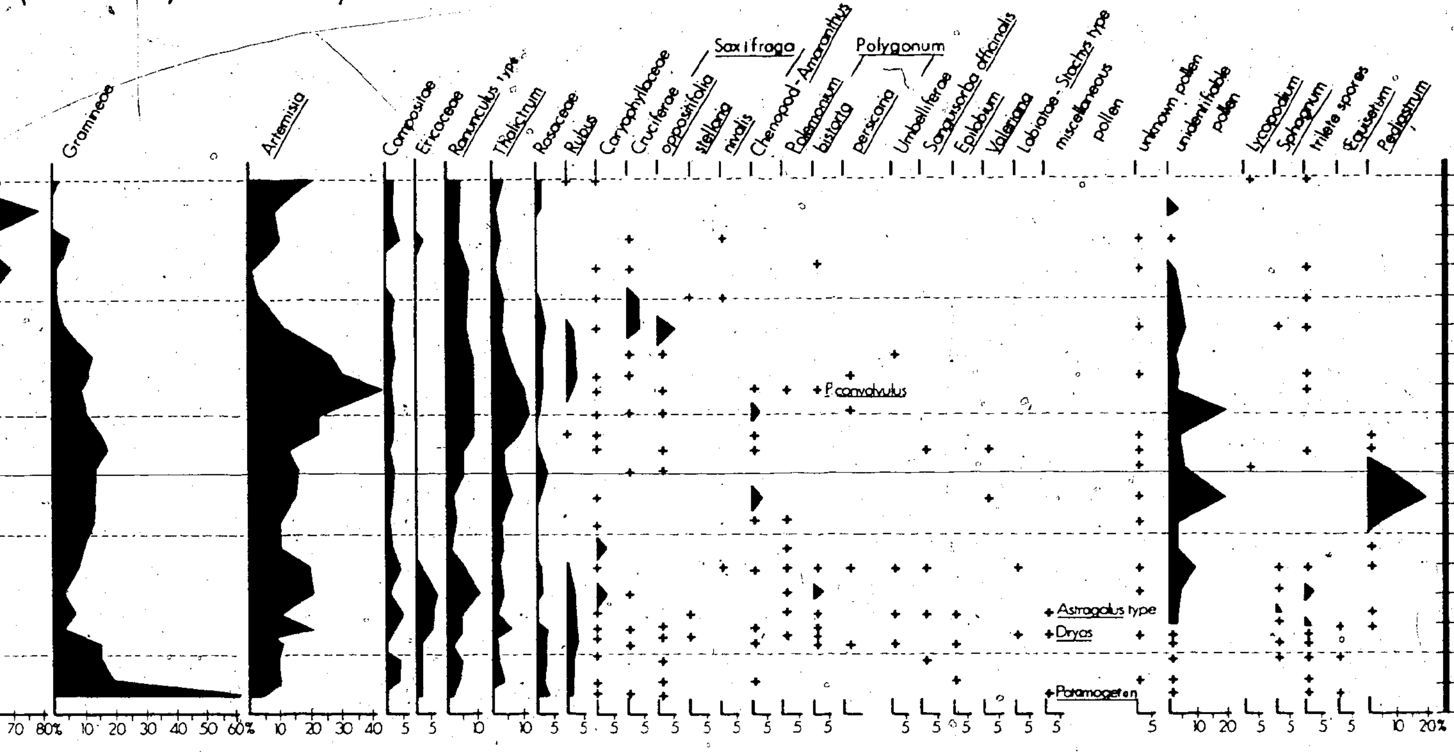
Epiguruk II pollen diagram.

Epiguruk - II, Kobuk River, Alaska (67°05'N; 158°10'W).



Σ = 200, indeterminant pollen & spores excluded, % Sum = Σ, + = < 2%

(67°05'N; 158° 10'W).



& spores excluded, % Sum = Σ, + = < 2%

C. E. Schweger, 1970.

arboreal pollen of Picea and Pinus is rare. Ranunculaceae pollen of the Ranunculus and Thalictrum types are the most frequent herbaceous taxa. Other herbaceous taxa reach less than 5 percent frequency.

To interpret this fossil pollen record in terms of vegetation type, comparisons must be made with modern surface pollen samples. Samples from shrub tundra north of the Brooks Range (Livingstone, 1955 and Table 7) are dominated by Cyperaceae (40 to 50%) and Betula (7 to 20%). But the percentage of Alnus (10 to 20%) and Picea (5 to 10%) make analogous comparisons with this environment unlikely. More similar are surface sample spectra from shrub tundra in northern Ungava, Quebec (Bartley, 1967) and the Northwest Territories (Ritchie and Lichti-Federovich, 1967). These localities are north of the range of Alnus, but within the range of shrub Betula. A pollen sample from Mackenzie King Island beyond the present limit of Betula does have high amounts of Gramineae (45%) and Cyperaceae (34%) while Alnus and Betula remain low. This sample represents sparse high arctic vegetation.

Hence, this fossil pollen record appears to represent a high arctic tundra vegetation within or near the limits of Betula shrubs. But this can be only a partial description, the high amounts of Artemisia pollen make this fossil record unusual. No modern tundra pollen spectra have Artemisia percentages as high as these. Similar percentages have been recorded in modern surface samples across the northern Great Plains and Wyoming from sagebrush (Artemisia) shrub - steppe vegetation or high plains grassland with Artemisia (McAndrews and Wright, 1969; Mott, 1969). Other researchers have discovered high Artemisia percentages in fossil pollen assemblages from Alaska. This suggests a widespread Artemisia-rich vegetation and not unique local conditions. The high percentages are believed to represent an abundance of dry sites (Colinvaux, 1967), pioneering environments (Matthews, 1973) or an expansion of steppe vegetation during the Wisconsin glacial (Hopkins, 1972). In effect, these are all related and clearly indicate a regional vegetation cover unlike that anywhere in Alaska at the present time. Over 20 species of Artemisia are now found in Alaska but nowhere do they dominate the vegetation. Hulten (1968) describes the habitats as rocky slopes, sandy slopes, dry slopes, dry hills, seashore, rocky shore, gravel bars, alpine meadows, and open forests. By analogy, the high Artemisia fossil pollen spectra must represent an open xeric or pioneering vegetation.

The vegetation represented by the Epiguruk II pollen record appears to have been a mixture of high arctic tundra and xeric steppe, perhaps best described as a steppe-tundra. Grasses, sedges and Artemisia dominated the vegetation with birch and willow shrubs growing in favorable habitats. A climate not only colder but much drier than present is implied.

The fluctuations in the pollen percentage curves for Cyperaceae, Gramineae and Artemisia (Figure 22) are probably related to changes in the local depositional environment rather than regional paleoclimatic changes. Ripple marks and peat balls at the contact of units A and B suggest an open, shallow water environment. The very high Gramineae pollen content of the basal sediments may indicate a grassy fen at this time, but, unfortunately, the emergent aquatic grasses cannot be taxonomically differentiated on the basis of their pollen.

Fluctuating water levels and wave erosion at the base of what would have been a sandy bluff (650 m., Figure 10) can account for the alternating sand and organic layers from near the base of this section to 15.0 m. (Table 9). Between 15.0 and 14.0 m. below the surface, calcium carbonate-rich silts were deposited. The lake must have deepened at this time, snails lived in this pond and Pediastrum colonies flourished. Aquatic sedges from shallow portions of the basin can account for the high Cyperaceae percentages. The marked drop in Cyperaceae and rise of Artemisia at 13.75 m. coincides with the influx of sand and suggests a local hydrological change. Perhaps the water level dropped and exposure of the sandy bluff face allowed sand to be washed into the basin. The exposed sandy bluff may have been densely colonized by Artemisia, accounting for its high percentages at this time. Above this, Cyperaceae pollen percentages steadily increase as the lake basin filled with organic-rich sediments and finally a bryophytic-sedge peat. At this point the environment must have been a wet tundra marsh or swamp.

The Betula curve percentage fluctuations may have paleoclimatic significance. Below 14.75 m. Betula pollen rises to over 20% but the percentage drops as the lake deepens and importantly remains low after the drop in water level. Below 15.0 m. birch shrubs were present locally, but above this their frequency must have dropped. A change from a shrub steppe-tundra to an open steppe-tundra is suggested; this change would seem to indicate the onset of a still cooler climate. Further evidence of this change is seen in the increased cryoturbation in the upper portion of unit B. Involuted bedding, frost cracks and ice-wedge casts all suggest a more severe climatic regimen. The question then arises as to whether this cold oscillation represents the onset of a glacial climate following an interstadial or an interglacial.

The deep core from Imuruk Lake, Seward Peninsula, revealed a high spruce pollen zone (i) preceding the Holocene spruce maximum. Colinvaux (1964) interpreted this period as representing a climate very similar to the present and correlated it with the Sangamon interglacial. Sediments representing Wisconsin interstadial (J2) have rare spruce pollen and can be interpreted as representing a middle-arctic shrub tundra vegetation (Colinvaux, 1964, 1967, and Colbaugh, 1968). Matthews (1974a) has demonstrated a Pleistocene spruce tree line stand nearer to Deering on the Seward Peninsula than at present. He correlated this period with the Sangamon interglacial. His work (Matthews, 1974b) in the Fairbanks region has demonstrated a mid-Wisconsin interstadial during which spruce tree line was lower in elevation than at present.

In a review of the paleogeography of Beringia, Hopkins (1972) reconstructed a taiga vegetation over Beringia (Alaska - Chukotka) during the Sangamon interglacial. He concluded that the spruce tree line extended beyond its present position and possibly beyond the divides in the Brooks Range. During the summer of 1973 I had the opportunity to visit a number of sections along the middle Koyukuk River Valley. Organic deposits believed to be of mid-Wisconsin age, on stratigraphic evidence, did not contain logs and wood such as are found in the Holocene sections deposited in a forest environment.

On the basis of the available evidence it appears that unit B represents deposition during a Wisconsin interstadial. Dreimanis and Raukas (1973) have reviewed the evidence and chronology for a mid-Wisconsin - mid-Weichselian interstadial. They see this interval as a complex of several interstadials covering the period 23,000 to 65,000 years B.P. Colbaugh (1968) established this interval as preceding 34,000 B.P. based upon a C-14 date at the top of pollen zone J2 at Imuruk Lake. Matthews (1974b) dated the interstadial in the Fairbanks region between 35,000 to 32,000 B.P. Unfortunately, the Epiguruk interstadial record is incomplete with a hiatus of over 16,000 years represented at the unconformity between units B and C. It seems unlikely, therefore, that the drop in birch pollen percentages in the upper portion of unit B is related to the onset of late Wisconsin glaciation.

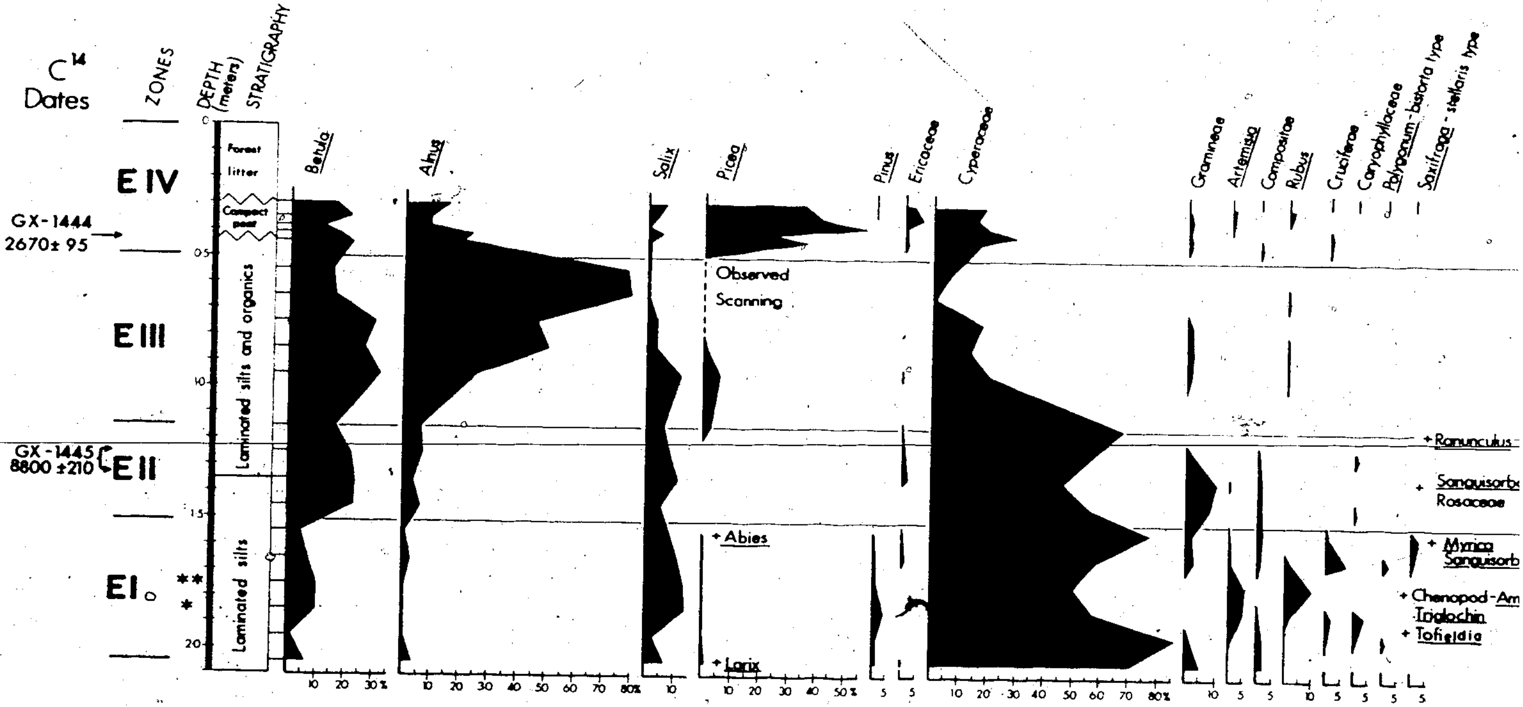
Description of Epiguruk I Pollen Diagram

[illegible]len diagram from Epiguruk I is shown in Figure 23. Pollen w[illegible] all samples from the ground surface to a depth of 2 [illegible] this to a depth of 5.45 m. the sediments were sterile. In the [illegible]-bearing sediments the amount of pollen was often very low, necessitating counts of 3 to 4 slides in order to reach a 200 grain total sum. The samples at 185 cm. and 175 cm. had only 77 and

Figure 23

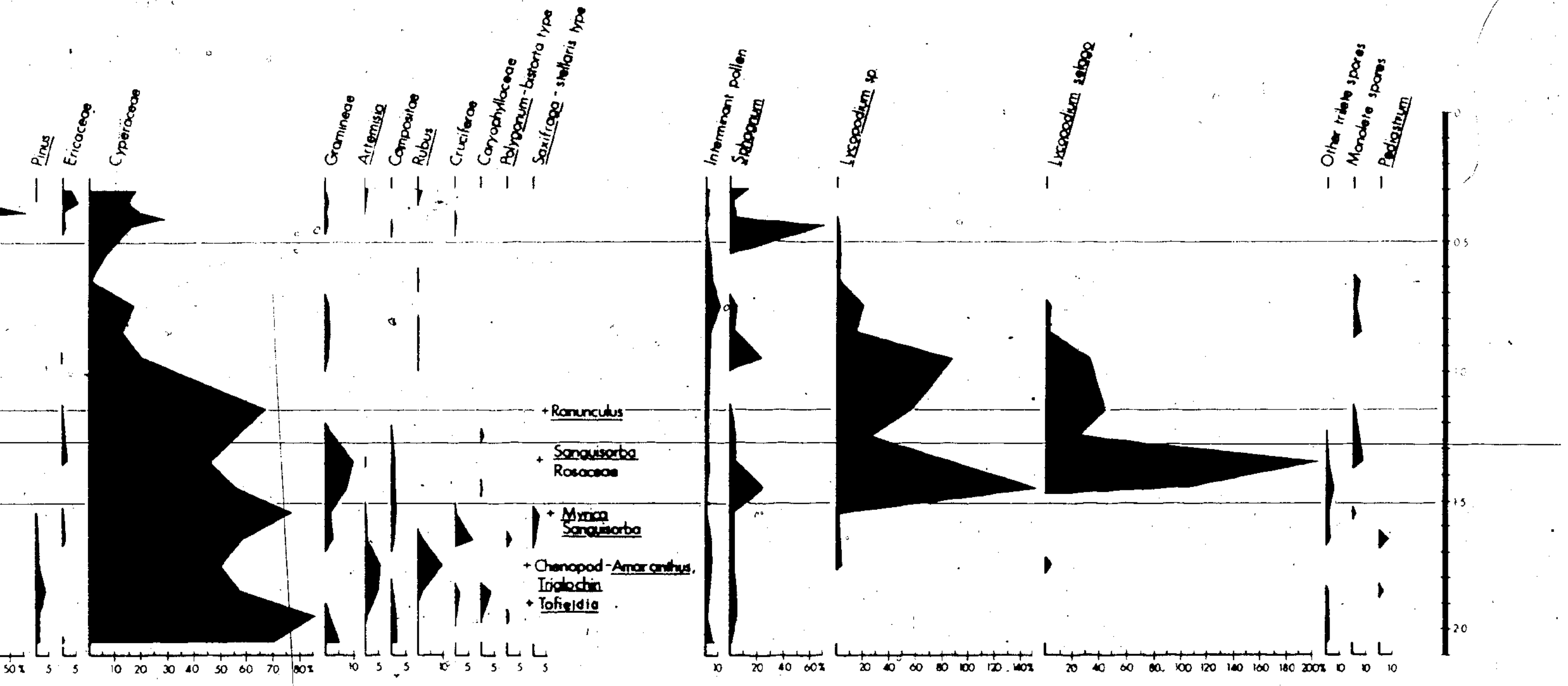
Epiguruk I pollen diagram.

Epiguruk - I, Kobuk River, Alaska, (67° 05' N; 158° 10'W)



Σ = 200 indeterminant pollen and spores excluded + = 1 grain
** = 94
* = 77

58° 10' W)



res excluded + = 1 grain % Sum=Σ C.E. Schweger, 1969.

94 grains respectively, even though all the extracted residue was examined. Zones were used to subdivide and describe the pollen diagram. The zone boundaries were based on significant fluctuations of the major pollen types. These zone designations are for convenience and may or may not have regional application.

Zone EI (210 - 150 cm.). This basal zone is characterized by very high amounts of Cyperaceae pollen, up to 85%, and an abundance of pollen from herbaceous taxa. Betula and Alnus pollen percentages are low; Salix, the only shrubby taxon that is relatively abundant, reaches 11%. Picea pollen is rare and Pinus very low. A number of herbaceous types are limited to this zone, these being Artemisia, Rubus, Cruciferae, Caryophyllaceae, Polygonum bistorta type and Saxifraga stellaris type. A spore flora is absent or reaches very low frequencies while Pediastrum algal colonies are found only in this zone. By extrapolation, using the two radiocarbon dates from this section and assuming a uniform rate of deposition, the base of Zone EI may be 12,000 years B.P.

Zone EII (150 - 115 cm.). Here Betula pollen increases to over 23% and Alnus rises to 8%. At the same time there is a decrease in the amount of herbaceous pollen, although Gramineae percentages peak at 10%. Pinus is absent and Picea appears only at the upper zone boundary where it reaches 3%. Sphagnum and Lycopodium spore content of the sediments increase greatly in this zone. Lycopodium reaches a distinct maximum.

Woody twigs first appear in sediments of this zone; a collection of twigs from a 10 cm. interval (125 - 135 cm.) was dated at 8,800 ± 210 B.P.

Zone EIII (115 - 50 cm.). *Alnus* pollen rises dramatically from 6% at the base of this zone to almost 80% of the pollen rain near the top of the zone. This tremendous increase in *Alnus* pollen imposes a statistical constraint on the other pollen types in the upper portion of this zone. *Betula* pollen increases to over 30% in the lower portion of this zone but decreases to 16% in the upper portion. *Salix* pollen percentages drop throughout this zone, and so does Cyperaceae, while *Picea* pollen almost disappears from the sample although it was observed in scanning the alder-rich slide. Even though the spores are not included in the total pollen sum and should not display the constraint, they too drop in the upper portion of this zone.

Zone EIV (50 - 0 cm.). The drop in the percentage of *Alnus* from its maximum and the sharp increase in *Picea* percentages to a maximum of 57% characterize this zone. *Betula* pollen increases slightly, as does *Salix* both as a result of the *Alnus* drop. Cyperaceae pollen also rises to a maximum of 30% from its previous low while Ericaceae pollen reaches a maximum of 7%. *Sphagnum* spores also reach a maximum, reflecting the change in sediment type from silts to peat. A radiocarbon date on peat from 43 cm. below surface dates the base of this zone at 2,670 ± 95 B.P.

Description of Epiguruk III
Pollen Diagram

The pollen diagram from Epiguruk III is shown in Figure 24. Although the fossil pollen of this section is abundant and preservation generally excellent, several sterile zones were identified. These sterile zones seem to be characteristically associated with blue-gray silt horizons and may represent periods of rapid silt deposition when pollen was highly diluted by inorganic sediments. The same pollen zones were employed to describe this pollen diagram. However, Zone EI (high Cyperaceae) is not present in this section.

Zone EII (525 - 235 cm.). As seen in Epiguruk I, *Betula* pollen remains high throughout this zone, 32 to 63%, while *Alnus* pollen percentages remain low, often less than 5%. *Picea* remains low, less than 5%, except for the spectra at 420 cm. where it jumps to 17%. Cyperaceae pollen fluctuates greatly and frequently, reaching a high of 42% and dropping to less than 10%. Gramineae pollen percentages remain generally high, rising to a 23% maximum. *Artemisia*, Compositae and a variety of other herbaceous types are also most frequent in this zone. The spore flora is again dominated by *Sphagnum*, Polypodiaceae and *Lycopodium*. The latter two are very abundant in the lower portion of this zone. A radiocarbon date from 460 cm. is 8,150 ± 128 B.P.; a second date from 282 cm. of 8,635 ± 210 B.P. creates an age inversion (Table 4). Since it is easier to account for older wood being redeposited into younger age sediments than for younger twigs being rebedded into older laminated silts, I reject the latter date as the age of the sediments.

<u>Figure 24</u>

Epiguruk III pollen diagram.

Epiguruk- III, Kobuk River, Alaska, (67°05'N, 158°10'W)

Σ = 200, indeterminant pollen and spores excluded

+ = 1 or 2 grains

% Sum = Σ

0'W)
Salix
Cyperaceae
Gramineae
Artemisia
Compositae
Ranunculaceae
Ericaceae
Rosaceae
Caryophyllaceae
Chenopod.-Amaranthus
Sanguisorba
Valeriana
Thalictrum
Umbelliferae
Cruciferae
Potamogeton
Unknown pollen
Indeterminant pollen
Sphagnum
Polypodiaceae
Lycopodium sp.
Lycopodium selago
other trilete spores
+ Saxifraga oppositifolia type
+ Polemonium
+ Equisetum
+ Pediastrum
0
.05
.10
.15
.20
.25
.30
.35
.40
.45
.50
pores excluded
+ = 1 or 2 grains
% Sum=Σ
C.E. Schweger, 1971.

Zone EIII (235 - 120 cm.). Alnus pollen begins to increase significantly at the base of this zone, reaching a maximum of 90% of the total flora. Betula drops from its former high percentages to as low as 4%. Cyperaceae remains generally low throughout the zone except for the sample collected from the peat band at 210 cm. which represents a local sedge growth. Gramineae remains very low throughout the rest of the diagram and Artemisia remains low through this zone. No doubt, here too, there is a constraint imposed on the other taxa by the very high percentages of Alnus pollen. Clumps of Alnus pollen were observed, these indicating an extra-local source of the Alnus. The spore content of the sediments jumps to high values in the lower portion of this zone.

Zone EIV (120 - 0 cm.). This zone sees Alnus pollen frequencies drop back to 25% while Picea pollen increases to a maximum of 38%. Percentages for Betula pollen also rise, reaching a 45% maximum. Cyperaceae percentages continue to fluctuate greatly; Gramineae remains very low and there is a significant decrease in the pollen of a variety of herbaceous elements although Artemisia and Ericaceae do show minor increases in frequency. The spore flora is also generally low. A radiocarbon date of 5,140 ± 120 B.P. from peat at 112 cm. dates the lower portion of this zone.

Interpretation of Epiguruk I and III Pollen Diagrams

The fossil pollen record presented here is broken into four zones, each being dominated by a different pollen type, namely Cyperaceae, Betula, Alnus and Picea respectively. By extrapolation from the available radiocarbon dates this is a 12,000 year record of vegetation development in the Onion Portage region. The estimated age of the zone boundaries are Zone EI, 12,000 to 10,000 B.P.; Zone EII, 10,000 to 7,000 B.P.; Zone EIII, 7,000 to 5,500 B.P.; Zone EIV, 5,500 to present. Obviously more dates are needed from additional sites in order to establish an accurate chronology.

This pollen record must be interpreted in terms of vegetation history. It may be possible to make a first order comparison with the modern vegetation zones of northwestern Alaska. The open tundra of the northern coastal plain is dominated by Cyperaceae and herbaceous elements; <u>Salix</u> is the only important shrub species. To the south, several kilometers inland, birch shrubs appear and become an important element in the shrub tundra of the Alaska north slope. Over 100 km. south of Barrow, the nearest alder bushes are found scattered primarily along river valleys and slopes. These become very important into the mountain divides. Spruce appears on the south side of the divides or about 300 to 400 km. south of the coast. Since Cyperaceae, <u>Betula</u>, <u>Alnus</u> and <u>Picea</u> are significant to the vegetation zones, it is tempting to correlate directly to the fossil pollen zone. This would give a paleoecological record in terms of a modern north-south vegetation gradient.

For a more meaningful reconstruction, the modern pollen surface sample record must be utilized. Two surface samples from lakes in the Barrow region, Alaska (Livingstone, 1955) yielded a record of <u>Betula</u> 7 - 5%, <u>Alnus</u> 5 - 10%, <u>Salix</u> 3 - 4%, <u>Picea</u> less than 2%, Cyperaceae 36 - 24%, and Gramineae 41 - 49%. This is quite similar to the zone EI pollen percentages but the very high grass pollen makes this modern record unusual. The high grass content may be due to emergent aquatic and wet tundra grasses (Dupontia and Alopecurus) common in the Barrow region (Britton, 1967) and therefore of only local significance.

The modern surface sample from Mackenzie King Island (Table 7) is also similar but again the percentage of grass pollen is very high (45%). This sample represents a high arctic and very sparse tundra vegetation. Surface samples representing the low arctic tundra from northern Quebec (Bartley, 1967) and a variety of localities in the Canadian Arctic (Ritchie and Lichti-Federovich, 1967) are also very similar. The very low amounts of Picea and low amounts of Betula and Alnus as well as the high percentages of Salix and dominance of Cyperaceae and Gramineae compare closely to the fossil pollen spectra in Zone EI. These modern environments represent an open sedge-moss tundra with willow and/or birch shrubs growing in restricted favorable localities.

It would seem that the vegetation represented by the pollen Zone EI must have been an open Cyperaceae-herbaceous tundra similar to the high arctic tundra across the northern coastal plain of Alaska or the middle regions of the Canadian High Arctic. Salix shrubs were no doubt present in favorable spots along drainages and near snowbanks. The dwarf birch shrubs (B. glandulosa - B. nana) may have been present, but if so, only in very small amounts.

A vegetation such as the above would have had a very low pollen productivity, perhaps as low as the modern Canadian High Arctic where Ritchie and Lichti-Federovich (1967) have estimated pollen influx into lakes at only 5 grains/cm.^{2}/year. They recorded a range of 22.5 to 65 grains/cm.^{2}/year at mid-Arctic sites and 52.5 to 762.5 grains/cm.^{2}/year at low-Arctic sites. Because of the low local productivity, any pollen representing long distance dispersal from distant sites becomes important in the relative percentages. For comparison, pollen production in the forest-tundra zone was measured at 275 to 2,372.5 grains/cm.^{2}/year and 1,157 to 8,353 grains/cm.^{2}/year in the northern boreal forest.

In view of these data the low percentage values for Betula (arboreal?), Alnus and Picea in Zone EI means that these important floral elements were a long distance from Onion Portage. Comparisons with the Barrow surface samples would suggest a forest-tundra ecotone several hundred kilometers south of the central Kobuk Valley. Pollen records from Fairbanks, 575 km. to the southeast, show that spruce was not present in this area until 8,100 B.P. (Matthews, 1970 and 1974b), still further south, in the Tangle Lakes area of the Alaska Range, spruce did not appear until 9,100 B.P. (Schweger, unpublished data). The question of a spruce refugium during the late Wisconsin will be discussed later.

The open tundra vegetation at Onion Portage lasted until about 10,000 years B.P., at which time the pollen record shows a significant increase in Betula and Alnus. Dwarf birch shrubs must have become common in this region while alder stands migrated closer to this region. Again, a comparison of modern and fossil pollen records (Livingstone, 1955; Ritchie and Lichti-Federovich, 1967; and Table 7) indicates a vegetation type very similar to the dwarf birch shrub tundra that now covers much of the Alaskan north slope and northern foothills region of the Brooks Range (Britton, 1967 and Spetzman, 1959). Betula glandulosa - B. nana shrubs were frequent across a sedge-herbaceous tundra and no doubt abundant in local habitats. Along with willow shrubs, they must have added a distinctive "woody" component to this vegetation (Figures 23 and 24).

Alnus pollen increases approximately 7,000 years B.P. At this time alders must have eventually migrated into the middle Kobuk Valley region and extensively colonized the landscape. The fossil pollen frequencies of Alnus at its maximum are only matched by surface samples from the alder zone on the Jade Mountains (Table 7, sample IX). High alder percentages are also recorded in lake sediments near the Brooks Range divide (Livingstone, 1955). Alders were probably very common, growing in dense groves along the river valleys and slopes. Although alder does not appear to be a prolific pollen producer, as demonstrated earlier, the dense stands can intercept the airborne pollen produced by the surrounding vegetation. The net effect is an increase in alder representation and a decrease in the pollen of other species.

The arrival of Alnus probably indicates the appearance of a transitional community between shrub tundra and the developing boreal forest. A similar community now exists near tree line in alpine situations, or beyond the spruce tree line near mountain divides. This community appears to have been relatively short-lived, as a rise of Picea pollen indicates the beginnings of spruce forest development.

Zone EIV represents the arrival of spruce and its subsequent spread across the landscape. However, it is difficult to interpret exactly the first appearance of Picea forest in this area. Forest vegetation has a higher pollen production than non-forest vegetation. Picea is also a wind-pollinated species. Because of these two factors Picea pollen may be relatively abundant in tundra near spruce forest. It could be assumed that the boreal forest would be represented in the pollen record before it actually arrived in the region. On the other hand, the very high Alnus percentages masked the significance of the other species so that it can only be assumed that Picea was definitely present when Alnus percentages began to drop. It is not possible to talk of the arrival of spruce as a tree line separating boreal forest from tundra. Since the Onion Portage region is now a forest-tundra mosaic, the vegetation development must have been one of increasing arboreal component. This makes the problem of dating the appearance of spruce forest a somewhat arbitrary and academic decision.

In both pollen diagrams (Figures 23 and 24) Picea pollen increases from zero percent to near 5% about 8,000 B.P. Another percentage increase occurs before 5,000 B.P. and this is followed by a large increase, up to 50%, approximately 3,000 B.P. The first increase suggests a long distance source for the spruce pollen; 2 - 15% Picea pollen is recorded in modern tundra surface samples. The second rise indicates an extra-local source (Janssen, 1966), perhaps in the central Kobuk Valley in the Onion Portage region, while the third rise would imply a local source immediate to the collection site. It is suggested here that spruce colonized the region of Onion Portage sometime between ca. 7,000 and 5,000 B.P. Unfortunately, the constraint imposed by the Zone EIII Alnus rise depresses the Picea percentages, making interpretation difficult.

Spruce would probably have migrated into this region following the river valleys and drainage systems where there is a more favorable soil thermal regimen. South-facing slopes with higher insolation would also have been optimal sites for early colonization. These factors make the paleoecological record from the Onion Portage archaeological site important, since it may provide the earliest record for the appearance of spruce in this region. Band 8 and 7 paleosols were formed under shallow permafrost conditions, poor drainage, extreme cryoturbation and probably a tundra vegetation cover. The fossil pollen record supports this conclusion. Band 6 paleosol is a podsol formed under conditions of deeper permafrost, improved drainage and little cryoturbation; the soil humus contains spruce macrofossils, indicating that spruce grew on the site. This supports the less precise fossil pollen record indicating that spruce migrated into this region between 6,000 and 5,500 B.P.

Since its appearance, spruce forest has apparently spread, occupying more and more of this region. There are several reasons for this. Climatic warming is an obvious factor but long-term acidification and edaphic succession cannot be overlooked. Still another factor is the development of the Kobuk River floodplain with more and more flood channels, sloughs and ox-bow lakes, each of which provide favorable shoreline substrate conditions for spruce. If climate were the dominant control on the movement of spruce, *Picea glauca*, the more pioneering white spruce would have been favored. If edaphic and successional factors were more in control, *Picea mariana*, the bog black spruce, would have been favored. Unfortunately, there is no way at present of separating these two species on the basis of fossil pollen grain morphology.

Betula papyrifera, the arboreal birch, and *Populus balsamifera* and *P. tremuloides* are also important elements in the Alaskan boreal forest. These species no doubt invaded the Onion Portage region at the same time as spruce. Unfortunately, again, it is not possible presently to separate the shrub birches from the arboreal birches on the basis of pollen grain morphology. And a further problem is the high susceptibility of *Populus* pollen to fungal decay and oxidation. As a consequence, it is rarely preserved in the fossil record. We must be content in identifying the boreal forest with the fossil *Picea* pollen record, although this is not entirely satisfactory.

In summary, the late glacial-Holocene fossil pollen record from Epiguruk indicates an open high arctic tundra giving way approximately 10,000 years ago to the development of a birch shrub tundra. This was in turn invaded by alder shrubs about 7,000 B.P. as the boreal forest-tundra transition zone moved northward. Boreal forest finally developed in this region 5,500 years ago and has continued to spread since then. This is a unidirectional record with no revertance to earlier, more cold-adapted vegetation types.

REGIONAL VEGETATION DEVELOPMENT DURING THE HOLOCENE

Livingstone (1955) was the first to publish complete pollen diagrams from arctic Alaska. His research defined a three-zone pollen sequence based on cores from lakes in the central Brooks Range. The basal zone I, dominated by Cyperaceae and Gramineae, is interpreted as representing herbaceous tundra; zone II records a sharp increase in <u>Betula</u> pollen and represents a birch shrub tundra; zone III records an increase in <u>Alnus</u> pollen and <u>Picea</u> south of the Brooks Range (zone IIIb and IIIc). These three zones were believed to represent vegetation similar to the Barrow region, the arctic north slope and the Brooks Range divide area.

This record is identical to the sequence from the Kobuk Valley. Livingstone's zones III band IIIc would be equivalent to zone EIV at Epiguruk. Unfortunately, these records were not C-14 dated but estimates place the base at 8,000 B.P. (Colinvaux, 1967). A valley fill deposit near Umiat, north of the Brooks Range, yielded a pollen record of a herbaceous zone, a birch zone and an alder zone. Radiocarbon dates placed the boundaries between the lower zones at 8,000 - 7,500 B.P. and the upper zones between 6,000 - 5,700 B.P. (Livingstone, 1957; Tedrow and Walton, 1964). Additional dates come from Colinvaux (1967) who analyzed the pollen content of dated buried peat samples from Barrow. <u>Betula</u> pollen appeared (3%) in the sediments dated 9,500 years B.P., <u>Alnus</u> (6%) not until 5,000 B.P. and from then on the vegetation has remained much the same. A two-zone herbaceous, birch sequence was discovered in peat sections from Ogotoruk Creek, near Cape Thompson, on the northwest coast (Heusser, 1963). Unfortunately, these sections were not dated.

Detailed and dated pollen studies are also available from the Seward Peninsula. Sediment cores from Imuruk Lake (Colinvaux, 1964; Colbaugh, 1968) provide a record into the Yarmouth Interglacial with the top three zones (K, L and M) overlapping with the Epiguruk record. The Imuruk Lake zone K is dominated by Betula, Salix and Gramineae pollen, zone L by Alnus and Picea and zone M by Alnus pollen, which drops in frequency in the upper portion of this zone.

Colbaugh (1968) summarizes the vegetational history a[illegible] Wisconsin open grass and sedge tundra invaded by dwarf birch (zone K) about 12,000 B.P., alder and spruce advance closer to Imuruk Lake after 10,700 B.P. (zone L) and remain close until after 8,600 B.P. (zone M), when they retreat to their present positions.

Matthews (1974a) has provided a long Pleistocene paleoecological record from Deering, Alaska. Although this is not a continuous pollen record since colluvial sediments and peats were studied, it does provide some comparative information. A late Wisconsin steppe-tundra vegetation dominated by Gramineae and Artemisia was dated at 12,400 B.P. By 9,000 B.P. Betula pollen increases as dwarf birches invade, Alnus increases as Gramineae drops and Artemisia pollen disappears.

Although these two records are only 55 km. apart, they differ in many respects; the appearance of dwarf birch at Imuruk Lake predates its appearance at Deering by nearly 3,000 years and the alder-spruce zone from Deering is not recorded at Imuruk Lake. Matthews (1974a) has discussed these differences, the most serious of which is the lack of a high alder-spruce pollen zone from Deering. He concludes that these two taxa may have moved towards Imuruk Lake from the south and that their pollen represents long distance transport into the lake. Any long distance pollen entering Imuruk Lake would be significant as the lake is several kilometers across and the coring sites are over a kilometer from the shore, and there would not be any local or extra-local pollen production. On the other hand, the record from Deering represents just these environments and long distance pollen would be significantly diluted by the local pollen production. Because of this the pollen record from Deering seems to be more comparable to that from Epiguruk, even though the late glacial vegetation at Deering is believed to have been a steppe-tundra. The percentages of Gramineae and Artemisia pollen are much higher in the pollen record (Deering Fm., Unit 2) from Deering than in that from Epiguruk.

The late glacial-Holocene fossil pollen records from northern Alaska can be subdivided into four zones that represent stages of vegetational development: herbaceous high arctic tundra to birch shrub tundra to alder-birch shrub tundra and to boreal forest south of the Brooks Range. Since each zone is largely characterized by the appearance and colonization of a region by a single species, which implies migration, they are time transgressive and not time correlative periods. A time lag for the spread and development of each community from region to region is implied. However, the scarcity of radiocarbon dates makes this difficult to demonstrate. Birch appears at Onion Portage about 10,000 B.P., at Deering 9,000 B.P. and at Umiat 8,000 - 7,500 B.P. (Figure 1). Alder appears at Onion Portage about 7,000 B.P. and at Umiat 6,000 - 5,700 B.P. These dates indicate lags of 2,500 and 1,300 years for the spread of birch and alder respectively between Onion Portage and Umiat, a distance of 370 kilometers.

The migration of spruce through the interior of Alaska is better known. The earliest date for the appearance of spruce is from a peat deposit exposed near Long Tangle Lake (146°4'W, 63°2'N) in the Alaska Range. Picea pollen reaches 22% and Picea glauca cones are abundant along with wood from Picea sp. and Populus sp. Spruce wood was dated at 9,000 ± 80 (UCLA - 1858) radiocarbon years B.P. (Schweger, unpublished data). Spruce appears in the pollen record at Antifreeze Pond near Snag, Yukon, at 8,700 B.P. (Rampton, 1971). Near Fairbanks there is evidence for the appearance of spruce and forested conditions as early as 8,500 B.P. (Matthews, 1970 and 1974b). Spruce finally appears near its present limit in the mid-Kobuk River Valley approximately 5,500 B.P.

From these and other study sites two patterns of species migration or succession appear. Alnus precedes Picea into the Brooks Range and Seward Peninsula region (Livingstone, 1955; Colbaugh, 1968; this paper). Picea precedes Alnus at sites in the Alaska Range and eastward into the Yukon Territory (Rampton, 1971 and Schweger, unpublished data). Two sites, still further east, near Fort Liard

(John Klondike Lake, Matthews, unpublished data) and on the Tuktoyaktuk Peninsula (Ritchie and Hare, 1971), both in the Northwest Territories, have revealed a similar sequence of spruce before alder in the history of forest development.

These differences raise several questions: did spruce and alder share the same glacial refugia? If so, can differential migration rates account for the different patterns of forest history? Alternatively, they may have had different refugia locations and their Holocene migrations followed different patterns. Hopkins (1972) concluded that *Alnus* appears in the fossil record earliest in the Kotzebue Sound - Seward Peninsula area and spread eastward and northeastward. He suggested that a refugium existe[illegible]here on the Bering Land Bridge (Beringia) and a second existed along the Pacific coast adjacent to the Cordilleran Glaciers. In view of the paleoecological records from the Mackenzie drainage (Ritchie and Hare, 1971 ; Matthews, unpublished pollen diagram, John Klondike Lake), a third alder refugium, possibly south of the continental ice mass, must be added.

The present distribution of *Alnus crispa* (Hulten, 1968) indicates its adaptation to a climate more severe than that which *Picea* can endure. In many ways it is more pioneering than *Picea*, especially *Picea mariana*, and being a nitrogen fixer (Van Cleve, Viereck and Schlentner, 1971), it effectively prepares its edaphic environment. Given a common refugium it would seem that *Alnus* would be able to spread and colonize Alaska during the early Holocene more successfully than *Picea*. Indeed, the different patterns of colonization support the idea of multiple refugia. Alternatively, they may also indicate unknown environmental factors that affected migration and colonization.

The problems of Alaskan paleoecology are actually related to the paleogeography of Beringia (Hopkins, 1967, 1972). During the Wisconsin glacial maximum the sea level dropped 125 m. This exposed the Chukchi and Bering Sea shelves, forming a broad shelf which joined Alaska with northeastern Siberia. The Beringian land mass created its own climate and joined the floral and faunal provinces of eastern Asia and North America. Since Beringia was flooded and breached during the Holocene marine transgression, paleoecological interpretations must deal with what now lies under water.

It now seems that during the Wisconsin glacial maximum, Beringia, including interior Alaska, was covered by a steppe-tundra and that spruce was not present (Colinvaux, 1967a; Matthews, 1970, 1974b; Hopkins, 1972). Pollen studies, however, on St. Paul Island, Pribilof Islands (Colinvaux, 1967a), indicate an abundance of Picea pollen before 10,000 B.P. when the islands were hills on south-central Beringia. This led Hopkins (1970, 1972) to suggest the existence of a spruce refugium in the present Yukon River delta region. Clockwise winds from the Arctic High pressure system would have blown pollen from this refugium southwestward to the Pribilof Islands. Hopkins felt that the full glacial climate of the refugium would have been sufficiently continental, with warm summers, and yet moist enough to support Picea. Further into the interior of Alaska the climate was too cold and dry and farther south the maritime influence may have created a climate too cool and cloudy for Picea growth (Sergin and Shcheglova, 1973). Pollen diagrams done by R.E. Giterman, Geological Institute, Moscow, U.S.S.R. (Hopkins, unpublished data) from Bristol Bay, southern Alaska (Figure 1) shed new light on the spruce refugium. These diagrams demonstrate that spruce and alder were absent from this region 12,400 years ago. They had migrated back into this region by 7,600 years B.P. A pollen spectrum from Goodnews Bay (Hopkins, unpublished data), dated at 11,500 B.P., indicates an open full glacial vegetation. These data place considerable doubt on the existence of a Picea refugium in southern Alaska or in the Yukon River delta region. But the high spruce pollen percentages on the Pribilof Islands must still be explained. Recent efforts to reconstruct atmospheric circulation over Alaska during the full-glacial may hold the answer. Streten (1974) concluded that during the glacials a summer low pressure cell developed and intensified in the Bering Sea of the North Pacific. This would have resulted in counter clockwise flow bringing western Pacific air into southern Beringia. In this way, Picea pollen from eastern Asia may have been carried to the Pribilof Islands. There is a need to determine which Picea species make up Colinvaux's St. Paul Island pollen records.

It appears that the development of the Alaskan vegetation from a full glacial steppe-tundra has been a long-term and complex process. The major forest species may have immigrated from refugia considerable distance from Alaska, possibly south of the Continental ice sheet in Alberta or Montana. Differential migration rates, multiple refugia and new combinations of environmental factors created unique vegetation assemblages. These make comparisons with modern vegetation units difficult at best. Paleoecological studies in Alaska have revealed a dynamic environment and vegetation during the late Quaternary.

THE LATE PLEISTOCENE-HOLOCENE PALEOCLIMATIC HISTORY OF NORTHWESTERN ALASKA

The late glacial - Holocene pollen sequence described for the Onion Portage region can be interpreted not only in terms of vegetational history, but paleoclimatic history as well. However, it must be made clear at the out-set that climate is only one of many environmental factors that influence vegetation. Paleoecologists and pollen-analysts initially emphasized paleoclimatic interpretations. More recently they have come to recognize the necessity of including many other factors into their interpretations (Iversen, 1960; Maxwell and Davis, 1972; and Davis, 1974). Paleoclimatic interpretations must be considered along with other interpretations that are based on biologic and ecologic factors.

At first the paleoenvironmental record from the Onion Portage region suggests a continually warming climate from a cold zone EI to a warm zone EIV with no climatic reversals, that is, cold-warm-cold or warm-cold-warm. Since these terms are very relative, greater precision is needed. Young (1971) has provided a very complete analysis of the climate and floristic zonation of the Arctic. Four zones describe the vegetation from the most severe climatic regions of the high Arctic to the relatively warm tundras near the spruce tree line. By comparing species restricted to the different zones, it is possible to correlate the Epiguruk pollen zones with his floristic zones. Floristic zone 2, dominated by grasses, sedges and herbaceous elements, is correlated with pollen zone El, zone 3 with Betula nana correlates with pollen zone EII and zone 4 with Alnus correlates with pollen zone EIII.

The modern climate characterizing the floristic zones comes from Young's analysis of weather data from stations in each zone; these data are summarized in Table 11. It is tempting to use the average mean temperature of the floristic zone as indicating the mean annual temperature of the correlative pollen zone. The difference between the appropriate floristic zones do not correlate with mean annual temperature; in many cases temperatures in a zone are above or below those of adjacent zones. In one case temperatures in zone 1 were higher than those in a timbered area. It would seem that winter temperatures, that contribute to the mean annual temperature, are not a significant factor in arctic floristic zonation. Mean annual precipitation also shows no significant correlation with vegetation zones. Young demonstrated that it is the summer temperature regimen that strongly correlates with the zones. To demonstrate this he calculates an "a" value, the sum of the mean temperatures for all the months having a mean temperature above 32°F. (Table 11).

The significance of the summer temperature as it relates to the growing season of plants has been discussed by several authors. Clebsch and Shank (1968) relate the vegetation gradient in the Barrow region directly to summer temperatures. Larson (1971) correlates the vegetation continuum in the central arctic-boreal forest with air mass frequencies representing summer and winter patterns and Hopkins

Table 11

Summary of Young's (1971) Floristic Zone Climatic Data and Pollen Zone Comparisons

Zone	Average Mean Annual Temp. (^{o}F)	Range of Station Averages (^{o}F)	Range of "a" Values*	Difference with Mean Annual Temp. of Onion Portage (22.5^{o}F)
Floristic Zone 2, and Epiguruk Pollen Zone 1	11.8	5.0 - 20.8	33 - 54	-10.7
Floristic Zone 3, and Epiguruk Pollen Zone 2	17.2	6.6 - 32.0	54 - 68	- 5.2
Floristic Zone 4, and Epiguruk Pollen Zone 3	24.6	2.0 - 40.5	68 - 95	+ 2.1

*The "a" value is the sum of the mean temperatures, for all the months having a mean temperature above 32^{o}F.

(1959) related the tree line in Alaska to summer temperature duration. Young pointed out that the northern limit of a given species is not directly correlated with an "a" value but assumes correlation between "a" and a critical amount of warmth available to the plant. The critical amount of warmth must be considered over the entire life cycle of the plant from germination of propagules, through growth and flowering to the production of fertile propagules. Warmth requirements are no doubt different at different stages of the life cycle, yet each stage must be completed if the population is to survive and perpetuate itself.

The correlations suggested between Young's (1971) floristic zones and the Epiguruk pollen zones (Table 11) imply a considerable reduction not only in mean annual temperature but summer temperature during the late Pleistocene and early Holocene. The "a" value for Barrow is 48, the vegetation of the Barrow region was used as an analogy for pollen zone EI. Savoonga, on the Seward Peninsula, represents a tundra vegetation analogy to zone EI; it has an "a" value of 64. Although the "a" values presented represent a range for each zone, unusually low values are found in regions of extreme maritime influence, unusually high values are found in regions of continental climate.

During the late glacial, represented by pollen zone EI, large areas of Beringia were still exposed as sea level had not returned to Holocene levels. Because of this, the Onion Portage region would have had a more continental climate with colder winters and perhaps warmer summers and, therefore, higher "a" values. Sergin and Shcheglova (1973) attempted to reconstruct the climate of Beringia along a transect from the southern coast to a spot 800 km. inland. The coastal station had a mean annual temperature of 14°F., a January mean of -22°F. and a July mean of 50°F.; 800 km. inland the temperatures were 3.2°F., -47°F. and 55.4°F., respectively. Their calculations point out the degree to which continentality may have influenced the late glacial climate of the Onion Portage region.

The highest "a" value Young recorded from his floristic zone 2 is 57, that is from Peary Land, northern Greenland. Even this is much lower than the "a" values suggested for the Onion Portage region during the late glacial in view of the increased continentality. Here is a glaring problem in the paleoclimatic reconstruction; the fossil pollen record gives evidence of a cold high arctic climate with low "a" values indicating cool summers. This is further supported by the evidence for a shallow permafrost table and perhaps a more rigorous freeze-thaw regimen. Yet the factor of continentality, a condition of the paleoclimate suggests warmer summers and more optimum growing conditions. In other words, the probable paleoclimate seems to have offered more favorable conditions than what is indicated by the interpreted vegetation.

Matthews (1974a) confronted the same problem in his paleoecological reconstruction near Deering. His late glacial record represents a grassy steppe environment and a climate colder than at present, yet his fossil insect assemblages contain many representatives of grassland types not now found in Alaska. Some are known to the south in British Columbia or the Northwest Territories. He concluded that the late glacial environment at Deering was a xeric steppe-tundra developed under a continental climate type.

Hopkins (1972) has also suggested that aridity may have been a key factor in the climate of Beringia and that it may have severely limited vegetation development. This view is supported by the reconstruction of only 120 mm./year of precipitation in the interior of Beringia (Sergin and Shcheglova, 1973). As mentioned previously, Alaska presently suffers from a moisture deficit and no doubt was under even greater stress at the time of Beringia. Another aspect of the climate, and especially a continental climate, is the degree of climatic variability. Data on means provide only one view of the climate, more important to the flora and fauna is the degree of variance since this determines the frequency and range of extremes. Young (1971) discussed the limiting factor of climatic variance for the modern tundra vegetation. No doubt this was also of even greater importance in the past. Although mean conditions may have supported a more warmth-adapted vegetation, the frequent extremes severely limited what ultimately survived.

A third factor in trying to explain the problem of the late glacial paleoclimate and vegetation is that of species availability. Although the paleoclimate may have had a more favorable growing season, the plant species able to respond may not have been present in order to do so. The vegetation of the late glacial was made up of what species were available from the species-poor full glacial assemblage. This factor will be discussed again later.

A further example of the problems encountered in Beringia paleoclimates, is that glaciers persisted in the Brooks Range until nearly 7,000 B.P. (Porter, 1966). The Anivik Lake Stade and the Range Front - Walker Lake Stades (Hamilton, 1969 and unpublished data) are late glacial advances of the Itkillik Glaciation. Porter (1966) concluded that the major difference between the glacial and modern climate of the Brooks Range was a lower mean summer temperature. This was needed to inhibit ablation and permit the growth and expansion of valley glaciers. Recent climatic warming in Alaska (Hamilton, 1965) has in fact brought about a retreat of Brooks Range glaciers (Hamilton, 1965; Porter, 1966).

In view of what has already been said, it is difficult to account for glaciation during a time when the climate was extremely arid with very little precipitation. Not only would there be little accumulation for ice formation but the summer ablation would be very high. This apparent contradiction may be resolved by considering other climatic factors besides summer temperatures as controlling glacier growth. Mean annual temperatures and summer temperatures increased through the late-glacial to the Holocene. But sea levels were also rising bringing moisture sources nearer to northern Alaska and presumably increasing precipitation over the Brooks Range. This could have had the effect of prolonging Brooks Range glacier activity into the early Holocene. By this time temperatures and ablation may have been too high to be offset by the increase in precipitation and the ice would have retreated terminating the Brooks Range late glacial sequence.

A steadily warming Holocene climate is evidenced in the pollen records from Onion Portage and elsewhere in the Brooks Range. Climate reversals are not apparent and it appears as if a modern climatic regimen was established in northwestern Alaska by 5,500 years B.P.

This view does not, however, correlate well with that of other researchers who have suggested dramatic Holocene climatic changes for northern Alaska. McCulloch and Hopkins (1966) originally defined a period of climate, warmer than present, for the Kotzebue Sound area between 10,000 and 8,300 years B.P. Evidence for this came from logs, beaver-gnawed wood, ice-wedge casts and buried soils below the permafrost table which suggested a westward expansion of the boreal forest into a region of shrub tundra vegetation. Hopkins (1972) has since retracted his identification of <u>Picea</u> macro-remains and he has supplied pollen samples for analysis from type locality A (Figure 2, 1966) and locality C (Figure 4, 1966). These samples are 7,270 ± 350 and 9,020 ±400 B.P. respectively. The resulting fossil pollen spectra (Table 12) compare closely with fossil pollen zone EII, 10,000 - 7,000 B.P., and represent a birch shrub-tundra rich in Gramineae. The <u>Betula</u> pollen may represent in part the arboreal species, and although no <u>Populus</u> pollen was counted it cannot be assumed that the species was absent. In fact, the presence of beaver would suggest that <u>Populus</u> was present. In any event, the original

Table 12

Pollen Analysis of Samples from Baldwin Peninsula, Kotzebue Sound*

	Sample A	Sample C
C-14 age	7,270 B.P.	9,020 B.P.
Betula	37.5	19.5 (24)
Alnus	1.5	3.5 (3.5)
Salix	6.5	13.5 (16)
Picea	2.5	0.5 (0.5)
Cyperaceae	17.5	13 (18.5)
Gramineae	24	17.5 (23.5)
Artemisia	7	7 (8.5)
Compositae	1	
Ericaceae	1	2 (2)
Umbelliferae	0.5	1 (1)
Rosaceae		1 (1.5)
Chenopodiaceae - *Amaranthus*		(0.5)
Epilobium	0.5	
Polygonum amphibium		(0.5)
Typha latifolia		21.5
Unknown pollen	0.5	0.5
Indeterminant	6	6
Lycopodium	1	1
Sphagnum	5	
Other trilete		8.5

*Percentage base is 200 grains excluding indeterminant and unknown pollen and spores. Brackets on Sample C show results of a second count excluding *Typha* pollen.

conclusion of a boreal forest advance cannot be substantiated and the pollen data suggest a vegetation cover representing not a warmer but a cooler climate than present.

This view is supported by Matthews (1974), who argued for the existence of tundra vegetation at Deering, along the north coast of Seward Peninsula, during the late glacial and early Holocene. He concluded, on the basis of alder pollen percentages from dated fossil peats, that the climate may have been colder than at present. Further contradictions arise, however; the presence of 22% Typha latifolia (cat-tail) and Polygonum amphibium pollen in the 9,000 year-old sample (Table 12) from the Baldwin Peninsula suggests warmer summer temperatures. At present these species are distributed into the interior of Alaska only as far as Fairbanks (Hulten, 1968). Since this is only a single sample it is extremely difficult to evaluate and certainly is little evidence for a major warmer climatic period.

Hopkins (1972) would extend the region affected by this warmer climate northeastward from Nome into Canada as far as the Mackenzie-Beaufort region. At this time Wisconsin age ice-wedges melted near Nome, in central Seward Peninsula around the coast of Kotzebue Sound (McCulloch and Hopkins, 1966). Deep thawing of the permafrost occurred in the Barrow region (Brown, 1965 and Brown and Sellmann, 1973) and the development of thermokarst features in the Mackenzie-Beaufort region reached a maximum 10,000 to 9,000 years B.P. (Rampton, 1973).

This period of warm climate is not, however, evident in the paleobotanical record based on fossil pollen studies (Matthews, 1974a), although Hopkins (1972) recorded macro-remains of arboreal birch, alder and aspen as far as 100 km. west of their present limits on the northern Seward Peninsula. Matthews does suggest that the very high percentages of Betula pollen, near 50% may represent in part arboreal birch, although he was unable to separate them morphologically. This sample dated 9,150 ± 150 B.P. (Deering Fm., Unit 2, Peat 6) contains no Picea or Populus pollen and Alnus is only a few percent. Although Colbaugh (1968) concluded that spruce and alder were nearer to Imuruk Lake between 10,700 and 8,600 B.P., Matthews (1974a) demonstrated that this conclusion is not necessarily warranted since the dating is imprecise and the sediment is an allochthonous peat from a lake terrace.

The discovery of a single Populus sp. log on the Alaskan north slope 50 km. beyond the nearest living grove of Populus balsamifera has been cited as evidence of the early Holocene warm period (Detterman, 1970). However, this log, dated at 8,400 ± 300 B.P., is an isolated occurrence and could have been river transported northward as it was found in terrace gravels.

The pollen evidence presented here, as well as earlier studies, does not support the hypothesis of an early Holocene warm period. Several reasons may account for this failure and the inability of pollen-analysis to record Populus and separate the birch species is part of the problem. But perhaps, more importantly, the vegetation may not have been able to respond to the changing climate. The vegetation of Beringia was greatly affected by the late Wisconsin glacial climates. Picea, Alnus and perhaps Populus and arboreal Betula were no doubt confined to refugia a considerable distance from northern Alaska, perhaps thousands of kilometers to the south. It would take time before these species could migrate into northern Alaska. Even though the climate may have been suitable, or even optimal, the species were not present in northern Alaska to respond.

Certainly differential migration rates and successional patterns played a role in the vegetation history of Alaska in much the same way as they did in Europe (Iversen, 1960) and in the Great Lakes region (Cushing, 1967; Wright, 1968). More recently Davis (1974) has demonstrated the late glacial - Holocene migration of arboreal species across the eastern United States. In some cases it took thousands of years for species migration into this region. She observed that during this period ecotones were established that reflected synchronous migration patterns and rates for species and not climate. These factors lessen the use of fossil pollen records for paleoclimatic interpretations but strengthen their application in paleoecology.

Almost all attempts at a paleoclimatic record for Alaska have dealt mainly with temperature. Since the evidence for an early Holocene warmer climate is based almost exclusively on changes in permafrost regimen, we might examine other factors that could affect permafrost besides temperature. The late Wisconsin glacial climate in Beringia was arid (Hopkins, 1972), moisture sources were far to the south, montane ice caps blocked moisture from entering interior Alaska and the Arctic high pressure cell dominated the climate. These factors must have persisted into the late glacial, and as mentioned earlier, aridity probably greatly affected the vegetation. Such a cold, arid climate means deep freezing and little snow cover for soil insulation, and, indeed, the geomorphic evidence indicates a strong periglacial climate. A snow depth of 240 mm./year has been postulated (Sergin and Shcheglova, 1973) for the interior of Beringia.

Beringia was transgressed and breached by a rising sea level 10,000 years ago (Creager and McManus, 1967) and sea level was within -30 m. about 10,000 B.P. and -15 m. by 8,000 B.P. (Hopkins, 1972). This transgression brought western Alaska under the influence of a maritime climate, which must have had a dramatic effect on the patterns and amount of precipitation, and increased the depth of winter snow cover over the region. A deepening snow cover, which acts as a good insulator, would greatly affect the equilibrium depth of the permafrost by preventing deep freezing and also preventing loss of geothermal heat. The net effect would be to drop the permafrost equilibrium depth over a broad region, a phenomenon similar to increasing the air temperatures, since ice-wedges would melt out, thaw lakes form and the soil active layer deepen.

A deeper late glacial - early Holocene snow cover has ramifications concerning the extinction of the Pleistocene megafauna in Alaska. Although terminal dates for species are few, they suggest late glacial - early Holocene extinction. The several proposed climatic causes of extinction have dealt almost exclusively with changes in temperature. The Pleistocene megafauna of Beringia formed a complex community dominated by grazers (Guthrie, 1968a, 1968b); as long as there was grass cover and access to the grasses during winter they thrived. But if snow cover increased in depth during the late glacial winters, grazing may have become not only difficult but impossible for many faunal elements such as the saiga antelope, horse and bison. The important survivors of extinction, moose and caribou, have important morphological and behavioral adaptations for deep snow conditions. Snow cover is another important aspect of climate and should not be neglected in paleoclimatic reconstructions; the fact may be that its importance in the late glacial history of Beringia has been overlooked.

The mid-Holocene warm interval, the Hypsithermal, approximately 7,500 to 4,500 B.P., is evidenced in many regions of North America including the Arctic (Ritchie and Hare, 1971). But in northern Alaska the evidence for a Hypsithermal period is not easily demonstrated (Hopkins, 1972). The pollen records from the Brooks Range region do not support a Hypsithermal climate in northern Alaska. The Brooks Range, like most mountain chains, has an important influence on the regional climate, which was, no doubt, the situation in the past as well. It may be that pollen records from northern Alaska are climatically insensitive and instead record the patterns of plant migration and succession. This certainly seems to be the case in the late Holocene for while glacial records (Porter, 1966; Hamilton, 1969) indicate a return to cooler and/or moister climate after the Hypsithermal, the pollen record discussed here does not record this climatic revertence. Instead, the pollen record suggests a continual spread of boreal forest which may be in response to a warm climate or the product of successional and edaphic changes.

The reconstruction of a paleoclimatic record for northern Alaska presents a number of complex problems and alternative explanations or speculations. Paleoecological and paleoclimatic explanation is, by its very nature, multicausal and the limitations of the methods now employed further complicate interpretations of the past. No doubt the paleoclimates of northern Alaska during the late glacial were complex and rapidly changing, leaving a record of apparent contradictions and incongruities.

LATE QUATERNARY PALEOECOLOGY OF THE ONION PORTAGE REGION - A SUMMARY

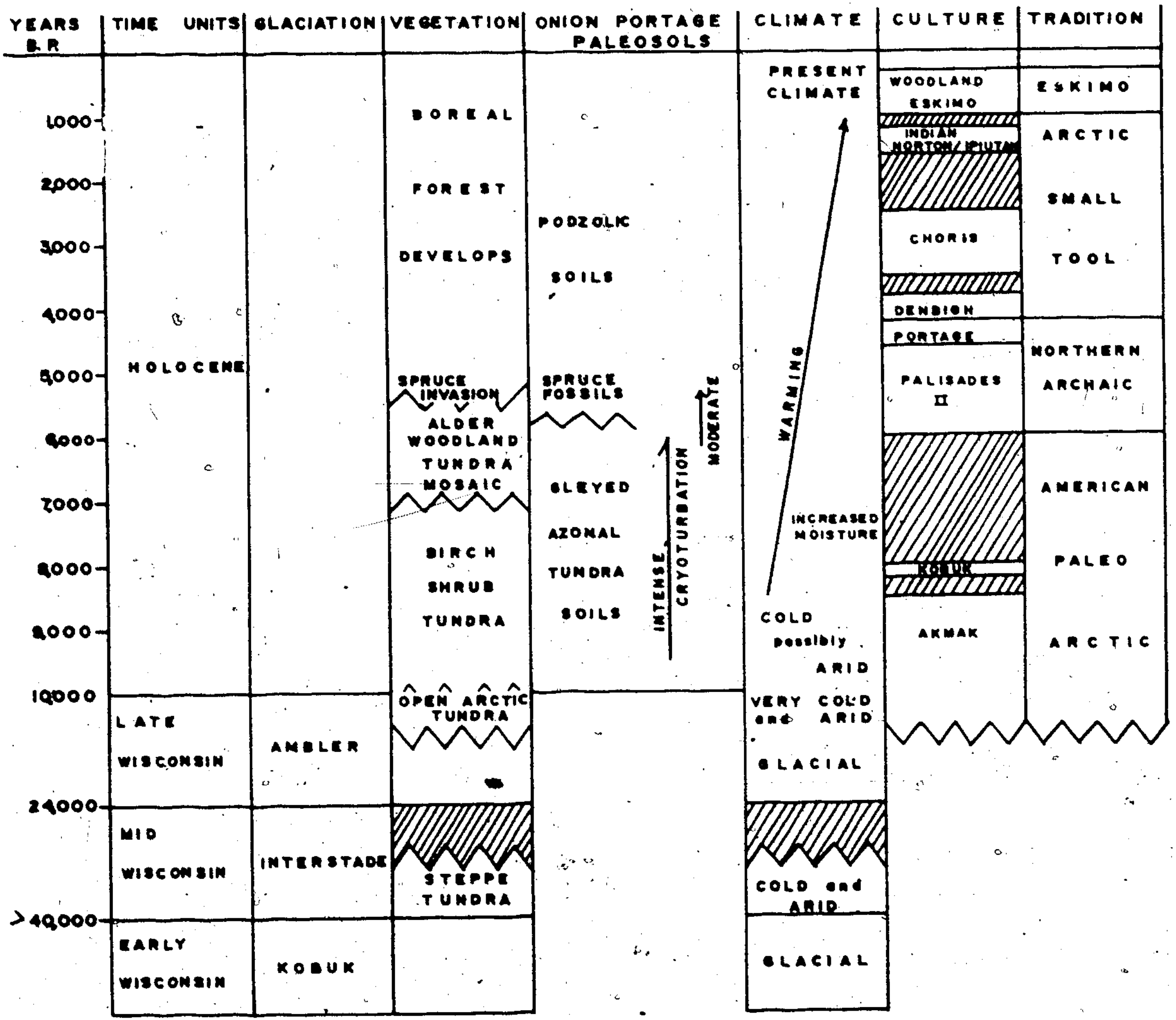
The late Quaternary paleoecological history of the Onion Portage region may now be summarized. Figure 25 presents a simplified review of the many lines of evidence and interpretations employed. Unfortunately, the simplicity of the diagram belies much of the complexity of the interrelationships and interpretations. Although additional information and integration is needed, it is still possible to evaluate one of the initial goals of the Onion Portage archaeological project, that is, to relate cultural and environmental changes.

During the early Wisconsin, glaciers extended south from the Brooks Range to within a few kilometers of Onion Portage. A cold, arid climate and a steppe-tundra vegetation are presumed to have dominated this region. The Wisconsin glacial was broken by an interstade here dated between greater than 40,000 to 24,000 B.P. A pollen record from the earlier portion of this interval reveals an open steppe-tundra vegetation dominated by graminoid species and Artemisia. A cold, arid climate is indicated. Glaciers advanced during the late Wisconsin to within 20 kilometers of Onion Portage. Again, a cold, arid climate and steppe-tundra vegetation is inferred.

The resolution of the paleoecological record improves during the late glacial and Holocene. Fossil pollen records from the Epiguruk exposure indicate that four distinct plant communities covered this region. From about 12,000 to 10,000 B.P. an open,

Figure 25

Summary diagram of late Quaternary paleoecological history of Onion Portage area.


YEARS B.P.
TIME UNITS
GLACIATION
VEGETATION
ONION PORTAGE PALEOSOLS
CLIMATE
CULTURE
TRADITION
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
24000
>40000
HOLOCENE
LATE WISCONSIN
MID WISCONSIN
EARLY WISCONSIN
AMBLER
INTERSTADE
KOBUK
BOREAL FOREST DEVELOPS
SPRUCE INVASION
ALDER WOODLAND TUNDRA MOSAIC
BIRCH SHRUB TUNDRA
OPEN ARCTIC TUNDRA
STEPPE TUNDRA
PODZOLIC SOILS
SPRUCE FOSSILS
GLEYED AZONAL TUNDRA SOILS
INTENSE CRYOTURBATION
MODERATE
PRESENT CLIMATE
WARMING
INCREASED MOISTURE
COLD possibly ARID
VERY COLD and ARID
GLACIAL
COLD and ARID
GLACIAL
WOODLAND ESKIMO
INDIAN
NORTON/IPIUTAK
CHORIS
DENBIGH
PORTAGE
PALISADES II
KOBUK
AKMAK
ESKIMO
ARCTIC SMALL TOOL
NORTHERN ARCHAIC
AMERICAN PALEO ARCTIC

high arctic tundra was present. The climate at this time was cold and possibly arid. Birch shrubs then invaded the area and a shrub-tundra covered the region until about 7,000 years ago. At this time alders spread into the Kobuk Valley creating an alder woodland-tundra mosaic. These vegetation changes suggest a warming climate but still colder than at present. Factors related to the geography of full-glacial refugia, rates of plant dispersal and migration and sea-level history contribute to the multivariate complexity of paleoclimatic interpretation.

The Onion Portage archaeological site has also yielded a paleoenvironmental record. A sequence of paleosols includes gleyed, azonal tundra soils formed during the time represented by cultural Bands 8/3 and 8/2. The Band 7 soil appears to be transitional with a gleyed tundra as well as a podzolic facies. Cryoturbation was active in the early history of the site. This greatly disturbed the sedimentary units representing pre Band 8, Band 8, Band 7 and in part Band 6. The greatest intensity of soil movement took place during the time represented by Bands 8 and 7, 10,000 to 6,000 years ago. These data indicate a shallow permafrost table and intense cryoturbation at a time when tundra covered this region.

The pollen records indicate that spruce finally appeared in the Kobuk Valley between 6,000 and 5,000 years ago. Spruce macrofossils are first found associated with the Band 6 paleosol. This paleosol, dated at 5,600 B.P., is a podzolic profile that displays a minimal amount of frost disturbance. The younger soil profiles are also podsols and contain spruce macrofossils in the humus.

Spruce may have been initially confined to the south facing slopes and valley bottoms. Since then it has apparently increased in frequency and cover resulting in the modern vegetation. Although the modern flora indicates this region to be a westward extension of the boreal forest, the central Kobuk Valley can best be characterized as a mosaic of shrub tundra communities and forest stands dominated by spruce and arboreal birch. It is in fact a broad complex ecotone between forest and tundra.

To complete the picture of Holocene paleoecology at Onion Portage, the archaeological record and materials must be translated into adaptive cultural systems. This task must legitimately be left to the archaeologists; however, it is possible to review some of the relationships that have now been established.

Anderson has divided the archaeological record at Onion Portage into three cultural traditions (see Figure 5). He uses, "the word 'tradition' to describe a continuity of cultural traits that persist over a considerable length of time and often occupy a broad geographic area" (Anderson, 1968, p. 27). Traditions are comprised of "complexes" which describe the distinctive archaeological remains of a culture.

The American Paleo-Arctic tradition, represented at Onion Portage by the Akmak and Kobuk Complexes, extends from possibly as early as 15,000 B.P. to 8,000 B.P. (Figures 5 and 25). Anderson (1968, 1970a and 1970b) considers this tradition as being most closely related to the Upper Paleolithic cultures of northeastern Asia and particularly to the Lake Baikal region of Siberia. he argued that from 15,000 to 10,000 B.P. Alaska was very much part of eastern Siberia as the Bering Land Bridge was exposed because of the low sea-level. Alaska was also isolated from the south by the Continental and Cordilleran ice sheets. Because of these geographic factors Alaska may have been part of a Siberian Upper Paleolithic "diffusion sphere" and therefore culturally part of Siberia (Anderson, 1970a).

Open steppe-tundra vegetation covered most of Siberia, Beringia and Alaska at this time (Hopkins, 1972 and Schweger, this report). This broad circum-Arctic zone, "may have supported economically and technologically similar groups between which ideas and artifact styles might easily pass" (Anderson, 1970a, p. 70). Enough differences exist between the Akmak Complex and those of Asia to infer "a long period of isolated regional development" (Anderson, 1968, p. 29).

The archaeological record at Onion Portage suggests that small groups of people occupied the site for short periods of time. Presumably these people were nomadic hunters that followed herds of migratory animals. At Onion Portage most likely caribou was the animal hunted.

The cultural-ecological specializations and adaptations to this late glacial environment must have been remarkable and obviously successful. However, following the Kobuk Complex (Band 8/3 and 8/1) the archaeological record indicates a cultural hiatus of 2,000 years, 8,000 to 6,000 B.P. Presumably, this region, or certainly Onion Portage, was abandoned or no longer functioned in the pattern of human settlement. This cultural hiatus spans pollen zones E11 and E111 and is therefore also an important period of ecological change. The climate may have become significantly warmer while the vegetation changed to a shrub tundra with birch and then alder. Although one hesitates to suggest an environmental deterministic view of human ecology, at this time, environmental conditions may have changed so rapidly and radically to preclude the adaptive strategy of the American Paleo-Arctic tradition.

The next evidence of occupation at Onion Portage is the Palisades II and Portage Complexes, represented by Bands 7, 6 and part of 5 (see Figure 5). These components mark a complete and radical departure from the earlier complexes. The artifacts are most closely related to styles found far to the southeast. In fact, Anderson (1968) pointed out that these Complexes are most closely related to those of the Great Lakes and eastern forested regions. These southern cultures had their origins between 8,000 and 6,000 years ago and represented Indian populations adapted to a woodland-oriented way of life. They have been grouped into what is known as the Archaic tradition.

Anderson has placed the Palisades II and Kobuk Complexes into a Northern Archaic tradition and hypothesized "that Archaic peoples, or at least the art of making tools in the Archaic tradition, moved northward into the Arctic along with the advancing forest" (Anderson, 1968, p. 31). The paleo-environmental data presented here record the first appearance of spruce trees in the Onion Portage region between 6,000 and 5,000 years ago. This affirms Anderson's hypothesis and represents one of the best examples from the archaeological record of cultural-environmental relationships. Presumably cultures of the Northern Archaic tradition were also adapted to a woodland environment. In this case it was the boreal forest which spread northwestward across North America; following the retreat of the glacial ice until it reached northwestern Alaska.

Cultural Band 4 marks the reappearance of Arctic culture at Onion Portage. The Denbigh Flint Complex very rapidly replaced the Northern Archaic. No satisfactory explanation for this cultural change is presently available. The Denbigh, Choris and Norton/Ipiutak Complexes (see Figure 5) represent the Arctic Small Tool tradition. These are the earliest peoples of Alaska who were equally at home on the coast and in the interior (Anderson, 1968). By mid Holocene sea-levels had stabilized and marine resources could be exploited along with those from inland. Onion Portage may have been used for fall caribou hunting while fish, seal and walrus were exploited at the coast. Perhaps the explanation for this cultural change lay in the expansion of the subsistence base and therefore greater economic diversity of the cultures of the Arctic Small Tool tradition.

The more recent portion of the archaeological record indicates a significant degree of regional specialization. Anderson (1968 and 1970c) believed that the assemblage of upper Band 2 (Figure 5) represents Indian, possibly an Athabaskan culture. It certainly represents a non-Eskimo adaptation to the northern boreal forest. Here we see the interesting phenomenon of a treeline region, the central Kobuk Valley, acting as a tension-line between Eskimo and Indian cultures. The forest-tundra mosaic may have in fact been occupied and utilized by both adaptive strategies. Indians and Eskimos possibly alternated exploitation of this area.

The Arctic Woodland Eskimo Complex is the most recent culture to have occupied Onion Portage and is represented by Band 1. This cultural adaptation is to the Kobuk Valley ecotone itself. In this situation the broad ecotone between forests and tundra was exploited as a separate environment and a unique culture evolved (Giddings, 1967).

The data and interpretations presented here have already demonstrated a variety of cultural adaptations to the changing Holocene environments of the Onion Portage region. This record demonstrates that significant interrelationships do exist between culture, as an adaptive system, and the environment. It also demonstrates the value of the paleoecological approach to archaeological research.

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APPENDICES

APPENDIX 1

VASCULAR FLORA OF THE ONION PORTAGE REGION

Lycopodiaceae

- Lycopodium alpinum L.
- Lycopodium annotinum L. ssp. annotinum
- Lycopodium complanatum L.

Equisetaceae

- Equisetum arvense L.
- Equisetum palustre L.
- Equisetum scirpoides Michx.
- Equisetum pratense L.

Polypodiaceae

- Cystopteris fragilis (L.) Bernh. ssp. fragilis

Cupressaceae

- Juniperus communis L. ssp. nana (Willd.) Syme

Pinaceae

- Picea glauca (Moench) Voss
- Picea mariana (Mill.) Britt., Sterns and Pogg.

Cyperaceae

- Carex aquatilis Wahlenb. ssp. aquatilis
- Carex bicolor All. var. androgyna (Olney)
- Carex bigelowii Torr.
- Carex brunnescens (Pers.) Poir.
- Carex canescens L.
- Carex membranacea Hook.
- Carex nesophila Holm
- Carex [illegible]carpa C.B. Clarke
- Eriophorum scheuchzeri Hoppe var. scheuchzeri
- Eriophorum vaginatum L. ssp. vaginatum

Gramineae

- Agropyron violaceum (Hornem.) Lange
- Agropyron macrourum (Turcz.) Drobov

Agrostis scabra Willd.
Arctagrostis latifolia (R. Br.) Griseb. var. latifolia
Arctagrostis latifolia (R. Br.) Griseb. var.
arundinaceae (Trim.) Griseb.
Bromus pumpellianus Scribn. var. arcticus (Shear) Pors.
Bromus pumpellianus Scribn. var. villosisimus Hult.
Calamagrostis canadensis (Michx.) Beauv.
Calamagrostis lapponica (Wahlenb.) Hartm.
Festuca altaica Trin.
Festuca rubra L.
Hierochloe alpina (Sw.) Roem. and Schult.
Poa alpina L.
Poa arctica ssp. longiculmis Hult.
Poa glauca M. Vahl
Poa leptocoma Trin.
Trisetum spicatum (L.) Richter ssp. spicatum
Trisetum spicatum ssp. molle (Michx.) Hult.

Iridaceae

Iris setosa Pall. ssp. interior (E. Anderson) Hult.

Juncaceae

Juncus alpinus Vill.
Juncus arcticus Willd. ssp. alaskanus Hult.
Juncus castaneus Sm. ssp. castaneus
Juncus triglumis L.
Luzula confusa Lindeb. ssp. multiflora
Luzula multiflora (Retz.) Lej. var. frigida ssp.
multiflora (Buchenau) Sam.
Luzula multiflora (Retz.) Lej. var. Kjellmaniana
(Miyabe Kudo) Sam.
Luzula parviflora (Ehrh.) Desv. ssp. parviflora

Juncaginaceae

Triglochin palustris L.

Liliaceae

Allium schoenoprasum L. var. sibiricum (L.) Hartm.

Melanthaceae

Tofieldia pusilla (Michx.) Pers.
Zygadenus elegans Pursh.

Orchidaceae

Cypripedium passerinum Richards.
Goodyera repens (L.) R. Br. var. ophioides Fern.

Platanthera hyperborea (L.) Lindl.
Spiranthes romanzoffiana Cham.

Potamogetonaceae

Potamogeton vaginatus Turcz.
Potamogeton filiformis Pers.

Dicotydedoneae

Betulaceae

Alnus crispa (Ait.) Pursh. ssp. *crispa*
Betula glandulosa Michx.
Betula nana L. ssp. *exilis* (Sukatsch.) Hult.
Betula papyrifera Marsh. ssp. *humilis* (Regel) Hult.

Boraginaceae

Mertensia paniculata (Ait.) Don var. *paniculata*

Caprifoliaceae

Linnaea borealis L.
Viburnum edule (Michx.) Raf.

Caryophyllaceae

Melandrium taylorae (Robins.) Tolm.
Moehringia lateriflora (L.) Fenzl
Minuartia dawsonensis (Britt.) Mattf.
Stellaria longipes (Goldie)
Wilhelmsia physodes (Fisch.) McNeill

Chenpodiaceae

Corispermum hyssopifolium L.

Compositae

Arnica alpina (L.) Olin ssp. *attenuata* (Greene) Maguire
Arnica frigida C.A. Mey.
Artemisia tilesii Ledeb. ssp. *tilesii*
Artemisia tilesii ssp. *elatior* (Torr. and Gray) Hult.
Aster sibiricus L.
Chrysanthemum bipinnatum (L.)
Erigeron humilis Graham
Matricaria matricarioides (Less.) Porter
Petasites frigidus (L.) Franch.
Saussurea angustifolia (Willd.) DC.
Senecio lugens Richards
Solidago multiradiata Ait. var. *multiradiata*

Cruciferae

Braya humilis (C.A. Mey.) Robins. ssp. *arctica*
(Bocher) Rollins

Capsella bursa-pastoris (L.) Medic.
Cardamine pratensis L. ssp. angustifolia (Hook.)
O.E. Schulz
Descurainia sophioides (Fisch.) O.E. Schulz
Draba longipes Raup.
Draba stenoloba Ledeb.
Erysimum cheiranthoides L. ssp. altum Ahti
Rorippa hispida (Desv.) Britt.

Elaegnaceae

Shepherdia canadensis (L.) Nutt.

Empetraceae

Empetrum nigrum L. ssp. hermaphroditum (Lange) Böcher

Ericaceae

Andromeda polifolia L.
Arctostaphylos alpina (L.) Spreng.
Arctostaphylos rubra (Rehd. and Wilson) Fern.
Arctostaphylos uva-ursi (L.) Spreng. var. uva-ursi
Cassiope tetragona (L.) D. Don
Chamaedaphne calyculata (L.) Moench
Ledum palustre L. ssp. decumbens (Ait.) Hult.
Ledum palustre L. ssp. groenlandicum (Oeder) Hult.
Loiseleuria procumbens (L.) Desv.
Oxycoccus microcarpus Turcz.
Vaccinium uliginosum L. ssp. alpinum (Bigel.) Hult.
Vaccinium vitis-idaea L. ssp. minus (Lodd.) Hult.

Fumariaceae

Corydalis sempervirens (L.) Pers.

Gentianaceae

Gentiana glauca Pall.
Gentiana propinqua Richards. ssp. propinqua
Menyanthes trifoliata L.

Leguminosae

Astragalus alpinus L. ssp. alpinus
Hedysarum alpinum L. ssp. americanum (Michx.) Fedtsch.
Hedysarum Mackenzii Richards.
Oxytropis kobukensis Welsh

Lentibulariaceae

Pinguicula vulgaris L. ssp. vulgaris

Nymphaceae

Nuphar polysepalum Engelm.

Onagraceae

Epilobium latifolium L.
Epilobium angustifolium L. ssp. *angustifolium*

Orobanchaceae

Boschniakia rossica (Cham. and Schlecht.) Fedtsch.

Polemoniaceae

Polemonium acutiflorum Willd.

Polygonaceae

Polygonum alaskanum (Small) Wight
Polygonum caurianum Robins.
Polygonum viviparum L.

Primulaceae

Dodecatheon frigidum Cham. and Schlecht.
Primula stricta Hornem.

Pyrolaceae

Moneses uniflora (L.) Gray
Pyrola chlorantha Swartz
Pyrola grandiflora Radius
Pyrola secunda L. ssp. *secunda*
Pyrola secunda L. ssp. *obtusata* (Turcz.) Hult.

Ranunculaceae

Aconitum delphinifolium DC. ssp. *delphinifolium*
Anemone multifida Poir.
Anemone parviflora Michx.
Anemone richardsonii Hook.
Aquilegia brevistyla Hook.
Caltha palustris ssp. *arctica* (R. Br.) Hult.
Delphinium glaucum S. Wats.

Rosaceae

Dryas integrifolia M. Vahl. ssp. *sylvatica* (Hult.) Hult.
Dryas octopetala L. ssp. *octopetala*
Potentilla fruticosa L.
Potentilla hookeriana (Lehm.) ssp. *hookeriana* var. *hookeriana*
Potentilla norvegica L. ssp. *monospeliensis* (L.) Aschers. Graebn.
Potentilla palustris (L.) Scop.

Rosa acicularis Lindl.
Rubus arcticus L.
Rubus chamaemorus L.
Sanguisorba officinalis L.
Spiraea beauverdiana Schneid.

Rubiaceae

Galium boreale L.

Salicaceae

Populus balsamifera L. ssp. *balsamifera*
Populus tremuloides Michx.
Salix depressa L. ssp. *rostrata*
Salix niphoclada Rydb. var. *niphoclada*
Salix glauca L. ssp. *acutifolia* (Hook.) Hult.
Salix phlebophylla Anderss.
Salix pulchra Cham.
Salix reticulata L. ssp. *reticulata*

Santalaceae

Geocaulon lividum (Rich.) Fern.

Saxifragaceae

Parnassia palustris L. ssp. *neogaea* (Fern.) Hult.
Saxifraga hirculus L.
Saxifraga punctata L. ssp. *nelsoniana* (D. Don) Hult.
Saxifraga spicata D. Don.

Scrophulariaceae

Castilleja caudata (Pennell) Rebr.
Pedicularis labradorica Wirsing
Pedicularis kanei Durand ssp. *kanei*
Pecicularis sudetica Willd.
Pedicularis verticillata L.

Umbelliferae

Cnidium cnidiifolium (Turcz.) Schischk.

Valerianaceae

Valeriana capitata Pall.

Violaceae

Viola epipsila Ledeb. ssp. *repens* (Turcz.) Becker

APPENDIX II

POLLEN AND SPORE COUNTS FROM EPIGURUK SECTIONS

EPIGUREK I POLLEN AND SPORE COUNTS

Sample Number	Depth cm.	Betula	Alnus	Salix	Picea	Pinus	Ericaceae	Cyperaceae	Gramineae	Artemisia	Compositae	Rubus	Cruciferae	Caryophyllaceae	Polygonum-bistorta	Saxifraga-stellaris	Miscellaneous Pollen	Indeterminant Pollen	Sphagnum	Lycopodium sp.	Lycopodium selago	Other trilete spores	Monolete spores	Pediastrum	Unknown Spore A
OP68- 9	30	33	34	13	70		8	38	1	1		4						4	30						
10	35	43	17	7	83		13	31	4	1		1						3	4						
11	38	24	18	1	115		1	39	2									5	10						
12	41	35	48	10	45			59	2				1					6	9						
13	44	45	40	2	74		3	32	2		1		1					3	147	5					
14	55	31	155	1				13										10	1	6					
15	65	37	157	2				3				1						14		2					
16	75	61	92	8				36	3									25	12	42	7		12		
17	85	57	100	8	3			27	4			1						9	7	32	3		5		
18	95	65	51	24	11		1	42	3			1						11	46	178	66		15		
19	105	Sterile																							
20	115	33	13	12	5		1	135									1[a]	4		116	87				
21	125	44	15	16			2	114	6		1			2				6	11	54	54	1	4		
22	135	47	8	22			4	92	21	1	3						1[bc]	5	8	176	408	3	9		
23	145	46	13	10				111	16		3			1				3	48	307	202	16	7		
24	155	9	1	16	2	1	1	155	4	1	3		1			3	1[bde]	2	4	2		5			6
25	165	15	5	22	2	3	2	117	6	2	2	4	14		4	1		9	7	[illegible]		7	2	4	12
26	175	10	1	14	1	11		47		3		5					1[fg]	9	1	4	2				3
27	185	8	2	10	3	1		44		3	1	1	1	2			1[h]	3	4			1		2	6
28	195	3	1	5	3	2		171	4	2	4		1	1	2			5	11			4			
29	205	14	7	14	4	3	1	141	10	1	4							17	2			4			3

[a] Ranunculus type

[b] Sanguisorba

[c] Rosaceae

[d] Myrica

[e] Abies

[f] Chenopod.-Amaranthus

[g] Triglochin

[h] Tofieldia

EPIGURUK II POLLEN AND SPORE COUNTS

Sample Number	Depth cm.	Betula	Alnus	Salix	Picea	Cyperaceae	Gramineae	Artemisia	Compositae	Ericaceae	Ranunculus type	Thalictrum	Rosaceae	Rubus	Caryophyllaceae	Cruciferae	Saxifraga oppositifolia	Saxifraga stellaris	Saxifraga rivalis	Chenopod.-Amaranthus	Polemonium	Polygonum bistorta	Polygonum viviparum type	Umbelliferae	Sanguisorba officinalis	Epilobium	Valeriana	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
GPb7 [illegible]	[illegible]	4	1	22	2	[illegible]	3	[illegible]	4		9	8		1	1	[illegible]																				3	
[illegible]	[illegible]			5	1	[illegible]		[illegible]	3	[illegible]	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	10		[illegible]	12	[illegible]	4	2	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	15	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	7	[illegible]	[illegible]	[illegible]	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1	[illegible]		[illegible]	[illegible]	[illegible]	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1	9		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	7		[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		2		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	6		11		[illegible]	3	[illegible]	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		9	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	10		[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		19		[illegible]	[illegible]	21	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	21	[illegible]	[illegible]	1	[illegible]	19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		13		[illegible]	[illegible]	[illegible]	[illegible]	3	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	1	1	1	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	7	11	3	[illegible]	[illegible]	[illegible]	1	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	4	[illegible]		[illegible]	[illegible]	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	11		[illegible]	[illegible]	[illegible]	5	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	[illegible]	[illegible]	1	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	18	[illegible]	25	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	42	1	14		[illegible]	[illegible]	[illegible]		1	[illegible]	[illegible]	[illegible]	6	[illegible]	1	2	1	[illegible]	1	[illegible]	1	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1	12	[illegible]	[illegible]	[illegible]	15	7[e]	1	[illegible]	[illegible]	[illegible]	[illegible]	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	2	17	2	[illegible]	[illegible]	[illegible]	6	1	6	8	3	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	2		[illegible]	[illegible]	[illegible]		1	[illegible]	[illegible]	[illegible]	1	[illegible]	1	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[a] P. [illegible] type

[b] Pi[illegible]

[c] Astragalus type

[d] [illegible]

[e] Potamogeton

APPENDIX III POLLEN AND SPORE COUNTS

Sample Number	Depth cm.	Betula	Alnus	Picea	Salix	Cyperaceae	Gramineae	Artemisia	Compositae	Ranunculaceae	Ericaceae	Rosaceae	Caryophyllaceae	Chenopodiaceae-Amaranthus	Sanguisorba	Valeriana	[illegible]	Umbelliferae	Cruciferae	Polygonum bistorta	Miscellaneous pollen	Potamogeton	[illegible]	[illegible]	[illegible]	[illegible]	Lycopodium	Lycopodium selago	[illegible]	Miscellaneous
OF67-525	5	12	55	43	11	51	2	1	1	1	3	1																		
524	17	31	51	36	1	35					4	1											[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
523	33	9[illegible]	69	28	1	7	1	3			2	1											[illegible]	[illegible]	13	13				
521	63	19	75	17	10	46	11	5	8	1	2	1	[illegible]		1					1			[illegible]	[illegible]	[illegible]	[illegible]	24			
519	87	Sterile																												
518	97	Sterile																												
517	113	23	51	35	16	69	5			1																				
516	127	Sterile																												
515	137	47	151		3																									
513	157	53	133	1	1	7	4	1		1				1																
512	167	27	174	9	5	34	6			2	2		1																	
511	177	Sterile																												
510	187	8	151	1	2	5				1			1																	
509	197	14	168	1		11		1	2																					
508	207	33	28	7	13	134	11	1				1	2																	
507	223	92	75	2	3	17	1[illegible]	2		1	4	1	2																	
503	233	127	21	2	[illegible]	2[illegible]	15	4	1		3																			
499	243	125	16	2	[illegible]	22	15	5	2	[illegible]		6																		
495	267	86	5	1	1	[illegible]	3	3	2	1	1	[illegible]	2																	
489	297	123	9	6	2	13	1[illegible]	8	4		2	3	2	1	1															
485	317	119	7	[illegible]	1	41	15			[illegible]	[illegible]	[illegible]	3	1	1															
481	337	87	2	10	5	57	29	3	3			1	1	1																
477	357	64	5	6	9	66	23	5	6	3	2	2	1																	
473	377	99	3	7	2	47	47	5	9	1	1	1		1																
469	397	149	157	9		12	3	2	4	1	2																			
466	412	69	7	4	17	63	16	11	3	2		1			1															
465	417	136	5	34	1	10	2	2	2		4	1																		
464	422	Sterile																												
462	433	Sterile																												
460	443	Sterile																												
457	447	151	[illegible]	10		31		1	2	3		1																		
454	473	178	3	3	2	7	1	2					2																	
453	477	112	7	2	7	50	7	2		3														29	32	34	[illegible]			
445	593	148	4	3		21	6	5		2	5	1	1											[illegible]	[illegible]	38	[illegible]	[illegible]		
449	521	152	3	5	1	23	3	3		4	2	3												14	41	14	[illegible]			3e

a Saxifraga oppositifolia

b Pinus

c Polemonium

d Equisetum

e Pediastrum