University of Alberta

# Full-glacial macrofossils, paleoecology and stratigraphy of the Bluefish Exposure, northern Yukon.

by

Grant Daniel Zazula ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment
of the requirements for the degree of
Master of Arts

Department of Anthropology

Edmonton, Alberta

Fall, 2002

0-612-81331-2

## University of Alberta

## Library Release Form

**Name of Author:** Grant Daniel Zazula

**Title of Thesis:** Full-glacial macrofossils, paleoecology and stratigraphy of the Bluefish Exposure, northern Yukon.

**Degree:** Master of Arts

**Year this Degree Granted:** 2002

Grant Daniel Zazula
12740-116 Street
Edmonton, Alberta
T5E 5H2
Canada

Date Aug. 28/2002

**University of Alberta**

**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 Full-glacial macrofossils, paleoecology, and stratigraphy of the Bluefish Exposure, northern Yukon submitted by Grant Daniel Zazula in partial fulfillment of the requirements for the degree of Master of Arts.

Charles Schweger.
Dr. Charles Schweger

ABeaudoin.
Dr. Alwynne Beaudoin

Dr. Nathaniel Rutter

Date 27/August/2002

# Abstract

Macrofossil analysis at the Bluefish Exposure (67°23'N, 140° 21.5'W) provides a record of full-glacial steppe, within a mosaic of vegetation types, including mid-rich fens, mesic graminoid meadows, and discontinuous tundra. Local vegetation was dependant on physical factors including, moisture, slope, drainage, aspect, and elevation. Comparisons with other multi-proxy data support the hypothesized "Mammoth Steppe" in the Bluefish watershed and substantial environmental variability across eastern Beringia. Terrestrial plant macrofossils yielded 8 AMS $^{14}C$ ages between 18,880 ±210 yr BP (AA45509) to 16,440 ±120 yr BP (AA45519), uncalibrated $^{14}C$ ages, dating the assemblage and deposition of the near-shore deltaic sediments associated with Glacial Lake Old Crow transgression. A synthesis of regional stratigraphic data indicates two phases of Glacial Lake Old Crow; Stage 1, *ca.* 35-22 ka BP, correlative to the all-time maximum advance of Laurentide ice; and Stage 2, *ca.* 22-16 ka BP, correlative to the Katherine Creek Phase Laurentide ice margin.

## Acknowledgements

Although this thesis represents the product of a long personal journey, this all would not have been possible without the assistance and guidance of many important people, whom I am grateful for. This thesis must be considered merely a part of an eternally growing, interrelated body of knowledge, and thus, in essence, many of the thoughts and ideas that are presented have sprouted from the roots established by many great individuals.

Firstly, my deepest gratitude is extended to my supervisors Charles Schweger and Alwynne Beaudoin. Charlie has been, and will always be, my mentor both professionally as a scholar, and personally, as a friend. Nearly all my knowledge of Beringian paleoenvironments that I have attempted to develop in this thesis have been developed through Charlie's careful guidance over the last several years. Alwynne kindly welcomed me into her lab early on in my graduate program, and spent countless hours assisting me with my discovery of the macrofossil world. Through many days in the museum basement and coffee breaks, Alwynne was a close scientific mentor and friend. Together, Charlie's and Alwynne's continual support and encouragement have guided me and inspired me to strive for excellence. This research would not have been possible without them.

This thesis would not have been possible without the kind assistance from many amazing people. Thank you to Alice Telka (Paleotec Services Inc.) and Nancy Bigelow (Alaska Quaternary Center), my fellow "macroteers", who kindly assisted with the identification of some of my specimens and who are great friends and scientists that I look up to. Thank you to John Matthews Jr. (Ohana Productions Ltd.) for providing me with unpublished data from the Bluefish Exposure and for establishing the base that this thesis was built upon. Alejandra Duk-Rodkin (Geological Survey of Canada) kindly taught me much about paleogeography and regional geomorphology, and greatly inspired and assisted me to examine the Old Crow region's stratigraphic issues. Alejandra also provided me unpublished data or hers and from the files of Owen Hughes at the Geological Survey of Canada in Calgary. Bernard Lauriol (University of Ottawa) and Jacques Cinq-Mars (Canadian Museum of Civilization) welcomed me into their field crews for the summer of 1999 and provided logistical support to carry out field research for this thesis. George McCourt encouraged me to work on the macrofossils and kindly allowed me to use his unpublished pollen data from the site. Ilka Bauer (University of Alberta) kindly took time out of her dissertation writing to identify the bryophyte remains. Scott Elias (Royal Holloway, University of London) examined invertebrate remains and developed a paleo-temperature reconstruction that was critical for this research. Thank you to Nat Rutter (University of Alberta) for his great field trips, the unpublished Eagle River data, and for being the external examiner on this thesis committee. Timothy Jull and Mitzi DeMartino from the National Science Foundation, University of Arizona, AMS Facility kindly provided the AMS radiocarbon dates that were crucial for this research. Thank you to Robert Mott (NRCan) for identifying wood samples. Peter Milot (Provincial Museum of Alberta) identified vertebrate remains. Carolyn Parker and Alan Batten (University of Alaska, Fairbanks Museum) assisted me during my visit to the Alaska herbarium and allowed me to sample their collections for reference material. Thank you to Darren Shaw and the MACI Anthropology Vislab for all

the technical assistance with putting this thesis together. Thank you to Harvey Friebe for his patience and assistance in the paleoecology lab.

Many of the ideas in this thesis were influenced by individuals through discussions, e-mails and interactions. For kindly sharing their time and thoughts, and providing encouragement throughout this project, I sincerely thank Dale Guthrie (University of Alaska, Fairbanks), Dick Morlan (Canadian Museum of Civilization), Duane Froese (Simon Fraser University), Paul Matheus (Alaska Quaternary Center), Hilary Birks (University of Bergen, Norway), John Westgate (University of Toronto), Mary Edwards (University of Alaska, Fairbanks), Les Cwynar (University of New Brunswick), Bas van Geel (University of Amsterdam), Ian Campbell (University of Alberta), Pamela Willoughby (University of Alberta) and Rolf Mathewes (Simon Fraser University).

For the financial support that was crucial for this research, I thank the Northern Scientific Training Program (NSTP), Canadian Circumpolar Institute (CCI), Faculty of Graduate Studies and Research (FGSR), University of Alberta, The Canadian Polar Continental Shelf Program, the Department of Anthropology, University of Alberta, and an NSERC grant to Charles Schweger.

I am lucky and thankful to have wonderful, close friends who have been a huge part of this whole experience. Robin Woywitka, Mark Nelson, Chris Thomas, Craig Kowalchuk, Jörg Bauer, Chris McNeil, Mark Watson, Lisa Wozniak, Jenaya Webb, Lori Kiel, Maija Prakesh, Will Green, Nathan Paradon, Rachel Moll, Dustin Rainey, Carol Adamczuk, thank you all for the laughs, good talks and for giving meaning to life after a day of sitting at a microscope. A special thanks to Laura Sikstrom who provided the spark to keep me going during many days of this journey.

Last, but certainly not least, I thank my family; Dan, Betty, John, and Nick Zazula, who have always supported me and encouraged me to follow my interests and curiosities about the world and for always giving me a good dose of reality when I needed it. I dedicate this thesis to them, for they have given unconditionally to me by planting the roots and nurturing my development that led to this accomplishment.

## Table of Contents

## List of Tables

## List of Figures

## List of Plates

# Chapter 1: Introduction

The nature of the full-glacial (oxygen isotope stage 2) vegetation in Alaska and Yukon (eastern Beringia) remains a topic of great interest and controversy. Dated macrobotanical remains from the Bluefish Exposure, northern Yukon, provide uncontestable evidence for the existence of steppe vegetation within a local mosaic of vegetation types. Together with dated large mammal remains from the nearby Bluefish Caves site, these multi-proxy data support Guthrie's (1990) hypothesized full-glacial "Mammoth-Steppe" biome within the Bluefish watershed.

## 1.1 The Yukon Refugium Project

During Pleistocene glacial intervals, northern Yukon and Alaska were connected by the Bering Land Bridge to northeast Asia, forming the unglaciated biotic refuge of Beringia (Figure 1). This refuge was the avenue of exchange for plant and animal populations, including humans, between the Old and New Worlds (Hopkins *et al.* 1982). The holistic inquiry into the nature of Pleistocene Beringia, driven by questions concerning the New World's earliest inhabitants, has stimulated considerable interdisciplinary research activity in the northern Yukon.

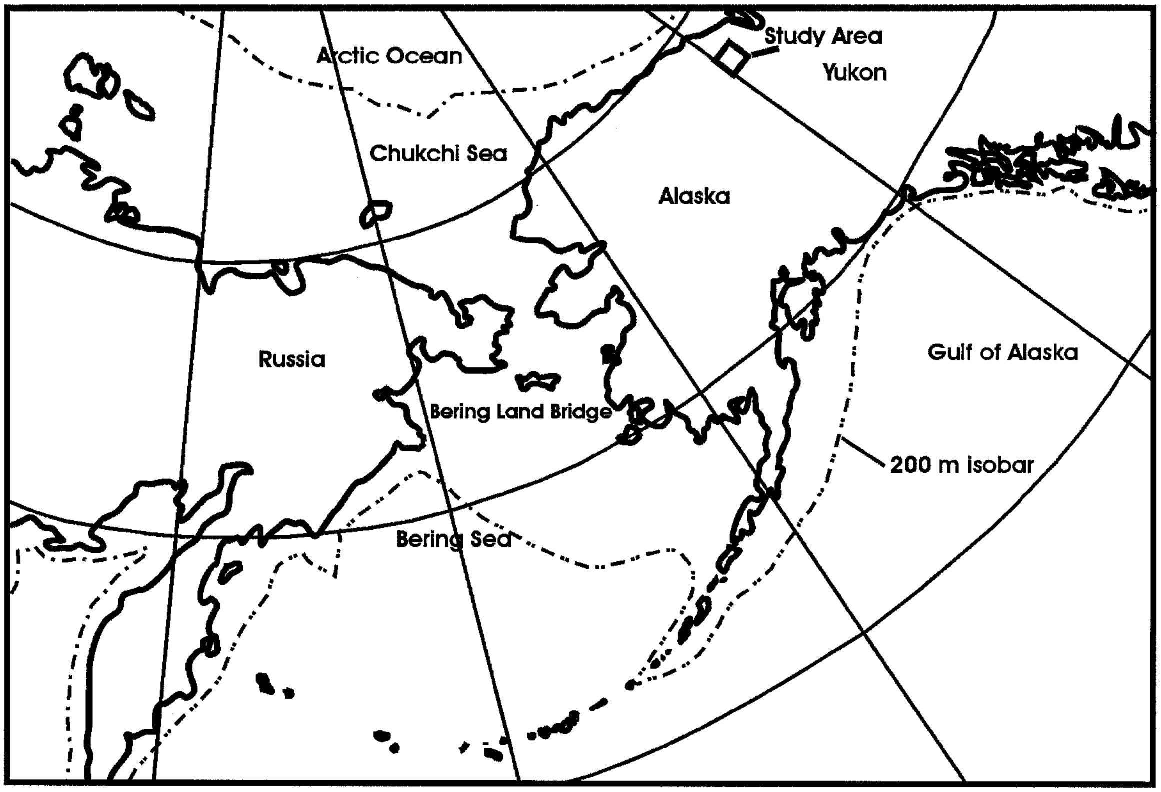


Figure 1. Map of Berigia with the study area. Modified after Goetcheus and Birks (2001).

Discoveries of Pleistocene-age bone artifacts in the Old Crow Basin and Bluefish Caves site indicated the potential of this region to answer questions about the New World's earliest peoples (Bonnichsen 1979; Cinq-Mars 1979; Cinq-Mars and Morlan 1999, Irving and Harrington 1973; Morlan 1977, 1980, 1986; Morlan and Cinq-Mars 1982). To examine systemically these Pleistocene-aged archaeological remains, the Yukon Refugium Project was initiated in 1975 under direction of archaeologist R.E. Morlan (Canadian Museum of Civilization). An interdisciplinary team of specialists in Quaternary geology, geochronology, paleontology, paleoecology, and archaeology focussed on the common goal of reconstructing the Pleistocene human-ecosystem of the northern Yukon refugium (Hughes *et al.* 1981, Morlan 1977, 1980).

Due to the controversial nature of Pleistocene archaeology in Beringia, a primary objective of the Yukon Refugium Project was to provide convincing contextual data to support the archaeological record. To accomplish these objectives, exposed river bluff sections were described and sampled for analyses. Geochronological and stratigraphic data were used to develop a chronology for regional geological events to which their archaeological discoveries could be related. Analysis of fossil pollen, plant macrofossils, fossil invertebrates, and fossil vertebrates provided much information on Pleistocene paleoenvironments. Together, this work provided a picture of the biophysical system that would have served as the interactive sphere for late Pleistocene cultural adaptations in the northern Yukon.

## 1.2 Thesis Objectives

Research presented in this thesis follows several decades of the interdisciplinary research established by the Yukon Refugium Project. In an attempt to contribute information for reconstructing the late Pleistocene paleoenvironment of the northern Yukon, fieldwork for this study was conducted at the Bluefish Exposure. This study site, designated as HH-75-24 by O.L. Hughes (Geological Survey of Canada), is located 30 km southwest of Old Crow, along the north bank of the Bluefish River on the southwestern edge of the Bluefish Basin, northern Yukon (67° 23' N, 140° 21.5 W). The objectives of this study are to examine two interdependent topics:

A) To establish a record of the full-glacial late Pleistocene vegetation through the analysis of plant macrofossils and compare these data with fossil pollen, invertebrate, and vertebrate data from the Bluefish watershed to reconstruct the local ecosystem. This will further our understanding of late Pleistocene herbivore-vegetation interactions, and serve as the ecological context for local hunter-gatherer adaptations. These topics are presented in Chapters 5, 6, and 7.

B) To document the stratigraphy and geochronology of the deposits at the study site and compare them with other sites in the region. These will establish a late Pleistocene geological history for the region relating the periods of glacial-lake inundation in the northern Yukon basins with different Laurentide ice margins. These topics are presented in Chapters 8, and 9.

The background information and data relevant to the regional late Pleistocene paleoecology, geological history, and physiography are presented in Chapters 1 and 2. Chapter 3 presents an overview of data from Bluefish Caves site. Chapter 4 presents previous data from the Bluefish Exposure and methodology utilized to obtain data for this thesis. The summary, conclusions, and archaeological implications are presented in Chapter 10. Appendix A presents descriptions and plates of macrofossils. Appendix B is a glossary of ecological terminology used in this thesis. Appendix C presents botanical nomenclature, common names and habitat descriptions of plant taxa. Appendix D contains macrofossil quantitative data.

## 1.3 Background

### A) The Paleoecology of Beringia

Controversy surrounds the composition of the Beringian vegetation and its capability to support a diverse mammal community during the full-glacial (oxygen isotope stage 2) interval *ca.* 24,000 to 14,000 yr Before Present (BP). Works by Colinvaux (1964), Hopkins (1967) and Guthrie (1968), on fossil pollen, paleogeography, and vertebrate paleontology, respectively, portrayed Beringia as a productive arctic-steppe ecosystem inhabited by a diverse Pleistocene grazing fauna (Guthrie 1990). Cwynar and Ritchie (1980) challenged this view, suggesting that low pollen influx in full-glacial "Herb Zone" assemblages indicated vegetation analogous to modern discontinuous fell-field tundra, an ecosystem that could not support a diverse mammal fauna. Further advocated by Colinvaux (1980, 1981) and Colinvaux and West (1984), this proposal sparked considerable debate and discussion because it threatened the notion of Beringia as a viable region for Pleistocene mammals and people (Schweger 1992). Debate concerning the Beringian "Productivity-Paradox" has focussed on how diverse, large mammals were able to live during a period of harsh glacial climate when this region could not maintain such a fauna today (Schweger *et al.* 1982).

Although the terms "steppe" or "tundra" are most prevalent in descriptions of Beringian paleovegetation, much data indicates that the environment of Beringia was not homogeneous, and these terms "" may not adequately describe this vast region, though elements of these vegetation types may have been more important than at present. Steppe here is defined as a xeric, treeless vegetation dominated by *Artemisia*, and perennial graminoids and forbs, and is most often characterized as one capable of providing adequate fodder for larger herbivores (Guthrie 1990, also see Appendix B). In contrast, tundra is defined here as vegetation where cold and short growing season effectively eliminates most trees, and is often described as incapable of sustaining large mammal populations (Cwynar and Ritchie 1980, also see Appendix B). Schweger and Habgood (1976) offered an intermediate position in the productive steppe versus depauperate tundra debate, recognizing that the full-glacial ecosystem, not unlike the modern landscape, is best described as a mosaic controlled by numerous micro-environmental factors (also Schweger 1976, 1992, 1997). Anderson and Brubaker (1994) and Barnosky *et al.* (1987) emphasized the importance of regional scale variation because summarized pollen data from across eastern Beringia indicate increased mesic conditions from east to west, with more xeric-adapted species common in northern Yukon, and more mesic communities in western Alaska (also Elias 1992; Elias *et al.* 1996, 1997; Guthrie 2001; Ritchie and Cwynar 1982).

Paleoenvironmental reconstructions for Beringia are mostly based on fossil pollen data. Beringian, full-glacial, "Herb-Zone" pollen assemblages are dominated by Poaceae (grass), Cyperaceae (sedge) and *Artemisia* (sage). These pollen types typically cannot be identified to genus or species, and are abundant in both present day steppe and tundra ecosystems. Hence, these pollen types offer only limited information for ecological conditions and paleoenvironmental reconstruction. Further, pollen records are ambiguous for reconstructing local environments because pollen has often-indeterminable source areas and pollen assemblages may be derived from several vegetation types. In contrast, plant macrofossils provide much more detailed local paleoecological records because they have local source areas, may be identifiable to a lower taxonomic level, and provide reliable AMS (Accelerator Mass Spectrometry) $^{14}C$ ages (Birks 1980; Birks and Birks 2000; Matthews 1974a, 1974b, 1982). Paleoecological reconstructions for Beringia should include both fossil pollen and plant macrofossils so that high resolution, detailed information relevant to both the regional and local vegetation is available (Birks and Birks 2000).

A fundamental problem with paleoenvironmental reconstructions of full-glacial Beringia is that much of the data are from isolated locations across this vast region, and may or may not be directly comparable. Few locations have provided detailed multi-proxy data, including fossil pollen, plant and insect macrofossils and vertebrates to be integrated for robust paleoenvironmental reconstructions. However, records from the Bluefish Exposure and Bluefish Caves within the Bluefish watershed provide an ideal multi-proxy, corroborative dataset to detail numerous ecological components and their probable processes within a confined geographic area. Excavations at the Bluefish Caves have produced evidence for co-existing large mammals and hunter-gatherer populations spanning the full-glacial interval (Cinq-Mars 1979, 1990; Cinq-Mars and Morlan 1999; Morlan and Cinq-Mars 1982). The geographic proximity of the Bluefish Exposure study site to the Bluefish Caves (*ca.* 30 km) and their temporal overlap indicate that they contain paleoenvironmental data that represent the same local ecosystem system. A robust reconstruction for the Bluefish watershed can then shed light on ecosystems and ecological processes in other areas of full-glacial Beringia.

## B) Regional Geological History

Pioneering stratigraphic work during the 1960's by O.L. Hughes (Geological Survey of Canada) recognized that late Quaternary advancements of the Laurentide ice to the east flank of the Richardson and Mackenzie Mountains had profound effects on the major drainages of the northern Yukon, Northwest Territories and Alaska. Hughes (1972) described exposures in the unglaciated northern Yukon basins as having two units of lacustrine sediments separated by a complicated sequence of unconsolidated alluvial, colluvial and lacustrine sediments.

During preglacial times, the northern Ogilvie Mountains, Bluefish, Old Crow, Driftwood and Bell Basins were all drained by the eastward flowing paleo-Porcupine River through McDougall Pass to the Mackenzie Delta (Duk-Rodkin and Hughes 1994; Hughes 1972). Hughes (1972) suggested that an early Wisconsinan Laurentide ice advance blocked McDougall Pass, diverting and reversing the paleo-Porcupine River, forming a vast glacial-lake in the interior basins. Glacial retreat allowed the eastward drainage to resume through McDougall Pass and normal lacustrine, colluvial and fluvial sedimentation continued in the basins. A re-advance of the Laurentide ice again diverted regional drainage, re-establishing the glacial-lake. By the time McDougall Pass became ice-free again, the western outlet at the Upper Ramparts near the Alaska/Yukon border had been eroded to a level below the pass and westward drainage of the Porcupine River was established (Hughes 1972). Hence, the chronology of glacial-lakes in the unglaciated northern Yukon is inherently tied to the chronology of Laurentide ice margins along the Richardson and Mackenzie Mountain Front.

Since the original work by Hughes, almost three decades of research have contributed much additional geochronological and stratigraphic data, providing greater detail for these events (Duk-Rodkin 1999; Duk Rodkin and Hughes 1994, 1995; Duk-Rodkin *et al.* 1996; Hughes 1985; Hughes *et al.* 1981; Lemmen *et al.* 1994; Matthews *et al.* 1987, 1990; Morlan 1980, 1986; Morlan *et al.* 1990; Schweger and Matthews 1991; Thorson and Dixon 1983; Walde 1986). Paleomagnetic studies indicate that the earliest of these lacustrine episodes is non-glacial in origin because of magnetically reversed sediments of probable Pliocene or early Pleistocene age (Pearce *et al.* 1982; Schweger 1989; Westgate *et al.* 1985). Stratigraphic work in Bonnet Plume Basin indicates that the maximum advance of Laurentide ice occurred during the late Wisconsinan (Hughes *et al.* 1981). Thus, only the uppermost lacustrine episode in the interior basin stratigraphies is glacial in origin, correlated to a late Wisconsinan Laurentide ice advance (Hughes *et al.* 1981; Schweger 1989). Further, extensive mapping and dating of the Laurentide ice margins has provided much important data leading to correlation of glacial and glaciolacustrine events (Duk-Rodkin 1999; Duk-Rodkin and Hughes 1995; Hughes 1985).

Because of its location at the southwestern edge of the Bluefish Basin, the Bluefish Exposure has potential to provide important geological data for the final phases of the inundation and drainage of the late Pleistocene glacial-lakes. These data would also refine the chronology for the adjacent Laurentide ice front along the Richardson and Mackenzie Mountains and evolution of regional drainage systems. This thesis will present a synthesis of these data to help establish greater temporal detail for regional geological events, archaeological remains and the role of the hypothesized "ice-free corridor" as a route for southward human dispersal.

# Chapter 2: General Setting

## 2.1 Physiography

The study area is situated at the eastern extremity of Beringia. Although Beringia proper is usually defined as an unglaciated region, the study area is adjacent to the Laurentide ice margin. Therefore, one must consider the effects of this continental ice sheet on both the regional paleoecology and the geological history. The physiography of the study area is presented in Figure 2. Physiographic descriptions of the unglaciated areas are presented below in a roughly east to west order

## 2.2 Unglaciated Areas

The unglaciated interior basins of the northern Yukon are bounded by the British Mountains to the north, the Old Crow Range to the west, the Keele and Ogilvie mountain ranges to the south, and by the Richardson Mountains to the east (Bostock 1948; Norris 1981). There are four unglaciated, structural basins situated in the northern Yukon. The Old Crow Basin is the northernmost, with the Bluefish Basin and Driftwood Basin to the southwest and southeast, respectively. The Bell Basin is southeast of the Driftwood Basin in the northern part of Eagle Plain. These basins all contain thick, extensive, unconsolidated late-Cenozoic deposits that have been exposed by Holocene incision. As the sediments extend below the bedrock thresholds of the respective basins, these basins are structural depressions produced by tectonic faulting and warping (Hughes 1972;

Hughes *et al.* 1981; Norris 1981). Numerous shallow thermokarst lakes are scattered throughout these basin lowlands.

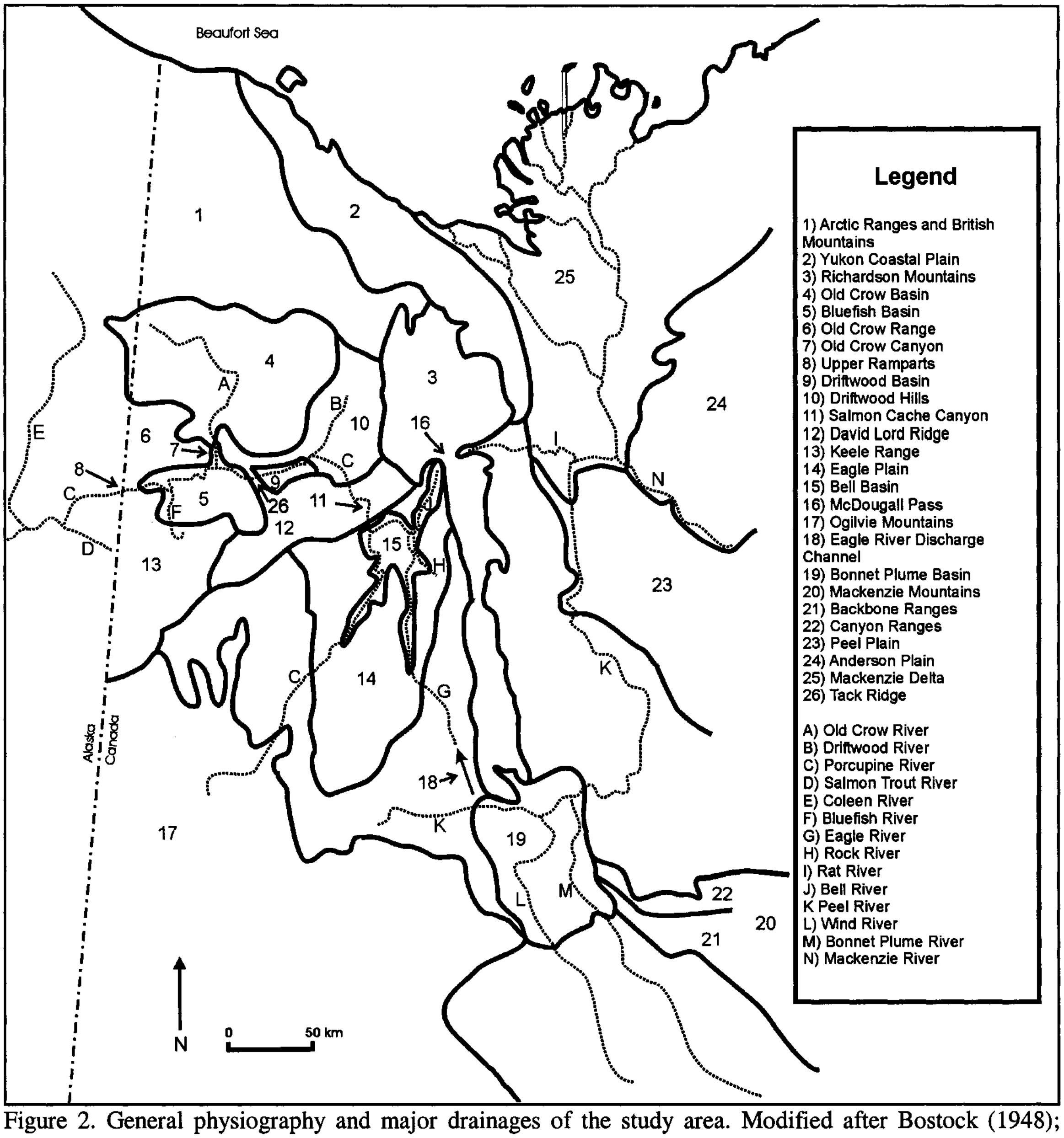


Figure 2. General physiography and major drainages of the study area. Modified after Bostock (1948); Duk-Rodkin and Hughes (1995); Hughes *et al.* (1981).

### *Bluefish Basin*

The Bluefish Basin is a lowland of approximately 1000 km$^2$, bordered to the north by a fault-bounded ridge of the Old Crow Range that divides the Old Crow and Bluefish

Basins (Norris 1981). The basin extends east-west from the junction of the Old Crow and Porcupine Rivers to the Ramparts near the Alaska border. The eastern edge is bounded by Tack Ridge and the Keele Range marks the southern limit.

The floodplain and lowest terraces of the Porcupine River occupy the valley inset about 60 m below the level of the basin floor. Most of the basin floor has elevations from 295 to 320 m asl and is poorly drained with numerous shallow thermokarst lakes. Shorelines surrounding the periphery of the Bluefish Basin are found between 295 to 366 m asl, however they are less distinct and discernable than those of the Old Crow Basin to the north (Hughes 1972).

Much of northern Yukon north of the Peel River is drained by the Porcupine River system through to the Bluefish Basin. The Porcupine River carries drainage of the Old Crow, Bell, Driftwood, and Bluefish Basins, western Richardson Mountains and northern Keele Range and Ogilvie Mountains. The Old Crow River drains the southern slopes of the Arctic Ranges and the Old Crow Basin, and then enters the Porcupine River from the north. The Driftwood River, which drains the Driftwood Hills, enters the Porcupine River from the northwest. David Lord Creek drains David Lord Ridge to the south and enters the Bluefish Basin via the Upper Porcupine. Arising from the Keele Range, the Bluefish River joins the Porcupine River from the south. The Porcupine River exits the basin into the Yukon River system through the steeply incised canyon near the Alaska border known as the Upper Ramparts of the Porcupine River.

West of the Upper Ramparts canyon in Alaska, the westward flowing Salmon Trout River enters the present Porcupine channel carrying drainage from the northwest side of the Keele Range. Further westward, the Coleen River enters the Porcupine River from the north, draining areas of the southern Brooks Range. These, in turn, meet with the Yukon River, continuing to Norton Sound through western Alaska.

The former drainage divide near the present Upper Ramparts of the Porcupine River played a pivotal role in the regional chronology of basin inundation and late Cenozoic evolution of northwest North American drainage systems (Duk-Rodkin and Hughes 1995; Thorson and Dixon 1983). At an elevation of 370 to 385 m asl, the former divide between the pre-glacial, westward Yukon River system and the eastward paleo-Porcupine River is approximately 15 km west of the Alaska border (Duk-Rodkin and Hughes 1995). The Porcupine River has incised a narrow, steep walled canyon through Early Cretaceous quartzite and argillites that made up the former divide. Geomorphic evidence suggests that incision commenced relatively recently, during the late-glacial, related to the establishment of permanent westward flow of the Porcupine River.

### *Bluefish Watershed*

Approximately 18,000 km$^2$ in area, the Bluefish watershed is defined as the hydrological catchment or drainage basin area that contributes water to the Bluefish River. The watershed is bounded by the Keele Range to the southwest, the Porcupine River to the north, and the Bluefish Basin to the northeast. Several small streams that drain the Keele Range flow into the northeastward trending Bluefish River. Elevations in the watershed range from approximately 250 m asl at the valley floor to 1000 m asl atop the highest peaks of the Keele Range. Surface area estimates for the Bluefish watershed (Ritchie 1984) indicate that approximately 15% is valley bottom (250 to 350 m asl), 65% is lower slope and midslope (350-650 m asl), and 20% is upland ridge (>650 m asl). The most considerable relief over short distances, with varied steepness (15 - 35°) and aspect are part of limestone and dolomite ridges and spurs that rise into the Keele Range above 650 m asl.

### *Old Crow Basin*

Old Crow Basin is the largest of the northern Yukon structural basins, measuring approximately 6,500 km$^2$ in area. The topography of the basin is remarkably flat, with elevations below 300 m asl and numerous shallow thermokarst lakes. The basin is drained by the Old Crow River and its tributaries, including the Timber, Black Fox, Johnson and Schaeffer Creeks. These rivers incise through unconsolidated late Cenozoic sediments to a depth of about 30 m, exhibiting stratigraphy similar to that in the Bluefish and Driftwood Basins (Morlan 1980, 1986). The Old Crow River flows southward into the Porcupine River through the Old Crow Canyon, which is incised through Paleozoic granites and Proterozoic quartzites and argillites of the Old Crow Range (Norris 1981). Well-defined shorelines surround the periphery of the Old Crow basin to 366 m asl in elevation (Hughes 1972).

### *Driftwood Basin*

The Driftwood Basin is a small low-lying area centered at the junction of David Lord Creek and Porcupine River. The basin is separated from the Bluefish Basin to the west by Tack Ridge. The Porcupine River drains Bell Basin into Driftwood Basin via Salmon Cache Canyon, which is deeply incised through the Porcupine River Formation, sandstones of Jurassic-age that make up David Lord Ridge (Norris 1981). The steep walls of this canyon suggest the incision commenced relatively recently, a result of regional drainage rearrangement during the late-glacial.

### *Bell Basin*

The Bell Basin is a low area, 40 to 50 km in diameter, at the north part of the Eagle Plain, centered on the junctions of the Eagle, Bell, Rock and Porcupine Rivers. It is bordered by the Richardson Mountains to the northeast, David Lord Ridge to the north and Porcupine Plateau to the south and west. Faint shorelines mark the periphery of the basin (O.L. Hughes and J.V. Matthews Jr., unpublished data).

South of the headwaters of the Eagle River, the Bell Basin is separated from tributaries of the Peel River drainage by a former divide reaching an elevation to 560 m asl. Through this divide, the Eagle River Discharge channel is a canyon like feature more than 1 km wide, incised through the Ford Lake Formation shale of Mississippian age (Norris 1981).

## 2.2 Glaciated Areas

Late Pleistocene advances of Laurentide ice from the west and northwest affected areas during the late Pleistocene that are relevant to this study. Descriptions of these areas are presented below in a south to north order.

### *Mackenzie Mountains*

Beginning north of the Liard River (about 59° 30' N), the Mackenzie Mountains form a northward continuation of the Rocky Mountains in an arc south and southeast of Bonnet Plume Basin. The Mackenzie Lowland to the east and the Peel Plateau to the north border the Mackenzie Mountains. They are composed of two distinct ranges, the Backbone Ranges along the main continental axis to the west, with peaks to a maximum of about 2500 m asl and the lower Landry and Canyon Ranges to the east and northeast. Geomorphic evidence indicates that ice lobes extended down major valleys while continental ice pressed up against the outermost ranges along the entire Mackenzie Mountain front (Duk-Rodkin and Hughes 1991).

### *Bonnet Plume Basin*

The Bonnet Plume Basin is situated southeast of the Eagle Plain, between and immediately adjacent to the Wind and Bonnet Plume Rivers. The confluence of the Peel, Wind and Bonnet Plume Rivers is located at the northern extremity of the basin. In Bonnet Plume Basin the eastward flowing Peel River has cut narrow canyons through a significant gap between Mackenzie and Richardson Mountains (Catto 1996). The western edge of the basin contains ice limit features defined by meltwater channels, moraines and shield erratics from Laurentide ice (Hughes *et al.* 1981).

### *Richardson Mountains*

North of Bonnet Plume Basin, the Richardson Mountains form a relatively narrow north-south trending barrier between the glaciated Peel Plateau and the Yukon Coastal

Plain from the unglaciated northern Yukon basins. In the south end of the Richardson Mountains, ridges are smooth and rounded with elevations to 915 and 1220 m asl. The north half of the range contains rugged ridges and steep rocky slopes separated by deep "V-shaped" valleys, with elevations to 1675 m asl. The geomorphology suggests continental ice pressed up against the entire eastern flank of the Richardson Mountains (Catto 1986; Duk-Rodkin and Hughes 1995).

McDougall Pass is a glacially modified valley forming the lowest pass through the Richardson Mountains at 315 m asl (Catto 1986). The nearly flat divide is drained by the Rat River to the east, and the Porcupine River, via the Little Bell and Bell Rivers, to the west. McDougall Pass is only slightly above the lower areas of the Bell, Old Crow and Bluefish Basins. However, seismic studies indicate a Pleistocene drift thickness of 170 m, therefore the preglacial bedrock elevation of the pass was approximately 150 m asl, serving as the eastern route for the paleo-Porcupine river (Duk-Rodkin and Hughes 1994).

### *Peel Plateau*

East of Richardson Mountains, Peel Plateau forms the transition between the Peel Plain and the mountains. Thick glacial drift sequences have been deeply dissected post-glacially by the Peel River and its tributaries that drain eastward to the Mackenzie Delta. The Peel River downstream of the Snake River is incised into the sloping plateau surface, indicating its origin as an ice-marginal meltwater channel (Catto 1986).

*Yukon Coastal Plain*

Yukon Coastal Plain includes all flat and gently sloping lands that lie adjacent to the northeastern edge of the Arctic Ranges, British, and Richardson Mountains and fringing the Beaufort Sea coast to the north. Areas adjacent to the mountains are primarily erosional surfaces or pediments that generally slope upwards to the southeast, rising to around 470 m asl in elevation (Rampton 1982). The coastal areas are typically flat, with local relief rarely exceeding 30 m and elevations generally below 60 m asl, except Herschel Island that rises up to 185 m asl. Unconsolidated sediments generally increase in thickness towards the coast.

## 2.4 Present Climate

The climate of northern Yukon is continental with wide extremes in temperature and very little precipitation (Wahl *et al.* 1987). Records from Old Crow (251m asl) indicate winters are long and cold with mean January temperatures of –33.7° C and an average of 9.1 mm of precipitation. Summers are short and variable although some days can be as warm as areas far to the south with July mean temperatures of 14.1° C and an average of 22.1 mm of precipitation (Figure 3). The St. Elias, Ogilvie and Richardson Mountains effectively block most atmospheric moisture, resulting in the relatively dry climate. Winds are typically light with generally calm conditions in winter (Wahl *et al.* 1987). The Northern Yukon is within the zone of continuous permafrost that can be found within a few decimeters below surface except under lakes and major stream channels. Surficial permafrost features include polygonal patterned ground throughout the interior basins.

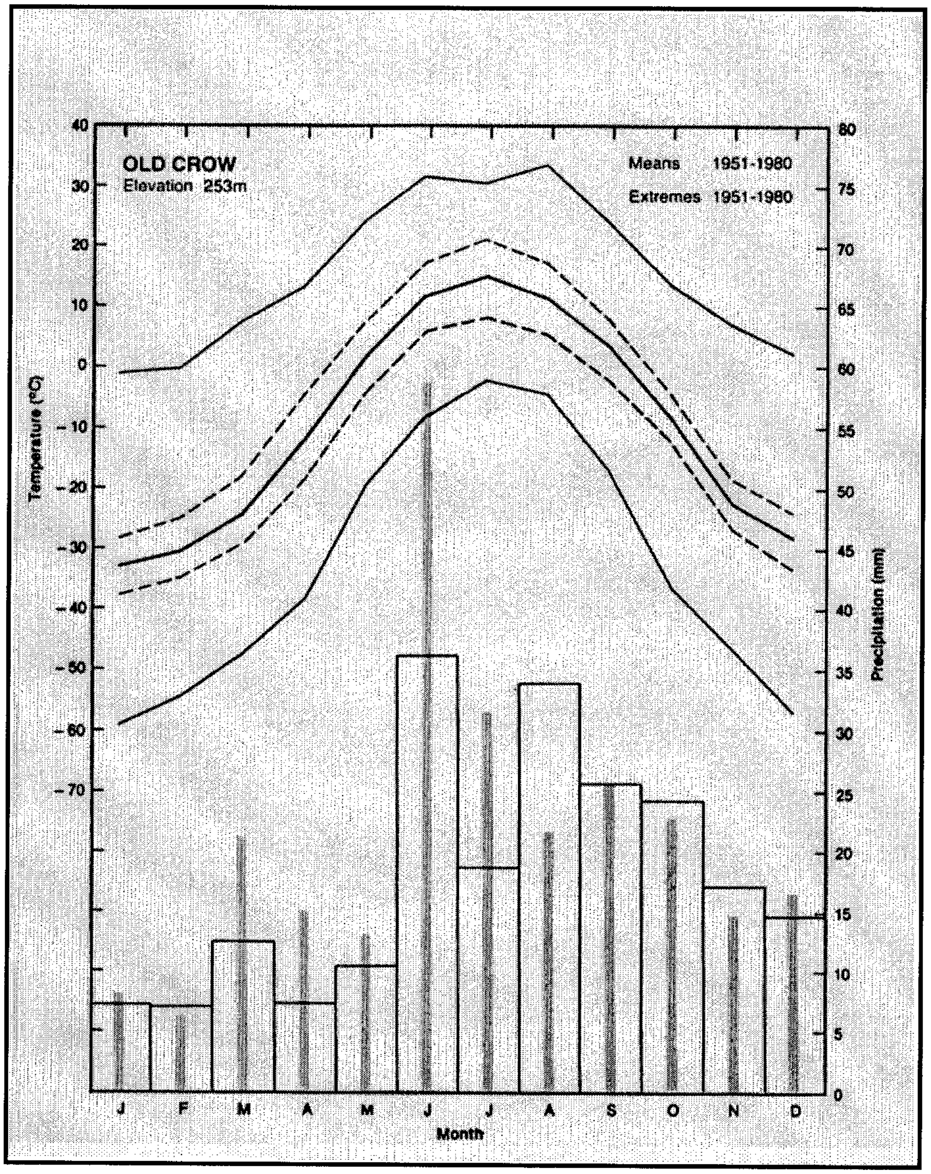


Figure 3. Temperature and precipitation means and extremes for Old Crow. After Wahl *et al.* (1987:158). Bar-graph represents monthly average and extreme highs for precipitation. Solid lines on line-graph represent monthly extremes in temperate and broken line represents mean monthly temperature.

## 2.5 Present Vegetation

There has been little systematic study of the Old Crow region vegetation, including the Bluefish Basin. Welsh and Rigby (1971), Hettinger *et al.* (1973), Oswald and Senyk (1977) and Ritchie (1984) provide general accounts. The most detailed floristic study was conducted by Ritchie and Cwynar (1976). The general account provided here is a summary from the above sources. An image of general vegetation along vegetated lowland floodplains is shown in Plate 1.

Poorly drained sites in lowland basins on acidic substrates are dominated by stands of *Picea mariana* (black spruce), with *Ledum decumbens* (Labrador-tea), *Vaccinium* spp. (blueberry, huckleberry, cranberry, bilberry), *Oxycoccus microcarpus* (cranberry), *Carex* sp. (sedge), *Rubus chamaemorus* (bog-raspberry) and *Sphagnum* spp. muskeg. Better-drained sites on recently deposited alluvium consist of *Picea glauca* (white spruce) stands with a thick understory of *Alnus crispa* (green alder), *Betula glandulosa* (shrub birch) and *Shepherdia canadensis* (soapberry). Forested gentle upland slopes on calcareous parent material consist of *Picea glauca* stands with interspersed *Populus tremuloides* (trembling aspen) and scattered shrubs of *Potentilla fruticosa* (shrubby cinquefoil), *Juniperus communis* (ground juniper) and lowlying ground cover of *Dryas* spp. (mountain avens), *Carex scirpoidea*, *Rhododendron lapponicum* (rhododendron), *Lupinus arcticus* (arctic lupine), *Salix* spp. (willow), and *Arctostaphylos rubra* (bearberry). Upland tundra on calcareous substrates consist of a closed, low vegetation of *Dryas integrifolia* and *Carex scirpoidea*, with lesser amounts of *Silene acaulis* (moss campion), *Androsace chamaejasme* (rock-jasmine), *Oxytropis campestris* (late yellow locoweed) and *Kobresia myosuroides*. Snow patch communities form distinctive vegetation in upland locales where snow persists late into the summer, and are dominated by several species of *Salix* spp., *Oxyria digyna* (mountain sorrel), *Saxifraga nelsoniana*, *Carex podocarpa*, and *Equisetum arvense* (field horsetail). Lowland mesic sites are common near lakes and streams forming a monotonous vegetation of *Eriophorum vaginatum* (cotton-grass) tussock tundra, typical of the Old Crow flats. Meadow communities that form a transition from aquatic to terrestrial ecosystems adjacent to thermokarst lakes are dominated by *Carex* species with *Carex aquatilis* being most abundant associated with *Salix* spp., *Eriophorum angustifolium*, *Calamagrostis canadensis* (blue-joint grass), *Potentilla palustris* (marsh cinquefoil), and a surface mat of *Drepanocladus* sp., *Sphagnum* sp., and *Calliergon* sp.

Limited botanical data is available from the Bluefish watershed. The only published plant collection was from a seepage area near Useful Lake (67° 09' N., 140° 22' W) in the Keele Range by Ritchie and Cwynar (1976). Also, Ritchie *et al.* (1982) and Ritchie (1984) make general descriptions about the Bluefish watershed vegetation. The description provided below is derived from these sources as well as my personal observations

Floodplains along the present Bluefish River contain *Salix* spp., *Alnus incana*, *Rosa* sp. (rose), and *Shepherdia canadensis* closest to the rivers, with *Populus* spp. (poplar) found somewhat further away, and *Picea glauca* found on raised, well-drained locales. The lower midslope region contains poorly-drained *Picea mariana* and sedge-ericad-moss woodlands. Further upslope, with increasingly better drainage, are closed stands of *Picea glauca* on cryic regosolic and brunisolic soils. Local treeline is near 650 m asl on the north facing slopes and about 10 to 20 m higher on the south facing slopes. Sparse herb tundra vegetation dominated by *Dryas octopetala*, *Hedyasarum mackenzii*, *Salix reticulata* (netleaf willow), *Arctostaphylos rubra*, *Saxifraga tricuspidata* (prickly saxifrage), *Carex scirpoidea*, and lichens are found on exposed limestone and dolomite ridge uplands of the Keele Range. These ridges have common seepage areas that foster the development of *Carex* sp. dominated vegetation with scattered clumps of *Eriophorum* sp. and various herbs.

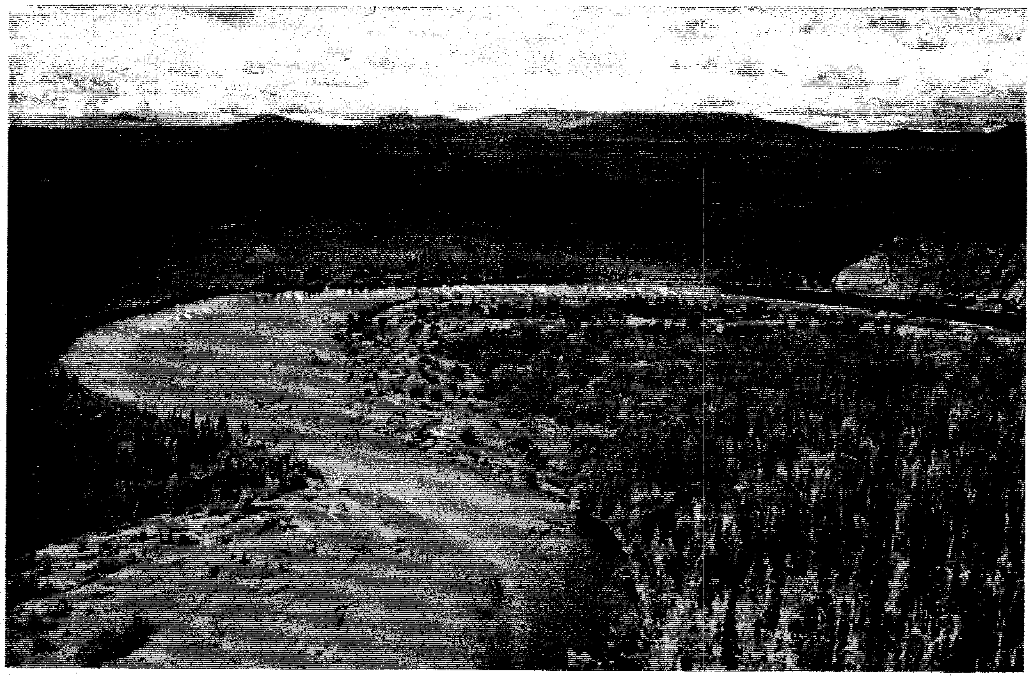


Plate 1. Forested floodplain vegetation along the Bluefish River. Bluefish Exposure is along the right side of the photo and the view is to the north. Photo by G. Zazula, July 1999.

## Chapter 3: The Bluefish Caves

At the western end of a high bedrock ridge overlooking the upper-middle course of the Bluefish River, a series of caves have provided crucial evidence for reconstructing the full-glacial environment of the Bluefish watershed (Cinq-Mars 1979, 1990; Cinq-Mars and Morlan 1999; Morlan and Cinq-Mars 1982). The Bluefish Caves (67° 09' N, 140° 45' W), at an elevation of approximately 600 m asl, are situated at the base of a limestone-dolomite upland ridge of the Keele Range.

Excavations at the Bluefish Caves (Cinq-Mars 1979, 1990; Cinq-Mars and Morlan 1999; Morlan and Cinq-Mars 1982) have yielded *in situ* evidence of a diverse contemporaneous community of large herbivorous mammals, small mammals, and carnivores, in addition to fish, birds and invertebrates, during the full-glacial interval *ca.* 25, 000 to 14, 000 yr BP (Table 1 and 2). Similar to numerous dated Pleistocene mammal fossil records from across eastern Beringia, the large mammal assemblage is dominated by grazers. The diverse Bluefish Caves fauna attests to the dramatic environmental differences between the full-glacial Pleistocene and the region today and must be accounted for in any paleoecological reconstruction.

Remains from the Bluefish Caves include evidence for hunter-gatherer activity. Artifacts include lithic tools and radiocarbon dated culturally modified bones and indicate at least sporadic human activity at the site throughout the interval of 25,000 to 10,000 years ago (Cinq-Mars 1979, 1990; Cinq-Mars and Morlan 1999; Morlan and Cinq-Mars 1982). The Bluefish Caves hunter-gatherers may have been part of a more widespread population evident from the Old Crow Basin (Cinq-Mars and Morlan 1999).

Table 1. Bluefish Caves Fauna. Data from Burke and Cinq-Mars (1996, 1998); Cinq-Mars (1979, 1990); Cinq-Mars and Morlan (1999); Harington and Cinq-Mars (1995); Youngman (1993).

| **Class** | **Order** | **Familly** | **Genus and Species** | **Common Name** |
|---|---|---|---|---|
| Insecta | Coleoptera | Carabidae | *Pterostichus* sp. | ground beetles |
| | | Staphylinidae | *Tachinus* sp | rove beetles |
| | | | *Olophrum* sp. | |
| | | Silphidae | *Silpha* sp. | carrion beetles |
| | | Byrrhidae | *Byrrhus* sp. | pill beetles |
| | | | *Morychus* sp. | |
| | | Scarabaeidae | *Aphodius* sp. | scarab beetles |
| | | Tenebrionidae | Genus? | darkling beetles |
| | | Curculionidae | *Lepidophorus lineaticollis* Kby. | weevils |
| Osteichthyes | | | cf. *Esox lucius* | northern pike |
| | | | *Thymallus arcticus* | arctic grayling |
| | | | cf. *Stenodus leucichthys* | inconnu |
| Aves | | | *Nyctea scandiaca* | owl |
| | | Tetraonidae | | ptarmigan, grouse |
| Mammalia | Insectivora | | Soricidae | shrew |
| | Lagomorpha | | *Lepus americanus* | snowshoe hare |
| | | | *Lepus arcticus* | arctic hare |
| | Rodentia | | *Spermophilus parryii* | arctic ground squirrel |
| | | | cf. *Peromyscus* sp. | mouse |
| | | | *Lemmus sibricus* | brown lemming |
| | | | *Dicrostonyx torquatus* | collared lemming |
| | | | *Microtus* spp. | voles |
| | | | *Clethrionomys* cf. *rutilis* | red-backed vole |
| | Carnivora | | *Canis lupus* | wolf |
| | | | *Alopex lagopus* | arctic fox |
| | | | *Vulpes vulpes* | red fox |
| | | | *Mustela eversmanni* | badger |
| | | | *Ursus arctos* | cave bear |
| | | | *Felis concolor* | cougar |
| | | | *Panthera leo atrox* | lion |
| | Perissodactyla | | *Equus lambei* | horse |
| | Artiodactyla | | *Rangifer tarandus* | caribou |
| | | | *Cervus elaphus* | wapiti |
| | | | cf. *Alces alces* | moose |
| | | | *Ovis dalli* | sheep |
| | | | *Bison* cf. *priscus* | bison |
| | | | *Saiga tatarica* | Saiga antelope |
| | | | *Ovibos moschatus* | muskox |
| | Proboscidea | | *Mammuthus* sp. | mammoth |

Archaeological data from the Bluefish Caves are highly significant in discussion surrounding the Peopling of the New World and eastern Beringia. These data indicate that humans may have been present in easternmost Beringia possibly several millennia before the *ca.* 12,000 year old "Beringian Tradition" sites from central interior Alaska (West 1996). However, the much of the earliest dated Bluefish Caves archaeological evidence is often discounted and wrongfully ignored within discussion regarding the earliest human occupation of eastern Beringia (West 1996).

Table 2. Radiocarbon dated faunal remains from Bluefish Caves. Data available online from Canadian Archaeological Radiocarbon Database (www.canadianarchaeology.com/radiocarbon/card/card/htm#index). Also, data from Burke and Cinq-Mars (1996, 1998); Cinq-Mars (1979, 1990); Cinq-Mars and Morlan (1999); Harington and Cinq-Mars (1995); Youngman (1993).

| **Taxa** | **Lab no.** | **Del $^{13}C$** | **$^{14}C$ Age yr BP** |
|---|---|---|---|
| *Mammuthus* sp. | CRNL-1220 | -22.9 | 12,845 +/-250 |
| | RIDDL-559 | -20.0 | 13,940 +/-160 |
| | GSC-3053 | -22.6 | 15,540 +/-130 |
| | CRNL-1221 | -22.6 | 17,880 +/-330 |
| | RIDDL-330 | -22.6 | 19,640 +/-170 |
| | RIDDL-223 | -22.6 | 20,230 +/-180 |
| | RIDDL-558 | -20.0 | 22,430 +/-260 |
| | CAMS-23470 | -20.6 | 22,740 +/-90 |
| | RIDDL-225 | -20.0 | 23,200 +/-250 |
| | RIDDL-224 | -20.0 | 23,910 +/-200 |
| *Equus lambei* | CRNL-1236 | -20.0 | 12,370 +/-440 |
| | GSC-2881 | -23.1 | 12,900 +/-100 |
| | RIDDL-278 | -20.0 | 17,440 +/-220 |
| | CRNL-1237 | -20.0 | 22,760 +/-530 |
| *Rangifer tarandus* | RIDDL-227 | -20.0 | 12,210 +/-210 |
| | CAMS-23468 | -19.0 | 12,830 +/-60 |
| | RIDDL-226 | -20.0 | 24,820 +/-115 |
| *Bison priscus* | CAMS-23471 | -19.8 | 23,710 +/-100 |
| | CAMS-23469 | -19.0 | 31,730 +/-230 |
| *Saiga tatarica* | RIDDL-279 | -20.0 | 13,390 +/-180 |
| *Alces alces* | CAMS-23472 | -19.7 | 11,570 +/-60 |
| *Ovis dalli* | CAMS-23473 | -19.6 | 13,580 +/-80 |
| *Ovibos moschatus* | RIDDL-557 | -20.0 | 14,370 +/-130 |
| *Felis concolor* | TO-1266 | | 18,970 +/-1490 |
| *Mustela eversmanni* | TO-1196 | | 33,550 +/-350 |
| *Nyctea scandiaca* | BETA-129151 | -19.9 | 13,350 +/-100 |

Fossil pollen from the loess deposits at the Bluefish Caves (Cave II) document the full-glacial vegetation in the watershed (Ritchie *et al.* 1982). Pollen assemblages from the lowest loess unit (Table 3; Appendix E) are similar to those from other full-glacial sediments in the northern Yukon, including Lateral Pond (Ritchie and Cwynar 1982) and Hanging Lake (Cwynar 1982). Herbaceous taxa dominate, including Poaceae, *Artemisia*, and Cyperaeae with minor amounts of arctic-montane taxa, namely, *Aconitum* (monkshood), *Pedicularis* (lousewort), *Phlox* (phlox), *Polygonum alaskanum* (knotweed), and *Oxytropis* (locoweed). Ritchie (1984:164) suggests that this pollen assemblage "indicates a landscape covered by a sparse herb tundra on upland surfaces and a complex of sedge-grass marshes with willows on the lowlands". Further, he suggests that the closest modern analog for this full-glacial pollen assemblage is the herb-tundra communities on South Banks and South Victoria island in the western Canadian Arctic (Ritchie 1984:165).

Data from the Bluefish Caves are crucial for reconstructing the full-glacial environment of the Bluefish watershed and interpreting the plant macrofossil data obtained from the Bluefish Exposure, as presented in this thesis. Together, multi-proxy data from these two sites including, fossil pollen, invertebrates, vertebrates, and archaeological remains must be integrated to enable a robust reconstruction of the local watershed paleoenvironment. Importantly for this study, fossil pollen and plant macrofossil data are mutually compatible, and when integrated, should enable a detailed reconstruction of the full-glacial vegetation within the local watershed due to the variable information that may be obtained from each respective data set. This, in turn, will then enable examination of probable herbivore-vegetation interactions and debate concerning the "Productivity-Paradox". Few, if any, other locales in eastern Beringia contain such a robust multi-proxy data set, making the Bluefish watershed a unique location to examine and further our knowledge of late Pleistocene environments of Beringia.

Table 3. Habitat characterization of minor pollen taxa from Bluefish Caves (Ritchie *et al.* 1982). Habitat data from Cody (1996).

| **Taxa** | **Cody's Habitat Description** |
|---|---|
| *Selaginella sibirica* | dry exposed rocks and ridges |
| *Myrica* | marshes, bogs, borders of lakes |
| *Polygonum alaskanum* | pioneer on freshly exposed surfaces |
| *Rumex* | moist alpine, disturbed, marshy |
| *Aconitum* | alpine tundra, meadows, slopes |
| *Papaver* | alpine tundra, open slopes, alpine meadows, often calcareous, rocky |
| *Saxifraga hieracifolia* | moist turfy, calcareous substrates |
| *Saxifraga tricuspidata* | dry rocky and gravelly places |
| *Hedysarum* | calcareous, gravels, riverbanks, |
| *Oxytropis* | rocky, gravelly, tundra, ridges |
| *Shepherdia canadensis* | riverbanks, clearings, subalpine and alpine slopes |
| *Epilobium* | often pioneer on burned areas, meadows, disturbed |
| *Phlox* | open, stony, dry, prairie |
| *Polemonium* | alpine tundra, meadows, peaty |
| *Pedicularis* | tundra, meadows, rocky slopes |
| *Plantago* | open slopes, disturbed, meadows, alkaline |
| *Galium* | riverbanks, floodplain, dry open slopes, meadow |

# Chapter 4: The Study Site: The Bluefish Exposure

## 4.1 Location

The Bluefish Exposure (HH – 75 –24) is located approximately 30 km southwest of Old Crow village (67° 23' N, 140° 21.5' W). Situated on the southwestern edge of the Bluefish Basin at 304 m asl, it is a bedrock and alluvial section, 43.5 m in height on the south-facing cutbank of a relatively tight meander of the Bluefish River (Figure 4; Plate 2).

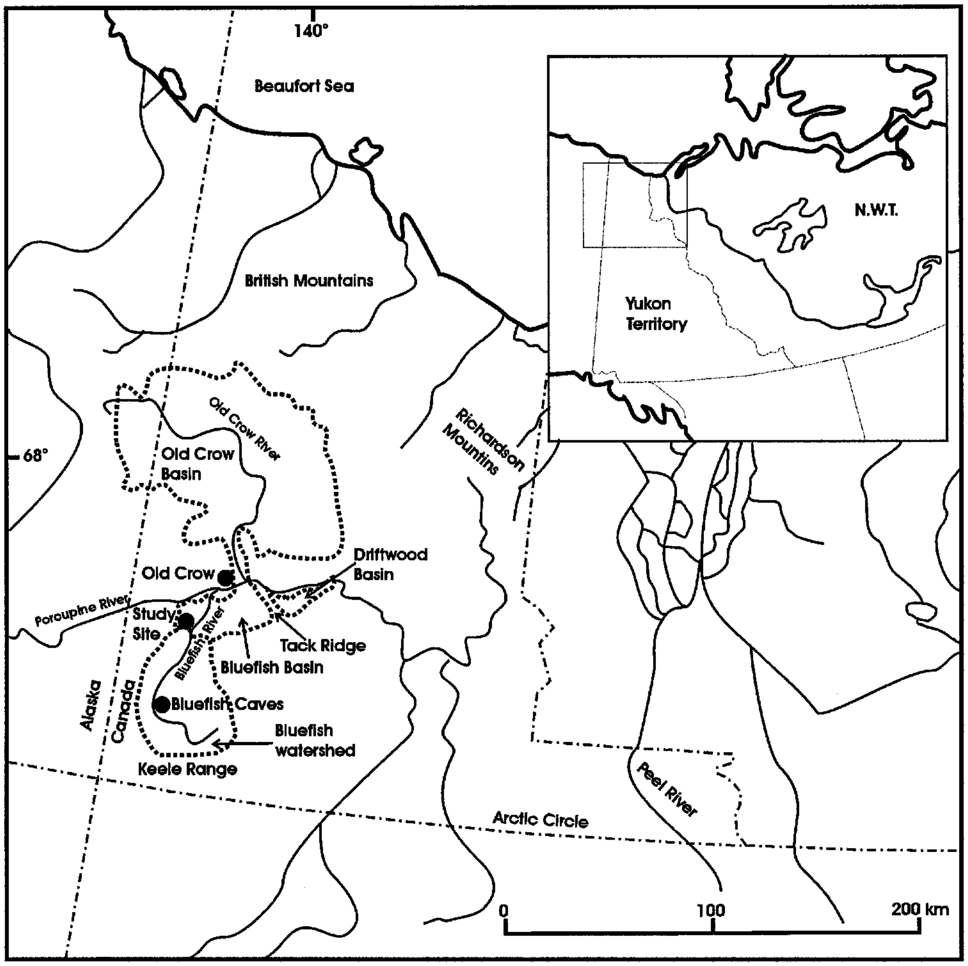


Figure 4. Map of Old Crow region of Northern Yukon with study site. Modified after Lauriol *et al.* (2002).

*Picea mariana* dominates the poorly-drained terrain above the exposure. The herb component and moss cover are similar to other poorly drained areas of the region. The sides of the exposed cutbank and other better-drained areas further back from the top of the exposure are inhabited by *Picea glauca*. The shrub layer is comprised of *Betula glandulosa*, *Shepherdia canadensis* and *Salix* spp, which have now vegetated much of the exposed section.

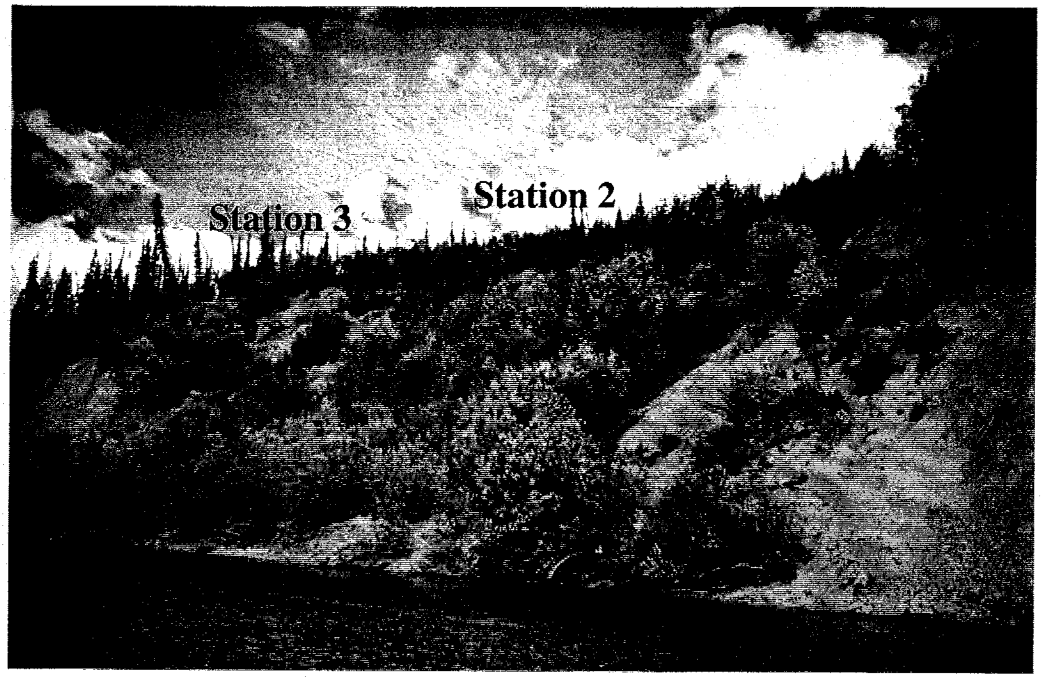


Plate 2. Bluefish Exposure study site. Photo by G. Zazula, July 1999.

## 4.2 Previous Work

The site was first visited by O.L Hughes (Geological Survey of Canada), R.E. Morlan (Canadian Museum of Civilization), J.V. Matthews Jr. (Geological Survey of Canada) and C.E. Schweger (University of Alberta) on June 27, 1975, as part of site surveys of the Yukon Refugium Project. At that time, two organic rich sediment samples were collected (REM 75-75 and REM 75-76) from Unit 10 and analysed for plant and insect macrofossils. O.L. Hughes, R.E. Morlan, and C.E. Schweger revisited the site on July 11, 1976 and collected four samples (REM 76-114, REM 76-115, REM 76-112 and REM 76-113). In the summer of 1977, C.E. Schweger, J.V. Matthews and G.H. McCourt (University of Alberta) visited the site to collect samples for fossil pollen, later presented by G.H. McCourt in a M.Sc. thesis (McCourt 1982). The site was not visited again until the summer of 1987, when C.E. Schweger, J.V. Matthews and A. Duk-Rodkin (Geological Survey of Canada) continued stratigraphic and paleoecological work prior to the Yukon field trips of the XII congress of the International Union for Quaternary Research. Published data from the Bluefish Exposure include radiocarbon dates (Blake 1987), fossil pollen (McCourt 1982), Pliocene plant macrofossils (Matthews and Ovenden 1990), late Pleistocene invertebrates (Matthews and Telka 1997), and paleoclimatic interpretations (Matthews *et al.* 1989).

## 4.3 General Stratigraphy

The Bluefish Exposure stratigraphic sequence consists of bedrock overlain by late Cenozoic alluvial and lacustrine sediments. The following stratigraphy for the site was established by previous work and through my own descriptions during field investigations in July, 1999 (Table 4; Figure 5).

Bedrock at the base of the section, Unit 1, is a brecciated dolomite with chert clasts equivalent to the Devonian Gossage formation (McCourt 1982). The lignite and organic rich alluvium of Units 2 to 8 are referred to as the Lower Bluefish Unit (McCourt 1982), and are considered Pliocene in age (Matthews and Ovenden 1990; C.E. Schweger, University of Alberta, unpublished data).

A major unconformity exists between Unit 8 of the Lower Bluefish unit and the overlying Middle Bluefish Unit, Unit 9. A fluvial channel cuts *ca.* 15.0 m through the Lower Bluefish Unit and Unit 1 and is filled with very coarse-grained sands and gravels. Radiocarbon dates from a well-preserved log *Picea* (REM 76-114) yielded ages of >43,000 yr BP (GSC–2373), >51,900 ± 1350 yr BP (GSC-2373-2), and >53,000 yr BP (GSC 2373-3). These sediments may represent the Last Interglacial (oxygen isotope stage 5e) when dense spruce forests occupied the region (C.E. Schweger, personal communication, 2002).

A disconformable contact between Unit 9 and the overlying Upper Bluefish Unit (Units 10, 11, and 12) is approximately 37.5 m from the water level (Plate 3). Unit 10 consists of *ca.* 1.70 m of alternating lenses of yellow-grey planar cross-laminated sands with limited organic remains and dark-grey, trough cross-laminated silts with abundant detrital organics on the bedding planes (Plate 4). Ice-lenses, ice-wedge pseudomorphs and evidence of cryoturbation are present throughout this unit. A bulk organic sample (REM-76-113) from slightly below the upper contact of Unit 10 yielded a radiocarbon date of 20,800 ± 200 yr BP (GSC-3946).

Unit 11 consists of a *ca.* 2.75 m sequence of nearly sterile glaciolacustrine sediments and is further subdivided into Units 11a, b, and c. Unit 11a consists of 0.50 m of massive olive-grey mottled silts with iron oxide staining. This is overlain by Unit 11b consisting of 0.60 m ice-rich, laminated, grey to dark-grey colored silty clay, typical of varved glaciolacustrine sediments. The varves are more defined at the base of the unit, becoming increasing obscured upwards. The contact between Unit 11b and the overlying Unit 11c is marked by a 0.05 m bed of yellow-light brown, current bedded medium grained sand. The remaining 1.60 m of sediments in Unit 11c consist of massive olive/grey mottled, clayey silt with thin current and ripple bedded medium grained sand lenses throughout. Capping the section, Unit 12 consists of 0.50 m of silty peat that is believed to have developed during the Holocene (McCourt 1982). Dark grey silts within the peat are probably aeolian in origin.

Table 4: Stratigraphy for Bluefish Exposure (HH-75-24), youngest at top (Adapted from McCourt 1982:42-43)

| Unit | Description | Thickness (m) |
|---|---|---|
| 12 | Autochthonous peat and silt; dark-grey to black; lower contact sharp, disconformable | 0.50 |
| 11c | Clayey silt with sand stringers; clayey silt, massive, mottled grey-olive; sand stringers, yellow-light brown, medium grained, current bedded and ripple bedded | 1.30 |
| 11b | Silty clay, dark grey, laminated, very friable, ice-lenses | 0.60 |
| 11a | Silt, olive-grey mottled, iron oxide, massive, lower contact gradational | 0.80 |
| 10 | Sand and silt; sand, yellow-grey, planar cross-laminations; silt, dark-grey, trough cross-laminations; detrital organics on bedding planes. Ice-lenses, ice-wedges and with cryoturbation features, upper contact gradational | 1.70 |
| 9 | Very coarse grained sand and gravel; spruce logs and abundant wood exposed; upper contact sharp, disconformable | 6.00 |
| 8b | Clayey silt with limited sand clay; detrital wood | 1.40 |
| 8a | Sandy silt, brown, ripple-bedded; twigs and large size wood fragments | 2.85 |
| 7b | Coarse sand with pebbles, poorly sorted, yellow-grey, loosely consolidated | 0.35 |
| 7a | Very fine grained sand with silt stringers, grey-yellow, consolidated | 0.17 |
| 6b | Silt, mottled dark grey to dark red brown; sand lenses, reddish brown; upper 0.3 meters massive, greenish grey | 1.80 |
| 6a | Silt at base, grades upward to fine grained sand, dark-brown; organic beds common | 0.70 |
| 5b | Fine-grained sand, grey-yellow; silt stringers, brown | 0.15 |
| 5a | Medium to coarse grained sand with pebble size gravel, grey-yellow; upper 0.20 meters reddish yellow; silt stringers, blue-grey | 1.60 |
| 4c | Sandy silt, blue grey; detrital organics; upper contact mixed with overlying sand | 0.55 |
| 4b | Sandy silt, blue grey; minor sand; organic detritus | 0.45 |
| 4a | Silt, blue grey; abundant sand, reddish yellow; limonitic concretions | 0.44 |
| 3 | Gravel, pebble and cobble sized with minor silt stringers; dark grey to yellow red; gravel lenses sit unconformably on underlying lignite | 0.40 |
| 2 | Coal, lignitized wood, black; silt and sand: grades upward to become a clayey silt, dark grey to dark brown,; scattered organic detritus and coarse grained sand | 2.10 |
| 1 | Dolomite, weathered, brecciated, friable, weathers yellow, white grey; chert silt matrix; upper 0.5 meters deeply weathered, yellowish red | 2.70 |

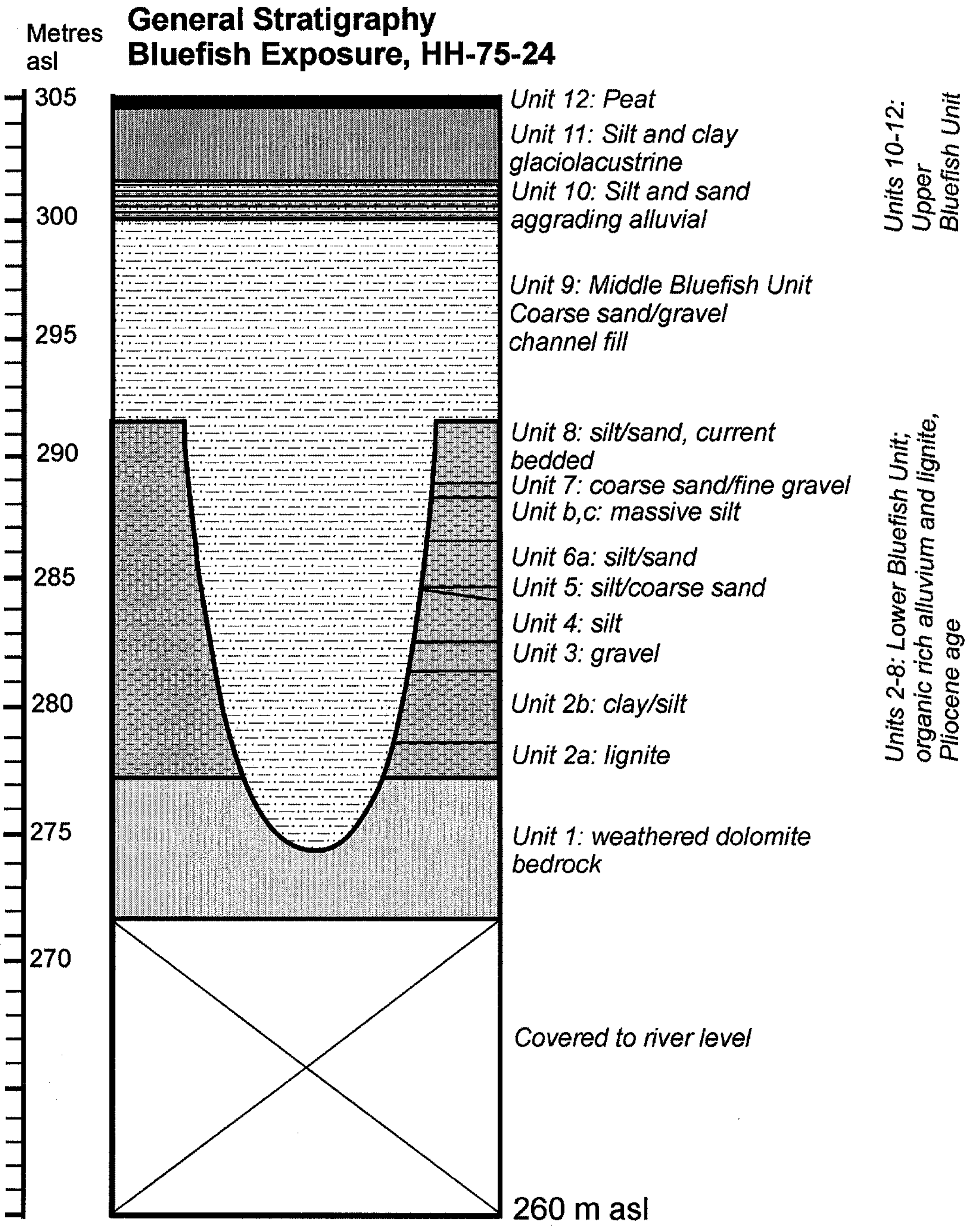


Figure 5. Generalized stratigraphy of the Bluefish Exposure.

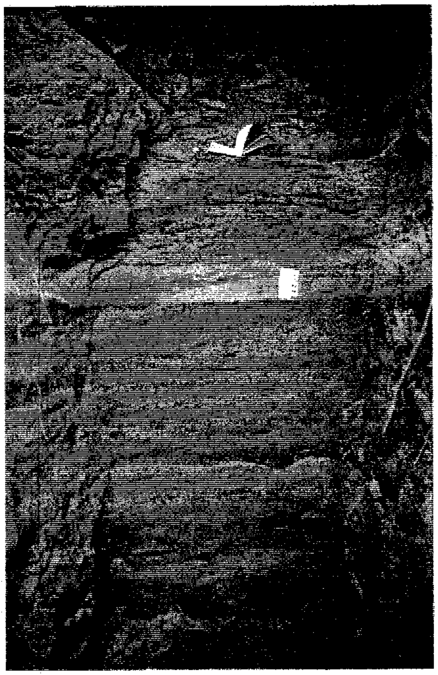


Plate 3. Units 10 and 11 in Upper Bluefish Unit at Bluefish Exposure. Photo by G. Zazula, July 1999.

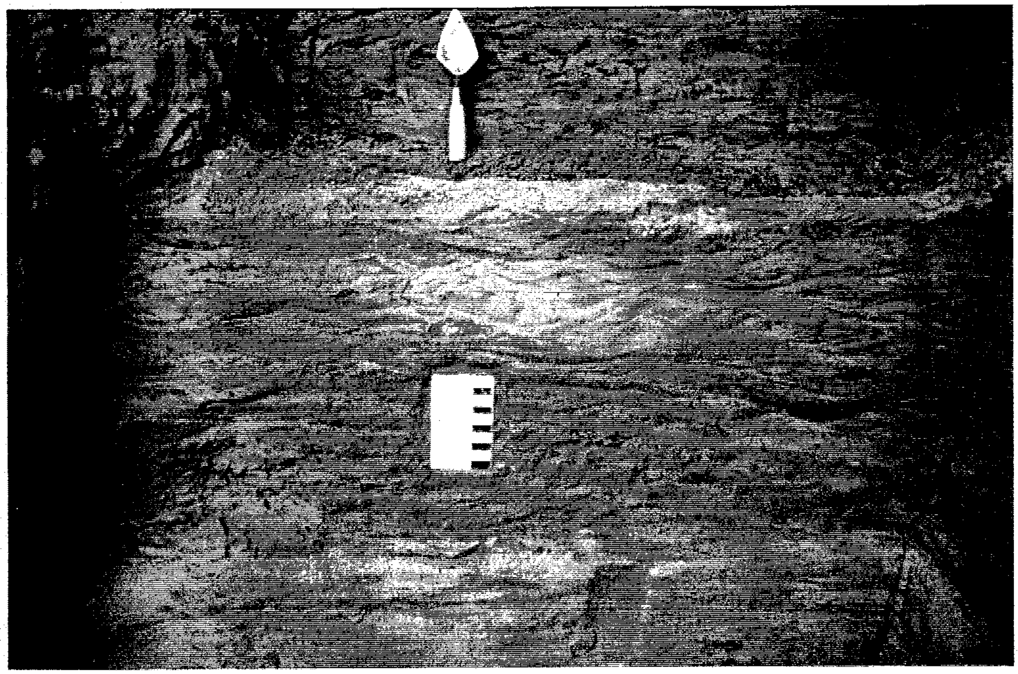


Plate 4. Unit 10 trough-crossbedded silts with detrital organics. Photo by G. Zazula, July 1999

### 4.4 Fossil Pollen Analysis

G. H. McCourt (University of Alberta) carried out the first pollen analysis of the Bluefish Exposure. McCourt divides the Upper Bluefish Unit pollen record into 4 distinct pollen zones; Zone 1, 2, 3 and 4 (McCourt 1982; Table 5; Appendix F). Zone BF 4 pollen assemblages are dominated by Poaceae (10-50%), Cyperaceae (5-35%) and *Artemisia* (10-40%). In addition, Chenopodiaceae–*Amaranthus*, Tubuliflorae, Liguliflorae, Caryophyllaceae (pink family), Brassicaceae (mustard family), *Arabis* type (rock cress), Papaveraceae (poppy family), *Saxifraga* (saxifrage), and Rosaceae – *Potentilla* type (cinquefoil) all contribute to the diverse herbaceous taxa, although they rarely exceed 2% (McCourt 1982). The arboreal component is practically non-existent, with *Picea*, *Betula*, *Alnus*, *Salix*, and Ericaceae (heath family) rarely reaching values greater than 5% except where there is an abrupt increase at the top of the zone.

McCourt interprets this assemblage as treeless, steppe-tundra vegetation with few, if any shrubs during a period of extreme cold and aridity (McCourt 1982). This assemblage is similar to other "Herb-Zone" pollen assemblages described throughout eastern Beringia. McCourt subdivided Pollen Zone BF 4 into three subzones (4a, 4b, and 4c) based on the changes in the ratio of *Artemisia* – Cyperaceae pollen. Subzone 4a marks the appearance of Mississippian-aged spores that are derived from the Ford Lake Formation shales, associated with the influx of water into the Bluefish Basin from the glacially diverted Peel River drainage through Eagle River Discharge Channel (Norris 1981; Schweger 1989; Walde 1986).

The overlying Pollen Zone BF 3 is unlike any zone in the pollen diagram, with Poaceae values reaching 60-80%. *Artemisia* is still relatively common but Cyperaceae eventually disappears altogether. Poaceae values this high are not known from any fossil pollen record from North America (McCourt 1982). McCourt (1982) interprets this as treeless and shrubless grassland with *Artemisia* in the northern Yukon during the cold and arid late Wisconsinan. Further, McCourt suggests that this grassland implies the absence of a shallow permafrost layer and that soils were warmer and better drained than they are at present.

A sterile zone (Pollen Zone BF 2) occurs near the top of the Upper Bluefish Unit in silt and clay rich glaciolacustrine sediments below the Holocene peat unit (McCourt 1982). The zone is dominated by Mississippian spores, similar to those in other section in Old Crow, Bell and Bluefish Basins (McCourt 1982; Schweger 1989). McCourt (1982) believes the lack of fossil pollen suggests a harsh cold and dry climate with very little vegetation growing in the area. However, perennial ice cover in the flooded basin or rapid deposition of clastic sediments may be explanations for the lack of pollen in the glaciolacustrine sediments (C.E. Schweger, personal communication, 2002).

Pollen Zone BF 1 is dominated by *Picea*, *Betula*, *Alnus*, and Ericaceae, indicating a Holocene vegetation similar to that found in the region today (McCourt 1982).

Table 5. Habitat characterization of minor pollen taxa from Upper Bluefish Unit (McCourt 1982). Habitat data from Cody (1996).

| **Taxa** | **Cody's Habitat Description** |
|---|---|
| *Shepherdia canadensis* | riverbanks, clearings, subalpine and alpine slopes |
| Chenopodiaceae-*Amaranthus* | disturbed areas |
| *Thalictrum* | alpine herbmats, meadows |
| *Potentilla* | open meadows |
| *Dryas* | alpine tundra, river flats, snow-bed |
| *Rubus chamaemorus* | moist peaty, turf |
| *Polygonum bistorta* | moist peaty tundra |
| *Polygonum amphibium* | borders of shallow ponds |
| *Rumex-Oxyria* | moist alpine, disturbed, marshy |
| *Saxifraga oppositifolia* | broken calcareous gravels |
| *Saxifrage hirculus* | wet mossy tundra |
| *Ribes* | moist woods |
| *Arabis* | open slopes, alpine, disturbed |
| *Galeopsis* | waste places |
| Papaveraceae | tundra, open slopes, alpine |
| *Polemonium* | alpine tundra, meadows, peaty |
| *Phlox* | open, stony, dry, prairie |

## 4.5 Fossil Invertebrates

Organic remains from the Upper Bluefish Unit proved to contain a rich invertebrate fauna. Samples collected by R.E. Morlan (Canadian Museum of Civilization) in 1975 (REM 75-75 and REM 75-76) and 1976 (REM 76-114, REM 76-115, REM 76-112 and REM 76-113) were analyzed by Matthews and Telka (1997). Fossil invertebrate data from Matthews and Telka (1997), and additional data from S.A. Elias (Royal Holloway, University of London, unpublished data) are presented in Table 6. The assemblage is dominated by fossils of the byrrhid beetle *Morychus* sp, and the weevil *Lepidophorus lineaticollis*, and co-dominants of *Amara alpina*, *Amara glacialis*, members of the subgenus *Cryobius*, and *Helophorus splendidus*.

Table 6. Subfossil invertebrates recovered from Upper Bluefish Unit. Data from samples REM 76-113, REM-112, REM 75-76, REM 76-76 (From Matthews and Telka 1997); GZ.O7.14.99.09, GZ.07.14.99.16, GZ.07.17.99.00 (Identifications by S.A. Elias).

| | | |
|---|---|---|
| **INSECTA** | | |
| **Plecoptera** | Family? | |
| **Heteroptera** | Saldidae | *Chiloxanthus* sp. |
| | Tingidae – lace bugs | *Derephysia foliaceae* (Fallen) |
| **Coleoptera** - beetles | Carabidae - ground beetles | *Amara alpina* Payk. |
| | | *Amara glacialis* Mann. |
| | | *Bembidion sordidum* group |
| | | *Carabus truncaticollis* Eschz. |
| | | *Carabus* sp. |
| | | *Dyschiriodes* sp. |
| | | *Elaphrus* sp. |
| | | *Pterostichus* (*Cryobius*) spp. |
| | | *P.* (*Cryobius*) *pinguedineus* Eschz. |
| | | *P.* (*Cryobius*) *ventricosus* Eschz. |
| | | *Pterostichus agonus Horn* |
| | | *Pterostichus bryanti Lth.* |
| | | *Pterostichus nearcticus* Lth |
| | | *Pterostichus sublaevis* J.Sahbl. |
| | | *Stereocerus haematopus* Dej. |
| | Dytiscidae - predaceous diving beetles | *Hygrotus* sp. |
| | Hydrophilidae - water scavenger beetles | *Helophorus splendidus.* Sahlb. |
| | | *Hydrophilus* sp. |
| | Staphylinidae - rove beetles | Aleocharinae |
| | | *Holoboreaphilus nordenskioeldi* Mäkl. |
| | | *Micralymma brevilingue* Schiodt. |
| | | *Olophrum latum* Mäkl. |
| | | *Stenus* spp. |
| | | *Tachinus brevipennis* J.Sahlb. |
| | Micropeplidae | *Micropeplus* sp. |
| | Scarabaeidae - scarab beetles | *Aphodius* sp. |
| | Byrrhidae - pill beetles | *Curimopsis* sp. |
| | | *Morychus* sp. |
| | | *Simplocaria* sp. |
| | Chrysomelidae - leaf beetles | *Chrysolina basilaris* (Say) |
| | | *Chrysolina* spp. |
| | Curculionidae - weevils | *Apion* spp. |
| | | *Ceutorhynchus* sp. |
| | | C. *subpubescens* LeC. |
| | | *Hypera seriata* (Mann.) |
| | | *Isochnus arcticus* (Kor.) |
| | | *Lepidophorus lineaticollis* Kby |
| | | *Notaris* sp. |
| | | *Rhynchaenus* sp. |
| | | *Stephanocleonus* sp. |
| | | *Vitavitus thulius* Kiss. |
| **Tricoptera** – caddisflies | Brachycentridae | Genus? |
| **Lepidoptera** - butterflies/moths | Noctuidae | *Euxoa churchillensis* (McD.) |
| **Diptera** – flies | Tipulidae - crane flies | Genus? |
| | Chironomidae - midges | Genus? |
| | Xylophagidae | *Xylophagus* sp. |
| **Hymenoptera** - wasps/ants | Family? | |
| | Braconidae | *Chelonus* sp. |
| **CRUSTACEA** | | |
| **Cladocera** - water fleas | | *Daphnia* sp, |
| **Notostraca** - tadpole shrimp | | *Lepiduris* sp. |
| **ARACHNIDA** | | |
| **Acari** - mites and ticks | Family? | |
| **Araneae** – spiders | Erigonidae | *Erigone* sp. |

## 4.6 Methods

Fieldwork for this study was conducted between July 14-17, 1999. The stratigraphy of the Upper Bluefish Unit was documented at three stations[1]. Here, the sediments were collected for macrofossil analysis. Trenches were excavated at least 1 m into the exposure with shovels and trowels to make sure a fresh face was exposed and to remove the possibility of sampling material that may have slumped down from above. Samples were taken at a 0.10 m interval so that the plant macrofossil samples had the same resolution as McCourt's (1982) pollen samples. To avoid contamination of samples each sample was taken using a clean trowel, and placed in large plastic bags, sealed and labeled immediately. Sample sizes ranged from approximately 500 to 4000 ml.

For laboratory analysis, 25 ml sediment subsamples were measured by water displacement and then sieved through stacked 1.18 mm, 0.25 mm, and 0.090 mm mesh screens (U.S. Standard Sieve Mesh numbers 16, 60, and 170, respectively) with a gentle but steady flow of tapwater to disaggregate the material and separate the sediment from macrofossils. Most of the organic detritus rested on the 0.25 mm sieve. The retained material was sorted using a binocular dissecting microscope into seven macrofossil groups; remains of trees, graminoids, herbaceous forbs, shrubs, mosses, sclerotia and fauna. Most macrofossils of vascular plants are in the form of seeds *sensu latu*, with few identifiable vegetative parts. Although 25 ml subsamples may be considered small compared to other plant macrofossil studies (West and Pettit 2000), the most organic rich subsamples contained more than 1000 identifiable specimens. Larger volumes of the

---

[1] One station collapsed while sampling. Only stations 2 and 3 were analysed.

richest samples were scanned to look for additional macrofossil types but none were found.

Plant macrofossil identifications were made with the aid of reference material from the Provincial Museum of Alberta, Paleoenvironmental Studies Laboratory at the University of Alberta, University of Alaska Museum Herbarium, and Geological Survey of Canada. Identifications were to the most precise taxonomic level possible based on morphological characteristics. Some herbarium seeds were boiled in sodium pyrophosphate solution in an attempt to replicate taphonomic processes that cause degradation of the subfossil specimens and further aid in identification. Available keys and macrofossil literature were also consulted (e.g. Berggen 1964, 1981; Katz *et al.* 1965; Körber-Grohne 1964; Lévesque *et al.* 1988; Martin 1951; Martin and Barkley 1961; Montgomery 1977). Plant nomenclature follows Cody (1996).

Identified vascular plant parts were counted in each subsample. Percentages were calculated for each taxon based on the total of all identified macrofossil specimens for all samples in the Upper Bluefish Unit combined. Thus, all analyzed subsamples are treated as a single data set. Certain vascular plant taxa that were not counted were also given estimated qualitative ordinal values; i.e. rare, occasional, frequent, and abundant to describe the number of specimens within the overall assemblage. Rare = <10 specimens; Occasional = 10-100 specimens; Frequent = 100-500 specimens; Abundant = >500 specimens. Moss specimens were also given qualitative ordinal values describing their estimated overall frequency in a single selected subsample, although no attempt was made to count them; Rare (least frequent), Occassional, Frequent, and Abundant (most frequent).

Selected plant macrofossils were used to obtain a series of nine AMS (Accelerator Mass Spectrometry) radiocarbon dates to provide a detailed chronology for the Upper Bluefish Unit and date specific taxa from the macrobotanical assemblage. Samples were submitted to the University of Arizona, National Science Foundation, AMS Laboratory. An AMS radiocarbon chronology is crucial because of uncertainties in conventional radiocarbon dates obtained from bulk organic matter in sediments (see Bigelow and Edwards 2001; Dyke *et al.* 2002 a,b; MacDonald *et al.* 1987).

Some invertebrate specimens were identified by S.A. Elias (Royal Holloway, University of London) in order to obtain Mutual Climatic Range (MCR) temperature estimates. Identifications of these specimens are in agreement with those published by Matthews and Telka (1997).

# Chapter 5: Upper Bluefish Unit Results

## 5.1 AMS Radiocarbon Dates

AMS radiocarbon dates from terrestrial vascular plant macrofossils in the Upper Bluefish Unit fall between *ca.* 18,880 to 16,440 yr BP (uncalibrated $^{14}$C ages)[1]. Calibrated calendric ages for this interval span 19,922 to 21,893 yr BP based on Calib. 4.3 (Stuiver *et al.* 1998). Specimens of *Drepanocladus vernicosus* stems and leaves yielded a radiocarbon date of 23,360 ±500 yr BP (Table 7; Figure 8). Because radiocarbon ages in this thesis are based on a variety of data sources, ages referred to in the text will be presented in radiocarbon years BP.

Table 7. AMS Radiocarbon dates from Upper Bluefish Unit of Bluefish Exposure.

| Station/ Sample # | Lab # | Material Dated | Del. $^{13}$C | Radiocarbon age yr BP | Stratigraphic Position | Comments |
|---|---|---|---|---|---|---|
| BF-Stn.2 GZ.07.16.99.26 | AA45510 | *Carex* sp. achenes | -26.0 | 16,440 +/-110 | 0.90 m above base of Unit 11a | highest datable organics in Upper Bluefish Unit |
| BF-Stn.2 GZ.07.16.99.16 | AA42629 | Poaceae sp. caryopses and *Artemisia* flowers | -26.4 | 17,400 +/-120 | 1.60 m above base of Unit 10 | |
| BF-Stn.3 GZ.07.17.99.16 | AA45505 | Poaceae sp. caryopses | -25.7 | 18,030 +/-250 | 1.60 m above base of Unit 10 | |
| BF-Stn.2 GZ.07.14.99.09 | AA45507 | *Taraxacum* sp. achenes | -26.8 | 17,710 +/-840 | 0.90 m above base of Unit 10 | |
| BF-Stn.2 GZ.07.14.99.09 | AA45506 | *Luzula/Juncus* siliques | -25.3 | 17,570 +/-140 | 0.90 m above base of Unit 10 | |
| BF-Stn.2 GZ.07.14.99.08 | AA42630 | Poaceae sp. caryopses, *Artemisia* flowers, *Potentilla* sp. achenes | -26.6 | 18,700 +/-130 | 0.80 m above base of Unit 10 | |
| BF-Stn.3 GZ.07.17.99.04 | AA45509 | Poaceae sp. caryopses | -26.0 | 18,800 +/-210 | 0.40 m above base of Unit 10 | |
| BF-Stn.3 GZ.07.17.99.00 | AA42631 | Poaceae sp. caryopses, *Artemisia* flowers, *Taraxacum* sp. achenes | -26.0 | 18,490 +/-160 | 0.01 m above base of Unit 10 | lowest datable organics in Upper Bluefish Unit |
| BF-Stn.3 GZ.07.17.99.00 | AA45508 | *Drepanocladus vernicosus* stems and leaves | -32.4 | 23,360 +/-600 | 0.01 m above base of Unit 10 | sample age probably suggests fractionation of "old" carbon by moss |

---

[1] Dates from the Bluefish Exposure are expressed as uncalibrated $^{14}$C ages throughout this thesis.

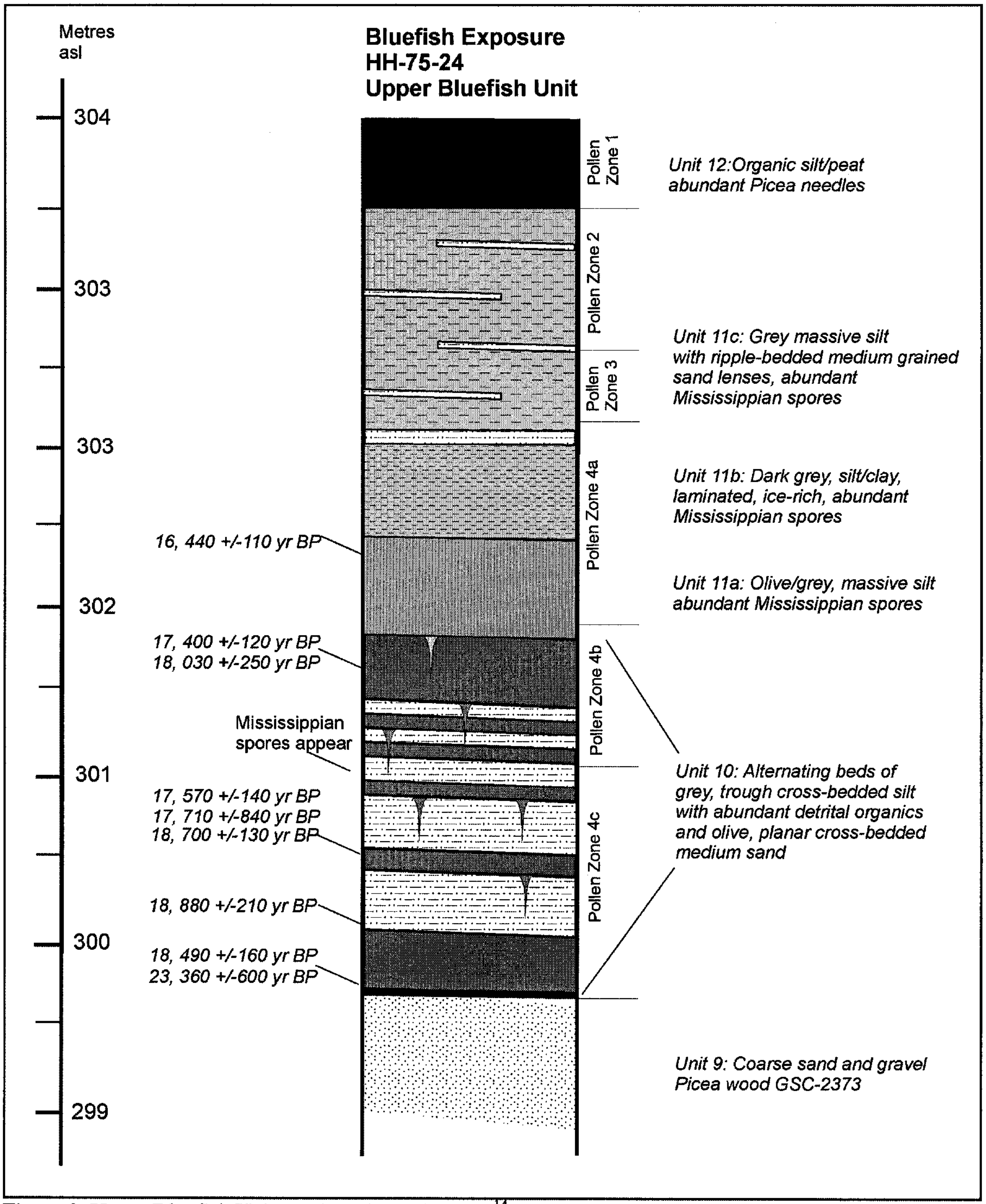


Figure 8. Upper Bluefish Unit stratigraphy with AMS $^{14}$C dates and McCourt's (1982) Pollen Zones.

## 5.2 Macrofossil Results

I analysed fifty-three 25 ml subsamples. Macrofossils were most abundant, and very-well preserved in the trough cross-bedded fine silt sediments of Unit 10. However, macrofossils were rare and often poorly preserved in the planar cross-bedded sand sediments of Unit 10. The glaciolacustrine sediments of Unit 11 were largely sterile, except some rare macrofossils in Unit 11a. There was a strong correlation between the overall abundance of organic detritus and frequency of identifiable plant macrofossils in the subsamples. Thus, the most organic rich samples from Unit 10 serve as the source for most of the identified macrofossil specimens and the basis for vegetation interpretation.

In total, 6240 plant macrofossils were counted, representing at least 33 genera or species (Table 8). Some taxa are represented by several hundred specimens per 25 ml subsample (for example, 482 *Poa* type caryopses), in contrast, others are known from single specimens (*Potamogeton* sp., *Scirpus* cf. *validus*, *Ranunculus* cf. *nivalis*, *Dryas octopetala*). There is a large degree of homogeneity in all these subsamples in terms of the plant taxa present and relative frequencies of those taxa. Descriptions and plates of the macrofossils are presented in Appendix A. Macrofossil quantitative data is presented in Appendix D.

The narrow temporal range of AMS radiocarbon dates and homogeneity of subsamples indicate that the macrofossil assemblage represents a time-slice of the vegetation in the Bluefish watershed at *ca.* 18,000 yr BP (uncalibrated). Variation in the overall quantity of macrofossil specimens in each subsample and variation in totals between subsamples are probably the result of taphonomic processes. The term "macrofossil assemblage" will refer to the combined composition of all subsamples analyzed.

Table 8. Identified vascular plant macrofossils from all samples in Upper Bluefish Unit. Nomenclature and habitat descriptions after Cody (1996).

| **Taxa** | **Common Name** | **Macrofossil Type** | **Total** | **%** | **Cody (1996) Habitat Description** |
|---|---|---|---|---|---|
| **Trees:** | | | | | |
| *Picea* sp. | spruce | needle fragments | 14 | 0.22% | forest |
| | | wood fragments | * | | |
| **Shrubs:** | | | | | |
| *Betula* sp. | birch | wingless nuts | 3 | 0.05% | |
| *Artemisia frigida* | prairie sagewort | leaves | ** | | open slopes, prairie, dry, disturbed |
| *Artemisia frigida/campestris* type | sage | flowers | 741 | 11.9% | |
| *Rubus idaeus* | wild red raspberry | achenes | 2 | 0.04% | woodland clearings |
| **Graminoids:** | | | | | |
| Poacaea undiff. | grass | caryopses | 288 | 4.62% | |
| | | florets | 1009 | 16.2% | |
| cf. *Festuca* sp. | fescue grass | caryopses | 6 | 0.10% | open areas |
| *Deschampsia* sp. | hair grass | caryopses | 151 | 2.52% | riparian, moist meadows, disturbed |
| *Elymus* sp. | wild rye grass | caryopses | 20 | 0.32% | open areas, sandy, meadows |
| *Poa* sp. | blue grass | caryopses | 1486 | 23.8% | open, well-drained |
| *Carex* undiff. | sedge | achenes | 5 | 0.08% | |
| *Carex aquatilis/bigelowii* type | sedge | achenes | 85 | 1.36% | wet meadows, periodic flooding |
| *Carex maritima* type | sedge | achenes | 63 | 1.01% | sandy, turfy places, dunes, floodplains |
| *Kobresia* sp. | | achenes | 11 | 0.18% | dry, open, tundra |
| *Scirpus* cf. *validus* | bulrush | achenes | 1 | 0.02% | shallow water, lakeshores |
| *Juncus/Luzula* sp. | rush | silique fragments | 465 | 7.45% | |
| *Juncus* sp. | bog rush | seeds | 12 | 0.19% | moist, riparian |
| cf. *Luzula* sp. | wood rush | seeds | 30 | 0.48% | alpine, tundra, riparian |
| **Forbs:** | | | | | |
| *Potamogeton* sp. | pondweed | achenes | 2 | 0.02% | shallow water, lake shores |
| *Chenopodium* sp. | goosefoot | seeds | 4 | 0.06% | disturbed areas |
| *Cerastium* cf. *beeringianum* | Beringian chickweed | seeds | 36 | 0.58% | tundra, meadow, woodland |
| *Cerastium* cf. arvense | field chickweed | seeds | 7 | | gravel slopes, open thickets, meadows |
| *Minuartia rubella* | sandwort | seeds | 55 | 0.88% | dry, sandy, rocky slopes |
| *Silene involucrata* | campion | seeds | 7 | 0.11% | moist, stony, gravelly, sandy |
| *Silene uralensis* | campion | seeds | 30 | 0.48% | alpine slopes, meadows, dunes |
| *Stellaria* spp. | chickweed | seeds | 35 | 0.56% | open, slopes, tundra, meadows |
| *Ranunculus* cf. *sceleratus* | celery-leaved buttercup | achenes | 16 | 0.26% | wet peaty, by streams, lakes |
| *Ranunculus* cf. *nivalis* | snow buttercup | achenes | 1 | 0.02% | moist herbmats, snow patch, riparian |
| *Papaver* sect. Scapiflora | arctic poppy | seeds | 135 | 2.16% | tundra, open slopes, alpine meadows, calcareous, rocky |
| Brassicaceae undiff. | mustard family | seeds | 41 | 0.66% | |
| *Draba* type | | seeds | 1264 | 20.3% | open slopes, tundra, sandy riverbanks |
| | | silique fragments | * | | |
| *Saxifraga oppositifolia* | opposite leaved saxifrage | leaf fragments | 13 | 0.21% | broken calcareous gravels, alpine tundra |
| *Dryas octopetala* | mountain avens | leaves | 1 | 0.02% | alpine tundra |
| *Potentilla* spp. | cinquefoil | achenes | 132 | 2.11% | open meadows |
| *Androsace septentrionalis* | fairy-candelabra | seeds | 49 | 0.79% | dry calcareous sandy, gravelly |
| *Achillea* sp. | yarrow | achenes | 4 | 0.06% | riverbanks, open, gravelly, sandy |
| *Taraxacum ceratophorum* | dandelion | achenes | 14 | 0.24% | woodland, heath to tundra |
| | | | Total = 6240 | | |

=* taxon present but not quantified; ** = taxon too abundant to quantify; "undiff." = undifferentiated

### A) Trees

The limited arboreal remains include rare, highly fragmented *Picea* sp. needles and/or needle tips found in the silt-rich subsamples from Unit 10. In addition, a well-rounded wood fragment 8 x 1.5 x 0.5 cm in size was identified as *Picea* sp. (R.J. Mott, NRCan, Wood Identification Report no. 2001-37). Additional wood fragments are consistent with the identified *Picea* specimen.

### B) Shrubs

The shrub flora represented in the macrofossil assemblage is limited in diversity. Silt-rich subsamples from Unit 10 contain flowers that refer to the subshrub *Artemisia frigida/campestris*, reaching up to 234 specimens/25ml. Many subsamples contained abundant leaves of *Artemsia frigida* indicating that the *Artemisia* flowers were likely also derived from that species.

Dwarf prostrate shrubs may be represented in the Bluefish Exposure by small woody stem or branch fragments found in the most organic rich samples. Many of these small woody specimens are well rounded, possibly indicating re-working from older deposits. However, they may represent lower, woody stem fragments of *Artemisia frigida* or the dwarf shrub-birch, because wingless nutlets of *Betula* sp. were found. Further, rare achenes of *Rubus idaeus* were recovered.

## C) Graminoids

Graminoids were the most abundant macrofossil type with Poaeceae remains the dominant type, comprising 48% of the macrofossil assemblage. These were most abundant in the silt-rich subsamples of Unit 10. Caryopses and florets were identified as Poaceae undet., *Poa* type., *Elymus* sp., *Deschampsia* sp. and cf. *Festuca.* Caryopses consistent with *Poa* sp. dominate (23.8%) the macrofossil assemblage, up to 482 specimens/25 ml. Some caryopses of *Poa* sp. were found attached to their paleas and lemmas. Abundant lemmas and paleas with rachilla consistent with *Poa* sp were also recovered. Caryopses of *Deschampsia* sp. were frequently recovered. The relatively large caryopses of *Elymus* sp. were occasional in the most silt-rich subsamples from Unit 10. Rare caryopses that resembled cf. *Festuca* sp. were recovered but this identification is considered tentative

Cyperaceae is represented by well-preserved achenes of *Carex* spp., *Carex maritima* type, *Carex aquatilis/bigelowii* type. These were recovered from the silt-rich subsamples from Unit 10 and, dominate the clay/silt-rich subsamples from Unit 11a. Achenes of *Kobresia* sp. were rare and only one specimen of *Scirpus* cf. *validus* was recovered. Of Juncaceae, silique fragments of *Juncus/Luzula* were recovered in most silt-rich subsamples of Unit 10, though a confident genus determination was not made. *Juncus* and cf. *Luzula* seeds were occasionally recovered.

## D) Forbs

The forb flora of the Bluefish Exposure assemblage is diverse. *Draba* type seeds dominate, comprising 19% of the assemblage, up to 219 specimens/25ml. In two subsamples, some *Draba* type seeds were found attached to silique fragments. Other taxa consistently found include seeds of *Cerastium* cf. *beeringianum*, *Cerastium* cf. *arvense*, *Minuartia rubella*, *Silene uralensis*, *Papaver* sect. *Scapilfora*, *Potentilla* spp., *Androsace septentrionalis*, and *Taraxacum ceratophorum.* Specimens of *Ranunculus* cf. *sceleratus,* and *Chenopodium* sp. are rare. Only one specimen each of *Ranunculus cf. nivalis* and the aquatic plant *Potamogeton* sp. were recovered. Identified leaves include rare specimens of *Saxifraga oppositifolia* and a single specimen of *Dryas octopetala.* Specimens of herbaceous forbs have variable quality of preservation. Many of the specimens of Caryophyllaceae and *Papaver* sect. *Scapilfora* are poorly preserved. Many of the *Draba* type seeds were very well preserved, while others were highly fragmented.

## E) Bryophytes

Bryophytes were abundant in the silt-rich subsamples of Unit 10 (Table 9). Sample GZ.07.14.99.09 (Station.2) was determined to have the greatest quantity and diversity of well-preserved moss remains and was chosen as a representative subsample for identification. No other taxa were recovered while picking other subsamples. Well-preserved stems and leaves of *Drepanocladus vernicosus*, *Scorpidium scorpioides,* *Calliergon giganteum* and *Calliergon stramineum* account for approximately 80% of all bryophyte remains. Well preserved branches of *Tomenthypnum nitens* and *Didymodon rigidulus* var. *icmadophila* were also occasionally recovered. Acrocarpic mosses, including *Bryum* sp., cf. *Tortula* sp. and *Dicranum* sp. were infrequent and poorly preserved.

*Drepanocladus vernicosus* leaves and stems yielded an AMS radiocarbon age of 23,360 ±600 yr BP (AA45508). The discrepancy of this age to those obtained from vascular plant macrofossils suggests fractionation of "old" carbon from the local carbonate rich substrates by fen bryophytes (MacDonald *et al.* 1987).

Table 9. Moss taxa identified from sample GZ.07.14.99.09 (loc.2) Unit 10 Bluefish Exposure by I. Bauer (University of Alberta) and R. Hastings (Provincial Museum of Alberta). Habitat information and nomenclature follows Janssens (1981).

| **Moss Taxa** | **Janssens (1981) Habitat Description** |
|---|---|
| **Dicranaceae** | |
| *Dicranum* sp. | on moist substrates, heaths, mesic tundra |
| **Pottiaceae** | |
| *Didymodon rigidulus* var. *icmadophila* | on open, calcareous soil, earth covered boulders, rocks in streams |
| cf. *Tortula* sp. | calcareous soils and rocks |
| **Bryaceae** | |
| *Bryum* sp. | on moist calcareous soils, above water table |
| **Amblystegiaceae** | |
| *Calliergon giganteum* | shallow pools, rich fens, edges of springs and streams |
| *Calliergon stramineum* | shallow pools, rich fens |
| *Drepanocladus vernicosus* | moist or wet calcareous soil, rich fens |
| *Scorpidium scorpioides* | moist or wet calcareous soil, rich fens |
| **Brachytheciaceae** | |
| *Tomenthypnum nitens* | moist or wet calcareous soil, rich fens, muskeg, tundra |

## F) Sclerotia

Remains of the fungal sclerotia *Cennococcum geophilum* (Fries.) were abundant in most subsamples. These small fruiting bodies form mycorrhiza with woody and herbaceous plants. Their occurrence in fluvial deposits may indicate soil erosion from the watershed (H.H. Birks, University of Bergen, personal communication, 2001).

## G) Fauna

The Bluefish Exposure assemblage contained a rich invertebrate fauna. Some invertebrate remains from this study were analysed by S.A. Elias (Royal Holloway, University of London), to supplement data from the site established by Matthews and Telka (1997).

Subsamples of medium grained sand from Unit 10 devoid of detrital plant material often contained small bone fragments. The only identifiable specimens were from sample GZ.07.14.99.06 (Stn.2); a lower left M1 tooth of *Dicrostonyx torquatus* (collared lemming) and an anterior half of a lower left mandible with no teeth from the family Arvicolidae (identifications by P. Milot, Provincial Museum of Alberta). In addition, two fish scales identified as *Thymallus arcticus* (arctic grayling) were found in sample GZ.07.17.99.00 (Stn.3) at the base of Unit 10.

## 5.3 Macrofossil Taphonomy

Taphonomic processes affect allocthonous macrofossils assemblages from alluvial deposits in a number of ways. The transportation from parent plants to study site must have been diverse, with overland movement by surface runoff (Holyoak 1984), or by spring or winter dispersal by wind (Glaser 1981). These, in addition to hydrological sorting processes, affected the selection of remains for deposition in the study site sediment. Thus, the overall sequence of events from plant, to sediment, to analysis, is very complex (West and Pettit 2000).

Most of the sieved subsamples were recovered from the 0.25 mm mesh screens, indicating that transportation and deposition selected for sediment and organic detritus 0.25 mm to 1.18 mm in size. The larger plant and wood fragments were only found along contacts between fine-grained silt and medium grained sand lenses. This size sorting undoubtedly favored preservation of smaller macrofossils. Size sorting may reflect aerodynamic and hydrodynamic properties of individual plant parts and/or hydrological properties of stream current.

Glaser (1981) indicates that for tundra environments, fluvially-deposited macrofossil assemblages are dominated by species that are most abundant in communities proximal to the fluvial setting and study site, and by those that are the most prolific producers of dispersible parts. Using this premise, the Bluefish Exposure allochtonous macrofossil assemblage should be dominated by species that are prevalent throughout the area, these include the valley bottom and midslope topographic areas within the watershed. Because the midslope comprises the majority of the surface area in the watershed (Ritchie 1984), the most abundant plants in the watershed should dominate the assemblage. Upland plants living above 650 m asl should be under-represented in the macrofossil assemblage as they are further away from the fluvial zone and study site. Vegetation zonation with elevation in the watershed may also influence the preservation potential of macrofossils. Macrofossils that have been transported shorter distances to the deposition site should be better preserved than ones from further away that require further transport. Thus, macrofossils from upland plant types should exhibit poor-preservation in comparison to those from plants that inhabited the riparian and midslope areas.

## 5.4 Comparison of Macrofossil and Pollen Assemblages

The plant macrofossil assemblage from the Bluefish Exposure complements the full-glacial pollen records from the site (McCourt 1982) and Bluefish Caves (Ritchie *et al.* 1982). Comparisons of taxa from macrofossil and pollen records are presented in Table 10.

Table 10. Comparison of identified taxa in the Bluefish Exposure macrofossil, pollen and Bluefish Caves pollen assemblages. * = taxon present.

| **Taxa** | **Bluefish Exposure Macrofossils** | **Bluefish Exposure Fossil Pollen** | **Bluefish Caves Fossil Pollen** |
|---|---|---|---|
| **Trees and Shrubs** | | | |
| *Picea* | * | * | * |
| *Pinus* | | * | * |
| *Larix* | | | * |
| *Populus* | | | * |
| *Betula* | * | * | * |
| *Salix* | | * | * |
| *Alnus* | | * | * |
| *Alnus crispa* | | | * |
| *Alnus incana* | | | * |
| *Shepherdia canadensis* | | * | * |
| Ericaceae | | * | * |
| *Artemisia* | * | * | * |
| *Artemisia frigida* | * | | |
| | | | |
| **Graminoids** | | | |
| Poaceae | * | * | * |
| *Deschampsia* | * | | |
| cf. *Festuca* | * | | |
| *Elymus* | * | | |
| *Poa* type | * | | |
| Cyperaceae | | * | * |
| *Carex* | * | | |
| *Carex aquatilis/bigelowii* type | * | | |
| *Carex maritima* type | * | | |
| *Kobresia* | * | | |
| *Scirpus* cf. *validus* | * | | |

| | | | |
|---|---|---|---|
| *Juncus/Luzula* | * | | |
| | | | |
| **Forbs** | | | |
| *Typha* | | * | |
| *Potamogeton* | * | | |
| Liliaceae | | | * |
| *Myrica* | | | * |
| *Polygonum alaskanum* type | | | * |
| *Polygonum amphibium* type | | * | |
| *Polygonum bistorta* type | | * | |
| *Rumex-Oxyria* | | * | * |
| Chenopodiaceae-*Amaranthus* | | * | * |
| *Chenopodium* | * | | |
| Caryophyllaceae | * | * | * |
| *Cerastium* cf. *arvense* | * | | |
| *Cerastium* cf. *beeringianum* | * | | |
| *Minuartia rubella* | * | | |
| *Silene involucrata* | * | | |
| *Silene uralensis* | * | | |
| *Stellaria* | * | | |
| Ranunculaceae | | * | * |
| *Aconitum* | | | * |
| *Ranunculus* cf. *sceleratus* | * | | |
| *Ranunculus* cf. *nivalis* | * | | |
| *Thalictrum* | | * | |
| Papaveraceae | | * | * |
| *Papaver* sect. *Scapiflora* | * | | |
| Brassicaceae | * | * | * |
| *Arabis* type | | * | |
| *Draba* type | * | | |
| Saxifragaceae | | | * |
| *Ribes* | | * | |
| *Saxifraga oppositifolia* type | * | * | |
| *Saxifraga hieracifolia* type | | | * |
| *Saxifrage hirculus* type | | * | |
| *Saxifraga tricuspidata* type | | | * |
| Rosaceae | | * | * |
| *Dryas* | | * | |
| *Dryas octopetala* | * | | |
| *Potentilla* | * | * | |
| *Rubus chamaemorus* | | * | |

| | | | |
|---|---|---|---|
| *Rubus idaeus* | * | | |
| Apiaceae | | * | |
| Fabaceae | | | * |
| *Hedysarum* | | | * |
| *Oxytropis* | | | * |
| *Epilobium* | | | * |
| *Androsace septentrionalis* | * | | |
| Gentianaceae | | * | |
| *Phlox* | | * | * |
| *Polemonium* | | * | |
| Labiatae | | * | |
| *Pedicularis* | | | * |
| *Plantago* | | | * |
| *Galium* | | | * |
| Tubuliflorae | | | * |
| Liguliflorae | | | * |
| *Achillea* | * | | |
| *Antennaria* type | | * | |
| *Taraxacum ceratophorum* | * | | |
| *Taraxacum* type | | * | |
| *Selaginella sibirica* | | | * |
| *Selaginella selaginoides* | | | * |
| *Sphagnum* | | * | * |

The dominant full-glacial pollen taxa, *Artemisia*, Poaceae, and Cyperaceae, are well documented in the macrofossil assemblage. Identification of these taxa to genera and/or species gives detailed ecological information because their pollen cannot be readily identified to that level of taxonomic resolution. Further, the identification of species and genera within these taxa indicate local presence of these plants within the Bluefish watershed. Further, the macrofossil record complements the pollen records by the identification of species and genera within the Caryophyllaceae, Rancunculaceae, Rosaceae, Saxifragaceae and Asteraceae families.

Because the members of the Poaceae family and *Artemisia* dominate both the pollen and macrofossil records, one can infer that these taxa were widespread within the watershed. The dominance of these taxa in the macrofossil assemblage (Poaceae: >48%, *Artemisia*: >11.9%) indicates they were highly abundant proximal to the valley bottom and deposition site. However, their abundance in the fossil pollen records (Poaceae, Bluefish Exposure: 10-50%, Bluefish Caves: 20-45%; *Artemisia*, Bluefish Exposure: 10-40%, Bluefish Caves: 5-15%) indicates that these taxa were not merely restricted to the valley bottom, but were dominant components of widespread vegetation that occurred throughout much of the watershed, contributing significantly to the watershed's pollen rain. Therefore, the macrofossil record of *Artemisia* and a variety of Poaceae do not merely reflect riparian zone vegetation.

In comparison to the pollen records, the macrofossil assemblage is nearly devoid of tree and woody shrub taxa, except rare *Picea* needle fragments, *Betula* nutlets and *Rubus idaeus* achenes. The low frequency of tree and shrub taxa in the pollen records (*Picea*, *Pinus*, *Populus*, *Larix*, *Alnus*, Ericaceae, and *Shepherdia canadensis*), coupled with their absence in the macrofossil assemblage, suggest that these are the product of long distance transport and or reworking from older deposits when dense forests dominated the regional vegetation (McCourt 1982, Ritchie *et al.* 1982).

The pollen records document the presence of many herbs not represented in the macrofossil assemblage, including *Epilobium*, Fabaceae, *Hedysarum* (licorice root), *Oxytropis*, Liliaceae, *Pedicularis*, *Plantago* (plantain), *Polygonum alaskanum* type, *P. amphibium* type, *P. bistorta* type (bistort), *Rumex-Oxyria*, *Saxifraga hieracifolia* type, *S. hiculus*, *S. tricuspidada*, *Aconitum*, *Thalictrum* (meadow rue), Apiaceae, Gentianaceae, *Galeopsis* type, *Polemonium* (Jacob's Ladder), *Phlox*, *Selaginella sibirica* (spike-moss), and *S. selaginoides*. The absence of macrofossils of the above taxa would probably suggest they were not present adjacent to the valley bottom or study site, and likely inhabited ares further upslope in the watershed. Pollen records for *Dryas octopetala* and *Saxifraga oppositifolia* are supported by the recovery of macrofossils.

# Chapter 6: Interpretations

## 6.1 Geological History of the Upper Bluefish Unit, Bluefish Exposure

Evidence from the Bluefish Exposure facilitates reconstruction of late Wisconsinan geological events at the southwestern edge of the Bluefish Basin. The AMS radiocarbon dates obtained for this study are the only dates directly obtained from sediments related to the glaciolacustrine inundation of the Bluefish Basin. These results date the maximum inundation and drainage of the Bluefish Basin.

Planar cross-bedded sands and trough cross-bedded silts of Unit 10 form an aggrading alluvial sequence deposited by the Bluefish River as base levels changed due to the rising late Wisconsinan glacial-lake in the Bluefish Basin (McCourt 1982, Schweger 1989). The absence of Mississippian spores in the lower 1.00 m of Unit 10 indicates that the clastic sediments were derived exclusively from Bluefish River watershed, with no sediment input carried by waters diverted into the basin through the Eagle River Discharge Channel (Schweger 1989; Walde 1986). Scales of *Thymallus arcticus* from Unit 10 basal sediments suggest that the cold water, Bluefish River was fast-flowing, carrying and depositing sediment during the transgressive phase of the glacial-lake that was beginning to form a southwest embayment up the Bluefish River valley. The overlapping radiocarbon dates of 18,880 ±210 yr BP (AA42631) and 18,700 ±130 yr BP (AA426300), 18,700 ±130 yr BP (AA42630), 18,490 ±160 yr BP (AA42631), and 17,570 ±140 yr BP (AA5507) obtained from the lower 1.00 m of Unit 10 indicate very rapid alluvial deposition at this time. This was the first time that the late Wisconsinan glacial-lake reached the southwestern edge of Bluefish Basin.

A gradational contact between Units 10 and the massive silts of Unit 11a signifies the transition from an aggrading alluvial to a shallow water lacustrine depositional environment (McCourt 1982). This sedimentological transition is accompanied by the input of Mississippian spores and sediments derived from the Eagle River Discharge Channel carried into the southwestern edge of the Bluefish Basin by an interconnected glacial-lake. Radiocarbon ages of 18,030 ±250 (AA45505) and 17,400 ±120 BP yr BP (AA42629) obtained 1.60 m above the base of Unit 10, in the transitional sediments suggests that glacial-lake transgression up the confined channel of the Bluefish River valley was very rapid in the southwest edge of the Bluefish Basin. A radiocarbon age near the top of Unit 11a indicates that the deposition of the laminated silty-clay, glaciolacustrine sediments of Unit 11b occurred after 16,440 ±110 (AA45510).

The laminated clays and silts of Unit 11b were deposited as further transgression resulted in a deep-water phase as the arm of the glacial-lake further extended southwest up the Bluefish River valley. This transgression reached its maximum elevation of 366 m asl based on shoreline positions found around the Bluefish Basin (Duk-Rodkin *et al.* 1996; Hughes *et al.* 1981; Lemmen *et al.* 1994). Limited organic remains within Unit 11b and the very fine-grained sediments suggest that the lake may have been ice covered through much of the year and nearly sterile.

The overlying Unit 11c contains a complicated package of massive lacustrine silts with medium grained, current and ripple-bedded sand lenses. An abrupt contact between Units 11b and 11c is initiated by 5 cm of ripple bedded sands, which are presumed to have originated from the Bluefish River, suggesting a rapid glacial-lake lowering. Additional ripple-bedded sand lenses within the massive glaciolacustrine silts of Unit 11c suggest repeated lake drainage events and resumed deep-water flooding with fluctuations in the position of the shoreline. Glacial-lake lowering events discharged water westward and initiated the incision of the Ramparts on the Porcupine River at the western edge of the Bluefish Basin (Duk-Rodkin and Hughes 1995).

## 6.2 Paleoecological Interpretations

Macrofossil data from the Bluefish Exposure provide significant information about the environment of the Bluefish watershed at *ca.* 18,000 yr BP. Because many of the plant macrofossils were confidently identified to genus and species, detailed ecological information is drawn from this assemblage. Habitat and ecological information was obtained for the taxa represented in the macrofossil and fossil pollen assemblages (McCourt 1982; Ritchie *et al.* 1982) following Cody (1996) (see Tables 3, 5, 8, and 9). Macrofossil data are compared with the watershed's fossil pollen data to reconstruct the full-glacial vegetation of the Bluefish watershed. The fossil pollen data should better represent vegetation more distal to the valley bottom, and better reflect the most widespread vegetation and that which is in higher elevations. The macrofossil assemblage should be dominated by taxa closer to the valley bottom and midslope topographic areas. The co-occurrence of certain abundant taxa in both datasets, therefore, should indicate that they are dominant components of a similar vegetation that was most widespread throughout the watershed.

Using habitat information, macrofossil and pollen taxa with similar habitat preferences were grouped into inferred vegetation types. The variable habitat preferences exhibited by macrofossil taxa indicates that the assemblage does not represent a single community, but rather a mosaic of vegetation types that were topographically dispersed throughout the watershed. The combined Bluefish macrofossil and pollen datasets are interpreted to represent physiognomical and compositional resemblance to littoral zone vegetation, mid-rich fens, mesic graminoid meadows, xeric steppe, and fell-field tundra, all within the watershed (Table 11). Using topographic data for the Bluefish watershed (Ritchie 1984), these vegetation types were placed into altitudinal zones based on habitat preferences (Figure 7). The locations of these vegetation types, not unlike today, are highly dependent on local physical variables including substrate, slope, drainage, aspect, elevation, and proximity to water (Schweger 1997). Further, these reconstructed vegetation types were compared with modern analogues. A glossary of ecological terms used in this interpretation is presented in Appendix B.

Table 11. Identified plant taxa from the Bluefish Exposure and Bluefish Caves grouped into vegetation types found within the watershed.

| **Tundra** | **Steppe** | **Meadow** | **Mid-Rich Fens** | **Littoral** |
|---|---|---|---|---|
| *Saxifraga oppositifolia* | *Artemisia frigida* | *Deschampsia* sp. | *Drepanocladus vernicosus* | *Potamogeton* sp. |
| *Dryas octopetala* | *Poa* sp. | *Carex aquatilis/bigelowii* type | *Scorpidium scorpioides* | *Scirpus* cf. *validus* |
| *Silene involucrata* | *Elymus* sp. | *Carex maritima* type | *Calliergon stramineum* | |
| *Silene uralensis* | cf. *Festuca* sp. | *Juncus* sp. | *Calliergon giganteum* | |
| *Papaver* sect. Scapiflora | *Luzula* sp. | *Ranunculus* sp. | | |
| *Draba* | *Chenopodium* sp. | *Rubus idaeus* | | |
| *Aconitum* * | *Androsace septentrionalis* | *Taraxacum ceratophorum* | | |
| *Galeopsis* | *Achillea* sp. | *Cerastium* sp. | | |
| *Hedysarum* * | *Minuartia rubella* | *Salix* sp. * | | |
| *Pedicularis* * | *Potentilla* spp. | | | |
| *Polemonium* * | *Draba* | | | |
| *Polygonum alaskanum* * | *Kobresia* sp. | | | |
| *Polygonum bistorta* * | *Cerastium* cf. *beeringianum* | | | |
| *Saxifraga tricuspidada** | *Cerastium* cf. *arvense* | | | |
| *Oxyria* * | Chenopdiaceae-*Amaranthus** | | | |
| *Oxytropis* * | *Phlox* * | | | |
| *Thalictrum* * | *Plantago* * | | | |
| *Selaginellla selaginoides.** | *Selaginella sibirica* * | | | |

* indicates full-glacial pollen taxa from Bluefish Exposure (McCourt 1982) and Bluefish Caves (Ritchie 1984; Ritchie *et al.* 1982).

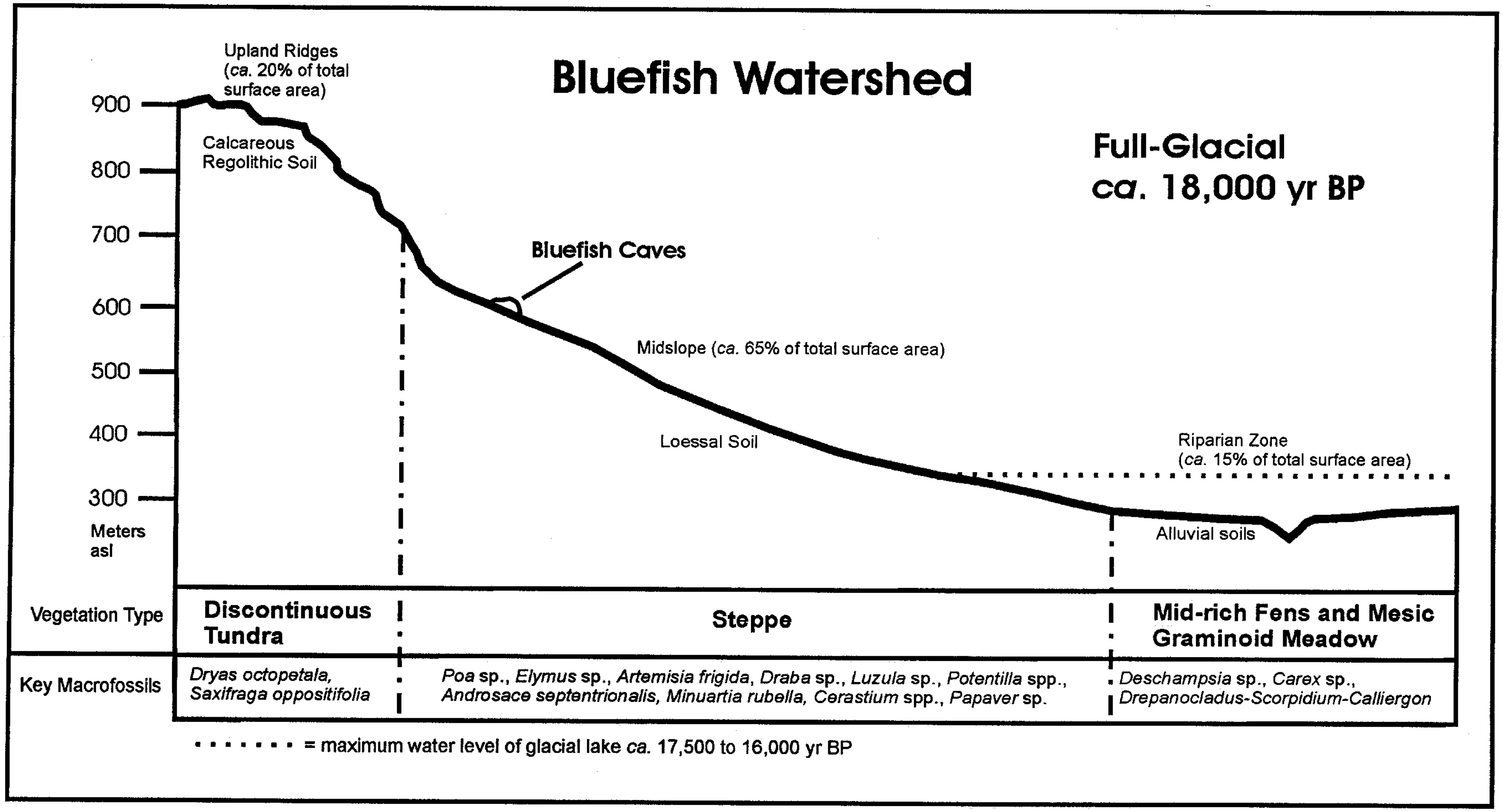


Figure 7. Topographic gradient with reconstructed vegetation zones for the full-glacial Bluefish watershed.

### A) Littoral, Mid-rich Fen, and Mesic Meadow Vegetation.

Littoral plants that occurred along shallow shoreline areas of the glacial-lake are not well represented in the Bluefish Exposure macrofossil assemblage, with only single specimens each of *Potamogeton* sp., and *Scirpus* cf. *validus.* The rare occurrences of these taxa are puzzling because the littoral zone would have been proximal to the study site and these taxa are prolific seed producers. However, full-glacial climates and limnological conditions may not have been conducive to the development of abundant littoral plants. The fast-flowing current of the Bluefish River may have prevented littoral plants from establishing at this locale. Importantly, typical littoral types grasses such as *Puccinellia* (goose grass) or *Glyceria* (manna grass) are not represented in the macrofossil assemblage.

The most abundant moss taxa share the characteristics of excellent preservation, inhabiting shallow, mid-rich fens, and often preferring calcareous or alkaline water conditions (Janssens 1981). The floodplain of the Bluefish River must have had perennial alkaline pools enabling the development of *Drepanocladus vernicosus*, *Scorpidium scorpioides*, and *Calliergon* dominated, mid-rich hygric fens. Excellent preservation of specimens suggests that they were growing proximal to the study site. Alkaline pH conditions were maintained by the predominance of dolomite and limestone bedrock and loess deposition.

*Deschampsia* sp., *Juncus* sp., *Carex aquatilis/bigelowii* type, *Carex maritima* type *Rancunculus* sp., *Rubus idaeus*, *Taraxacum ceratophorum*, and a variety of Caryophyllaceae all have habitat preferences for moist riparian zones that are frequently disturbed by overbank flood events or cutbank erosion. This suggests that macrofossils of these taxa probably represent a mesic graminoid meadow that formed along the floodplain and riverbanks. Specimens of *Carex aquatilis/bigelowii* type and *Carex maritima* type typically float in water as an adaptation for seed dispersal in a wetland habitat. Further, the excellent preservation of the *Carex* achenes and *Deschampsia* caryopses relative to those of the upland tundra type taxa indicates close proximity to the site and/or river channel. Mesic meadows may have occurred up to an elevation of 350 m, but their distribution is restricted by local available soil moisture. Mesic sedge-grass meadows are the probable source of the Cyperaceae pollen evident from the pollen records of the watershed (McCourt 1982; Ritchie *et al.* 1982). Although not present in the macrofossil assemblages, pollen of *Salix* spp. indicates that it may have been a component of the floodplain meadow vegetation (Ritchie *et al.* 1982). The close proximity to perennial water sources and fine-grained alluvial soils suggest the rich, mesic meadow vegetation that surely yielded high aboveground biomass.

These riparian zone, mid-rich fens and mesic meadows bear compositional and physiognomic resemblance to a number of "Mesic Graminoid Herbaceous" vegetation types described by Viereck *et al.* (1992:176) and the "*Carex* Meadows on Lowlands" vegetation described by Ritchie (1984:62). These vegetation types, commonly dominated by *Carex aquatilis*, sometimes with prostrate willows, and often abundant *Drepanocladus* and *Scorpidium*, and remain wet through most of the year. *Deschampsia beringensis* and/or *D. caespitosa* are a often dominant grass within these vegetation types. A mesic graminoid meadow interpreted from the macrofossil assemblage is consistent with

Ritchie's (1984) and Ritchie *et al.*'s (1982) reconstructed lowland vegetation for the Bluefish watershed based on the fossil pollen record from Bluefish Caves.

Mid-rich fens and mesic meadows made up the riparian zone proximal to the Bluefish River, comprising approximately 15% of the total surface area of the Bluefish watershed. Importantly, these vegetation types indicate that permanent water sources were probably available through combinations of precipitation and seepage sources. The latter is common in the region today as evident by numerous karst features in the carbonate bedrock (Cinq-Mars and Lauriol 1985).

### B) Steppe Vegetation

*Artemisia frigida Poa* type, *Elymus* sp. and *Luzula* sp., *Potentilla* spp., *Papaver* sect. *Scapiflora,* Brassicaceae, *Draba* sp., *Chenopodium* sp., *Achillea* sp., *Cerastium* cf. *arvense, Minuartia rubella* and *Androsace septentrionalis* are often pioneer taxa on dry open areas, preferring fine-grained exposed substrates, and tolerance of or with a preference for soil disturbance. Macrofossils of these taxa probably represent xeric steppe vegetation, dominated by bunchgrasses and other graminoids, sage, and diverse forbs. Because both the fossil pollen and macrofossil datasets are dominated by Poaceae and *Artemisia,* the principal taxa that comprise steppe vegetation, these data together indicate that steppe was a widespread vegetation throughout the watershed and probably inhabited the midslope topographic area between 350 and 650 m asl and the most xeric locales in the valley bottom. The presence of *A. frigida* is crucial to reconstructing the full-glacial ecology because it is characterized by a deep and extensive rooting system, and high reproductive rates. Both are adaptations to aggressively colonizing dry, disturbed soils with deep active layers and moisture deficits (Cooperrider and Bailey 1986). Thus, because the full-glacial Bluefish watershed was a nearly treeless, xeric landscape, that was continually under the influence of multiple disturbance factors (including loess deposition and herbivore trampling) *Artemisia frigida* probably aggressively colonized, and was dominant and widespread. Abundant *Artemisia frigida* macrofossils may be the best indicator of steppe vegetation and suggests that much of the *Artemisia* pollen in the watershed was derived from that species. Because steppe probably inhabited much of the midslope topographic area, and the midlslope comprises *ca.* 65% of the total surface area (Ritchie 1984), steppe was the dominant vegetation type within the watershed during the full-glacial. Further, minor pollen types (<10%), including *Phlox*, *Plantago*, *Chenopodium*-Amaranthaceae and *Selaginella sibirica* (McCourt 1982; Ritchie *et al.* 1982) also probably represent components of the Bluefish watershed steppe vegetation.

*Poa*, *Elymus*, *Artemisia frigida* and many of the abovementioned forbs are often found today as part of extrazonal steppe vegetation on open, dry, south facing slopes with high net radiation in central Alaska (Edwards and Armbruster 1989; Lloyd *et al.* 1994; Murray *et al.* 1983; Roland 1996; Walker *et al.* 1991;Young 1976, 1982), Yukon (Laxton *et al.* 1996; Vetter 2000) and northeast Eurasia (Roland 1996); atop dry facies of high-center polygons in the Arctic (Young 1989); continental prairies of North America (Cooperrider and Bailey 1986); and zonal steppe of Eurasia (Yurtsev 1963, 1982).

Extrazonal steppe of Alaska and Yukon has also been proposed to be a probable analogue for full-glacial Beringian vegetation by Edwards and Armbruster (1989); Laxton *et al.* (1996); Lloyd *et al.* (1994); Murray *et al.* (1983); Walker *et al.* (1991); and

Young (1976, 1982). A physiognomic, ecological and compositional vegetation analogue for the reconstructed Bluefish watershed steppe vegetation may be found in Viereck *et al.*'s (1992:162) "Midgrass-Shrub" vegetation type with additional affinities to "Midgrass-Herb" vegetation type found on dry slopes of interior Alaska. The Midgrass-Shrub type is dominated by medium–height grasses, including *Elymus innovatus*, *Poa* spp. (with abundant *Poa glauca*), *Festuca altaica*, *Calamagrostis purparescens* and *Artemisia frigida*. The composition of this vegetation is largely controlled by moisture and soil pH. The most common form of this vegetation type is expressed on dry, south-facing slopes with slightly alkaline loamy soils where the lack of moisture and alkalinity enables *Artemisia frigida* to replace the ericaceous shrubs (Viereck *et al.* 1992). Midgrass-Herb vegetation is physiognomically and compositionally similar to the Midgrass-Shrub vegetation, but contains more abundant small flowering forbs such as *Achillea millefolium*, and a number of *Potentilla* (Viereck *et al.* 1992). While the comparison is not perfect, similarities in structure, dominant plant genera, and some species suggest a probable vegetation analogue to full-glacial steppe of the Bluefish watershed.

Using known habitat preferences (Cody 1996) for a number of genera represented in the Bluefish watershed paleoecological dataset, and the probable modern analogues, inferences may be made regarding a number of plant species that probably comprised the full-glacial steppe. The grass component was probably dominated by *Poa glauca,* a xerophilous low growth, tufted, bunch-grass that is the most common member of the *Poa* genus found in extrazonal and zonal steppe (Edwards and Armbruster 1989; Roland 1996; Vetter 2000; Walker *et al.* 1991; Yurtsev 1963, 1982). The *Elymus* sp. specimens probably represent stands of the tall bunch-grass *Elymus innovatus,* that are now common on active dune deposits (Young 1982). Specimens representing flowering forbs suggest the steppe probably included *Potentilla pensylvanica*, *P. nivea*, P. *gracilis, Achillea millefolium*, and several types of *Draba,* including *Draba nemorosa, D. nivalis, D. cana* and *D. cinerea.* A few acrocarpic mosses specimens of *Dicranum* sp., and *Didymodon rigidulus* var. *icmadophila* probably represent a sparse moss cover on the steppe mineral soils in more mesic locales.

Matthews and Telka (1997) suggest that insect specimens from the Upper Bluefish Unit, Bluefish Exposure support the existence of dry substrates with open steppe vegetation. As with many late Pleistocene localities, the assemblage is dominated by the byrrhid beetle *Morychus* sp., and weevil *Lepidophorus lineaticollis*, with various frequencies of tundra beetles, *Amara alpina*, *Amara glacialis*, the subgenus *Cryobius*, and *Helophorus splendidus,* indicating dry exposed substrates. Further, the presence of the lace bug *Derephysia foliaceae* further supports the interpretation of full-glacial steppe because it has only been collected from alpine meadows in western Oregon, a vegetation type that has physiognomic and compositional similarities to hypothesized full-glacial steppe (Matthews and Telka 1997).

### C) Discontinuous Tundra Vegetation

Plants with habitat preferences for upland tundra are poorly represented in the Bluefish Exposure macrofossil assemblage. *Saxifraga oppositifolia*, *Dryas octopetala,* and some specimens of *Silene uralensis, S. involucrata, Cerastium* sp., *Draba* type and

*Papaver* sect. *Scapiflora* probably reflect long-distance dispersal from upland tundra plants. These taxa are less frequent and display poor-preservation in comparison to others in the macrofossil assemblage. However, upland tundra plants are well represented as minor components of the pollen records of both Bluefish Caves and Bluefish Exposure, and include *Aconitum, Hedysarum*, *Pedicularis*, *Polemonium*, *Rumex*, *Saxifraga hieracifolia* type, *S. hiculus* type, *S. tricuspidada* type, *Polygonum alaskanum*, *Polygonum bistorta* (bistort), *Oxyria*, *Oxytropis*, *Selaginella selaginoides*, and *Thalictrum*. These forb taxa have preferences for exposed ground in arctic-alpine tundra areas, and probably represent sparse, xeric, discontinuous or fell-field tundra nearer to and upon extensive limestone bedrock ridges above 650 m asl, the elevation marking the most significant break in slope in the watershed. Because the areas above 650 m asl comprise *ca.* 20% of the overall surface area, this discontinuous tundra vegetation was not the dominant full-glacial vegetation type within the Bluefish watershed as proposed by Ritchie (1984) and Ritchie *et al.* (1982).

The upland discontinuous tundra on exposed calcareous cryic, regolithic soils has compositional and physiognomical affinities to the "Alpine Herb" vegetation type described by Viereck *et al.* (1992:191) and discontinuous fell-field described by Ritchie (1984). This vegetation type is common in uplands where low temperatures, winds, limited moisture, dry, cold soils limit growth of erect shrubs, and is conducive to establishment of sparse, herb dominated tundra. As Ritchie (1984) describes, these environments often experience winds that form drifts of dirty snow that melt much earlier in the spring causing a moisture flush, leading to the development of snowpatch communities with more mesic taxa, including *Salix* spp.

## 6.3 Discussion

The lack of abundant macrofossils and pollen (>10%) of arboreal taxa from the Bluefish Exposure dataset indicate that trees or forests were not present during the full-glacial in the Bluefish watershed. The limited specimens of poorly preserved *Picea* needle fragments, and rounded wood pieces are probably reworked from older deposits that contain evidence of widespread forests in the region.

A key issue in the reconstruction of the paleoecology of Beringia centers on the significance of abundant *Artemisia* in pollen records that extend into the full-glacial interval. The significance of *Artemisia* pollen is so problematic that it has been selectively discarded from full-glacial pollen assemblage matrices while using multi-variate methods in the search for modern analogues (e.g., Anderson *et al.* 1989). This seriously limits the effectiveness of the method and the veracity of the conclusions. As a consequence, identification of *Artemisia frigida* macrofossils is crucial 1) because it demonstrates that *Artemisia* was present and abundant; 2) because species of *Artemisia* cannot be distinguished on the basis of pollen and the numerous species in the genus represent a wide range of preferred habitats.

Birks and Birks (2000) and Goetcheus and Birks (2001) advocated that the lack of *Artemisia* macrofossils in full-glacial assemblages in western Alaskan records (Elias *et al.* 1996, 1997; Goetcheus and Birks 2001) suggests that *Artemisia* was generally rare in the vegetation of that area and "the contemporaneous pollen recorded in upland Beringia may be largely long-distance transported" (Goetcheus and Birks 2001:143). However, the coexistence of abundant *Artemisia* pollen (up to 40-50%) and macrofossils (>12%) in the

Bluefish watershed dataset indicates that *Artemisia* plants were locally widespread and probably present at other localities in eastern Beringia where *Artemisia* pollen is abundant in full-glacial pollen records.

Young (1982) has argued that a number of species including *Artemisia alaskana, A. arctica, A. campestris, A. norvegica* and *A. furcata* were the most likely contributors of the full-glacial pollen rain, with *A. frigida* and *A. tilesii* locally abundant in the most disturbed areas. Ritchie and Cwynar (1982) challenged this view suggesting that soils with deep active layers allowing *A. frigida* to establish would not have been present during the full-glacial, because that would imply a thermal regime incompatible with regional paleoclimatic reconstructions. Alternatively, Ritchie and Cwynar (1982) suggest that *A. norvegica* would have been the dominant types found on exposed regosolic soils in extensive fell-field environments. The Bluefish Exposure record indicates the *A. frigida* was an important plant, and probably the dominant *Artemisia* species within the watershed, and likely at other xeric Eastern Beringian locales.

A number of plant taxa that are found in pollen records from the watershed are surprisingly rare or absent from the macrobotanical assemblage. Pollen taxa including Fabaceae (pea family), *Polygonum*, *Plantago*, *Calamagrostis* (reed bent grass) and *Selaginella sibrica* are all absent, but they are expected to be components of steppe vegetation. Although *Calamagrostis* is often associated with *Artemisia frigida* and *Poa* spp. in extrazonal steppe, its absence in the macrofossil record may be taphonomic. Experiments with sodium pyrophosphate treatment of *Calamagrostis purparescens* caryopses indicate it does not preserve well. *Elymus* sp. macrofossil remains are rare yet the well-preserved remains are relatively much larger than the other macrofossils (to 6.0

mm in length). *Elymus* plants may have been abundant in the full-glacial midslope steppe and proximal to the river but hydrological sorting may have eliminated the caryopses from becoming part of the macrofossil assemblage. The rarity of *Kobresia* sp. in the Bluefish macrofossil assemblage is perhaps unusual in that it is found at sites on Seward Peninsula, western Alaska, where it dominated the full-glacial, upland vegetation *ca.* 17,500 yr BP preserved under tephra (Goetcheus and Birks 2001). *Chenopodium* macrofossils make up 0.04% of the assemblage but Chenopodiaceae-*Amaranthus* pollen reaches 5% at the Bluefish Exposure (McCourt's 1982) and 5-<10% at Bluefish Caves (Ritchie *et al.* 1982), and it typically inhabits disturbed xeric sites, such as active floodplains, making its rarity in the macrofossil assemblage surprising. The absence of *Sphagnum* sp. macrofossils is interesting because McCourt (1982) indicates it occurs up to 10% in pollen zone BF4a at the Bluefish Exposure and is known from numerous full-glacial pollen sites throughout eastern Beringia (Gajewski *et al.* 2001). However, McCourt's (1982) spores may be the product of reworking from older deposits, as maybe the case with other localities because the spores are highly resistant and easily re-deposited (C.E. Schweger, personal communication, 2002). The absence or rarity of macrofossils representing ericads and other woody shrubs indicates that cold, dry soils probably did not provide suitable substrates for their establishment. Further, the predominance of calcareous substrates was not conducive for establishment of ericads, or other plants that prefer acidic substrates.

# Chapter 7: Environmental Mosaics and the Full-Glacial Bluefish Ecosystem

Paleoecological investigations at the Bluefish Exposure, and comparisons with other full-glacial dated macrofossil assemblages, demonstrate variability at both the meso-scale (Bluefish watershed) and macro-scale (eastern Beringia), lending support to the notion of mosaics addressed by many researchers (e.g., Anderson *et al.* 1988; Anderson and Brubaker 1994; Barnosky *et al.* 1987; Edwards *et al.* 2000; Goetcheus and Birks 2001; Guthrie 2001; Ritchie 1984; Schweger and Habgood 1976; Schweger 1976, 1982, 1992, 1997; Schweger *et al.* 1982).

Macrofossils and fossil pollen from the Bluefish Exposure and Bluefish Cave support a watershed scale mosaic, highly dependent on slope, local drainage, elevation, aspect and substrate. Reconstructed vegetation types include; near shore littoral, mid-rich fens, mesic riparian meadows, midslope steppe, and upland discontinuous tundra. The commonly cited terms prevalent in the Beringian paleoecological literature such as "steppe", or "tundra" cannot subsume all these vegetation types. Such broad terminology is no longer adequate in discussions concerning full-glacial environments of Beringia. Local and regional scale variability must be acknowledged. Local reconstructions should be rooted in locally derived data, and caution must be taken when applying those reconstructions beyond that specific locale. Further, regional reconstructions must acknowledge both the mosaic nature of local vegetation, and the incredible environmental variability across the continental region of Beringia.

## 7.1 Watershed Mosaic

Gleason (1926) concluded that plant "communities" are the result of individualistic responses of plants to specific changes in local physical factors and environments. Paleoecology has embraced the individualistic approach to community development because it accounts for the unique mixture of species seen in the paleoecological record that reflect the dynamics of past environmental change (eg. MacDonald 1993; Schweger 1997).

Edwards and Armbruster (1989), Lloyd *et al.* (1994) and Roland (1996) documented the importance of local site characteristics on composition and distribution of extrazonal steppe vegetation along altitudinal gradients on slopes in Alaska where the lack of moisture prevents the establishment of forests. These floristic studies demonstrate that the distribution of steppe plants is predominantly controlled by individualistic responses of plants to competition for light, available moisture and other associated micro and macroclimatic effects of elevation (Roland 1996). On the present subarctic landscape of Alaska and Yukon, zonal forests prevent sufficient net solar radiation from reaching the ground, limiting steppe plants to certain disjunct, south-facing, dry, open localities (Roland 1996). Variability in the amount of net solar radiation and other microclimatic factors controls the occurrence of steppe plants and may produce substantial variation in the composition and species richness of steppe communities.

Edwards and Armbruster (1989), Lloyd *et al.* (1994) and Roland (1996) observed that the coldest high elevation areas on steppe-dominated slopes often support a mixture of steppe plants and drought tolerant tundra plants. In these areas there is a transitional ecotone with increasing elevation between steppe and tundra resulting from an overall decrease in soil temperature, soil moisture, and length of growing season (Edwards and Armbruster 1989; Lloyd *et al.* 1994;

Roland 1996). These factors eliminate steppe plants from inhabiting higher elevation locales on dry slope sites. Within these transitional ecotones, the individualistic responses of steppe and tundra plants results in the potential to form a wide variety of combinations and associations (Roland 1996).

During the full-glacial, increased cold temperatures and aridity (Anderson and Brubaker 1993, 1994; Barnosky *et al.* 1987; Bartlien *et al.* 1991, Hopkins *et al.* 1982; Kutzbach 1987) prevented establishment of tress in Beringia, enabling steppe plants to inhabit the majority of the landscape. However, individualistic responses of plants to local site characteristics resulted in substantial compositional variability within the steppe vegetation. Local moisture eliminated many steppe plants from becoming more widespread in valley bottoms. Further, colder soils and shorter growing seasons in uplands resulted in discontinuous fell-field tundra devoid of many steppe plants. Thus, vegetation "zones" reconstructed for Bluefish watershed did not have clearly defined borders. Transitional ecotones probably occurred at lower elevations between 300 and 350 m asl, with mixtures of mesic-meadow and steppe plants. Further, transitional ecotones probably occurred in the high elevations between 600 and 750 m asl, with mixtures of tundra and steppe plants These ecotones exhibited plant communities resulting from individualistic responses to altitudinal gradients similar to those observed by Edwards and Armbruster (1989) Lloyd *et al.* (1994), Roland (1996).

## 7.2 Regional Mosaic

Macrofossil and pollen data sets from the Bluefish watershed, near the eastern extremity of eastern Beringia, can be compared with those from western Alaska in order to test the suggestion of increasing aridity from west to east across full-glacial eastern Beringia, as put forward by Anderson and Brubaker (1994) and Barnosky *et al.* (1987). Macrofossils dating from 20,000 to 14,000 yr BP from the now submerged Bering Land Bridge were interpreted by Elias *et al.* (1997: 293) as representing "birch-graminoid tundra with small ponds containing aquatic plants". There is no *Artemisia* or other steppe or grassland taxa macrofossils, and little or no *Artemisia* pollen in their dataset (Elias *et al.* 1997: 302-303). Further, macrofossils dating to *ca.* 17,500 yr BP from upland vegetation preserved under tephra on the Seward Peninsula were interpreted by Goetcheus and Birks (2001: 144) as representing a full-glacial "dry, meadow and herb-rich tundra, often dominated by herb- *Kobresia myosuroides* with a mixture of grasses, sedges, and herbs and a continuous understory of mosses". No macrofossils of *Artemisia* were recovered by Goetcheus and Birks (2001:143). Both macrofossil records from western Alaska show no or no compositional affinities to graminoid-*Artemisia* dominated steppe and differ substantially from the Bluefish Exposure full-glacial paleoecological data.

Anderson and Brubaker (1994), Barnosky *et al.* (1987), Bartlein *et al.* (1991) and Guthrie (2001) suggest that differences in vegetation from western Alaska and the northern Yukon reflect climatic patterns resulting from proximity to oceanic moisture, and glacial ice, respectively. Guthrie (2001) suggests this resulted in a more mesic "Beringian Buckle" in the Bering Land Bridge area and western Alaska within the megacontinental belt of arid steppe. Areas proximal to the Bering Land Bridge were influenced by the shallow, but mostly ice covered, Bering and

Chukchi seas, with a greater amount of low cloud cover (Guthrie 2001; Kutzbach 1987). Guthrie (2001) suggests that the decreased solar radiation and increased moisture effectively limited the distribution of steppe plants in this area. Swedish botanist Hultén (1937) first postulated this Pleistocene refugium in the Bering Land Bridge area for mesic adapted tundra plants in order to account for the present distribution of plants in northeast Eurasia and western Alaska. Paleoecological records obtained from the "Beringian Buckle" suggest increased mesic conditions with increased tundra plant types and less xerophytic steppe plants (eg. Anderson and Brubaker 1994; Barnosky *et al.* 1987; Elias 1992; Elias *et al.* 1996, 1997; Goetcheus and Birks 2001).

When compared with the records from western Alaska (Elias *et al.* 1996, 1997; Goetcheus and Birks 2001), macrofossil and pollen data from the Bluefish watershed (McCourt 1982; Ritchie *et al.* 1982) and others from northern Yukon (Cwynar 1982; Ritchie and Cwynar 1982), support increasing aridity from west to east across unglaciated eastern Beringia (Barnosky *et al.* 1987; Brubaker and Anderson 1994). The exposed continental shelf increased continentality in the northern Yukon, helping to maintain an arid climate. Most atmospheric moisture would have been blocked from reaching the northern Yukon by the Laurentide ice to the east, the St. Elias Mountains and Cordilleran ice to the south, and the largely frozen Arctic Ocean to the north (Kutzbach 1987). Southerly flow and anticyclonic circulation off the Laurentide ice sheet produced katabatic winds that further intensified the aridity (Kutzbach 1987). Full-glacial paleoecological records from northern Yukon are dominated by taxa indicative of arid conditions and exposed ground (Cwynar 1982; McCourt 1982; Ritchie and Cwynar 1982; Ritchie *et al.* 1982). Abundant *Artemisia* pollen and *A. frigida* macrofossils from the Bluefish Exposure may be the best proxy-indicator for arid conditions the northern Yukon.

Again, one has to be careful in not over generalizing when reconstructing the paleoecology in a particular locale, as both evidence from western Alaska and Bering Land Bridge, (Elias *et al.* 1997, 1997; Goetcheus and Birks 2001) and Bluefish watershed indicate environmental mosaics. Moisture gradients had significant effects on the composition of the full-glacial vegetation, whether locally in a single watershed, or regionally across a megacontinental area of Beringia.

Vertebrate paleontologists have long known that there was an apparent biogeographical filter that prevented the exchange of Pleistocene megafauna from both sides of the Bering Strait (Guthrie 2001). For example, the arid adapted woolly rhino (*Coelodonta antiquitatis*), never reached the New World. Likewise, the North American camel (*Camelops*), American kiang (*Equus* sp.), short-faced bear (*Arctodus*), muskoxen (*Bootherium*), and badger (*Taxus*), were never able to pass through this mesic barrier and reach northeast Asia (Guthrie 1990, 2001). This mesic "Beringian Buckle" acted more like a filter than a barrier, because many of the Pleistocene megafauna, mammoth (*Mammuthus*), Bison, horse (*Equus lambei*), and saiga antelope (*Saiga tatarica*) were freely exchanged between the Old and New Worlds (Guthrie 2001). To account for the Pleistocene distribution of mammals that inhabited both the New and Old Worlds, Guthrie (2001) suggests that some arid steppe occurred in the central Bering Land Bridge area in a mosaic with mesic lowland vegetation (Elias *et al.* 1996, 1997; Goetcheus and Birks 2001). Invertebrate assemblages also reflect this moisture gradient, with more tundra species in western Alaska and increasingly more arid adapted insects to the east (Elias 1992, 2001). Guthrie (2001:561) suggests that the relatively more mesic conditions in western Alaska and central Bering Land Bridge represent a minor interruption in the megacontinental Beringian arid steppe belt during the full-glacial. Multi-proxy evidence indicates that this arid "Mammoth Steppe" was apparently well expressed in the Bluefish watershed.

## 7.3 The Full-Glacial Bluefish Ecosystem

Data from the Bluefish Exposure and Bluefish Caves can be incorporated with others from eastern Beringia to qualitatively reconstruct the Bluefish watershed ecosystem with probable components and their interactions (Figure 8; see Schweger 1992, 1997). Attempting such reconstructions is inherently difficult due to complexities with the application of contemporary ecological theory and models to a limited paleoenvironmental dataset. However, certain key issues can be addressed to further advance our knowledge of Beringian paleoenvironments.

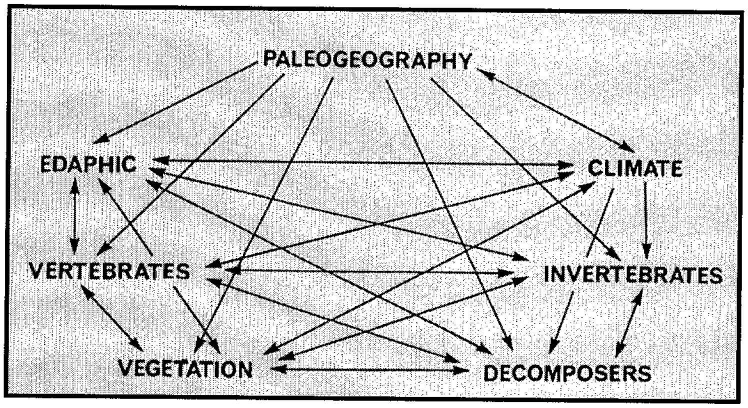


Figure 8. Diagram of the Beringian ecosystem model. From Schweger (1992:37, Figure 1).

### *Paleogeography*

At *ca.* 18, 000 yr BP, the Bluefish Exposure site was approximately 200 km west of the Laurentide ice margin (Duk-Rodkin 1999). At this time, Glacial Lake Old Crow was in a transgression phase in the Bluefish and Old Crow Basins, eventiually reaching an elevation of 366 m (Duk-Rodkin and Hughes 1995). Sediments from the Upper Bluefish exposure suggest that the Bluefish River flowed into the flooded Bluefish Basin, forming a near-shore deltaic environment at the site (McCourt 1982). Specimens of *Thymallus arcticus* in the macrofossil record indicate fast flowing water in the Bluefish River (McAllister and Harington 1969.

### *Paleoclimate*

Regional macro-scale paleoclimatic reconstructions for eastern Beringia stress the importance of macro-scale cold and aridity (Anderson and Brubaker 1993, 1994; Barnosky *et al.* 1987; Bartlein *et al.* 1991; Hopkins 1982; Kutzbach 1987). Mutual Climatic Range (MCR) analysis of fossil insects from the Bluefish Exposure indicate that average summer temperatures were as much as 5.5° C colder than present, while winters were about 2.8° C warmer (Elias 2001; S.A. Elias, unpublished data). These estimates are in agreement with Milankovitch insolation variation for Beringia that predict a summer insolation minimum with a corresponding winter insolation maximum for 65° N latitude during the LGM. (Kutzbach 1987; Bartlein *et al.* 1991; Elias 2001). Loess deposited at Bluefish Caves indicates an arid, windy climate in the watershed (Cinq-Mars and Morlan 1999). Snow cover was probably thin and discontinuous, forming drifts that were dirty with loess (Hopkins *et al.* 1982). The presence of *Saiga tatarica* at Bluefish Caves supports this paleoclimatic reconstruction. *Saiga* has physiological adaptations to dry, dusty conditions and is currently restricted to the arid steppes of Eurasia with a snow cover of only 10-30 cm/yr (Bannikov *et al.* 1967; Harington and Cinq-Mars 1995).

Guthrie (2001) suggests that generally clear skies were a crucial factor in the full-glacial ecosystem. Increased macro-scale continentality decreased the overall amount of cloud cover across eastern Beringia, creating generally clear skies (Guthrie 2001). This coupled with high latitudinal position resulted in high net radiation and increased absorption of solar energy on the landscape in summer (Guthrie 2001). High net radiation accelerated evapotranspiration, deepening the active layer, warming up and drying out the soils. On the other hand, clear winter skies during the long dark winters created net radiation loss to the black night sky, forming cold dry soils (Guthrie 2001). Decreased albedo on darkened snow drifts would have melted snow much earlier in spring, producing a rapid spring green up and nutrient flush (Guthrie 1990; Schweger *et al.* 1982). It may seem paradoxical that insect paleoclimatic data and the corresponding Milankovitch summer insolation minimum indicate much colder than present summer air temperatures (Elias 2001), However, Guthrie (2001) suggests that the effect of clear skies, and resultant increased absorption of solar radiation, created warmer and better drained soils than present, enabling the widespread establishment of bunchgrasses, *Artemisia* and other steppe plants.

### *Soils*

Guthrie (1990, 2001), McCourt (1982) and Schweger (1992, 1997) hypothesized that full-glacial Beringian soils were warm, dry, and much better drained with deeper active layers than soils found in the region today. This hypothesis is supported by macrofossils of deep-rooted steppe plants such as *Poa* and *Elymus* bunchgrasses and *Artemisia frigida* in the Bluefish watershed. Guthrie (1990, 2001), Höfle *et al.* (2000), Laxton *et al.* (1996), and Schweger (1992) suggest that incremental deposition of loess created highly productive full-glacial soils that were nutrient rich, slightly alkaline pH, and had high nutrient-carbon turnover rates. Loess accumulation created much exposed mineral soils with constant disturbance, favoring an open, pioneer herbaceous vegetation (Schweger 1992, 1997). Schweger (1992, 1997) suggested that loessal soils were a crucial factor in the maintenance of Beringian steppe and reconstructed the hypothetical Glacial Rego Brown Soil (Agriculture Canada Expert Committee on Soil Survey

1987). In a study to test Schweger's (1992) loessal hypothesis, Laxton *et al.* (1996) demonstrated that glacially derived loess increased species biomass, diversity, and available nutrients in grasslands in the Kluane lake region of southwest Yukon. The loessal, Glacial Rego Brown soil described by Schweger (1992) probably supported the steppe vegetation in the Bluefish watershed.

### *Vertebrates*

Any paleoecological reconstruction for Beringia must account for the dietary requirements of a diverse, contemporaneous herbivore fauna, as suggested by the "Productivity-Paradox" (Schweger *et al.* 1982) and the effects of the fauna on the composition of the vegetation. Within the Bluefish watershed, these mammals include dated mammoth, bison, horse, caribou, muskox, sheep and Saiga (Cinq-Mars 1979, 1990; Cinq-Mars and Morlan 1999; Harington and Cinq-Mars 1995; Burke and Cinq-Mars 1996, 1998; see Tables 1 and 2). The Bluefish watershed habitat mosaic was crucial for maintaining the diverse large mammal herbivore community. Redmann (1982) and Bliss and Richards (1982) indicate that large mammal herbivore biomass and diversity is increased by both increased plant species richness and landscape habitat diversity. Further, French (1979) and Redmann (1982) indicate that herbivore activity helps maintain habitat by stimulating primary production, and increasing species diversity and richness by nutrient cycling from manuring, removal of standing dead biomass, and mechanical disturbance of the soil through trampling. The herbivore community at Bluefish Caves probably contributed to the full-glacial ecosystem in these ways.

Burkes and Cinq-Mars (1996, 1998) established mortality profiles from *Equus lambei* teeth at Bluefish Caves and integrated them with the sites pollen data (Ritchie *et al.* 1982) to reconstruct probable herbivory behavior in the Bluefish watershed. Burkes and Cinq-Mars (1998) drew from modern ethological data from the closely related extant *Equus caballus*, which generally inhabit steppe-like regions, are capable of enduring a wide variety of climates, and form small, stable bands that seasonally use different habitats within their territorial range (Berger 1986). Burke and Cinq-Mars (1998) suggest there was a seasonal movement of horses in the Bluefish watershed between valley bottoms, which sheltered them in the winter, and the sparsely vegetated upland plateau, that was accessible only in summer. During the winter months, the horses may have descended into the valley to seek shelter among willow stands. Also, the slopes around the caves, and the caves themselves may have provided shelter from sudden storms (D'Andrea and Gotthardt 1984). Reconstructing the seasonal foraging behavior for the rest of the Pleistocene large-mammals is beyond the scope of this paper, but one can assume that the other grazers followed similar patterns.

Using the Burke and Cinq-Mars (1998) seasonal habitat model, data from Bluefish Caves and Bluefish Exposure suggest that steppe vegetation on the midslope region could have served as a fall/winter/spring range. Bunchgrasses, *Artemisia frigida* and pioneering forbs would have provided nutritious above ground fodder during these seasons. Large mammal dietary studies indicates that *Artemisia frigida* is an important and often preferred fodder in all seasons except summer, with high values of dry matter digestibility, digestible protein, and energy yield for domestic sheep, cattle, bighorn sheep, antelope, deer, elk, Saiga antelope and bison (Bannikov *et al.* 1967; Cooperrider and Bailey 1984). Further, macrofossil remains from the gastrointenstinal tract of a 26,280 yr BP *Equus lambei* carcass from Last Chance Creek, Yukon indicates a diet rich in *Poa*, *Artemisia frigida*, *Potentilla*, *Draba*, and Caryophyllaceae. Herbivores would have grazed on these plant taxa in the Bluefish watershed (A. Telka and C.R. Harington, unpublished data). Evidence from frozen carcasses (Ukraintseva 1993) and tooth samples (Guthrie 2001) indicates that the large mammals of Beringia were predominantly grazing on grasses. Dry, windy conditions on gentle slopes created a pattern of discontinuous snow cover that enabled access to winter fodder, a crucial factor enabling survival of the winter population bottleneck (Guthrie 1990). Snow patch communities near loess dirtied, melting snow drifts, probably provided green, nutrient rich fodder early in the spring (Schweger *et al.* 1982). The riparian zone, rich in *Deschampsia* and *Carex* dominated mesic meadows would have also provided abundant, nutritious fodder and an important water source in the spring, summer, and fall. In contrast to the reconstructions offered by Ritchie *et al.* (1982), data from Bluefish Exposure and Bluefish Caves (Burke and Cinq-Mars 1996, 1998) indicate that the midslope area around Bluefish Caves can be considered within the ecological tolerances of *Equus lambei*, and, therefore, cannot be a marginal habitat of discontinuous tundra. Thus, the ecological requirements of water, shelter, and food for the large-mammal community were met during full-glacial times within the Bluefish watershed, largely because of habitat mosaics. Paleobotanical and paleontological data from the Bluefish watershed support the Guthrie's (1990) hypothesized full-glacial "Mammoth Steppe" in this local context.

# Chapter 8: Review of Regional Late Pleistocene Stratigraphy

Radiocarbon dates from the Upper Bluefish Unit, Bluefish Exposure are significant for detailing the late Pleistocene chronology of Glacial Lake Old Crow in the northern Yukon basins and relation to the glacial chronology of Laurentide ice (Lemmen *et al.* 1994; Duk-Rodkin and Hughes 1995). This review and synthesis of published and unpublished stratigraphic and geochronological data situates the Bluefish Exposure stratigraphy within a regional geological history (Figure 9, Table 12). A glacial limits map for the Yukon (after Duk-Rodkin 1999) is presented in Figure 10. The stratigraphies for the Bluefish, Old Crow and Driftwood Basins are presented in Figure 11, and the Bell Basin in Figure 12. Sites reviewed were chosen for their detailed stratigraphic data and/or reliable ages within the range of radiocarbon dating. Only late Pleistocene data are described.

## 8.1 Stratigraphy of Sites in Unglaciated Areas

### A) Bluefish Basin

#### Ch'ijee's Bluff: HH-228

Located on the Porcupine River, 15 km downstream from Old Crow village, Ch'ijee's Bluff is a *ca.* 55 m high exposure situated near the middle of the Bluefish Basin (67° 28' N, 139° 54' W, 287 m asl). Hughes (1972) described the site numbered HH-228, and the stratigraphy was further refined by Lichti-Federovich (1974), Matthews *et al.* (1987, 1990), Pearce *et al.* (1982), Schweger (1989), Schweger and Matthews (1991), and Westgate *et al.* (1985). As a result, Ch'ijee's Bluff serves as an informal type-site for the Bluefish Basin (C.E. Schweger, personal communication, 2002).

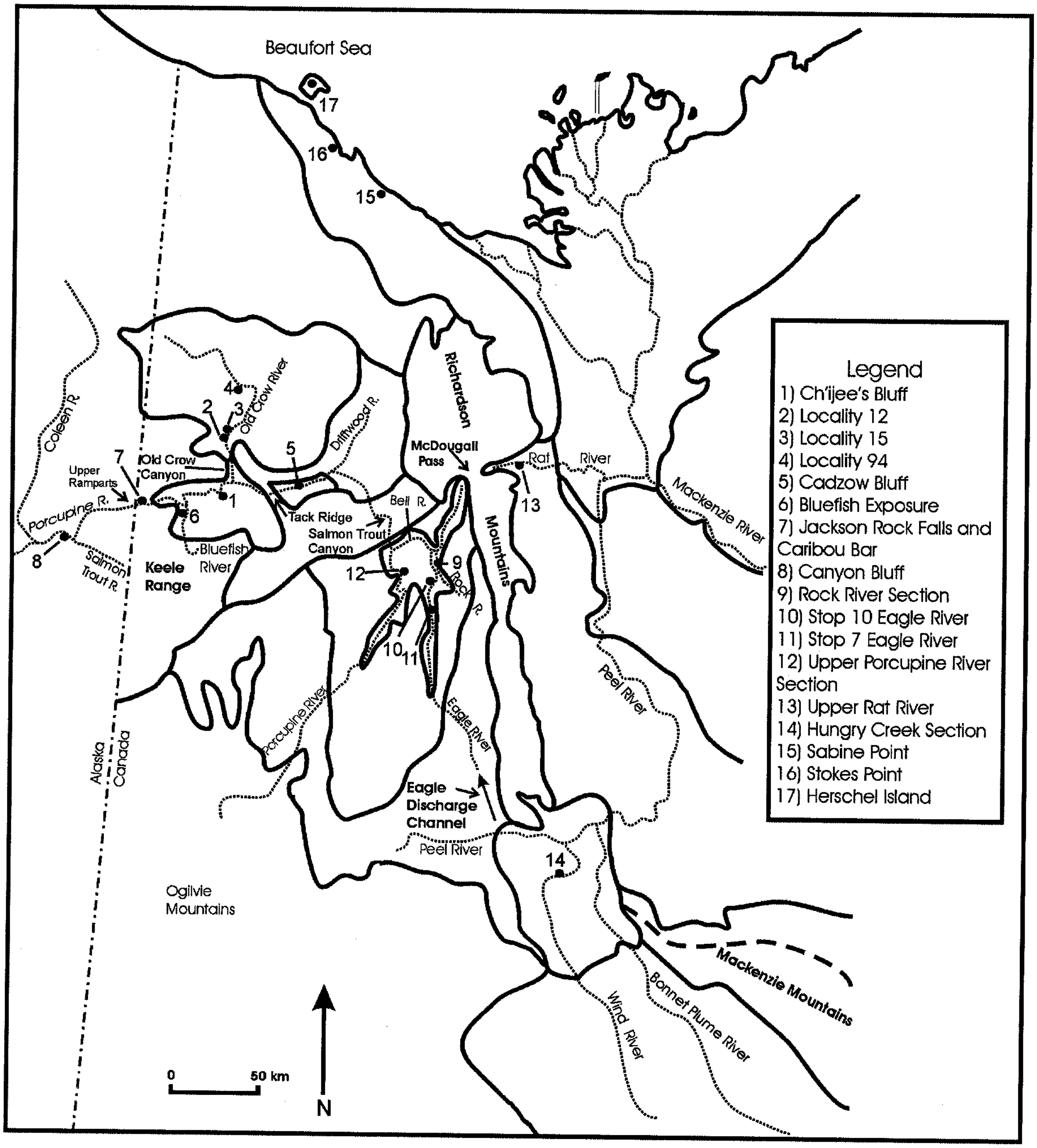


Figure 9. Locations of sites mentioned in this chapter (except the Mackenzie Mountain sites).

Unit 4 separates the lower, non-glacial lacustrine unit (Schweger 1989; Westgate *et al.* 1985) from the upper glaciolacustrine sediments and is further subdivided into three sub-units (Unit 4a, 4b, 4c). Unit 4a is 5-8 m of alluvial sands and gravel. Unit 4b consists of 4-6 m of alluvial sands, lacustrine silt and organic silt or peat, and contains the Old Crow Tephra, a regional stratigraphic marker dated to 140,000 to 150,000 yr BP (Westgate *et al.* 1985). Unit 4c is a 6-10 m thick complicated package of lacustrine and alluvial sediments informally termed the "variegated sands and silts" (C.E. Schweger, personal communication, 2002) with abundant autochthonous peat and detrital organics (Matthews *et al.* 1990). Mississippian spores appear in the pollen record near the top of Unit 4c and reach peak abundance in the overlying glaciolacustrine sediments (Matthews *et al.* 1987; Matthews *et al.* 1990; Schweger 1989; Schweger and Matthews 1991). These spores have their origins in the Mississippian-aged shales of the Ford Lake Formation that have been incised as the Eagle River eroded the Eagle River Discharge Channel (Schweger 1989; Utting 1986). Finite radiocarbon ages of 30,590 ±220 yr BP (TO-219) and 32,400 ±770 yr BP (GSC-952) provide ages for the upper sediments in Unit 4c and the influx of Mississippian spores.

The overlying upper glaciolacustrine Unit 5 exhibits up to 5 m of ice-rich rhythmically laminated clay and silt sediments typical of varves from a deep-water glacial-lake (Matthews *et al.* 1990). Exposures at the downstream end indicate a gradation from varved clays to massive silty-clay near the top of the unit (Matthews *et al.* 1987). Capping the section, Unit 6 consists of organic silts that grade upward to woody peat. A radiocarbon age of 10,740 ± 180 yr BP (GSC-121) from Unit 6 provides a minimum age for drainage of Glacial Lake Old Crow and the onset of peat formation.

### B) Old Crow Basin

Incision by the Old Crow River and its tributaries has resulted in numerous bluff exposures, including Locality 12 (67° 50' N, 139° 34.1 W, 300 m asl), Locality 15 (67° 51.1' N, 139° 49.6' W, 300 m asl) REM 78-1 (68° 53' N, 139° 46' W) and HH-68-13 (68° 3.5' N, 139° 43' W). Lichti-Federovich (1973), Matthews *et al.* (1987), Morlan (1980, 1986), and Morlan *et al.* (1990) provide a general composite stratigraphy for the basin.

Unit 2 separates the lower, non-glacial lacustrine unit (Pearce *et al.* 1982; Schweger 1989; Westgate *et al.* 1985) from the upper glaciolacustrine sediments and is further subdivided into two sub-units (Unit 2a, 2b). Unit 2a is approximately 15 m thick and contains a complicated sequence of reworked glaciolacustrine clays, colluvial sediments and alluvial silts, sands and gravels the with the Old Crow Tephra about 0.30-1.00 m below the upper contact (Morlan 1980, 1986; Westgate *et al.* 1985). At localities in the southern area of the basin, an unconformable contact referred to as Disconformity A, separates Unit 2a from the overlying Unit 2b. This erosional contact can be traced at a number of localities along the course of the Old Crow River and was probably formed during the earliest transgression of Glacial Lake Old Crow in the basin (Matthews *et al.* 1987, Morlan 1980, 1986; Morlan *et al.* 1990). Overlying Disconformity A, Unit 2b contains approximately 5-7 m of cross-bedded fluvial silts and sands, lacustrine sediments and colluvial facies with Mississippian-aged spores (Morlan 1980; Walde 1986), correlative with Unit 4c at Ch'ijee's Bluff (Schweger 1989). Bone artifacts found along bluffs in the Old Crow Basin are all found within Unit 2a above Disconformity A (Morlan 1980, 1986).

Finite radiocarbon dates obtained from Unit 2b of 31,400 ±660 yr BP (GSC-2739, Locality 12); 31,300 ±640 yr BP (GSC-1191, HH-68-13-16A); 35,700 ±600 yr BP (RIDDL-137, REM 78-1); 35,500 ±1050 yr BP (GSC-2507, Locality 12); 34,100 ±500 (RIDDL-728, REM 78-1); 32,200 ±500 (RIDDL-729, REM-78-1); 34,700 ±600 (RIDDL-139, REM 78-1) place an age on the influx of glacially diverted drainage and Mississippian spores into Old Crow Basin (Schweger 1989; Morlan *et al.* 1990; Walde 1986). Further, Morlan (1986) and Morlan *et al.* (1990) report that over 40 redeposited mammal bones found along the Old Crow river have AMS radiocarbon ages between 25,200 ±400 yr BP (RIDDL-191) to 39,500 ±1600 yr BP (RIDDL-127), and probably originated from Unit 2b (see Dyke *et al.* 2002; Morlan 1986; Morlan *et al.* 1990; Thorson and Dixon 1983). Overlying Unit 2b, Unit 3 contains approximately 5 m of ice-rich, glaciolacustrine clay sediments that contain abundant Mississippian spores. Overlying the glaciolacustrine sediments is the Unit 1 fluvial sands, that yielded a bison bone with an age of 12,460 ±440 yr BP (Locality 11, I-3574) This date provides a minimum age for drainage of Glacial Lake Old Crow and resumed fluvial deposition in Old Crow Basin (Morlan *et al.* 1990).

### C) Driftwood Basin

#### Cadzow Bluff: HH-62-222

Cadzow Bluff (67° 34' N, 138° 54' W, 300 m asl), approximately 30 km upstream from Old Crow on the Porcupine River, has yielded two AMS radiocarbon dates on a probiscidean tusk found 0.50 m below the upper glaciolacustrine unit. The tusk was recovered in a sequence of lacustrine and fluvial sediments similar to those of upper Unit 4c immediately below the upper glaciolacustrine unit at Ch'ijee's Bluff and Unit 2b in the Old Crow Basin (Morlan 1986, Morlan *et al.* 1990). Ages of 24,700 ±250 yr BP (RIDDL-229) and 25,170 ±630 yr BP (NMC-1232) indicate that the deep-water phase of Glacial Lake Old Crow in Driftwood Basin is younger than *ca.* 24,000 yr BP.

## D) Bell Basin

### Rock River Section: HH-75-1

The Rock River Section (67°14.7' N, 137° 03.7 W, 280 m asl) is a 32 m high alluvial exposure along the Rock River in the Bell Basin. At the base, Unit 1 contains over 7 m of organic rich silts and autochthonous peat that yielded radiocarbon dates as old as >43,000 yr BP (GSC-2585) to 41,100 ± 1650 yr BP (GSC-2574) on *Salix* sp. wood. The upper 0.60 m of Unit 1 contains a zone of silt and fine sand overlain by 0.10 m of finely laminated silt and fine sand with Mississippian spores (C.E. Schweger, unpublished data). *In situ* rodent fecal pellets recovered from these laminated silt and sand sediments, 0.20 m below the upper contact with overlying Unit 2a, yielded a radiocarbon age of 34,220 ± 170 yr BP (TO-124; Schweger and Matthews 1991).

Unit 2a contains 7 m of ice-rich rhythmically laminated glaciolacustrine clays. The lower part of the unit exhibits approximately 350 to 400 recognized varves that become obscured upwards (O.L. Hughes and J.V. Matthews Jr., unpublished data). Above, Unit 2b consists of 13 m of jökulhaup-type sediments, containing alternating cyclic beds of laminated clays and ripple marked fine sands that probably represent successive glaciolacustrine discharge events (Hughes *et al.* 1981; O.L. Hughes and J.V. Matthews Jr., unpublished data; Schweger and Matthews 1991). These are overlain by Unit 2a, consisting of 8 to 9 m of laminated glaciolacustine clays. Capping the section, the 3 m thick Unit 3 peats lie unconformably above the lacustrine sediments.

### Eagle River: HH-80-10

Sediments similar to those of Units 2b and 2c of the Rock River Section are exposed at locality HH-80-10 on the Eagle River (67° 04' N, 136° 06' W, 320 m asl). Beginning 8.5 m above the river level are 23.5 m of jökulhaup-type sediments comprising approximately 10 cyclic units of alternating ripple bedded sand and massive silt and/or clay. These cyclic sediments are overlain by 10.5 m of ripple cross-bedded, fine to medium sands with silt. The uppermost 5.5 m of the section consist of glaciolacustrine clay similar to that of Unit 2c at Rock River. A radiocarbon date of 31, 700 ±456 yr BP (GSC-3984) was obtained in ripple cross-bedded sands in association with a granite shield clast at the 17 m level (N.W. Rutter[1], University of Alberta, unpublished data).

Stratigraphies similar to both Rock River Section and HH-80-10 are also exhibited at site HH-80-7 on the Eagle River (67° 49' N, 137° 04' W; N.W. Rutter

---

[1] Stratigraphy described as in N.W. Rutter's field notes from 1980 visit to site. Obtained from the files of O.L. Hughes, Geological Survey of Canada, Terrain Sciences, Calgary with permission from A. Duk-Rodkin.

unpublished data) and Stop 17 on the Upper Porcupine River (67° 12'N, 137° 32' W; J.L. Pilon[2], Archaeological Survey of Canada, unpublished data).

### E) Upper Ramparts of Porcupine River, Yukon

Data from the Jackson Rock Falls site (67° 25' 35" N, 40° 52' 10" W) has provided evidence for the onset of aeolian deposition at the western edge of the formerly inundated Bluefish Basin with a radiocarbon date of 14,860 ±120 yr BP (BETA-88793). This age is in agreement with an IRSL (Infrared Stimulated Luminescence) date of 15,000 ± 10% yr BP also obtained at the site (Lauriol *et al.* 2002). These ages for sedimentation in the Bluefish Basin after the drainage of Glacial Lake Old Crow are supplemented with an additional IRSL date of 16,000 yr BP from the Caribou Bar site on Porcupine River (67° 25'26" N, 140° 47' 50" W). This IRSL age obtained on alluvial sands indicates resumed alluvial deposition after glacial-lake drainage (B. Lauriol, personal communication, 2002).

### F) Lower Porcupine Alluvial Terraces of Alaska

Stratigraphic work on the lower Porcupine River in Alaska by Thorson (1989) and Thorson and Dixon (1983) describes the alluvial history of that portion of the river and inferred relationships to the northern Yukon basins. Stages of the Porcupine River were defined on the basis of alluvial sediments and terrace formation west of Upper Ramparts. At an elevation of 200 m asl, at the Canyon Bluff site, sheets of coarse gravel were

---

[2] Stratigraphy described as in J.L. Pilon's field notes from 1980 visit to site. Obtained from the files of O.L. Hughes, Geological Survey of Canada, Terrain Sciences, Calgary, with permission from A. Duk-Rodkin.

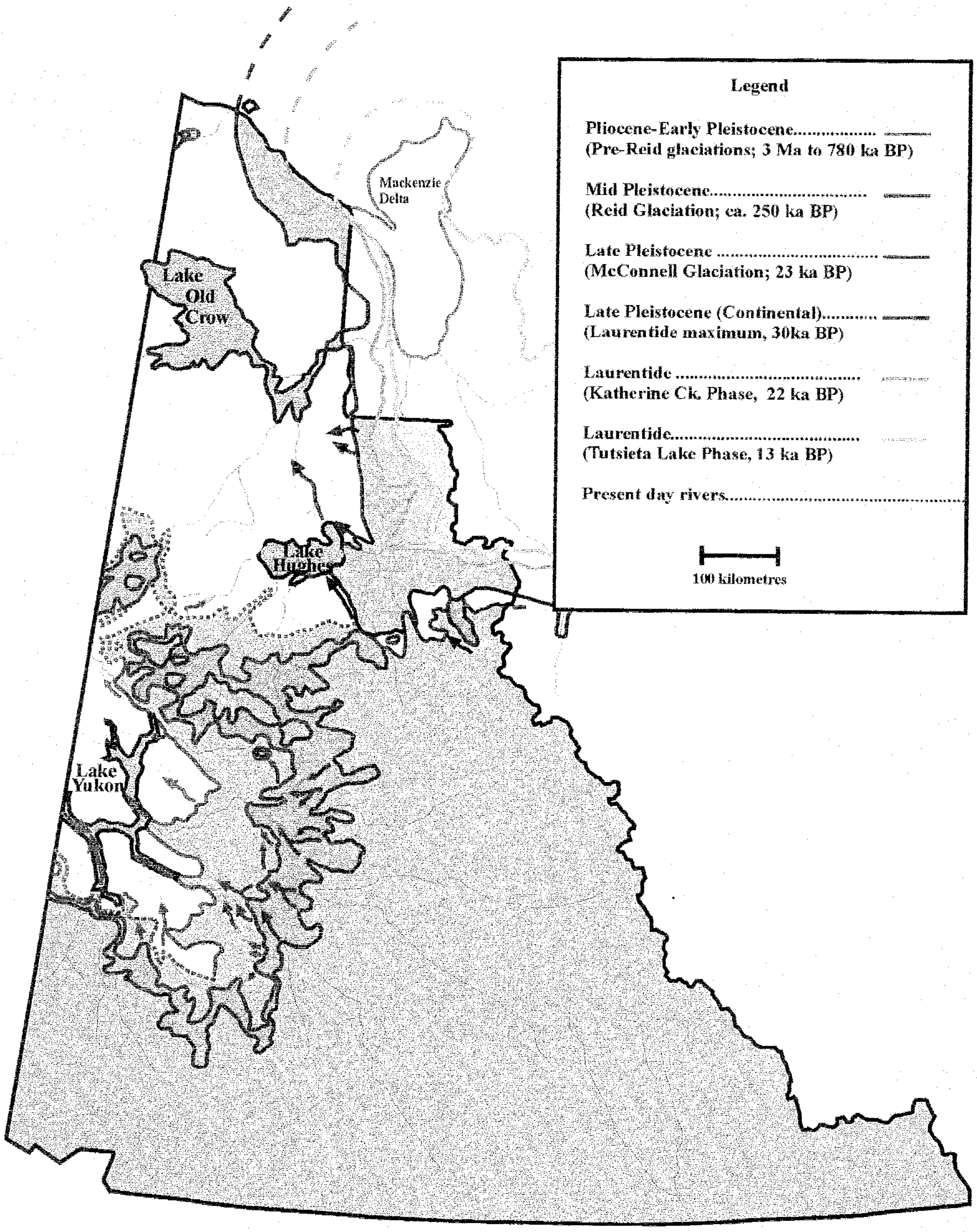
spread over the width of the valley by a high discharge braided river. Peat below these sediments yielded an infinite radiocarbon age of >35,000 yr BP (BETA-1823). Thorson and Dixon (1983) suggest that the only source of discharge for this event would be strong-overflow from the inundated northern Yukon basins. Thorson and Dixon (1983) suggest that this event would have initialized incision of the Upper Ramparts on the Porcupine River near the Alaska/Yukon border. These deposits are only found along the alluvial terraces west of where Salmon Trout River enters the westward flowing channel of the Porcupine River.

Thorson and Dixon's (1983) valley fill stage (Stage 7), indicated by fine alluvial deposits, began shortly before 30,600 yr BP and ended sometime after 26,600 yr BP, suggesting westward overflow from the Yukon basins did not occur during this interval (Thorson and Dixon 1983). A period of deep incision and stripping of earlier terraces (Stage 8) commenced sometime after 26,000 yr BP (Thorson 1989). This event suggests strong glacial-lake overflow from the Yukon basins. The deep incision culminated in a much lower position of the Porcupine River, clearly below the surfaces of the Bluefish and Old Crow Basins (Thorson and Dixon 1983). Incision of the Upper Ramparts was rapid during this event, lowering the channel elevation and establishing the westward flow of the Porcupine River into the Yukon River system.

## 8.2 Chronology of Glaciated Areas

### A) Mackenzie Mountains

Work in the Mackenzie Mountains has defined limits for the all-time maximum and Katherine Creek Phase re-advance of Laurentide ice (Figure 10; Duk-Rodkin 1999; Duk-Rodkin and Hughes 1991, 1995; Duk-Rodkin *et al.* 1996; Lemmen *et al.* 1994). The Laurentide ice limits are well defined by ice marginal features and shield erratics, traceable from the Mackenzie Mountain Front in the southeast to Richardson Mountains in the northwest, (Duk-Rodkin and Hughes 1991). Shield erratics and meltwater channels are located as high as 1558 m asl in the Landry Ranges, south of the Keele River, and 1430 m asl in the Canyon Ranges, north of the Keele River (Duk-Rodkin and Hughes 1991). These high elevation features mark the all-time maximum limit of Laurentide ice (Duk-Rodkin and Hughes 1991). Shield erratics and moraine ridges are also located at lower elevations along Katherine Creek at 1280 m (64 57' N, 127 34' W) related to the later Katherine Creek Phase readvance of the Laurentide ice (Duk-Rodkin and Hughes 1991).



Glacial Limits Map of Yukon

Figure 10. Glacial limits of the Yukon Territory. After Duk-Rodkin (1999). Used with Permission from A. Duk-Rodkin, Geological Survey of Canada.

Cosmogenic ages ($^{36}$Cl exposure method) for the deposition of shield erratics in the Canyon Ranges date the all-time maximum and Katherine Creek Phase of the Laurentide ice. At an elevation of 1311 m asl, large boulders perched high on a bare bedrock bench, 3.5 km west of the Little Bear Creek section (64° 20' N, 126° 37' W), yielded $^{36}$Cl ages indicating glacial retreat from the all-time maximum position shortly after *ca.* 30,000 yr BP (Duk-Rodkin *et al.* 1996: 891; Lemmen *et al.* 1994). $^{36}$Cl ages from shield errratics from lower elevations at Little Bear Creek indicate that retreat from the Katherine Creek Phase position was underway by *ca.* 19,000 yr BP (Duk-Rodkin *et al.* 1996). The Katherine Creek Phase of Laurentide ice correlates with advance of the Cordilleran ice in southern and central Yukon (Duk-Rodkin *et al.* 1996). Dates of 23,900 ±1140 yr BP (GSC-2811) and 26,350 ±280 yr BP (TO-393) obtained below McConnell glaciation till provide a limiting age for Cordilleran ice advance (Jackson and Harington 1991, Klassen 1987). Evidence from the Mackenzie Mountains indicates that the Late Wisconsinan ice sheet was the only continental ice sheet to reach the Richardson and Mackenzie Mountains (Duk-Rodkin *et al.* 1996; Lemmen *et al.* 1994).

## B) Bonnet Plume Basin

### Hungry Creek Section: HH-72-54

Stratigraphic studies by Hughes *et al.* (1981) in the Bonnet Plume Basin at the Hungry Creek Section (63° 34.5' N, 135° 30' W) detailed a single Laurentide till of late Wisconsinan age, designated as the Hungry Creek Till. Shield erratics at an elevation of

974 m asl mark the all-time maximum limit of the Hungry Creek Lobe of Laurentide ice in the basin (Duk-Rodkin, personal communication, 2002).

At the base of the Hungry Creek Section, Unit 1 consists of approximately 5 m of gravels with possible paleosol development that may indicate an early Pleistocene age (C.E. Schweger, personal communication, 2002). Unit 2a consists of laminated silts and clays, typical of varved glaciolacustrine sediment with dropstones of Canadian Shield origin (Hughes *et al.* 1981: 358). This glaciolacustrine unit grades upward into Unit 2b, fluvial-deltaic sediments of alternating silts and organic rich sands implying the retreat of Laurentide ice (Hughes *et al.* 1981: 358). Unit 2b yielded a beaver-chewed *Picea* wood piece dating to 36,900 ± 600 yr BP (GSC-2422). Immediately beneath Hungry Creek Till, Unit 3 is a channel fill that cuts through the underlying units suggested to represent glacial outwash (Hughes *et al.* 1981). Although some stratigraphic problems are exhibited at Hungry Creek (C.E. Schweger, personal communication, 2002) the site is crucial in that it indicates a single Laurentide glaciation of Bonnet Plume Basin after 36, 900 yr BP. Subsequent retreat of the Hungry Creek lobe caused Glacial Lake Hughes to occupy the entire Bonnet Plume Basin, with 27 m of glaciolacustrine silts and clays deposited on top of Hungry Creek Till in the lower reaches of Wind and Bonnet Plume Rivers (Duk-Rodkin and Hughes 1995; O.L. Hughes and J.V. Matthews Jr., unpublished data).

### C) Peel Plateau and McDougall Pass

Catto (1986) recognized three glacial events in the Peel Plateau and along the eastern flanks of the Richardson Mountains. The first glacial advance is marked by the Brown Bear sediments that may date to the Middle Pleistocene, however its age is not confidently assigned and its areal extent is unknown (Catto 1996).

A second glacial advance from the Canadian shield resulted in the deposition of the "Snake River" till in the southern Peel Plateau and Upper Rat River Valley of McDougall Pass (Catto 1996). In McDougall Pass, this advance deposited 150 m of glacial drift and shield erratics that are found to an elevation of 884 m asl (Duk-Rodkin *et al.* 1996; A. Duk-Rodkin, personal communication, 2002). The continuity of glacial limit features with those in Mackenzie Mountains indicates that this advance is correlative with the all-time maximum Laurentide ice at *ca.* 30,000 yr BP (Duk-Rodkin and Hughes 1995; Duk-Rodkin *et al.* 1996; Lemmen *et al.* 1994).

A third glacial event resulted in the deposition of till in the southern Peel Plateau (Catto 1996) correlative to the Katherine Creek Phase re-advance of Laurentide ice (Duk-Rodkin and Hughes 1995). This ice marginal position is recognized by a major meltwater channel system that lies about 270 m below that of the Laurentide all-time maximum, and is traceable as a continuous feature from Rat River to the south for approximately 100 km (Duk-Rodkin and Hughes 1995). The Katherine Creek Phase Laurentide ice margin was east of McDougall pass (Duk-Rodkin and Hughes 1995).

Blockage of the lower Rat River by Katherine Creek Phase ice flooded the Upper Rat River valley with Glacial Lake Old Crow to an elevation of 366 m in McDougall

Pass (Catto 1996). Organic remains from basal lacustrine sediments in upper Rat River valley yielded radiocarbon dates of 21,300 ±270 yr BP (GSC-3371) and 21,200 ±240 yr BP (GSC-3813). Overlying cyclic ripple-bedded sediments indicate that periodic drops in glacial-lake levels may have occurred during the glaciolacustrine history in the upper Rat River valley (Catto 1986; O.L. Hughes and J.V. Matthews Jr., unpublished data). Retreat of Laurentide ice subsequently formed lakes impounded along the ice front correlative to the later Tutsieta Lake Phase (Duk-Rodkin and Hughes 1995; Hughes 1985).

## D) Yukon Coastal Plain

At least two advances of Laurentide ice are recognized on the Yukon Coastal Plain with earlier and intervening episodes of non-glacial sedimentation (Rampton 1982). The earliest ice advance resulted in the widespread deposition of Buckland till with clearly defined ice marginal features along the flanks of the Buckland Hills (Rampton 1982). The Buckland Glaciation was assigned an Early Wisconsinan age because of the subdued morphology of the moraines and radiocarbon date of 22,400 ±400 yr BP (GSC-1262) atop Buckland drift. However, subsequent work supports its correlation with the Late Wisconsinan all-time maximum as evident in the Mackenzie and Richardson Mountains (Duk-Rodkin and Hughes 1995; Dyke *et al.* 2002a; Hughes *et al.* 1981; Lemmen *et al.* 1994). Retreat from the Buckland ice limit was well underway by 16,200 ±150 yr BP (RIDDL-756), as shown by a date on an *Equus lambei* bone overlying terminal moraine till on Herschel Island (Dyke *et al.* 2002a; Harington 1989). A less extensive Sabine Phase glaciation is defined by moraines and associated outwash features within the Buckland limit and correlates with the Katherine Creek Phase evident along Mackenzie Mountains (Duk-Rodkin and Hughes 1995; Duk-Rodkin 1999). A date of 14,400 ±180 yr BP (GSC-1792) on limnic peat overlying Sabine Phase till indicates ice-free conditions by this time (Dyke *et al.* 2002a; Rampton 1982).

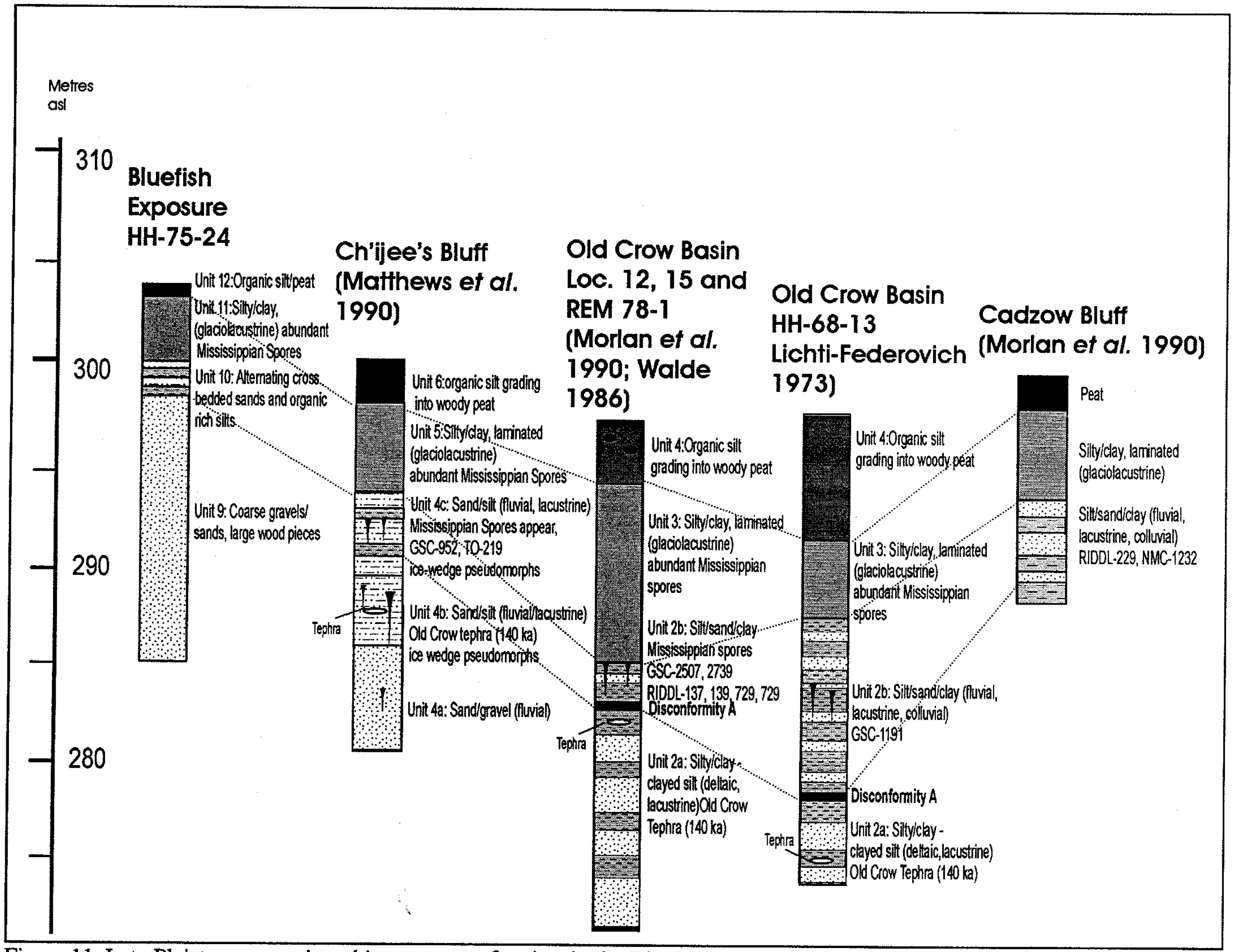


Figure 11. Late-Pleistocene stratigraphic sequences for sites in the Bluefish, Old Crow and Driftwood Basins.

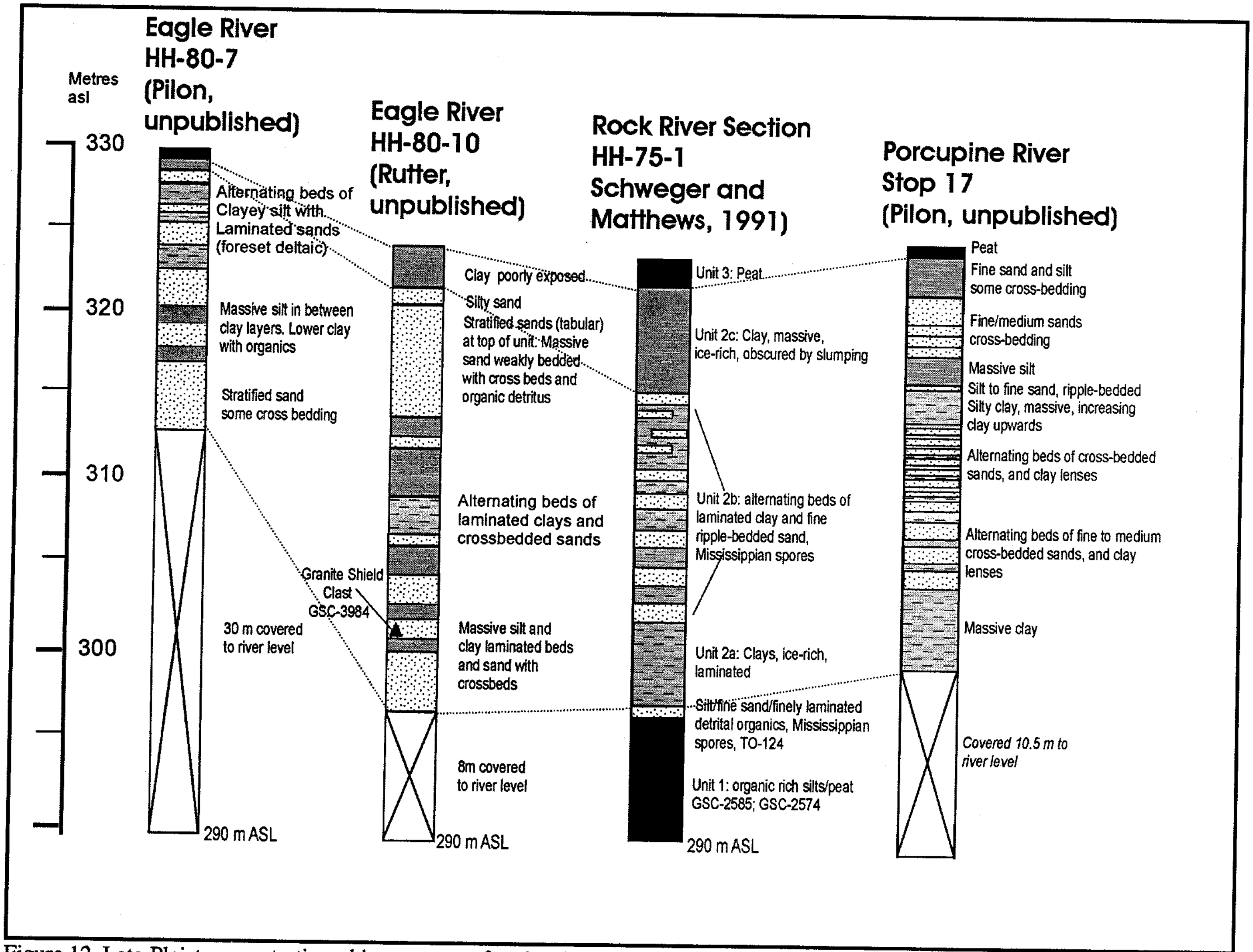


Figure 12. Late-Pleistocene stratigraphic sequences for sites in the Bell Basin.

Table 12. Regional geochronological data from the study region. AMS $^{14}$C = Accelerator Mass Spectrometry radiocarbon, conv. $^{14}$C = Conventional radiocarbon, IRSL=Infared Stimulated Luminescence

| Date | Lab. No. | Reference | Locality | Material | Stratigraphy | Lat. (N) | Long. (W) | Elev. (m asl) | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 16,440 +/-110 | AA45510: AMS $^{14}$C | This study | Bluefish Exposure | *Carex* sp. | Unit 11a | 67° 23' | 140° 22' | 300 | maximum age for final drainage of Glacial Lake Old Crow |
| 17,400 +/- 120 | AA42629: AMS $^{14}$C | This study | Bluefish Exposure | Poaceae, *Artemisia* | Unit 10 alluvial silts | 67° 23' | 140° 22' | 300 | dates initial transgression of glacial lake to SW edge of Bluefish Basin, |
| 17,570 +/-140 | AA45506: AMS $^{14}$C | This study | Bluefish Exposure | *Luzula/Juncus* siliquees | Unit 10 alluvial silts | 67° 23' | 140° 22' | 300 | as above |
| 17,710 +/-840 | AA45507: AMS $^{14}$C | This study | Bluefish Exposure | *Taraxacum* achenes | Unit 10 alluvial silts | 67° 23' | 140° 22' | 300 | as above |
| 18,700 +/- 130 | AA42630: AMS $^{14}$C | This study | Bluefish Exposure | Poaceae, *Artemisia* | as above | 67° 23' | 140° 22' | 300 | as above |
| 18,490 +/- 160 | AA42631: AMS $^{14}$C | This study | Bluefish Exposure | Poaceae, *Artemisia* | as above | 67° 23' | 140° 22' | 300 | as above |
| 18,880 +/-110 | AA45509: AMS $^{14}$C | This study | Bluefish Exposure | Poaceae caryopses | as above | 67° 23' | 140° 22' | 300 | as above |
| 18,030 +/- 250 | AA45505: AMS $^{14}$C | This study | Bluefish Exposure | Poaceae caryopses | as above | 67° 23' | 140° 22' | 300 | as above |
| 23,360 +/- 600 | AA45508: AMS $^{14}$C | This study | Bluefish Exposure | *Drepanocladus* stems/leaves | as above | 67° 23' | 140° 22' | 300 | as above |
| 20,800 +/-200 | GSC-2946: conv. $^{14}$C | Blake 1987 | Bluefish Exposure | organic detritus | as above | 67° 23' | 140° 22' | 300 | date likely too old because of aquatic moss fragments in bulk sample |
| >40,000 | GSC2373: conv. $^{14}$C | Blake 1987 | Bluefish Exposure | *Picea* wood | Unit 9 coarse sand and gravel | 67° 23' | 140° 22' | 275 | |
| >51,900 | GSC-2373-2: conv. $^{14}$C | Blake 1987 | Bluefish Exposure | *Picea* wood | as above | 67° 23' | 140° 22' | 275 | |
| >53,000 | GSC-2373-3: conv. $^{14}$C | Blake 1987 | Bluefish Exposure | *Picea* wood | as above | 67° 23' | 140° 22' | 275 | |
| 30, 590 +/-220 | TO-219: AMS $^{14}$C | Matthews *et al.* 1990 | Chi'jee's Bluff | plant detritus | Unit 4c, fluvial silts, sands and lacustrine silts underneath upper glaciolacustrine unit | 67° 28' | 139° 54' | 275 | dates initial influx of water from diverted Peel River, incision of Eagle River Discharge Channel, and earliest transgression glacial lakes |

|  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| 32,400 +/-770 | GSC-952: conv. $^{14}C$ | McAllister and Harington 1969 | Chi'jee's Bluff | shells | as above | 67° 28' | 139° 54' | 275 | as above |
| 10,740 +/-180 | GSC-121: conv. $^{14}C$ | Lichti-Fedorovich 1974 | Chi'jee's Bluff | autochthonous peat | peat overlying glaciolacustrine clays | 67° 28' | 139° 54' | 280 | minimum age on glacial-lake drainage |
| 14,860 +/-120 | BETA-88793: AMS $^{14}C$ | Lauriol *et al.* 2002 | Jackson Rock Falls | wood fragment | aeolian silt above fluvial sand and gravel | 67° 25' | 140° 52' | 350 | age of loess deposition after drainage of glacial-lakes |
| 15,000 +/-10% | IRSL | Lauriol *et al.* 2002 | Jackson Rock Falls | aeolian silt | aeolian silt above fluvial sand and gravel | 67° 25' | 140° 52' | 350 | age of loess deposition after drainage of glacial-lakes |
| 16,000 | IRSL | Lauriol pers.com. 2002 | Caribour Bar | fluvial sand |  | 67° 28' | 140° 48' | 300 | age of normal fluvial deposition on Porcupine River after drainage of glacial lakes |
| 31,300 +/-640 | GSC-1191: conv. $^{14}C$ | Lichti-Federovich 1973 | Old Crow HH-68-13 | plant detritus | Unit 2b, fluvial silts, sands and lacustrine silts underneath upper glaciolacustrine unit | 67° 03' | 139° 49' | 300 | dates initial influx of water from diverted Peel River, incision of Eagle River Discharge Channel, and earliest transgression glacial lakes |
| 31,400 +/-660 | GSC-2739: conv. $^{14}C$ | Lowdon and Blake 1979 | Old Crow Loc.12 | autochthonous peat | as above | 67° 50' | 139° 40' | 300 | as above |
| 35,500 +/-1050 | GSC-2507: conv. $^{14}C$ | Schweger and Matthews 1991 | Old Crow Loc. 12 | autochthonous peat | as above | 67° 50' | 139° 40' | 300 | as above |
| 35,700 +/-600 | RIDDL-137: AMS $^{14}C$ | Morlan *et al.* 1990 | Old Crow REM 78-1 | bone | as above | 68° 53' | 139° 46' | 300 | as above |
| 34,100 +/-500 | RIDDL-728: AMS $^{14}C$ | Morlan *et al.* 1990 | Old Crow REM 78-1 | bone | as above | 68° 53' | 139° 46' | 300 | as above |
| 32,200 +/-500 | RIDDL-729 AMS $^{14}C$ | Morlan *et al.* 1990 | Old Crow REM 78-1 | bone | as above | 68° 53' | 139° 46' | 300 | as above |
| 34,700 +/-600 | RIDDL-139 AMS $^{14}C$ | Morlan *et al.* 1990 | Old Crow REM 78-1 | bone | as above | 68° 53' | 139° 46' | 300 | as above |
| 25,200 +/-400 | RIDDL-191: AMS $^{14}C$ | Morlan *et al.* 1990 | Bank of Old Crow River | bone | likely Unit 2b, above Disconformity A |  |  |  | part of series of 40 mammal bone dates that likely correspond to earliest stage of glacial-lakes |
| 39,500 +/-1600 | RIDDL-127: AMS $^{14}C$ | Morlan *et al.* 1990 | Bank of Old Crow River | bone | as above |  |  |  | as above |
| 12,460 +/-440 | I-3574: conv. $^{14}C$ | Morlan 1980 | Old Crow CRH-11 | bison bone | above glaciolacustrine clay |  |  | 260+ | minimum age for drainage of glacial-lakes |
| 24,700 +/-250 | RIDDL-229: AMS $^{14}C$ | Morlan *et al.* 1990 | Cadzow Bluff | mammoth tusk | fluvial silts, sands and lacustrine silts underneath upper glaciolacustrine unit | 67° 34' | 138° 54' | 300 | maximum age for onset of deep water transgression of glacial-lake |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 25,170 +/-630 | NMC-1232: AMS $^{14}C$ | Morlan *et al.* 1990 | Cadzow Bluff | mammoth tusk | as above | | | 300 | as above |
| >43,000 | GSC-2585: conv. $^{14}C$ | Schweger and Matthews 1991 | Rock River | *Salix* wood | basal peats below glaciolacustrne clays | 67° 15' | 137° 04' | 460 | age on peat formation before the onset of earliest transgression of glacial-lakes |
| 41,100 +/-1650 | GSC 2574: conv. $^{14}C$ | Schweger and Matthews 1991 | Rock River | autochthonous peat | as above | 67° 15' | 137° 04' | 460 | age on peat formation before the onset of earliest transgression of glacial lakes |
| 34,220 +/-120 | TO-124: AMS $^{14}C$ | Schweger and Matthews 1991 | Rock River | rodent faecal pellets | 20 cm below glaciolacustrine clays | 67° 04' | 136° 06' | 460 | maximum age for onset of Peel River diversion and earliest transgression of glacial lakes |
| 31,700 +/-456 | GSC-3984 | Rutter 1980 unpublished | Eagle River HH-80-10 | wood fragment | 17 m above river in cyclic cross-bedded sands | 67° 12' | 137° 32' | | associated with granite shield clast, age for glacial diversion of Peel River |
| 36,900 +/-600 | GSC-2422: conv. $^{14}C$ | Hughes *et al.* 1981 | Hungry Creek | *Picea* wood | alluvium underneath till | 65° 35' | 135° 30' | | maximum date on last ice advance |
| 21,300 +/-270 | GSC-3371: conv. $^{14}C$ | Catto 1986 | Upper Rat River | organic detritus | lacustrine silt | 67° 43' | 135° 51' | 220 | date on maximum level of glacial lakes in interior basins and Upper Rat River |
| 21,200 +/-240 | GSC-3813: conv. $^{14}C$ | Catto 1986 | Upper Rat River | organic detritus | lacustrine silt | 67° 43' | 135° 51' | 220 | as above |
| 12,400 +/-120 | GSC-3691: conv. $^{14}C$ | Catto 1996 | Caribou River | autoch. peat | above till | 66° 13' | 135° 11' | | age for deglaciation of Tutsieta Lake Phase ice |
| 22,400 +/-240 | GSC-1262: conv. $^{14}C$ | Rampton 1982 | Stokes Point | peat | fine sand overlying till | 69° 15' | 138° 48' | 6 | minimum age on Buckland Till (glacial maximum) |
| 14,400 +/-180 | GSC-1792: conv. $^{14}C$ | Rampton 1982 | Sabine Point | peat | overlies til, underlacustrine clay | 69° 05' | 137° 51' | 18 | minimum age of Sabine Phase (equivalent to Katherine Creek phase) |
| 16,200 +/-150 | RIDDL-765: AMS $^{14}C$ | Harington 1989 | Herschel Island | horse bone | overlies Buckland Till | 69° 37' | 136° 56' | | as above |

# Chapter 9: Late Pleistocene Regional Geological History

New stratigraphic and radiocarbon data from the Bluefish Exposure refines the late Pleistocene chronology of northern Yukon basins, and their relationships to Laurentide ice margins. Because the Bluefish Exposure is situated at the southwestern extremity of the Bluefish Basin, radiocarbon dates from the site place important constraints on the timing of maximum flooding and drainage of the inter-connected Glacial Lake Old Crow that occupied the Bluefish, Old Crow, Driftwood, Bell Basins, and Upper Rat River valley (Duk-Rodkin and Hughes 1995; Duk-Rodkin *et al.* 1996; Lemmen *et al.* 1994).

A key to synthesizing the chronologies of Laurentide ice limits and glacial-lakes is the occurrence of the Mississippian spores in the sedimentary sequences in the northern Yukon basins. The former divide between the Peel and Eagle Rivers (560 m asl), is marked by the Eagle River Discharge Channel that is incised through shales of the Mississippian-aged Ford Lake Formation where these distinctive spores originate. Breaching of this divide requires Laurentide ice extending into Bonnet Plume Basin to divert the Peel River northward, initializing the incision of the Eagle River Discharge Channel (Duk-Rodkin and Hughes 1995). Abundant Mississippian spores from this Formation are found in sediments of Old Crow, Bluefish and Bell Basins. Their occurrence can only be attributed to the glacial diversion of the Peel River and the formation of Glacial Lake Old Crow (Lemmen *et al.* 1994; Schweger 1989). Therefore, radiocarbon dates obtained from sediments containing Mississippian spores provide correlative ages for initial formation of Glacial Lake Old Crow and advance of Laurentide ice into Bonnet Plume Basin and McDougall Pass.

## 9.1 Glacial Lake Old Crow

Two phases of late Pleistocene Glacial Lake Old Crow correlative to dated Laurentide ice margins are evident (Duk-Rodkin *et al.* In Review).

### A) Glacial Lake Old Crow

### Stage 1: *ca.* 35,000 to 22,000 yr BP

The earliest evidence for glacial-lake formation in the Old Crow, Bluefish and Driftwood Basins, Glacial Lake Old Crow Stage 1, comes from sediments beneath the laminated, upper glaciolacustrine units (Figure 13). Ages for the onset of flooding in the Old Crow Basin are provided by finite radiocarbon dates of 31,400 ±660 yr BP (GSC-2739); 31,300 ±640 yr BP (GSC-1191); 35,700 ±600 yr BP (RIDDL-137); 35,500 ±1050 yr BP (GSC-2507); 34,100 ±500 (RIDDL-728); 32,200 ±500 (RIDDL-729); 34,700 ±600 (RIDDL-139) obtained from Unit 2b. At Ch'ijee's Bluff, central Bluefish Basin, radiocarbon dates from upper Unit 4c indicate initiation of minor glaciolacustrine episodes from 32,400 ±640 yr BP (GSC-952) to 30,590 ±220 (T0-219). The latest age for this interval of transgressions is from the proboscidean tusk found at Cadzow Bluff in Driftwood Basin dating to 24,700 ±250 yr BP (RIDDL-229) and 25,170 ±630 yr BP (RIDDL-229). These dates originate from sediments indicating fluvial, lacustrine and colluvial episodes associated with the influx of Mississippian spores that mark the glacial diversion of Peel River and incision of Eagle River Discharge Channel. Alternating sedimentary regimes indicate repeated short-lived glacial-lakes that subsequently drained with resumed non-glaciolacustrine sedimentation in the basins. The lack of correlative sediments at the Bluefish Exposure indicates that Glacial Lake Old Crow Stage 1 occupied restricted areas of lower elevation in the Old Crow, Bluefish and Driftwood Basins and never reached the 366 m maximum level shorelines that surround the basins.

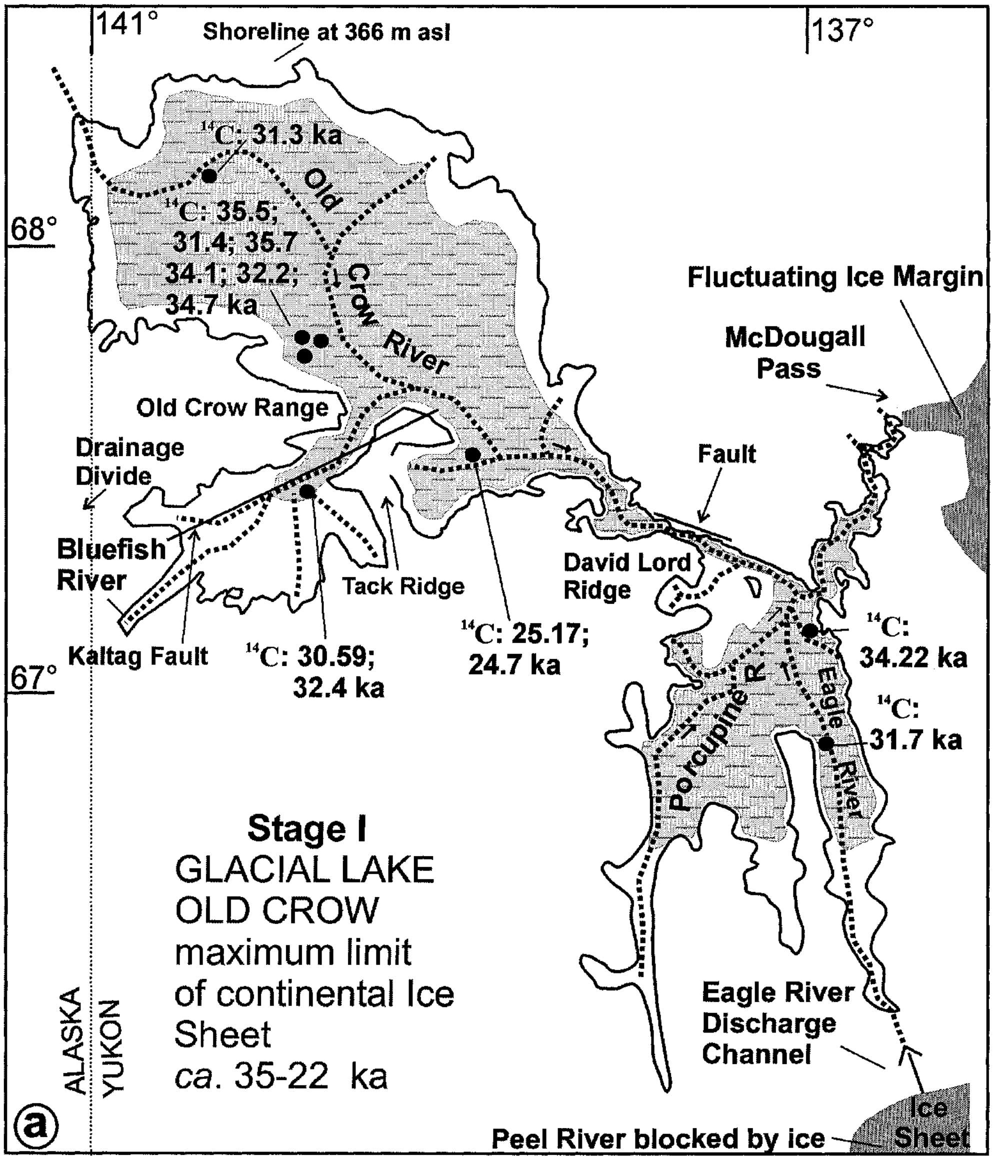


Figure 13. Glacial Lake Old Crow Stage 1 with paleo-drainage, *ca*. 34,000 to 22,000 yr BP. After Duk-Rodkin *et al*. (In Review).

The series of over 40 redeposited mammal bones AMS dated between 40,000 to 24,000 yr BP indicate that a single, continuous, glacial-lake could not have occupied the Old Crow Basin through that interval (Morlan *et al.* 1990). Instead, drained, exposed land surfaces within the Old Crow Basin were able to attract a diverse mammal community. Intermittent flooding would have effectively pushed the Pleistocene mammals out of the Old Crow Basin, seeking higher elevations beyond the glacial-lake shoreline. Glacial-lake drainage and re-vegetation saw the mammals return to the Old Crow Basin.

The Bell Basin, proximal to the diverted Peel River, probably flooded earlier than the Old Crow and Bluefish Basins. The influx of Mississippian spores evident in the upper 0.20 m of Unit 1 at Rock River section is dated to 34,220 ±170 yr BP (TO-124), providing an age for the onset of inundation in the Bell Basin. The Mississippian spores are found immediately below the thick sequence of laminated glaciolacustrine sediments, indicative of a stable, deep-water lake. Isostatic depression due to Laurentide ice along the Richardson Mountain Front may have permitted a deep-water lake to persist there immediately after diversion of the Peel River and before spillage northwestward into Old Crow and Bluefish Basins (O.L. Hughes and J.V. Matthews Jr., unpublished data).

At Rock River Section, cyclic sediments between two laminated deep-water glaciolacustrine units point to several jökulhlaup-like discharge events northeast through McDougall Pass, lowering the level of Glacial Lake Old Crow Stage 1 (Duk-Rodkin and Hughes 1995; O.L.Hughes and J.V. Matthews Jr., unpublished data; Schweger 1989). The current bedded sediments within the lacustrine sequence of Upper Rat River valley (Catto 1986) were also probably deposited as a result from these discharged events. At

Eagle River, HH-80-10, the 31,700 ±560 yr BP (GSC-3984) date associated with a granite shield clast in jökulhlaup-like sediments also correlates to this interval with eastward discharge events. The age on the granitic shield clast indicates a glacial advance into Bonnet Plume Basin at some point before *ca.* 32,200 BP.

During Glacial Lake Old Crow Stage 1, topographic barriers restricted the free flow of water between the interior basins. Paleogeographic reconstructions formulated by deleting erosional features and simplifying contour lines with similar surficial geology enable paleohydrological reconstruction for paleo-drainage for Glacial Lake Old Crow Stage 1 (Figure 13). The Old Crow Range formed an east-west barrier between the Old Crow and Bluefish Basins, facilitating southeastward drainage of the Old Crow Basin to the paleo-Porcupine River. The Bluefish Basin drained northeast along the southwest-northeast trending Kaltag Fault (Norris 1981), forming a junction with the Old Crow Basin drainage immediately north of Driftwood Basin. Paleo-Porcupine River and Bell Basin drainage continued eastward through McDougall Pass joining with meltwater channels of the Laurentide ice to the Mackenzie Delta (Duk-Rodkin and Hughes 1995). The paleo-Porcupine drainage from the Ogilvie Mountains would not have followed its present course northward across David Lord Ridge via Salmon Cache Canyon. Instead, the eastward paleo-Porcupine River continued through low-lying areas along fault traces north of David Lord Ridge (Norris 1981), joining with the northeast trending drainage from Ogilvie Mountains, and continuing eastward to McDougall Pass. The steep, nearly vertical walls of the present Salmon Cache Canyon suggest its incision did not begin until the establishment of westward drainage of Porcupine River during final drainage of Glacial Lake Old Crow Stage 2. Although numerous faults are found in the region

(Norris 1981), there is no evidence of late Pleistocene neo-tectonism within the stratigraphic sections of the northern Yukon (C.E. Schweger, personal communication, 2002).

Since Thorson and Dixon (1983) provide no evidence of glacial lake overflow events or incision of the Upper Ramparts between 35,000 and 24,000 yr BP on the Lower Porcupine River, drainage in the northern Yukon basins must have continued eastward along meltwater channels through McDougall Pass (Duk-Rodkin and Hughes 1995). A fluctuating Laurentide ice margin in McDougall Pass facilitated eastward drainage and was responsible for the alternating sequences of lacustrine and alluvial sediments with Mississippian spores in the Old Crow, Bluefish, and Driftwood Basin and thick cyclic sediments throughout Bell Basin. Fluctuations in the Laurentide ice margin may be due to climatic oscillations during the late Mid-Wisconsinan interstadial as climates became colder and increased ice accumulated, leading into marine isotope stage 2 or the late Wisconsinan glacial advance (Matthews *et al.* 1990). Rapid oscillations of the ice limit are consistent with a warm based Laurentide ice sheet with substantial basal meltwater (Beget 1989; A. Duk-Rodkin, personal communication, 2002). Ice marginal features related to oscillations of this magnitude may not be readily visible because successive events would effectively remove evidence of their occurrence.

It was during Glacial Lake Old Crow Stage 1 that the Laurentide ice reached its all-time maximum limit along the eastern flanks of the Richardson and Mackenzie Mountains, Bonnet Plume Basin and McDougall Pass (Duk-Rodkin and Hughes 1995; Lemmen *et al.* 1994). Glacial Lake Old Crow Stage 1 was impounded by the 2 km long margin of the Laurentide ice lobe that occupied McDougall Pass (Lemmen *et al.* 1994).

Cosmogenic $^{36}$Cl ages obtained from shield erratics indicate that the Laurentide ice reached the all-time maximum position along Richardson and Mackenzie Mountains, and into Bonnet Plume Basin and McDougall Pass by *ca.* 30,000 yr BP (Duk-Rodkin *et al.* 1996). This age is in agreement with evidence from the northern Yukon Basins that indicate glacial diversion of the Peel River and incision of the Eagle River Discharge Channel by *ca.* 35,000 yr BP. Thus, this suggests that Laurentide ice advanced into Bonnet Plume Basin and McDougall Pass by *ca.* 34,000 yr BP and commenced retreat after reaching the all-time maximum position after *ca.* 30,000 yr BP. This evidence suggests that the Laurentide ice in the northwest sector was in a period of advance possibly at least ten thousand years earlier than in other areas of western Canada (Dyke *et al.* 2002a; Jackson *et al.* 1997).

Repeated regression events of Glacial Lake Old Stage 2 would have resulted in abundant fine-grained sediments exposed on the basin floors. These sediments may have then been the source of the abundant full-glacial loess deposits that contain abundant Pre-Quaternary spores found within the Bluefish Caves full-glacial sediments (Cinq-Mars 1979, 1990; Cinq-Mars and Morlan 1999; Ritchie *et al.* 1982; Appendix E).

## B) Glacial Lake Old Crow
## Stage 2: *ca.* 22,000 to 16,000 yr BP

Glacial Lake Old Crow Stage 2, is characterized by a period of extensive, deep-water inundation covering an area of *ca.* 13, 000 km$^2$ in Bluefish, Driftwood, Old Crow, and Bell Basins, and the Upper Rat River Valley to a maximum elevation of 366 m asl (Figure 14; Duk-Rodkin and Hughes 1995). This extensive glacial-lake was connected to

Glacial Lake Hughes in Bonnet Plume Basin via the Eagle River Discharge Channel (Duk-Rodkin and Hughes 1995).

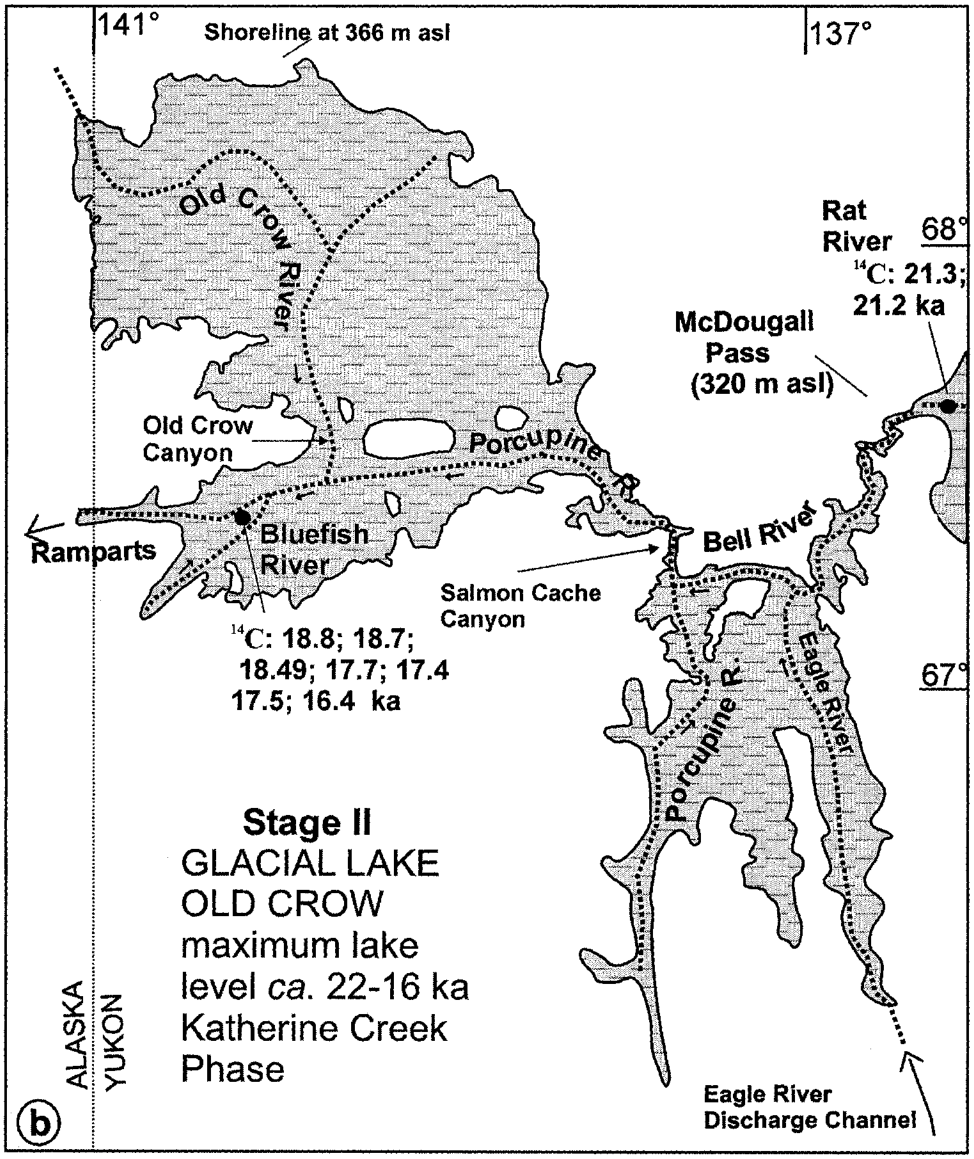


Figure 14. Glacial Lake Old Crow Stage 2, *ca.* 22,000 to 16,000 yr BP with present drainage. After Duk-Rodkin *et al.* (In Review).

Stratigraphic sections in Old Crow, Bluefish and Driftwood Basins all indicate thick, laminated glaciolacustrine sediments deposited above the initial influx of Mississippian spores. The onset of the deep-water phase is evident at Cadzow Bluff after

24,700 ±440 yr BP (RIDDL-229). Also, the series of AMS dates from redeposited bones in Old Crow Basin abruptly terminates at *ca.* 25,000 yr BP (Morlan *et al.* 1990), signifying the onset of extensive deep-water flooding that eliminated terrestrial herbivores from the basin (Thorson and Dixon 1983). These dates correlate with the onset of deep-water glacial lake formation in Upper Rat River valley by 21,300 ±270 yr BP (GSC-3371) (Catto 1986). Overlying Hungry Creek Till in Bonnet Plume Basin, over 27 m of glaciolacustrine sediments deposited by Glacial Lake Hughes correlate to Glacial Lake Old Crow Stage 2.

The radiocarbon dates from Bluefish Exposure indicate that Glacial Lake Old Crow Stage 2 reached the maximum elevation along the southwestern edge of Bluefish Basin sometime after 16,440 ±110 (AA45510). Thus, if we regard the Rat River valley dates of *ca.* 21,000 yr BP as the onset of deep-water flooding, it took *ca.* 4,500 years to fill all the interconnected basins to the high lake-water level.

Estimates for the length of time required for Glacial Lake Old Crow to reach maximum water levels at 366 m asl must consider the combined discharge from the Porcupine and Peel Rivers and their tributaries, combined with a substantial amount of meltwater from both Bonnet Plume Basin and through McDougall Pass. The combined mean annual discharge from the Porcupine and Peel Rivers contain sufficient water to fill Glacial Lake Old Crow in about 65 years (O.L. Hughes, unpublished data). With the addition of substantial glacial meltwater from a wet-based Laurentide ice sheet, it can be assumed that these basins could have probably been filled to the high water stand in even shorter time. However, full-glacial climates with extreme cold and aridity may have resulted in river discharges significantly lower than those today on the Peel and

Porcupine drainages. A decrease in discharge would have significantly slowed the rate of transgression.

Glacial Lake Old Crow Stage 2 was impounded by the Katherine Creek Phase Laurentide ice margin that was east of McDougall Pass and Bonnet Plume Basin (Duk-Rodkin and Hughes 1995). $^{36}$Cl dates on shield erratics indicate a probable age of 22,000 to 17,000 yr BP for the Katherine Creek Phase limit (Duk-Rodkin and Hughes 1995; Duk-Rodkin *et al.* 1996). The Katherine Creek Phase ice margin must have been stable for an extended time period to enable deposition of abundant, laminated lacustrine sediments and creation of well-defined shorelines to 366 m asl surrounding Old Crow and Bluefish and Bell Basins.

Glacial Lake Old Crow Stage 2 breached topographic divides that separated the Old Crow, Driftwood and Bluefish Basin. Glacial Lake Old Crow Stage 2 overtopped much of the former divide at Tack Ridge that separated the Bluefish from the Driftwood Basin. Also, the east-west divide formed by the Old Crow Range granites separating the Old Crow from the Bluefish Basins was breached. Overtopping former divides facilitated easier dispersal of water between Old Crow, Driftwood and Bluefish Basins.

### C) Final Drainage of Glacial Lake Old Crow
### *ca.* 16,000 to 15,000 yr BP

Geomorphic evidence suggests that incision of the Ramparts of the Porcupine River occurred rapidly from a single large drainage event that rearranged regional drainage patterns. The relatively soft Proterozoic dolomites, argillites and quartzites would have been incised easily by strong overflow as Glacial Lake Old Crow Stage 2 breached the former divide near the Alaska-Yukon border, establishing the present westward drainage of Porcupine River (Thorson 1989). Further, this drainage event probably produced the scabland features seen as lakes cut into the surface of basalt flows on the surfaces above and adjacent to the Lower Porcupine River of Alaska (Thorson 1989). Westward regional drainage established the present channel of the Old Crow River through the Old Crow Canyon and the present channel of the Bell and Porcupine Rivers, which incised Salmon Cache Canyon through David Lord Ridge at the northwest edge of Bell Basin.

Retreat of Laurentide ice from Katherine Creek Phase limit to the Tutsieta Lake Phase limit after *ca.* 17,000 yr BP (Duk-Rodkin and Hughes 1995) terminated the ice impoundment of Glacial Lake Old Crow. However, 150 m of Laurentide drift blocked McDougall Pass to an elevation of 320 m asl, preventing the re-establishment of eastward drainage. Thorson and Dixon (1983) indicate high westward discharge on the lower Porcupine River terraces sometime after 26,000 yr BP, which resulted in the scouring and stripping of earlier terraces, planation and deposition of coarse gravels. This event must correlate with the final drainage of Glacial Lake Old Crow because there is no correlative evidence for earlier westward discharge events from the northern Yukon during the late Pleistocene.

Drainage of Glacial Lake Old Crow Stage 2 is evident by a number of dates from the Old Crow and Bluefish Basins. The drainage of Old Crow Basin was completed by 12,460 ±440 yr BP (I-3574) based on a radiocarbon dated bison bone immediately above the glaciolacustrine unit. The date from the top of Unit 11a at Bluefish Exposure indicates that the drainage of Bluefish Basin occurred sometime after 16,440 ±110

(AA45510). This correlates well with resumed alluvial and aeolian deposition, near the Ramparts at the western edge of the recently drained Bluefish Basin, by 14,860 ±120 yr BP (BETA-88793) and 15,000 ± 10% yr BP at the Jackson Rock Falls site (Lauriol *et al.* 2002), and 16,000 yr BP at the Caribou Bar site (B. Lauriol, personal communication, 2002). Thus, the final drainage of Glacial Lake Old Crow occurred between 16,440 and *ca.* 15,000 yr BP. Further, these ages indicate that Glacial Lake Old Crow only maintained its maximum shoreline level of 366 m asl for between *ca.* 440 and 1,400 years. Final drainage in the basins left behind abundant fine-grained sediments that were re-deposited as loess along the terraces of the Porcupine River during the late-glacial (Lauriol *et al.* 2002).

# Chapter 10: Summary, Conclusions, and Implications

## 10.1 Thesis Objectives

The northern Yukon has been the focus of extensive interdisciplinary research on Quaternary paleoenvironments. The Yukon Refugium Project established the focus for much of this research; with the goal of providing detailed contextual data to support the interpretations of late Pleistocene archaeological remains in the Old Crow region. In an attempt to add to the record of late Pleistocene paleoecology and chronology, the Bluefish Exposure site was studied to analyse plant macrofossils and document stratigraphy and geochronology. The study site was chosen because of its known organic rich deposits, its location on the southwestern periphery of the Bluefish Basin and geographic proximity to the Bluefish Caves site. The results obtained could then be assembled with other datasets to reconstruct the paleoecology of the Bluefish watershed and provide comparison to eastern Beringia as a whole. This topic related to the "Productivity Paradox" which has drawn controversy for decades. Finally, results could be synthesized to provide a late Pleistocene geological history of glacial-lake intervals.

## 10.2 Summary and Conclusion of Results

Macrofossil analysis of the Upper Bluefish Unit, Bluefish Exposure, provides a detailed record of the vegetation in the Bluefish watershed *ca.* 18,000 yr BP. The variable habitat preferences of the watershed's fossil pollen and plant macrofossil taxa indicate that the assemblage represented different vegetation types with resemblance to littoral vegetation, mid-rich fens, mesic graminoid meadows, steppe, and upland discontinuous tundra. Perennial local moisture in Bluefish River floodplain favored *Drepanocladus-Scorpidium-Calliergon* dominated mid-rich, calcareous fens, and *Deschampsia-Carex* mesic meadows. Steppe, rich in bunchgrasses *Poa* and *Elymus*, diverse herbaceous forbs and *Artemisia frigida* inhabited the midslope region (350-650 m asl) on exposed loessal soils. Uplands on exposed regosol soils and bedrock ridges, above 650 m asl, were increasingly devoid of steppe plants, inhabited by xeric vegetation analogous to modern fell-field discontinuous tundra. Trees were absent and shrubs were a minor part of the overall vegetation.

Vegetation of the Bluefish watershed constituted a mosaic, highly dependent on local factors including moisture availability, slope, drainage, aspect and elevation. Vegetation associated with the diverse habitats provided abundant, nutrient rich fodder for the Pleistocene large-mammal herbivore community throughout the year. In contrast to those of Ritchie *et al.* (1982) and Ritchie (1984), this reconstruction supports the idea that the watershed was not a marginal habitat, or one that can be entirely described as either "steppe" or "tundra". However, data from the watershed are consistent with Guthrie's (1990) hypothesized "Mammoth Steppe" biome, as steppe was the dominant vegetation type in the watershed that contained the full plethora of full-glacial vertebrates. Rejection of the Beringian, productive arctic-steppe hypothesis (Guthrie 1990; Schweger *et al.* 1982) is no longer acceptable and the search for modern analogues without the inclusion of *Artemisia frigida* and bunchgrasses is misleading. The closest compositional and physiognomic analog to the predominant steppe vegetation in the

Bluefish watershed are the extrazonal steppes on dry bluffs with high solar radiation in Alaska and Yukon, and zonal steppe of Eurasia. Comparisons with sites in western Alaska demonstrate significant regional variations in the vegetation across eastern Beringia during the full-glacial interval. This study exemplifies the importance of using pollen, macrofossil and paleontological data together in reconstructing full-glacial Beringian environments.

A synthesis of geochronological and stratigraphic data from the Bluefish Exposure with those from other dated sites enable reconstruction of two intervals of Glacial Lake Old Crow. Stage 1 is a series of topographically restricted, short-lived lakes correlative with the all-time maximum limit of Laurentide ice between *ca.* 35,000 and 22,000 yr BP. The appearance of Mississippian spores in sediments of the northern Yukon basins, marks incision of Eagle River Discharge Channel by *ca.* 35,000 yr BP due to diversion of the Peel River drainage northward by Laurentide ice in Bonnet Plume Basin. The lack of correlative sediments at the Bluefish Exposure indicate that Stage 1 never reached the southwest edge of Bluefish Basin and the water level was below the 366 m asl shorelines found on the periphery of the Old Crow and Bluefish Basin. Drainage by jökulhaup-type lake lowerings continued eastward along melt-water channels of the Laurentide ice through McDougall Pass to the Mackenzie Delta. These data lend support to $^{36}$Cl ages for the all-time-maximum Laurentide ice advance in the northwest region at *ca.* 30,000 yr BP (Duk-Rodkin *et al.* 1996).

Dates from the Upper Rat River valley indicate that transgression associated with Glacial Lake Old Crow began *ca.* 22,000 yr BP. The 18,880 ±210 yr BP (AA45509) date and stratigraphic evidence from the Bluefish Exposure further document alluvial aggradation associated with the transgression of Glacial Lake Old Crow Stage 2 to the southwestern edge of the Bluefish Basin. Further transgression led to deposition of laminated, glaciolacustrine sediments after 16,440 ±110 yr BP (AA4551), providing evidence for the Stage 2 maximum water-level to 366 m asl when a quiescent glacial-lake occupied the Bluefish, Old Crow, Driftwood and Bell Basins, McDougall Pass and the Upper Rat River valley. Glacial Lake Old Crow Stage 2 was impounded to the east by the Katherine Creek Phase Laurentide Ice *ca.* 22,000 to 16,000 yr BP and to the west by a divide near the Alaska-Yukon border. Final drainage of Glacial Lake Old Crow between *ca.* 16,440 and 15,000 yr BP permanently established westward drainage of the Porcupine River to the Yukon River system by the rapid incision of the Upper Ramparts.

Results of this study indicate that exposures on margins where rivers entered basins, with aggrading alluvial deposits related to the formation of glacial-lakes, can provide ideal sites for paleoecological and stratigraphic studies. The excellent preservation of organic remains in this type of depositional setting enables the paleoecologist to obtain a plethora of data, including, fossil pollen, small mammals, fish, mosses, vascular plants, and insects. These records enable the reconstruction of both local and regional paleoenvironments from multi-proxy evidence within a narrow temporal context. Further, the locations of these sites often reflect environments that were utilized by prehistoric fauna and human populations. Excellent preservation of terrestrial plant macrofossils enables the establishment of a detailed AMS radiocarbon dated chronology that is very useful in correlative studies for regional geological events. In relation to glacial-lake formation, these sites provide detailed information for the final stages of transgression and drainage along basin margins. Such sites should be investigated in the other basins of unglaciated northern Yukon and Alaska to further detail local environmental mosaics and the diverse environments within late Pleistocene eastern Beringia.

## 10.3 Archaeological Implications

Much discussion on the paleoenvironments of Beringia has focussed on the "Productivity Paradox"; the biological productivity of the full-glacial vegetation and the ability to support large mammal herbivore, and in turn, human populations. The reconstructed ecosystem for the Bluefish watershed at *ca.* 18,800 and 16,500 yr BP indicates that much of the environment cannot be characterized as a depauperate fell-field tundra or a marginal habitat for large herbivores and/or humans. Data support interpretations of a productive vegetation that provided sufficient, nutritious fodder to sustain herbivores during all seasons. Large mammal herbivores present within the watershed throughout the year suggests there may have been no need for humans to seasonally migrate to other regions in pursuit of game. Herbivores would have followed a seasonal habitat round within the watershed that may have been replicated by hunting groups that preyed upon these fauna. Hunter-gatherers were active ecological components, significantly impacting the ecosystem through utilization of the diverse Pleistocene fauna for subsistence. Further, the presence of humans must have also increased fire frequency, significantly impacting the composition and patterning of vegetation (Schweger *et al.* 1982).

Although only speculative, evidence of arctic grayling in the full-glacial Bluefish River and Bluefish Caves indicates they too may have comprised an important component of the hunter-gatherer diet. Because this fish requires cold, fast flowing water, the Bluefish River could not have dried up or remained perennially frozen during full-glacial times. A water-source was consistently available to both animals and people in the valley bottom. Macrobotanical remains of ***Rubus idaeus*** and ***Chenopodium*** indicates these edible fruits and seeds could have been utilized by humans.

The geological history established by synthesizing stratigraphic and geochronological data from the Bluefish Exposure with those from the interior Yukon basins and Laurentide ice data place important age constraints for human occupation in the region. *In situ* bone artifacts in the Old Crow Basin are all found above Disconformity A and below the thick upper lacustrine unit. These correlate to Glacial Lake Old Crow Stage 1 *ca.* 35,000 to 22,000 yr BP, characterized by intermittent short-lived glacial lakes and an oscillating terrestrial and lacustrine environment. During this interval, evidence from bone artifacts places hunter-gatherer groups in the Old Crow basin.

The intermittent flooding and subsequent drainage produced an environment that probably was conducive to the establishment of productive vegetation. This vegetation, in turn, was utilized by the herbivores, that were then hunted by humans. Short periods of glacial-lake inundation forced both the herbivores and humans out of the basin, and their record of habitation may then be found in the regions uplands. Subsequent lake drainage would then enable herbivores and humans to again inhabit the basin.

The establishment of Glacial Lake Old Crow Stage 2 with a period of glacial-lake transgression to the 366 m asl maximum shorelines, gradually forced herbivores and humans out of the basins between *ca.* 22,000 to 16,000 yr BP. As proposed by Cinq-Mars and Morlan (1999), the archaeological record for the interval of Glacial Lake Old Crow Stage 1 in the Old Crow Basin, is later complemented during the Stage 2 interval in the uplands as evident at the Bluefish Caves site. A prolonged glacial-lake in the basins resulted in hunter-gatherers seeking out areas in the productive midslope elevations between flooded lowlands and harsh discontinuous tundra uplands. The similarities in the bone tool industries of the Old Crow Basin and Bluefish Caves suggests a possible cultural continuity within the Old Crow region from *ca.* 35,000 to 15,000 yr BP (Cinq-Mars and Morlan 1999).

Reconnaissance for *in situ* archaeological deposits should also be focused along the margins of the Old Crow and Bluefish Basin. The shorelines along the inundated basins probably would have been productive habitats for large herbivores, and, in turn, hunter-gatherers. The 366 m maximum level shoreline associated with Glacial Lake Old Crow Stage 2 may be the best area to find *in situ* archaeological deposits, because they probably would not have been destroyed by previous transgressions events.

The advance of Laurentide ice along the entire Richardson and Mackenzie Mountain front at *ca.* 35,000 yr BP places temporal constraints on the possibility of the proposed "ice-free corridor" as a route of human dispersal from eastern Beringia south into continental North America. Although the interval with Glacial Lake Old Crow Stage 1 was characterized by a fluctuating ice margin, areas in the two major passages through the mountains, McDougall Pass and Bonnet Plume Basin, would have been either blocked by glaciers, flooded by glacially impounded waters and/or characterized by ice-marginal environments with meltwater and outwash channels. Even during short periods when these were not blocked by ice, these environments would not have been welcoming to any human group or herbivore population attempting to traverse them *ca.* 34,000 to 22,000 yr BP (see Catto 1996). The establishment of Glacial Lake Old Crow Stage 2, impounded by the Katherine Creek Phase of the Laurentide ice, would have served as a barrier to migration along the eastern slopes for any terrestrial organism until after *ca.* 15,000 yr BP. Further arguments suggesting the non-viability of the "ice-free corridor" as a corridor for human migration until after the establishment of widespread cultures south of the ice sheet at *ca.* 12,500 yr BP are presented by Catto (1996), Jackson and Duk-Rodkin (1996) and Mandryk *et al.* (2001).

## References Cited

Agriculture Canada Expert Committee on Soil Survey. 1987. The Canadian System of Soil Classification, Second Edition. *Agriculture Canada Publication*, 1646. 164pp.

Anderson, P.M., and L.B. Brubaker. 1993. Holocene vegetation and climate histories of Alaska. In: Wright, H.E. Jr., J.E. Kutzbach, T. Webb III, W.F. Ruddiman, F.A. Street-Perrott, and P.J. Bartlein (Eds.), *Global Climates since the Last Glacial Maximum*, pp. 386-400, University of Minnesota Press, Minneapolis.

-1994.Vegetation history of northcentral Alaska: A mapped summary of Late-Quaternary Pollen Data. *Quaternary Science Reviews*, Vol.13, pp. 71-92.

Anderson, P.M., R.E. Reanier, and L.B. Brubaker. 1988. Late Quaternary vegetation history of the Black River region, northwestern Alaska. *Canadian Journal of Earth Sciences*, Vol. 25, pp. 84-94.

Anderson, P.M., P.J. Bartlein, L.B. Brubaker, K. Gajewski, and J.C. Ritchie. 1989. Modern analogs of late-Quaternary pollen spectra from the western interior of North America. *Journal of Biogeography*, Vol. 16. pp. 573-596.

Bannikov, A.G., L.V. Zhirnov, L.S. Lebedeva, and A.A. Fandeev. 1967. *Biology of the Saiga.* Israel Program for Scientific Translations, Jerusalem.

Barnosky, C.W., P.M. Anderson, and P.J. Bartlein. 1987. The northwest U.S. during deglaciation; vegetation history and paleoclimatic implications. In: Ruddimann, W.F., and H.E. Wright, Jr. (Eds.), *North America and Adjacent Oceans during the Last Deglaciation*, The Geology of North America, Vol. K-3, pp. 289-321, The Geological Society of America, Boulder.

Bartlein, P.J., P.M. Anderson, M.E. Edwards, and P.F. McDowell. 1991. A framework for interpreting paleoclimatic variations in Eastern Beringia. *Quaternary International*, Vol. 10, No. 12, pp. 73-83.

Beget, J. 1989. Was the Late Pleistocene Northwest Laurentide Ice Sheet Wet-Based? In: Carter, D.L., T. D. Hamilton, and J.P. Galloway (ed.), *Late Cenozoic History of the Interior Basins of Alaska and the Yukon*, pp.22-24, U.S. Geological Survey Circular 1026.

Bennike, O. 1990. The Kap Kobenhavn Formation: stratigraphy and palaeobotany of a Plio-Pleistocene sequence in Pearly Land, North Greenland. *Meddelelser om Gronland*, Geoscience, Vol. 23.

Berger, J. 1986. *Wild horses of the Great Basin*. Chicago, Illinois, University of Chicago Press.

Berggren, G. 1964. *Atlas of seeds. Part 2. Cyperaceae*. Swedish Natural Science Research
Council, Stockholm. 68 pp.

-1981. *Atlas of seeds*. Part 3. Salicaceae – Crucifereae. Swedish Museum of Natural History, Stockholm. 259 pp.

Bigelow, N.H., and M.E. Edwards. 2001. A 14,000 yr paleoenvironmental record from Windmill Lake, Central Alaska: Lateglacial and Holocene vegetation in the Alaska Range. *Quaternary Science Reviews*, Vol. 20, pp. 203-215.

Birks, H.H. 1980. Plant macrofossils in Quaternary lake sediments. In: Elster, H.-J., and W. Ohle (Eds.), *Ergebnisse Der Limnologie*, pp. 2-59, E. Schweizerbart'sche Verlagsbuchhandlung (Nägele u. Obermiller), Stuttgart.

Birks, H.H., and H.J.B. Birks. 2000. Future uses of pollen analysis must include plant macrofossils. *Journal of Biogeography*, Vol. 27, pp. 31-35.

Blake, W., Jr. 1984. Geological Survey of Canada Radiocarbon Dates XXIV. *Geological Survey of Canada*, Paper 84-7.

-1987. Geological Survey of Canada Radiocarbon Dates XXVI. *Geological Survey of Canada*, Paper 86-7.

Bliss, L.C. and J.H. Richards. 1982. Present day arctic vegetation and ecosystems as a predictive tool for the arctic-steppe mammoth biome. In: Hopkins, D.M., J.V. Matthews Jr., C.E. Schweger, and S.B.Young (Eds.), *Paleoecology of Beringia*, pp. 241-257, Academic Press, New York.

Bonnichsen, R. 1979. *Pleistocene Bone Technology in the Beringian Refugium*. Archaeological Survey of Canada No. 89, Mercury Series, National Museum of Man, Ottawa.

Bostock, H.S. 1948. Physiography of the Canada Cordillera, with special reference to the area north of the fifty-fifth parallel. *Geological Survey of Canada*, Memoirs, No. 247, 106 pp.

Burke, A., and J. Cinq-Mars 1996. Dental characteristics of Late Pleistocene *Equus lambei* from the Bluefish Caves, Yukon Territories, and their comparison with Eurasian horses. *Géographie physique et Quatenaire*, Vol. 50, No. 1, pp. 81-93.

-1998. Paleoethological Reconstruction and Taphonomy of *Equus lambei* from the Bluefish Caves, Yukon Territory, Canada. *Arctic*, Vol. 51, No. 2, pp. 105-115.

Catto, N.R. 1986. *Quaternary Sedimentology and Stratigraphy, Peel Plateau and Richardson Mountains, Yukon and Northwest Territories.* Unpublished Ph.D. thesis Department of Geology, University of Alberta. 728 pp.

-1996. Richardson Mountains, Yukon-Northwest Territories: The Northern Portal of the Postulated "Ice-Free Corridor". *Quaternary International*, Vol. 32, pp. 3-19.

Cinq-Mars, J. 1979. Bluefish Cave I: A Late Pleistocene Eastern Beringian Cave Deposit in the Northern Yukon. *Canadian Journal of Archaeology*, Vol.3, pp. 1-32.

-1990. La Places des Grottes du Poisson-Bleu dans la Préhistoire Béringienne. *Revista de Arqueologia Americana*, Vol. 1, pp. 9-32.

Cinq-Mars, J. and B. Lauriol. 1985. Le Karst de Tsi-it-toh-choh: Notes Préliminaires sur Quelques Phénoménes Karstiques du Yukon. *Annales de la Société Géologique de Beligique*, Vol. 108, pp.185-195.

Cinq-Mars, J. and R.E. Morlan. 1999. Bluefish Caves and Old Crow Basin: A New Rapport. In: Bonnichsen, R. and K.L. Turnmire (Eds.), *Ice Age People of North America: Environments, Origins, and Adaptations.* pp. 200-212. Oregon State University Press, Corvallis.

Cody, W.J. 1996. *Flora of the Yukon Territory.* NRC Research Press, Ottawa, Ontario, Canada.

Colinvaux, P.A. 1964. The environment of the Bering land bridge. *Ecological Monographs*, Vol. 34, pp. 297-329.

-1980. Vegetation of the Bering land bridge revisited. *Quarterly Review of Archaeology*, Vol. 5, pp. 10-16.

-1981. Historical ecology of Beringia: the south land bridge coast at St. Paul Island. *Quaternary Research*, Vol. 16, pp. 18-36.

Colinvaux, P.A., and F.H. West. 1984. The Beringian ecosystem. *Quarterly Review of Archaeology*, Vol. 5, pp. 10-16.

Cooperrider, A.Y., and J.A. Bailey. 1986. Fringed Sagebrush (*Artemisia frigida*) – a neglected Forage Species of Western Ranges. In: McArthur, E.D., and B.L. Welch. (Eds.), pp. 46-54. *Proceedings – Symposium on the Biology of Artemisia and Chrysothamnus, Provo, Utah, July 9-13, 1984.*

Cwynar, L.C. 1982. A late-Quaternary vegetation history from Hanging Lake, Northern Yukon. *Ecological Monographs*, Vol. 52, pp. 1-24.

Cwynar, L.C., and J.C. Ritchie. 1980. Arctic steppe-tundra: a Yukon perspective. *Science*, Vol. 208, pp. 1375-1377.

D'Andrea, A.C., and Gotthardt, R.M. 1984. Predator and scavenger modification of recent equid skeletal assemblages. *Arctic*, Vol. 37, No. 3, pp. 276-283.

Duk-Rodkin, A. 1999. Glacial Limits Map of Yukon Territory. *Geological Survey of Canada*, Open File 3694, Indian and Northern Affairs Canada Geoscience, Map 1999-2, scale 1:1000000.

Duk-Rodkin, A., R.W. Barendregt, D. G. Froese, F. Weber, R. Enkin, R. Smith, P. Waters, and R. Klassen. *In Review*. Timing and extent of Plio-Pleistocene glaciations in Northwestern Canada-Eastcentral Alaska.

Duk-Rodkin, A., R.W. Barendregt, C. Tarnocai, and F.M. Phillips. 1996. Late Tertiary to Late Quaternary record in the Mackenzie Mountains, Northwest Territories, Canada: stratigraphy, paleomagnetism, and chlorine-36. *Canadian Journal of Earth Sciences*, Vol. 33, pp. 875-895.

Duk-Rodkin, A., and O.L. Hughes. 1991. Age Relationships of Laurentide and Montane Glaciations, Mackenzie Mountains, Northwest Territories. *Géographie physique et Quaternaire*, Vol. 45, No. 1, pp. 79-90.

Duk-Rodkin, A., and O.L. Hughes. 1992. Pleistocene Montane Glaciations in the Mackenzie Mountains, Northwest Territories. *Géographie physique et Quaternaire*, Vol. 46., No. 1, pp. 69-83.

Duk-Rodkin, A., and O.L. Hughes. 1994. Tertiary-Quaternary Drainage of the Pre-glacial Mackenzie Valley Corridor. *Quaternary International*, Vol. 22/23, pp. 221-241.

Duk-Rodkin, A., and O.L. Hughes. 1995. Quaternary Geology of the Northeastern Part of the Central Mackenzie Valley Corridor, District of Mackenzie, Northwest Territories. *Geological Survey of Canada*, Bulletin, No. 458.

Dyke, A.S., J.T. Andrews, P.U. Clark, J.H. England, G.H. Miller, J. Shaw, and J.J. Veillette. 2002 a. The Laurentide and Innuitian ice sheets during the Last Glacial Maximum. *Quaternary Science Reviews*, Vol. 21, pp. 9-31.

-2002 b. Radiocarbon Dates pertinent to defining the Last Glacial Maximum for the Laurentide and Innuitian Ice Sheets. *Geological Survey of Canada*, Open File 4120.

Edwards, M.E., P.M. Anderson, L.B. Brubaker, T.A. Ager, A.A. Andreev, N.H. Bigelow, L.C. Cwynar, W.R. Eisner, S.P. Harrison, F.-S. Hu, D. Jolly, A.V. Lozhkin, G.M.

MacDonald, C.J. Mock, J.C. Ritchie, A.V. Sher, R.W. Spear, J.M Williams, and G. Yu. 2000. Pollen-based biomes for Beringia 18,000, 6000 and 0 $^{14}C$ yr BP. *Journal of Biogeography*, Vol. 27, pp. 521-554.

Edwards, M.E., and W.S. Armbruster. 1989. A Tundra-Steppe Transition on Kathul Mountain, Alaska, U.S.A. *Arctic and Alpine Research.* Vol. 21. No.3, pp. 296-304.

Elias, S.A. 1992. Late Quaternary beetle faunas of Southwestern Alaska: evidence of a refugium for mesic hygrophilous species. *Arctic and Alpine Research*, Vol. 24, pp. 133-144.

-2001. Mutual climatic range reconstructions of seasonal temperatures based on Late Pleistocene fossil beetle assemblages in Eastern Beringia. *Quaternary Science Reviews*, Vol. 20, pp. 77-91.

Elias, S.A., and O. Pollak. 1987. *Photographic atlas and key to windblown seeds of alpine plants from Niwot Ridge, front range, Colorado, U.S.A.* University of Colorado, Institute of Arctic and Alpine Research, Occasional Paper No. 45.

Elias, S.A., S.K. Short, and H.H. Birks. 1997. Late Wisconsinan Environments of the Bering Land Bridge. *Palaeogeography, Palaeoclimatology, Palaeoecology*, Vol. 136, pp. 293-308.

Elias, S.A., S.K. Short, C.H. Nelson, and H.H. Birks. 1996. Life and times of the Bering land bridge. *Nature*, Vol. 382, pp. 60-63.

French, N.R. 1979. Principal Subsystem Interactions in Grasslands. In: French, N.R. *Perspectives in Grassland Ecology: Results and Applications of the US/IBP Grassland Biome Study*, pp.173-190, Springer-Verlag, New-York.

Gajewski, K., A. Viau, M. Sawada, D. Atkinson, and S. Wilson. 2001. *Sphagnum* peatland distribution in North America and Eurasia during the past 21,000 years. *Global Biogeochemical Cycles*, Vol. 15, No.2, pp. 297-310.

Glaser, P.H. 1981. Transport and Deposition of Leaves and Seeds on Tundra: A Late-Glacial Analog. *Arctic and Alpine Research*, Vol. 13, No. 2, pp. 173-182.

Gleason, H.A. 1926. The individualistic concept of plant association. *Bulletin of the Torrey Botanical Club*, Vol. 53, pp. 7-36.

Goetcheus, V.G., and H.H. Birks. 2001. Full-glacial upland tundra vegetation preserved under tephra in the Beringia National Park, Seward Peninsula, Alaska. *Quaternary Science Reviews*, Vol. 20, pp. 135-147.

Guthrie, R.D. 1968. Palaeoecology of the large-mammal community in interior Alaska during the late Pleistocene. *American Midland Naturalist*, Vol. 70, pp. 346-363.

-1990. *Frozen Fauna of the Mammoth Steppe: The Story of Blue Babe.* The University of Chicago Press, Chicago.

-2001. Origin and causes of the mammoth steppe: a story of cloud cover, wooly mammal tooth pits, buckles, and inside-out Beringia. *Quaternary Science Reviews*, Vol. 20, pp. 549-574.

Harington, C.R. 1989. Pleistocene Vertebrate Localities in the Yukon. In: Carter, D.L., T.D., Hamilton, and J.P. Galloway (Eds.), *Late Cenozoic History of the Interior Basins of Alaska and the Yukon*, pp.93-98. U.S. Geological Survey Circular 1026.

Harington, C.R., and J. Cinq-Mars. 1995. Radiocarbon dates on saiga antelope (*Saiga tatarica*) fossils from Yukon and Northwest Territories. *Arctic*, Vol. 48, pp. 1-7.

Hettinger, L.A., Janz, A., and Wein, R.W. 1973. Vegetation of the Northern Yukon. *Arctic Gas Biological Reports Ser*ies, 1, pp. 1-171.

Höfle, C., M.E. Edwards, D.M. Hopkins, D.H. Mann, and C.-L. Ping. 2000. The Full-Glacial Environment of the Northern Seward Peninsula, Alaska, Reconstructed from the 21,500-Year-Old Kitluk Paleosol. *Quaternary Research*, Vol. 53, pp. 143-154.

Holyoak, D.T. 1984. Taphonomy of Prospective Plant Macrofossils in a River Catchment on Spitsbergen. *The New Phytologist.* Vol. 98, pp. 405-423.

Hopkins, D.M. (Ed.) 1967. *The Bering Land Bridge.* Stanford University Press, Stanford.

Hopkins, D.M., J.V. Matthews, Jr., C.E. Schweger, and S.B. Young (Eds.). 1982. *Paleoecology of Beringia*, Academic Press, New York. 489 pp.

Hughes, O.L. 1972. Surficial Geology of Northern Yukon Territory and Northwestern District of Mackenzie, Northwest Territories. *Geological Survey of Canada,* Paper 96-36.

Hughes, O.L. 1985. Late Wisconsinan Laurentide Glacial Limits of Northwestern Canada: The Tutsieta Lake and Kelly Lake Phases. *Geological Survey of Canada*, Paper 85-25.

Hughes, O.L., C.R. Harrington, J.A. Janssens, J.V. Matthews, Jr., R.E. Morlan, N.W. Rutter, and C.E. Schweger. 1981. Upper Pleistocene Stratigraphy, Paleocology, and Archaeology of the Northern Yukon Interior, Eastern Beringia 1. Bonnet Plume Basin. *Arctic* Vol. 34, No. 4., pp. 329-365.

Hughes, O.L., N.W. Rutter, J.V. Matthews, Jr., and J.J. Clague. 1989. Unglaciated areas

(Quaternary stratigraphy and history, Canadian Cordillera). In: Fulton, R.J. (ed.), Chapter 1, *Quaternary Geology of Canada and Greenland.* Geological Survey of Canada, Geology of Canada, no. 1 (also Geological Society of America, The Geology of North America, v. K-1).

Hultén, E. 1937. Outline of the History of Arctic and Boreal Biota During the Quaternary Period. *Bokförlags Akiebolaget Thule,* Stockholm. 168 pp.

-1968. Flora of Alaska and Neighboring Territories. A Manual of Vascular Plants. Stanford University Press, New York. 1088 pp.

Irving, W.N., and C.R. Harington. 1973. Upper Pleistocene radiocarbon-dated artifacts from the northern Yukon, *Science*, Vol. 179, pp. 335-340.

Irving, W.N., A.V. Jopling, and B.F. Beebe. 1986. Indications of Pre-Sangamon Humans near Old Crow. In: Bryan, A.L. (Ed.), *New Evidence for the Pleistocene Peopling of the Americas*, pp. 49-63. University of Maine, Center For the Study of Early Man, Orono.

Jackson, L.E. and A. Duk-Rodkin. 1996. Quaternary geology of the ice-free corridor: glacial controls on the peopling of the New World. In: Akazawa, T., and E.J.E. Szathmary (Eds.), *Prehistoric Mongoloid Dispersals,* pp. 214-227. Oxford University Press.

Jackson, L.E., and C.R. Harington. 1991. Middle Wisconsinan mammals, stratigraphy and sedimentology at the Ketza River site, Yukon Territory. *Géographie physique et Quaternaire*, Vol. 45, pp. 69-77.

Jackson, L.E., Phillips, F.M., Shimamura, K., Little, E.C., 1997. Cosmogenic $^{36}$Cl dating of the Foothills erattics train, Alberta, Canada. *Geology,* Vol. 25, pp. 195-198.

Janssens, J.A. 1981. *Subfossil Bryophytes in Eastern Beringia: Their Paleoenvironmental and Phytogeographical Significance*. Unpublished Ph.D. dissertation, Department of Biology, University of Alberta.

Katz, N.J., S.V. Katz, and M.G. Kipiani. 1965. *Atlas and keys of fruits and seeds occurring in the Quaternary deposits of the USSR.* Nauka, Moscow, 365 pp. In Russian.

Klassen, R.W. 1987. The Tertiary-Pleistocene stratigraphy of the Liard Plain, southeastern Yukon Territory. *Geological Survey of Canada,* Paper 86-17.

Körber-Grohne, U. 1964. *Bestimmungsschlussel für subfossile Juncus-samen and Gramineen-Fruchte.* Probleme der Kustenforschung im Sudlichen Nordseegebiet 7, August Lax, Hildesheim.

Kutzbach, J.E. 1987. Model simulations of the climatic patterns during the deglaciation of North America. In: Ruddiman, W.F. and H.E. Wright, Jr. (Eds.), *North America and Adjacent Oceans during the Last Deglaciation*, The Geology of North America, Vol. K-3, pp. 425-446, The Geological Society of America, Boulder.

Lauriol, B., Y. Cabana, J. Cinq-Mars, M., Geurts, and F.W. Grimm. 2002. Cliff-top eolian deposits and associated molluscan assemblages as indicators of Late Pleistocene and Holocene environments in Beringia. *Quaternary International*, Vol. 87, pp. 59-79.

Laxton, N.F., C.R. Burn, and C.A.S. Smith. 1996. Productivity of Loessal Grasslands in the Kluane Lake Region, Yukon Territory, and the Beringian "Production Paradox". *Arctic*, Vol.49, No.2, pp. 129-140.

Lemmen, D.S., A. Duk-Rodkin, and J.M. Bednarski. 1994. Late Glacial Drainage Systems Along the Northwestern Margin of the Laurentide Ice Sheet. *Quaternary Science Reviews*, Vol. 13. pp. 805-828.

Lichti-Fedorovich, S. 1973. Palynology of six sections of Late Quaternary sediments from the Old Crow River, Yukon Territory. *Canadian Journal of Botany*, Vol. 51, pp. 553-564.

Lichti-Fedorovich, S. 1974. Palynology of Two Sections of Late Quaternary Sediments from the Porcupine River, Yukon Territory. *Geological Survey of Canada*, Paper 74-23.

Lévesque, P.E.M., H. Dinel, and A. Larouche. 1988. *Guide to the identification of plant macrofossils in Canadian Peatlands*. Research Branch, Agriculture Canada, Publication No. 1817, Ottawa.

Lloyd, A.H., W.S., Armbruster, amd M.E. Edwards. 1994. Ecology of a steppe-tundra gradient in interior Alaska. *Journal of Vegetation Science*, Vol.5, pp. 897-912.

Lowdon, J.A. and Blake, E., Jr. 1979. Geological Survey of Canada radiocarbon dates XIX. *Geological Survey of Canada Paper 79-7.*

MacDonald, G.M. 1993. Methodological falsification and the interpretation of palaeocological records: the cause of the early Holocene birch decline in western Canada. *Review of Palaeobotany and Palynology*, Vol. 79, pp. 83-97.

MacDonald, G.M., Beukens, R.P., Kieser, W.E. and Vitt, D.H. 1987. Comparative radiocarbon dating of terrestrial plant macrofossils and aquatic moss from the "ice-free corridor" of western Canada. *Geology*, Vol. 15, pp. 837-840.

Mandryk, C.A.S., H. Josenhaus, D.W. Fedje, and R.W. Mathewes. 2001. Late Quaternary paleoenvironments of Northwestern North America: implications for inland versus coastal migration routes. *Quaternary Science Reviews*, Vol. 20, pp. 301-314.

Martin, A.C. 1951. Identifying pondweed seeds eaten by ducks. *Journal of Wildlife Management*, Vol. 15, pp. 253-258.

Martin, J.B., and W.D. Barkley. 1961. *Seed Identification Manual.* California University Press, Berkeley.

Matthews, J.V. Jr. 1974a. Quaternary environments at Cape Deceit (Seward Peninsula, Alaska): evolution of a tundra ecosystem. *Bulletin of the Geological Society of America*, Vol. 85, pp. 1353-1384.

-1974b. Wisconsinan environment of interior Alaska: pollen and macrofossil analysis of a 26 meter core from Isabella Basin (Fairbanks, Alaska). *Canadian Journal of Earth Sciences*, Vol. 11, pp. 828-841.

-1982. East Beringia During Late Wisconsin Time: A Review of the Biotic Evidence. In: Hopkins, D.M., J.V. Matthews Jr., C.E. Schweger, and S.B.Young (Eds.), *Paleoecology of Beringia*, pp. 127-150, Academic Press, New York.

Matthews, J.V., Jr., O.L. Hughes, and C.E. Schweger. 1987. Stop 30: Twelvemile Bluff Exposure. In: *Guide Book A-20 (a) and (b), Quaternary research in Yukon.* C.A.S. Smith, and S.R. Morison (ed.), INQUA XII Congress. Ottawa, Canada. National Research Council of Canada, pp. 95-98.

Matthews, J.V., Jr.,and L.E. Ovenden. 1990. Late Tertiary Macrofossils from Localities in Arctic/Subarctic North America: A Review of the Data. *Arctic*, Vol. 43, no.4, pp. 364-392.

Matthews, J.V. Jr., C.E. Schweger, and O.L. Hughes. 1989. Climatic Change in Eastern Beringia During Oxygen Isotope Stages 2 and 3: Proposed Thermal Events. In: Carter, D.L., T.D., Hamilton, and J.P. Galloway (Eds.), *Late Cenozoic History of the Interior Basins of Alaska and the Yukon*, pp. 34-38. U.S. geological Survey Circular 1026.

Matthews, J.V., Jr., C.E. Schweger, and J.A. Janssens. 1990. The Last (Koy-Yukon) Interglaciation in the Northern Yukon: Evidence from Unit 4 at Ch'ijee's Bluff, Bluefish Basin. *Géographie physique et Quaternaire*, Vol. 44, No. 3, pp. 341-362.

Matthews, J.V. Jr., and A. Telka. 1997. Insect Fossils from the Yukon. In: H.V. Danks and J.A. Downes (Eds.), *Insects of the Yukon*, pp. 911-962, Biological Survey of Canada (Terrestrial Arthropods), Ottawa.

McAllister, D.E., and C.R. Harrington. 1969. Pleistocene grayling, *Thymallus*, from Yukon, Canada. *Canadian Journal of Earth Science*, Vol. 6, pp. 113-1191.

McCourt, G.H. 1982. *Quaternary Palynology of the Bluefish Basin, Northern Yukon Territory.* Unpublished M.Sc. thesis, Department of Geology, University of Alberta.

Montgomery, F.H. 1977. *Seeds and fruits of plants in eastern Canada and northeastern United States.* University of Toronto Press.

Morlan, R.E. 1977. The Yukon Refugium Project. *National Museum of Man Canadian Studies Report 1.*

Morlan, R.E. 1980. Taphonomy and Archaeology in the Upper Pleistocene of the Northern Yukon Territory: A Glimpse of the Peopling of the New World. *Archaeological Survey of Canada, Paper No. 94.* 398 pp.

Morlan, R.E. 1986. Pleistocene archaeology in Old Crow basin: a critical reappraisal. In: Bryan. A.L. (Ed.), *New Evidence for the Pleistocene Peopling of the Americas*, pp. 27-48. University of Maine, Center for the Study of Early Man, Orono.

Morlan, R.E., and J. Cinq-Mars. 1982. Ancient Beringians: Human occupation in the Late Pleistocene of Alaska and the Yukon Territory. In: Hopkins, D.M., J.V. Matthews, Jr., C.E. Schweger, and S.B. Young, (eds.), *Paleoecology of Beringia*, pp. 353-381. New York: Academic Press.

Morlan, R.E., and J.V. Matthews, Jr. 1978. New dates for early man. *GEOS*, Winter 1978, pp. 2-5.

Morlan, R.E., D.E. Nelson, T.A. Brown, J.S. Vogel, and J.R. Southton. 1990. Accelerator Mass Spectrometry Dates on Bones from Old Crow Basin, Northern Yukon Territory. *Canadian Journal of Archaeology*, Vol. 14, pp. 75-92.

Murray, D.F., B.M. Murray, B.A. Yutsev, and R. Howenstein. 1983. *Biogeographic significance of steppe vegetation in subarctic Alaska.* IV International Permafrost Conference, Fairbanks, Alaska, pp. 883-887, National Academy Press, Washington D.C.

Norris, D.K. 1981. *Geology; Old Crow, Yukon Territory.* Geological Survey of Canada Map 1518A.

Oswald, E.T. and J.P. Senyk. 1977. *Ecoregions of Yukon Territory.* Fisheries and Environment Canada, 115 pp.

Pearce, G.W., J.A. Westgate, and S. Robertson. 1982. Magnetic reversal history of

Pleistocene sediments at Old Crow, northwestern Yukon Territory. *Canadian Journal of Earth Sciences*, Vol. 19, pp. 919-929.

Rampton, V. N. Quaternary Geology of the Yukon Coastal Plain. *Geological Survey of Canada Bulletin* 317.

Redmann, R.E. 1982. Production and Diversity in Contemporary Grasslands. In: Hopkins, D.M., J.V. Matthews Jr., C.E. Schweger, and S.B.Young (Eds.), *Paleoecology of Beringia*, pp. 223-239, Academic Press, New York.

Ritchie, J.C. 1984. *Past and Present Vegetation of the Far Northwest of Canada.* University of Toronto Press, Toronto.

Ritchie, J.C., J. Cinq-Mars, and L.C. Cwynar. 1982. L'environment tardiglaciaire du Yukon septentional, Canada. *Géographie physique et Quaternaire*, Vol. 36, pp. 241-250.

Ritchie, J.C. and L.C. Cwynar. 1976. *Northern Yukon Research Programme Report of Activities, 1975-76, Palaeobotany Section.* University of Toronto, Toronto.

-1982. The Late-Quaternary vegetation of the northern Yukon. In: Hopkins, D.M., J.V. Matthews Jr., C.E. Schweger, and S.B.Young (Eds.), *Paleoecology of Beringia*, pp. 113-126, Academic Press, New York.

Ritchie, J.C., K.A. Hadden, and K. Gajewski. 1987. Modern pollen spectra from lakes in arctic western Canada. *Canadian Journal of Botany*, Vol. 65, pp. 1605-1613.

Roland, C.A. 1996. *The Floristics and Community Ecology of Extrazonal Steppe in the Yukon and Kolyma River Drainages.* Unpublished M.Sc. thesis, University of Alaska, Fairbanks.

Schweger, C.E.1976. *Late Quaternary Paleoecology of the Onion Portage Region, Northwest Alaska.* Unpublished Ph.D. Dissertation, Department of Geology, University of Alberta.

Schweger, C.E. 1982. Late Pleistocene vegetation of eastern Beringia – pollen analysis of dated alluvium. In: Hopkins, D.M., J.V. Matthews Jr., C.E. Schweger, and S.B.Young (Eds.), *Paleoecology of Beringia*, pp. 95-112, Academic Press, New York.

Schweger, C.E. 1989. The Old Crow and Bluefish Basins, Northern Yukon: Development of the Quaternary History. In: Carter, D.L., T.D., Hamilton, and J.P. Galloway (Eds.), *Late Cenozoic History of the Interior Basins of Alaska and the Yukon*, pp. 30-33. U.S. Geological Survey Circular 1026.

-1992. The Full-Glacial ecosystem of Beringia. *Prehistoric Mongoloid*

*Dispersal Project*, Report 7, pp. 35-51. Tokyo.

-1997. Late Quaternary Palaeoecology of the Yukon: A Review. In: H.V. Danks and J.A. Downes (Eds.), *Insects of the Yukon*, pp. 59-72, Biological Survey of Canada (Terrestrial Arthropods), Ottawa.

Schweger, C.E., and T. Habgood. 1976. The late Pleistocene steppe-tundra in Beringia – A critique. *AMQUA Abstracts*, Vol. 4, pp. 80-81.

Schweger, C.E., and J.V. Matthews, Jr. 1991. The Last (Koy-Yukon) Interglaciation in the Yukon: Comparisons with Holocene and Interstadial Pollen Records. *Quaternary International*, Vol. 10-12, pp. 85-94.

Schweger, C.E., J.V. Matthews Jr., D.M. Hopkins, and S.B. Young. 1982. Paleoecology of Beringia – a synthesis. In: Hopkins, D.M., J.V. Matthews Jr., C.E. Schweger, and S.B.Young (Eds.), *Paleoecology of Beringia*, pp. 425-444, Academic Press, New York.

Stuiver, M., P.J. Reimer, E. Bard, J.W. Beck, G.S. Burr, K.A. Hughen, B. Kromer, F.G. McCormac, J. Plicht, and M. Spurk. 1998. Radiocarbon Vol. 40., pp. 1041-1083.

Thorson, R.M. 1989. Late Quaternary Paleofloods along the Porcupine River, Alaska: Implications for Regional Correlation. In: Carter, D.L., T.D., Hamilton, and J.P. Galloway (Eds.), *Late Cenozoic History of the Interior Basins of Alaska and the Yukon*, pp. 51-54. U.S. geological Survey Circular 1026.

Thorson, R.M., and J.E. Dixon, Jr. 1983. Alluvial history of the Porcupine River, Alaska: Role of glacial-lake overflow from northwest Canada. *Geological Society of America Bulletin*, Vol. 94, pp. 576-589.

Ukraintseva, V.V. 1993. Vegetation cover and environment of the Mammoth Epoch in Siberia. In: Agenbroad, L.D., J.I. Mead, and R.H. Hevly (Eds.), *The Mammoth Site of Hot Springs, South Dakota Inc.*, S. Dakota, 309 pp.

Utting, J. 1986. *Palynological examination of Carboniferous outcrops on the Eagle Valley, requested by O.L. Hughes (NTS 116 I).* Geological Survey of Canada, Report No.1-JU-86.

Vetter, M.A. 2000. Grasslands of the Aishihik-Sekulmun Lakes Area, Yukon Territory, Canada. *Arctic*, Vol. 53, No. 2, pp. 165-173.

Viereck, L.A., C.T. Dyrness, A.R. Batten, and K.J. Wenzlick. 1992. *The Alaska vegetation classification*. General Technical Report PNW-GTR-286. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Wahl, H.E., D.B. Fraser, R.C. Harvey, and J.B. Maxwell. 1987. *Climate of the Yukon.* Environment Canada, Atmospheric Environment Service, Climatological Studies, Number 40.

Walde, K. 1986. *Pollen Analysis and taphonomy of locality 15 alluvial sediments, Old Crow Basin, Yukon.* Unpublished M.A. thesis, Department of Anthropology, University of Alberta, 114 pp.

Walker, M.D., D.A. Walker, K.R. Everett, and S.K. Short. 1991. Steppe vegetation of south-facing slopes of pingos, central arctic coastal plain, Alaska, U.S.A. *Arctic and Alpine Research*, Vol. 23, No.2, pp. 170-188.

Welsh, and Rigby. 1971. Botany and Physiognomic Reconnaissance of Northern Yukon. *Brigham Young University Scientific Bulletins Biological Series.*, Vol. 14, No. 2, 64 pp.

West, F.H. 1996. *American Beginnings: The Prehistory and Palaeoecology of Beringia.* The University of Chicago Press.

West, R.G. and M. E. Pettit. 2000. Plant macroscopic remains from recent sediments of Banks Island, Northwest Territories, and Bathurst Island, Nunavut, Canada, and the interpretation of Quaternary cold stage plant macroscopic assemblages. *Journal of Quaternary Sciences*, Vol. 14, No. 2, pp. 177-184.

Westgate, J.A., R.C. Walter, G.W. Pearce, and M.P. Gorton.1985. Distribution, stratigraphy, petrochemistry, and palaeomagnetism of the late Pleistocene Old Crow tephra in Alaska and the Yukon. *Canadian Journal of Earth Sciences*, Vol. 22, pp. 893-906.

Young, S.B. 1976. *Is steppe-tundra alive and well in Alaska? AMQUA Abstracts*, Vol. 4, pp. 84-88.

-1982. The vegetation of land-bridge Beringia. In: Hopkins, D.M., J.V. Matthews Jr., C.E. Schweger, and S.B.Young (Eds.), *Paleoecology of Beringia*, pp. 179-191, Academic Press, New York.

-1989. *To the Arctic: An Introduction to the Far Northern World.* John Wiley & Sons.

Youngman, P.M. 1993. The Pleistocene small carnivores of eastern Beringia. *Canadian Field-Naturalist.* Vol. 107, No. 2, pp. 139-163.

Yurtsev, B.A. 1963. On the Floristics Relations between Steppes and Prairies. *Botaniska Notiser*, Vol. 116, pp. 396-408.

# Appendix A: Descriptions of Macrofossil Specimens from the Upper Bluefish Unit

## 1. Fungi imperfecti

*Cennococcum geophilum* Fries.

Plate 5.

Remarks. - Sclerotia of the imperfect fungus *C. geophilum* are abundant in most Bluefish Exposure macrofossil samples. The sclerotia are black, and vary in size from *ca.* 10 mm to 3 mm. The smaller are often more spherical, and the larger tend to be irregular in shape. The sclerotia are most often entire, but some were found broken. Commonly, the sclerotia float in water, thus easily picked with a paintbrush.

Recent distribution. – *C. geophilum* is common in the northern hemisphere, especially in temperate and arctic climates (see Bennike 1990).

Ecology. – *C. geophilum* is a common facultative ecto-mycorrhiza forming fungus growing under various ecological conditions. It usually forms mycorrhiza with woody plants, but it may also do so with herbaceous plants and lives in forests, heaths, meadows, in moss polsters or in arable soil (Bennike 1990). The occurrence of *C. geophilum* sclerotia in fluvial sediments may indicate soil erosion from the local watershed (H.H. Birks, personal communication, 2001).

## 2. Musci

Descriptions and habitat data of bryophyte taxa follows that of Janssens (1981). Identification of subfossil remains were made by I. Bauer (University of Alberta) and R. Hastings (Provincial Museum of Alberta) to the lowest level of taxonomic precision possible. These specimens were obtained by wet-screening a 100 ml subsample of

GZ.07.14.99.09 (Station 2). This subsample contained the most abundant bryophyte remains with the greatest diversity and best preservation.

### Dicranaceae

*Dicranum* sp.

Material. - Leaves highly fragmented, poorly preserved.
Remarks. – Leaves straight, no papillae; alar cells with thick cell walls, rectangular, medial cells aligned longitudinally in straight rows.
Ecology. – Most species of *Dicranum* grow on moist substrates, heaths, mesic tundra to muskeg. Not typical of fens.
Identified by: – R. Hastings.

### Pottiaceae

*Didymodon rigidulus* var. *icmadophila* Hedw.

Material. – Moderately well preserved leaves.
Remarks. – Leaves widely ovate-lanceolate, slightly erect-recurved, weakly keeled; apex acute; costa stout, wide in relation to lamina width, disappearing into the multistratose lamina at the apex, in transverse section epidermal cells with large lumina; margins recurved, bistratose, entire; medial cells subquadrate to rounded, in distinct longitudinal rows, firm-walled, smooth or slightly rough, without clearly developed papillae; basal cells shortly rectangular, thin-walled, gradually differentiated from medial cells.
Ecology. – On calcareous rocks and soil, on earth-covered boulders, in wet-habitats, often on rocks in streams.
Identified by: I. Bauer.

cf. *Tortula* sp.

Material. – Poorly preserved leaves.
Remarks. – Some specimens resemble *Tortula*, but poor preservation makes this identification tentative.
Ecology. – Typically found on calcareous rocks and soils. Never found in fens.
Identified by: I. Bauer.

### Bryaceae

*Bryum* sp.

Material. – Leaves highly fragmented, poorly preserved. Rare.
Remarks. – Most species of *Bryum* can be only identified with complete gametophytic and sporophytic material. However, the material does not represent *B. pseudotriquetrium.*
Ecology. – Most *Bryum* species inhabit moist, often calcareous soils, above the water table.
Identified by: I. Bauer.

### Amblystegiaceae

*Calliergon giganteum* (Schimp.) Kindb.

Material. – Well preserved branches with leaves and stems.
Remarks. – Branch leaves sometimes ovate-oblong; costa reaching in most mature leaves to the apex; apex cucullate; alar cells in a large convex group that reaches the costa except for one or two basal cells in between costa and the group; cells strongly differentiated, walls thin and hyaline, often not preserved.
Ecology. – Emergent or sometimes submerged at high water, in shallow, usually temporary pools or at edges of springs and brooks, bogs, rich fens, and wooded coniferous swamps; pH 7.1-7.5.

Identified by: I. Bauer.

*Calliergon stramineum* (Brid.) Kindb.

Material. – Very well preserved branches with leaves and stems.

Remarks. – Leaves oblong-ovate; apex obtuse; alar cells gradually differentiated, in a long narrow group reaching up along the margins; apical cells frequently partially differentiated in nematogon initials.

Ecology. – Often submerged in shallow pools, in fen and bogs, occasionally admixed with *Sphagnum*. pH 7.9.

Identified by: I. Bauer.

*Drepanocladus vernicosus* (Lindb. *Ex* C. Hartman) Warnst.

Plates 6,7.

Material. – Very well preserved branches with leaves and stems.

Remarks. – Leaves falcate-secund to circinate, ovate-lanceolate, 1.6-2.7 mm long, maximal width 0.7-0.8 mm, basal width 0.5-0.7 mm; apex slenderly acuminate; margins entire; costa weak or strong, ending in the upper part of the lamina; upper leaf cells elongate, 31-75 μm long, 3.9-6.2 μm wide, walls thin or thick walled and porose; alar cells not differentiated from the other basal cells, rectangular, walls thick, porose and brown. Stem with circular transverse section, diameter 280-380 μm, no central strand, epidermal calls small and with thick outer walls.

Ecology. – In moist or wet, often shaded habitats on calcareous substrata and in rich fens. Usually not submerged. pH ranges from 5.2-8.0.

*D. vernicosus* has a distribution restricted to former glaciated and periglacial areas.

Identified by: I. Bauer.

*Scorpidium scorpioides* (Hedw.) Limpr.

Plates 8,9.

Material. – Moderately well preserved leaves and stems. Leaves often fragmented and lacerated.

Remarks. – Leaves widely ovate to cordate-ovate, falcate-second; apex apiculate; costa absent; medial cells with thick porose walls; alar cells gradually differentiated, a few inflated and with thin hyaline walls.

Ecology. – In tufts or mats in moist or wet habitats on calcareous ground, often in fens mixed with *Drepanocladus* sp. On irrigated rocks, sometimes submerged in shallow lakes or pools among sedges. Indicator of rich-fens and calcareous water.

*S. scorpioides* is a very characteristic and common Pleistocene fossil of eastern Beringia.

Identified by: I. Bauer.

### Brachytheciaceae

*Tomenthypnum nitens* (Hedw.) Loeske

Plate 10.

Material. – Very well preserved, branched leaves on stems.

Remarks. Fragments pinnately or frequently densely branched; leaves imbricate, narrowly ovate-lanceolate to lanceolate, strongly plicate, sharply and narrowly acuminate; costa single, strong or weak, reaching into the upper half of the lamina, often with abundant abaxial rhizoids formed in the lower leaves; margins entire; medial cells elongate, linear, very narrow, with blunt ends; alar cells gradually and poorly differentiated, quadrate and thick-walled.

Subfossil specimens are a rich brown color, in contrast to the golden color of living populations.

Ecology. – In moist or wet habitats, often rich fens mixed with other mosses. Pronounced calciphile, common in circumboreal muskeg and tundra.

Identified by: I. Bauer.

# 3. Vascular Plants

Nomenclature, distribution and habitat data follows that of Cody (1996). Description terminology of macrofossils follows that of Montgomery (1977), and Berggren (1964, 1981).

## 3.1 Gymnospermae

**Pinaceae** "spruce family"

*Picea* sp.

Plate 11.

Material. Detrital wood (rounded), and needle fragments. The fragmentary preservation of needles and rounded, abraded surface of small identified detrital wood fragments (from sample GZ.07.14.99.09 identified by R.J. Mott, wood identification report No. 2001-37) suggests that these remains represent reworked organic material from older deposits. The needles have 4 distinct ridges that form an acute tip.

Remarks. Two species of the genus *Picea* inhabit the Yukon Territory; *P. mariana and P. glauca* (further divided into the subspecies *P. glauca* var. *albertiana* and *P. glauca* var. *porsildii*). The fragmentary needle remains did not allow for further identifications beyond *Picea* sp. Both are large evergreen coniferous trees. *P. glauca* typically inhabits well drained exposed situations but also in bogs and muskeg, forming both the alpine and arctic treeline. *P. mariana* dominates lowland muskeg.

## 3.2 Angiospermae

**Betulaceae** "birch family"
*Betula* sp.

Plate 12.

Material. – Often fragmented wingless nutlets.

Remarks. – Nutlets of *Betula* sp. are often wingless, thus preventing a confident species determination based on morphological characteristics. However, a remnant of the wing is present on these specimens. The nutlets are obovate in shape 1.5-2.5 mm long and 1-1.5 mm wide. There is often a remnant of the style at the apex.

Ecology and Distribution. – *Betula* spp. are widespread in distribution and may be either trees or shrubs.

**Poaceae** "grass-family"

*Deschampsia* sp.Beauv.
hair grass

Plates 13-17.

Remarks. – Caryopses of *Deschampsia* are approximately 2.0 mm long and 1.0 mm wide. The general shape of the fruit is oval, being more wide in the middle than the base or the apex. The hilum is oval near to the middle of the fruit, near the base. The apex is gently round, blunt at the tip, with a coloured caruncle at the stylar base. The surface is slightly lustrous and dark reddish brown, with faint longitudinal striations apparent. Comparisons with herbarium specimens boiled in sodium pyrophosphate indicate that the subfossil remains closely resemble those of *Deschampsia caespitosa* (PMA specimen # B89.51.64 5582).

Ecology.- Most species of *Deschampsia* inhabit moist situations in meadows, tundra, lakeshores, gravel bars or disturbed situations.

Confirmed by: A. Beaudoin.

*Elymus* sp. L.
wild-rye

Plates 18,19.

Remarks. – Caryopses of *Elymus* sp. are relatively large, *ca.* 3-6 mm long and 1-1.5 mm wide, and tapers to an acute point at the apex and are generally obovate in long section. The hilum terminates near the apex of the fruit. The apex is generally blunt with a small acute point in the center. The surface colour is reddish brown. Comparison with herbarium material boiled in sodium pyrophosphate indicated that the subfossil remains closely resemble *Elymus innovatus* (PMA specimen # B89.511375 519.23).

Ecology. – Most species of *Elymus* are rhizomatous or tufted grasses growing up to 120 cm. They prefer gravelly or sandy substrates, including dunes, hillsides, open slopes, disturbed areas and dry eroding riverbanks. Most species of *Elymus* are good fodder sources for large herbivores in winter and spring, but nutrient value decreases rapidly when plants mature during the summer.

Confirmed by: A. Beaudoin.

cf. *Festuca*

Plate 20.

Remarks. – Caryopses that resemble *Festuca* sp. are *ca.* 2.0 mm long and 0.7 mm wide. The apex of the fruit is blunt. They have a long narrow hilum that extends roughly two-thirds the way up the caryopses. There appears to be lines of cells that radiate outwards from the apical end of the hilum when viewed under a compound light microscope. The fruits are light brown in colour.

Ecology and distribution. – The densely tufted bunchgrasses of the genus *Festuca* have a wide ecological and geographic distribution.

*Poa* type

blue grass

Plates 21-26.

Material. Caryopses consistent with *Poa* sp. dominate most Bluefish Exposure assemblages.

Remarks. – Caryopses of *Poa* type are *ca.* 1.8 mm long and 0.7 mm wide. The small dark brown hilum is oval to round in shape and found slightly off center near the base of the fruit. They often have a fold running up the center of the fruit. The surface is reddish brown in colour, often slightly translucent, with cell structure that one can faintly see under the dissecting microscope. Most specimens are naked caryposes, with a few remaining attached to their lemmas and paleas. The similarity of the naked caryopses, and florets without caryposes to those intact florets suggests that all represent the genus *Poa*. Comparisons with herbarium material boiled in sodium pyrophosphate indicated that the subfossil remains most closely resembled members of the genus *Poa*.

Ecology. – At least 16 species of *Poa* inhabit the Yukon Territory. Most occupy open meadows, waste and disturbed areas, grassy slopes, and riverbanks. *Poa glauca* is often a dominant plant of south facing extrazonal steppe communities on Yukon, Alaska and the Russian far-east (Lloyd *et al.* 1994; Roland 1996). A specific determination was not possible; however the size of the lemmas and other features show they do not represent *Poa alpigena* or *P. lanata*, two common species of wet or near aquatic sites (Hulten 1968). Most species of *Poa* are palatable and nutritious, having high forage value for grazing ungulates.

Confirmed by: A. Telka and A. Beaudoin.

**Cyperaceae** “sedge family”

*Carex maritima* type.

Plate 27.

Remarks. – Naked achenes of *Carex maritima* type are found in most samples. They Bluefish Exposure specimens closely resemble those of *C. maritima* but specific identifications are usually not possible without the enclosing perigynium. Most modern species of the genus *Carex* exhibit considerable intraspecific variability, further making identification difficult. Specimens of *Carex maritima* type are lenticular in cross-section and elliptical in outline with the base slightly acuminate. They typically measure to 1.5 mm X 1.0 mm X 0.8 mm. The surface is slightly areolate, lustrous and black. The achenes of *Carex* are often very well preserved in many samples. Many of the best preserved specimens float in water.

Ecology. – The genus *Carex* is characteristic of wet and moist soil and it is important in many wet land areas. Some members of the genus grow in upland areas. Because a more specific identification was not attained, comments on ecology are not very useful. However, because many members of the genus inhabit wetland areas, and these specimens often float in water, it is likely that the *Carex maritima* type specimens represent those from riparian plants.

Confirmed by: A. Telka.

*Carex aquatilis/bigelowii* type

Plates 28,29.

Remarks. – The achenes of *Carex aquatilis/bigelowii* type are less abundant than the other types (see above). Specimens are very thin and lenticular in cross section and broadly obovate in outline with an erect or slightly bent style. They typically measure *ca.* 1.5 mm (without style) X 1.0 mm and are very thin. The surface is slightly areolate, lustreless and brown colored.

Ecology. – *C. aquatilis* is circumpolar, nonarctic in distribution and is found in shallow water by margins of ponds and sloughs and sheltered river flats. *C. bigelowii* is found in moist or peaty soil and in moist areas of alpine tundra. As further identification was not attained, the ecology of these specimens remains uncertain. Most members of the genus inhabit wetland areas.

Confirmed by: A. Telka.

*Kobresia* sp.

Plate 30.

Remarks. – Achenes of *Kobresia* sp. are rare in the Bluefish Exposure sediments. Achenes are obovate in long-section and trigonous in cross section. The slightly lustrous surface is slightly striate and brown in colour. They measure *ca.* 2.2 mm long X 1.2 mm wide.

Distribution. – Circumpolar; in North America, Labrador to Alaska, south to the mountains to Utah and Colorado; in the Yukon Territory mostly west of longitude 133° W. *K. myosuroides* was the dominant vascular taxa found in full-glacial assemblage from the Seward Peninsula (Goetcheus and Birks 2001).

Ecology. – Found in dry locations, usually calcareous sandy heath and windswept ridges.

Confirmed by: A. Beaudoin.

*Scirpus* cf. *validus* Vahl

Plate 31.

Material. A single achene of *Scirpus* cf. *validus* was recovered.

Remarks. – Achenes of *S.* cf. *validus* are *ca.* 1.0 mm long, 0.6 mm wide, and 0.4 mm thick. They are obovate in long-section, and depressed ovate in cross-section. The achene is almost flat on one face and convex on the other. The stylar beak is inconspicuous or almost lacking. The surface is light yellowish-brown to cream and faintly areolate. There are four spiny bristles of the same colour as the achene surface, nearly twice as long as the achenes.

Recent distribution. – North America; from Newfoundland to southeast and central Alaska, south to Georgia, Missouri, Texas, and California; in the Yukon Territory considered rare, but known to be more widespread in the southern part.

Ecology. – Wet marshes and lakeshores, water up to 1 m deep along sheltered lakeshores.

Confirmed by: A. Beaudoin.

**Juncaceae** "rush family"

*Juncus sp.*
bog rush

Plates 32,33.

Remarks. – Seeds of *Juncus* sp. obliquely elliptic in long-section, short caudate at each end, elliptic in cross-section. They are very small, typically measuring approximately 0.7 mm long X 0.2 mm wide. The testa is thin, with the cells transversely elongated and arranged in longitudinal rows, giving it a "striated" appearance.

Recent distribution.- At least 14 species of *Juncus* found in the Yukon, most being circumpolar or amphiberingian in distribution.

Ecology. – Most species of this genus are perennial, grass-like herbs common in moist open areas including alluvial river flats, riverbanks, moist meadows and lake margins. Substrates range from sandy to calcareous to gravelly soils.

cf. *Luzula* sp.
Wood-rush

Plates 34,35.

Remarks. – A few specimens resemble the seeds of *Luzula* sp. They elliptic in outline measuring approximately 1.1 mm long X 0.4 mm wide. The surface is finely striate and reddish-brown in colour. There is a prominent caruncle, or tuft at the apex. The seeds of *Luzula* look very similar to that of *Juncus* sp., but often are larger and more robust.

Recent distribution and ecology. Many *Luzula* are circumpolar in distribution found near streams in slightly mesic meadows.

*Luzula*/*Juncus* sp.

Plate 36.

Remarks. – The siliques of *Luzula* sp. and *Juncus* sp. are nearly indistinguishable from each other. They are elliptical in outline with an acute and mucronate apex. The inner surface has a prominent medial ridge which represents parietal (trilocular) placentation. There are visible striations perpendicular to the placentation. The dorsal surface of the capsules are dull and brown in color. The typical size of the specimens are *ca.* 2.7 mm long and 1.5 mm wide.

Commonly, specimens are flattened or curved inwards. Most specimens are fragmented or broken in small pieces but occasionally remain entire.

Recent distribution. – *Luzula* and *Juncus* are widespread genera throughout the circumpolar regions including the Yukon Territory.

Ecology. – Although some species inhabit bogs and marshes, most members of *Juncus* and *Luzula* grow in dry or moist open tundra or meadows, slopes, fell-field and riverbanks.

Confirmed by: A. Telka.

**Chenopodiaceae** "goosefoot family"

*Chenopodium* sp.

Plate 37.

Remarks. – Seeds of *Chenopodium* were rare in the Bluefish Exposure samples. They are slightly elliptical in outline with a conspicuous ridge on the lateral margin. They measure approximately 0.9 mm X 0.8 mm. The surface is smooth, lustrous, and black.

Recent distribution and ecology– Most *Chenopodium* are very widespread geographically, typical of dry, disturbed settings.

**Brassicaceae** "mustard family"

Brassicaceae sp.

Plate 38.

Remarks. - Some seeds of the Brassicaceae family were found that are significantly larger than that of the *Draba* type described below. They are of similar size and surface morphology to that of *Draba* but are approximately 1.5-2.0 mm long X 0.8-1.2 mm wide. Because of their larger size dimensions, I did not consider them as part of the *Draba* type.

*Draba* type

Plates 39,40.

Remarks. The seeds of the Brassicaceae family are very similar and the less than great preservation conditions of most specimens makes precise identification difficult. *Draba* type seeds dominated the herbaceous forb component of the Bluefish Exposure sediments. However, the most of the Bluefish Exposure specimens appear to correspond to those of *Draba* sp. Seeds are obovate in long-section; elliptic in cross-section; surface is areolate and scalariform, reddish brown colour, cotyledons incumbent, radicle prolonged at base; tip of radicle mostly acute, as long or slightly longer than that of cotyledons, usually incurved; radicular furrow distinctly marked externally on both faces. They typically measure approximately 1.0 mm long X 0.6 mm wide.

Ecology. Alpine, rocky slopes, open tundra, dry grassy slopes, gravelly slopes, often calcareous, disturbed situations.

Confirmed by: A. Telka

**Potamogetonaceae** "pondweed family"

*Potamogeton* sp.

Plate 41.

Material. - A single achene of *Potamogeton* was found in sample GZ.07.17.99.04 (Station. 3).

Remarks. - The achenes of *Potamogeton* are obliquely obovate in long-section and elliptic in cross section with the sides slightly flattened. The specimen is 2.2 mm long X 1.2 mm wide X 0.8 mm thick. A remnant style base is found at the apex of the achene. The specimen is split along the lateral margin and only a single half is present. The inside of the endocarp is exposed, displaying the embryo and comma. The surface is light yellowish-brown in colour, faintly reticulate.

Recent distribution. - *Potamogeton* is a widespread genus with a circumpolar, nonarctic distribution.

Ecology. - *Potamogeton* are commonly found along margins of lakes and ponds.

**Ranunculaceae** "crowfoot family"

*Ranunculus* cf. *nivalis*

Snow buttercup

Plate 42.

Material. – A single achene of *Ranunculus* cf. *nivalis* was found in sample GZ.07.17.99.00 (Station 3).

Remarks. – Achenes of *Ranunculus* cf. *nivalis* are obovate with the adaxial margin nearly straight with a small notch 1/3 from the base and the abaxial edge strongly convex. There is a remnant of the stylar base. The specimen measures approximately 2.0 mm long X 1.5 mm wide. The surface is porous and buff in colour.

Recent distribution. – Circumpolar; arctic; in North America, Greenland and Labrador south to northern British Columbia; found throughout much of the Yukon Territory.

Ecology. – In wet moss by brooks and in herbmats near the edge of melting snow.

*Ranunculus* cf. *sceleratus.* L.
Celery-leaved buttercup

Plate 43.

Remarks. – The achenes of *Rancunculus* cf. *sceleratus* are obliquely obovate in outline and have a conspicuous marginal ridge that is thinner in width than the middle of the achene. They measure *ca.* 1.9 mm long, 1.5 mm wide, and 0.8 mm thick. The stylar beak is inconspicuous or almost lacking. The achene surface is faintly areolate and the color is light brown.

Recent distribution. –*Ranunculus sceleratus* are Amphi-Beringian in distribution; in the Yukon Territory known from as far north as McDougall Pass in the Richardson Mountains.

Ecology. – Wet peaty places by pools, streams, or lakes and in springy places.

Confirmed by: A Beaudoin.

**Papaveraceae** "poppy family"
*Papaver* sect. *Scapiflora* Reichenb.
arctic poppy

Plates 44,45.

Remarks. –Seeds of *Papaver* sect. *Scapiflora* are narrowly reniform in outline, usually larger at one end than the other, with the larger end often displaying a prominent caruncle. The testa is semi-translucent, with a strongly reticulate surface. The seeds measure *ca.* 0.9 mm long, 0.6 mm wide, and 0.4 mm thick. It is impossible to separate the many forms of *Papaver* sect. *Scapiflora* by seed morphology (Berggren 1981; Bennike 1990). This section includes a number of species found today in the Yukon, including *P. radicatum* Rottb., *P. lapponicum* (Tolm.), and *P. nudicaule* L. Specimens of *Papaver* sect. *Scapiflora* are often poorly preserved with broken or fragmented testa and flattened.

Recent distribution. – The species of the section of *Scapiflora* are circumpolar in distribution.

Ecology. – *Papaver* sect. *Scapiflora* species are very common in arctic and alpine regions, especially in open habitats. In the Low Arctic species of this section are mostly confined to fell-field sites with little snow cover during the winter. *Scapiflora* species grow in both acidic and alkaline soils, but they show some preference for calcareous soil (Bennike 1990). In addition, native *Scapiflora* species found today in the Yukon Territory are described from in open gravelly places, alpine tundra turf, steep rocky slopes, and creek and river beds.

Confirmed by: A. Telka.

## Caryophyllaceae

*Cerastium* cf. *arvense* L.
Field chickweed

Plate 46.

Remarks. – Seeds are cuneate in outline with the tip of the radicle usually straight but not appressed. The notch between radicle and cotyledon is usually open. They typically measure *ca.* 1.0 mm long X 0.8 mm wide. The surface has elliptical papillae in roughly concentric rows that are obscured closer to the centre. There are distinct protuberances on the edge of the papillae.

Recent distribution – Circumpolar; in North America, Newfoundland to British Columbia; in the Yukon Territory known north to latitude 64°N.

Ecology. – Gravel slopes, open thickets, and subalpine meadows.

*Cerastium* cf. *beeringianum* Cham. & Schlecht.
Beringian mouse-ear chickweed

Plate 47.

Remarks. – Seeds are elliptic-pyriform; tip of the radicle is slightly longer than the cotyledons and often strongly curved and appressed to the latter. They typically measure *ca.* 1.5 mm long X 1.2 mm wide. The surface is lustreless with stelliform laterally arranged in nearly concentric rows. The stelliform along the lateral margins are rather acute while the rest are often more rectangular, all with distinct protuberances.

Recent distribution. – Amphi-Beringian; extending eastward across Canada to the Atlantic Provinces and south through the Rocky Mountains into the western United States; found throughout the Yukon Territory.

Ecology. – Rocky, gravelly, or sandy places from alpine tundra to heath, woodllands, and meadows.

*Minuartia rubella* (Whalenb.) Grasebn. Ex Asch. & Graebn.
Sandwort

Plate 48.

Remarks. – Seed is retortiform in outline. They are very small, typically measuring *ca.* 0.6mm long X 0.4 mm wide. The surface is lustreless, covered with distinct slightly curved wrinkles, radially arranged to the marginal notch. The are distinctive elongate pappilae in concentric rows around the seed.

Recent distribution. – Circumpolar, arctic-alpine; Greenland and Newfoundland to Alaska; found throughout much of the Yukon Territory.

Ecology. – Frequent in dry, gravelly, sandy or rocky places.

*Silene involucrata* (Cham. & Schlecht.) Bocquet

Plate 49.

Remarks – The seeds of *S. involucrata* are triangular in shape, approximately 1 mm in diameter with a narrow wing. The surface is rugulate and dark reddish-brown to black in colour. The surface of the seed has elongate pappilae.

Recent distribution. – Circumpolar; in North America from Greenland and northern Labrador to Alaska; widely scattered in the Yukon Territory.

Ecology. – Moist stony, gravelly, or sandy places.

Confirmed by: A. Telka.

*Silene uralensis* Rupr.

Plates 50,51.

Remarks. – Seeds are semi-circular to reniform in shape with a semi-circular wing. The seeds are 1.25 mm in diameter without the wing, and 2 mm with wing attached. The cells in the wing are isodiametric in outline. There are elongate papillae on the surface of the seed. Specimens of *Silene uralensis* are often very well preserved with much or the entire delicate wing remaining attached to the seed. The wing is probably an adaptation for wind dispersal.

Recent distribution. – This species is circumpolar, arctic and alpine in North America, Greenland, and northern Quebec to Alaska, and south in the mountains of British Columbia to Montana, Idaho, and Colorado.

Ecology. – The species grow in moist alpine slopes and meadows and often prefer calcareous soils.

Confirmed by: A. Telka.

*Stellaria* sp.
Chickweed

Plate 52.

Remarks. – Seeds are circular to circular-obovate with the tip of the radicle and that of the cotyledon typically equal in length, with an appressed marginal notch. They typically measure approximately 1.2 mm long X 1 mm wide. The surface is lustreless with close, blunt, rectangular stelliform papillae, laterally arranged in concentric rows.

Recent distribution and ecology. – The genus is widely distributed both geographically and ecologically.

**Primulaceae** "evening primrose family"

*Androsace septentrionalis* L.
Fairy-candelabra

Plate 53.

Remarks. – The seeds of *A. septentionalis* are dome shaped or elliptical in outline, flattened with a prominent fold often in the middle. The testa is semi-translucent and reddish-brown colored, with distinctive circular reticulation. The seeds measure 1.1 mm long X 0.8 mm wide. The fold present in sub-fossil specimens is likely due to flattening, as modern herbarium specimens are irregular in shape and relatively thick.

Recent distribution. - *A. septentionalis* is circumpolar in distribution; in North America, Newfoundland, Gaspe, Quebec, James Bay to Alaska, south to Arizona, and California; throughout much of the Yukon Territory north to the Arctic coast.

Ecology. – This species is found in semi-open to open dry calcareous sandy or gravelly places. Common on south-facing dry bluffs in Central Alaska and Yukon Territory, rock outcrops, and especially disturbed sites.

Confirmed by: A. Telka.

**Saxifragaceae** "saxifrage family"

*Saxifraga oppositifolia* L.
purple saxifrage

Plates 54,55.

Material. Scale-like leaves.

Remarks. The leaves of *S. oppositifolia* are scale-like, oblong to broadly obovate, 2-4 mm long, entire, leathery, bristly-ciliate, marcescent, opposite, connate-clasping, 4-ranked. Specimens from Bluefish Exposure consist of opposite leaf pairs.

Recent distribution. Circumpolar, wide ranging arctic-alpine; in North America, Greenland to Alaska, south to Gaspé, Quebec, Idaho, and Wyoming; and found throughout much of the Yukon Territory.

Ecology. Forms small mats on rocky areas, calcareous soils and gravels.

Confirmed by: H.H. Birks.

**Rosaceae** "rose family"

*Dryas octopetala* L.

Material. – A single *D. octopetala* leaf was recovered in sample GZ.07.14.99.09 (Station 2).

Remarks. – The leaves of *D. octopetala* are ovate-oblong, crenate-dentate, with strongly revolute margins. The bottom side have branching veins from a prominent midvein and the top is strongly rugose and dull. The single specimen recovered was 4.25 mm long and 2.00 mm wide.

*Dryas octopetala* leaves have two common forms, depending on where the plant grows (Bennike 1990). Small narrow leaves with strongly revolute margins are the wind adapted type, whereas leaves larger leaves are lee-type. This suggests the single specimen represents a member of an exposed, fell-field site.

Recent distribution. - *D. octopetala* is of nearly circumpolar arctic and alpine range, extending eastward to the slopes of the Mackenzie and Richardson mountains of western District of Mackenzie; throughout much of the Yukon Territory.

Ecology. – *Dryas octopetala* is a very important heliophilous dwarf-shrub in Arctic and alpine tundra. If often dominates (sometimes forming Dryas heaths) areas of dry soil which lose their snow early in spring. The species is also characteristic of fell-field sites and areas of moist soil, even sites with heavy snow cover. It does not grow in snow patch communities. Sites with alkaline soils are preferred (Bennike 1990).

*Potentilla* spp.

Cinquefoil

Plates 56-58.

Remarks. The achenes of *Potentilla* spp. are obliquely ovate in long-section and elliptical in cross section; style is sub-terminal; surface is faintly punctate to smooth. Few specimens exhibit faint angular striations on the surface. They typically measure *ca.* 1.5 mm X 1.0 mm. Examination of herbarium collections indicates that several species are represented in the Bluefish Exposure assemblage. Morphology indicates they do not represent *P. palustris*, a bog plant, or the highly sculptured achenes of *P. fruiticosa.*

Ecology. – Most plants within the genus are perennial herbs. They are primary members of open vegetation, and many species grow on dry sites.

*Rubus idaeus* L. s.l.

wild raspberry

Plate 59.

Remarks. The achenes of *Rubus idaeus* are obliquely elliptic in long-section and elliptic in cross-section with a ridged margin. They measure *ca.* 2.0 mm long X 1.2 mm wide. The surface is reticulate or alveolate with a woody or porous in appearance. The remains from the Bluefish Exposure assemblage are all split in half along the lateral margin.

Recent distribution. *Rubus ideaus* is circumpolar in distribution; in North America from Newfoundland and Labrador to British Columbia and Alaska, south to North Carolina, northern Mexico, and California; in the Yukon Territory found north to the Porcupine River valley.

Ecology. Typically found in woodland clearing, and often prefer disturbed situations such as riverine cut-banks and bulldozer road-cuts.

**Asteraceae** "composite family"

*Achillea sp.* L.

Yarrow

Plate 60.

Remarks. Achenes are obovate in long-section, elliptical in cross-section, measuring 2.4 mm long X 0.8 mm wide. Margin has a narrow wing, surface is finely longitudinally striate. There is remnant style base, but the pappus is not present.

Recent distribution. East Asia; North America; from Alaska to Manitoba, and disjunct to Gaspé Peninsula in Quebec, reaching the Arctic coast in northwestern District of Mackenzie; in the Yukon Territory widespread.

Ecology. Rocky or gravelly riverbanks or lakeshores and roadsides.

Confirmed by: A. Telka

*Artemisia frigida / campestris* type

Plates 61-68.

Material. – flowers.

Remarks. – Flowers refer to either *A. fridga* (L.) or *A. campestris* (L. s.l.). They are ca. 2.7 mm long and *ca.* 0.8 mm wide. They contain 5 glabrous petals, connate, forming a radial and tubular corolla. They were determined to be either *A. frigida* or *A. campestris* by their overall size and morphology. *A. furcata* is ruled out because of different cuticle structure. *A. tilesii* is not represented because they have revolute petal tips. *A. norvegica* is not represented because they have pubescent petals with revolute tips (J.V. Matthews Jr., unpublished data). The abundance of leaves referring to *A.frigida* in most samples that contain *A. frigida/campestris* type flowers suggests that most of the flowers may refer to *A. frigida.*

Ecology – *A. frigida* is a dominant on dry extrazonal steppe communities on south-facing river bluffs of the Kolyma (Russia), Yukon and Porcupine River drainages and zonal steppe and grasslands in Eurasia and North America. *A. campestris* is common on riverbeds, prairie and rocky slopes, open areas, waste areas, and roadsides.

*Artemisia frigida* L.
fringed sagebrush

Plates 66-69.

Material. Leaves

Remarks. Leaves are twice-pinnatifid, with linear to linear-filiform divisions. Smaller leaves are less dissected. Leaves have distinctive veination.

Recent distribution. Central Asia and North America; from southern Manitoba to British Columbia and the eastern part of Alaska, north to the Arctic coast in western District of Mackenzie, and south to Minnesota, Arizona, New Mexico, and Texas; in the Yukon Territory north to about latitude 64° 30' N and then disjunct to the Porcupine River area. *A. frigida* is a dominant on dry extrazonal steppe communities on south-facing river bluffs of the Kolyma (Russia), Yukon and Porcupine River drainages (Roland 1996).

General botanical characteristics. *A. frigida* is a low, mat-forming suffrutescent perrenial subshrub with physiological characters typical of both cool and warm season plants. It typically reaches 10 to 40 cm in height and rarely exceeds 60 cm. A woody base gives rise to semiherbaceous annual stems. It is noted for its relatively deep and extensive tap root. It has tremendous reproductive potential which enables it to spread, reseed, ad invade new sites.

Ecology. *A. frigida* typically grows in full-sunlight on dry, porous, gravelly, sandy, or shallow loam soils. It is often described as a pioneer or early seral species on disturbed sites. Evidence is strong that *A. frigida* is one of the better sub-shrubs in terms of forage value. Studies indicate *A. frigida* is a major component of seasonal diets of many wildlife species, including Saiga antelope (*S. tatarica*), bighorn sheep (*Ovis canadensis*), Dall sheep (*Ovis dalli*), pronghorn antelope (*Antilocarpa americana*), elk (*Cervus canadensis*), bison (*Bison bison*). Analyses show it is highly palatable for wild herbivores and has relatively high levels of dry matter digestibility, digestible energy, and digestible protein during all seasons except summer (Cooperrider and Bailey 1986). Although it is considered an increaser, invader, or an indicator of overgrazing, individual plants are quite susceptible to heavy grazing. Grazing pressure results in an increased number of individual plants of *A. frigida*, accompanied by a shift in population structure to young plants rather than middle-aged or older ones. The shift to a younger population of plants adds to the overall forage value of *A. frigida* in a particular area.

Confirmed by: A. Telka

*Taraxacum ceratophorum* (ledeb.) DC. s.l.
Dandelion

Plate 70.

Remarks. Achenes of *Taraxacum ceratophorum* are *ca.* 4.4 mm long X 1.25 mm wide. The pappus is not present on the Bluefish Exposure specimens. They are obovate in long-section, tapering to a beak and elliptical in cross section. The surface has numerous (10-15) longitudinal ribs that smooth below the middle and spiny or muricate above. The achenes are olive-drab to brown colour.

Recent distribution. Circumpolar; in North America, Greenland and Labrador to Alaska, south to Maine, New Hampshire, New Mexico, and California; found throughout the Yukon Territory.

Ecology. Woodland and heath to tundra.

## 4. Fauna

*Thymallus arcticus* “arctic grayling”

Plate 71.

Material. – Scales.

Remarks. – The scales of the subfossil specimens of *Thymallus arcticus* have four lobes and measure *ca.* 2.5 mm wide X 2.9 mm long. The scales have concentric rings on the surface. They were compared with modern reference material at the Provincial Museum of Alberta. Also, comparable to descriptions of fossil specimens reported by McAllister and Harington (1969).

Ecology and Distribution. – Arctic grayling is commonly found in clear cold waters of fast-flowing rivers and sometimes lakes in the circumpolar region. They are known from Middle-Wisconsinan deposits at Ch’ijee’s Bluff, dated to 32,400 ±770 yr BP (McAllister and Harington 1969).

All plates are of Bluefish Exposure subfossil specimens unless otherwise noted.

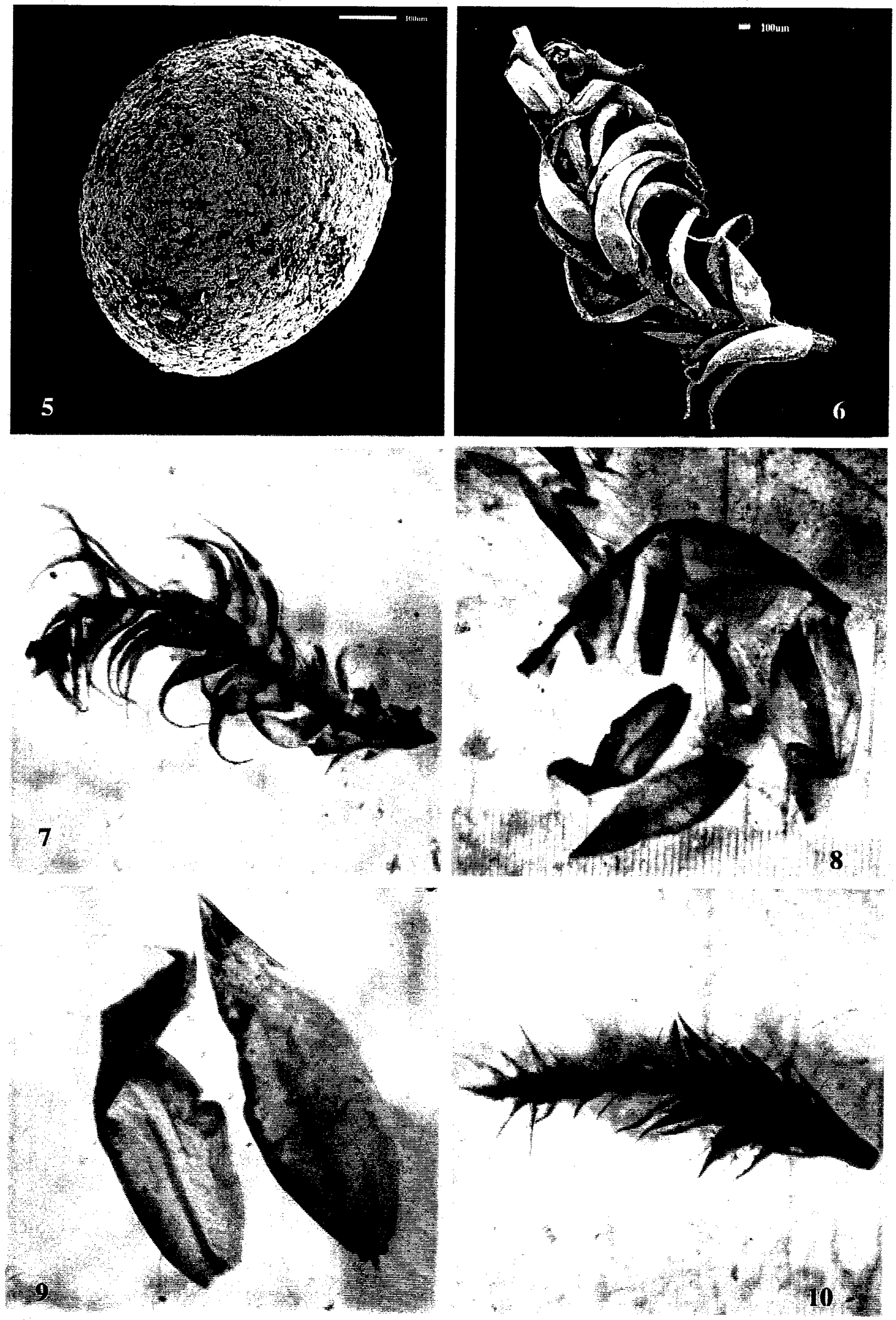


Plate 5) *Cennococcum geophilum* fungal sclerotia, (Scale Bar (SB) = 100 $\mu$m); 6) *Drepanocladus vernicosus* stem with leaves (SB = 100 $\mu$m); 7) *Drepanocladus vernicosus* stem with leaves; 8) *Scorpidium scorpioides* stems with leaves; 9) *Scorpidium scorpioides* leaves; 10) *Tomenthypnum nitens* stem

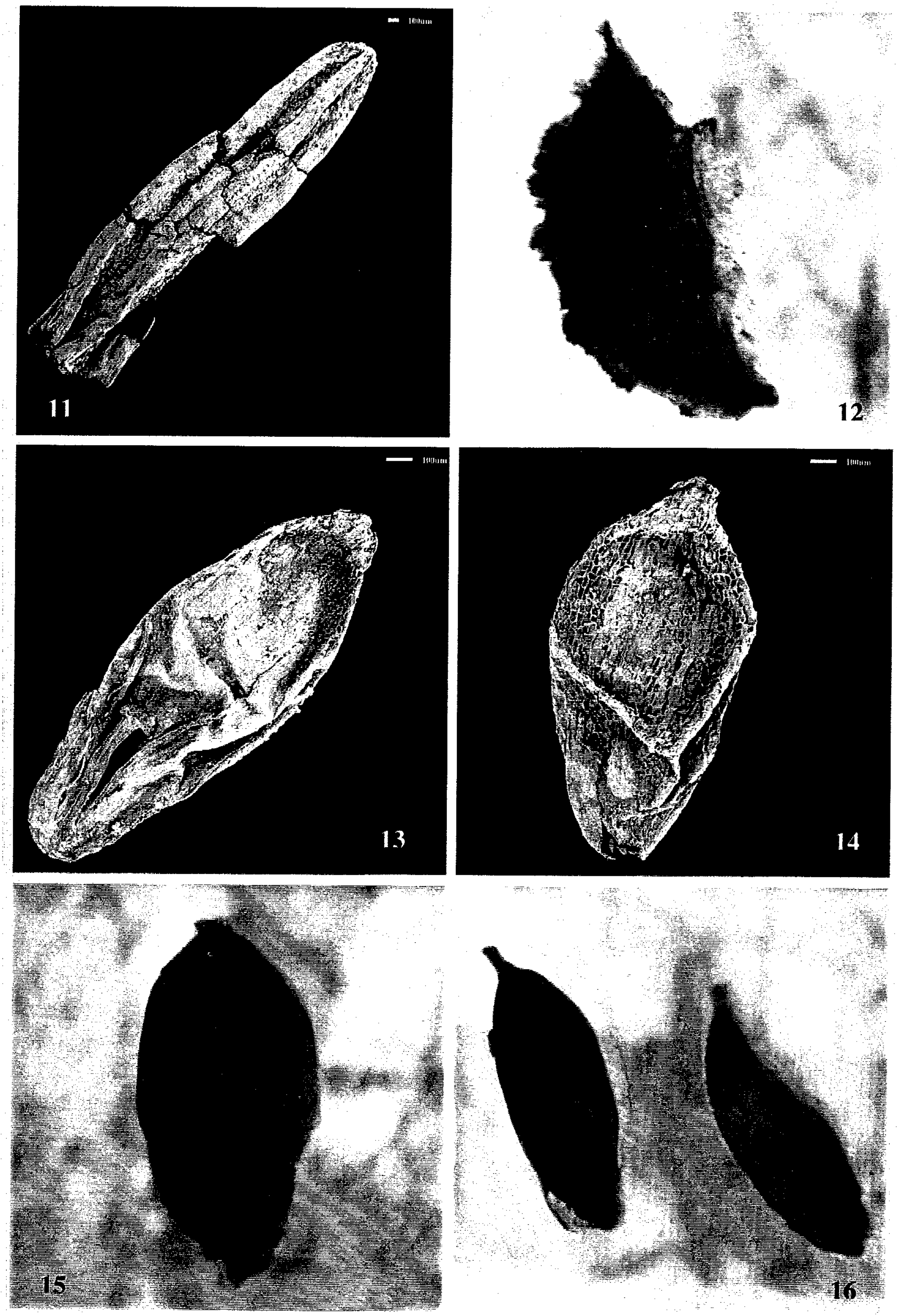


Plate 11) *Picea* sp. needle fragment (SB = 100 µm); 12) *Betula* sp. nutlet fragment; 13-15) *Deschampsia* sp. caryopsis (SB = 100 µm); 16) Subfossil *Deschampsia* sp. caryopsis (left) and modern *Deschampsia caespitosa* caryopsis (right)

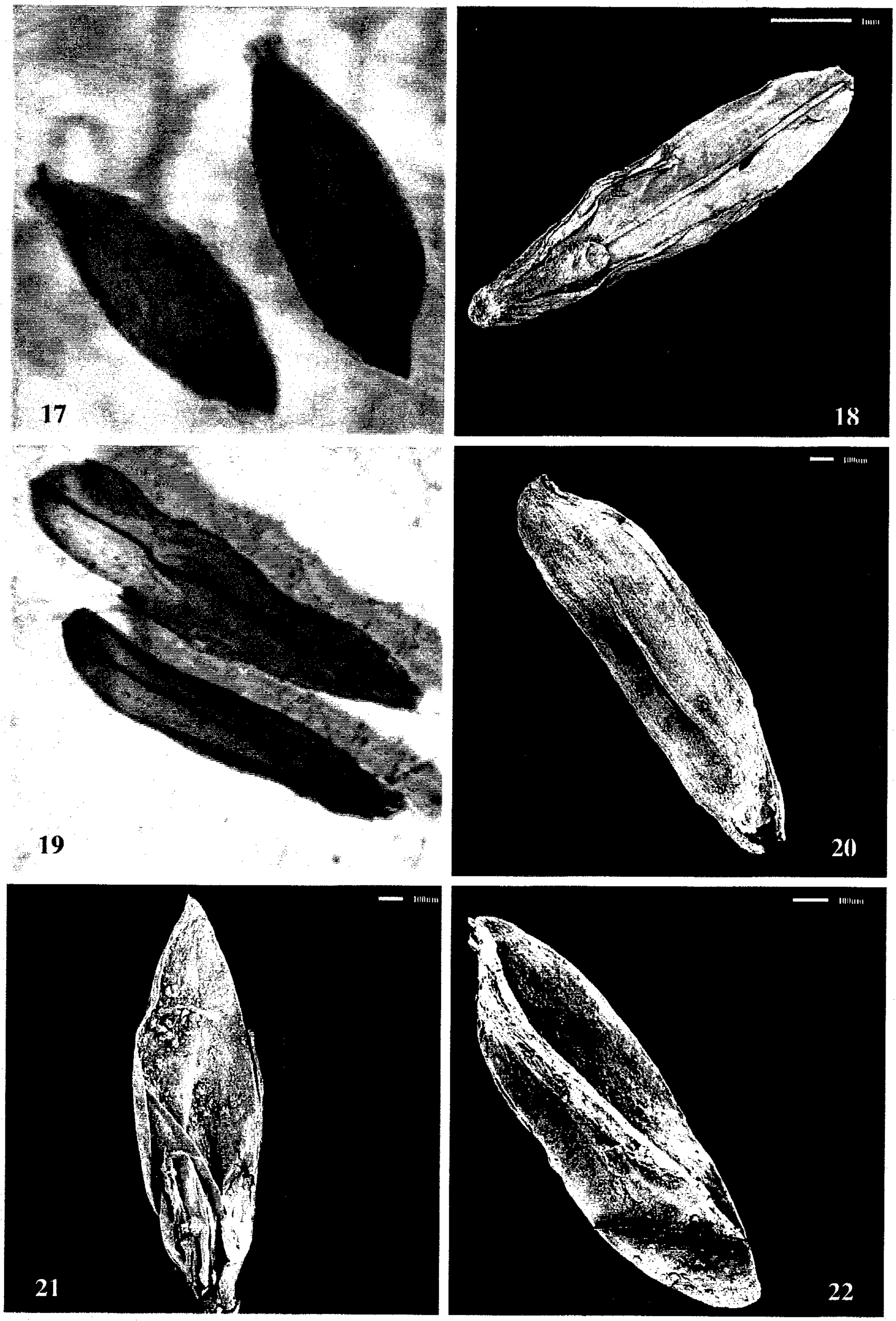


Plate 17) Two Modern *Deschampsia caespitosa* caryopses; 18) *Elymus* sp. caryopsis (SB = 1.00 mm); 19) Two *Elymus* sp. caryopses; 20) *Festuca* sp. caryopsis; 21-22) *Poa* type caryopsis (SB = 100 $\mu$m)

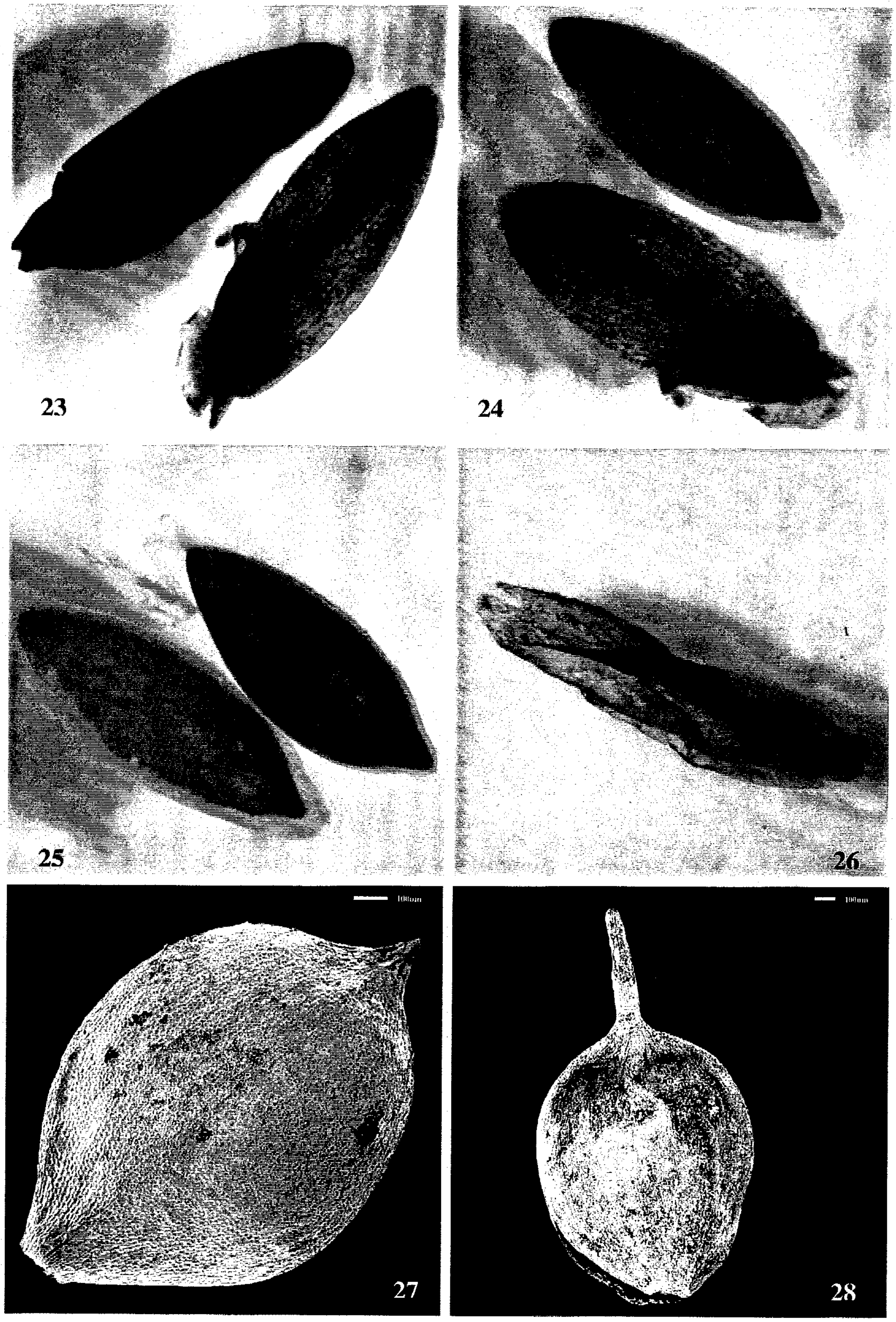


Plate 23) Two *Poa* type caryopses; 24) Subfossil *Poa* type caryopsis (bottom-left) and modern *Poa glauca* (top-right); 25) Two modern *Poa glauca* caryopses; 26) *Poa* type floret; 27) *Carex maritima* type achene (SB = 100 μm); 28) *Carex aquatilis/bigelowii* type achene (SB = 100 μm)

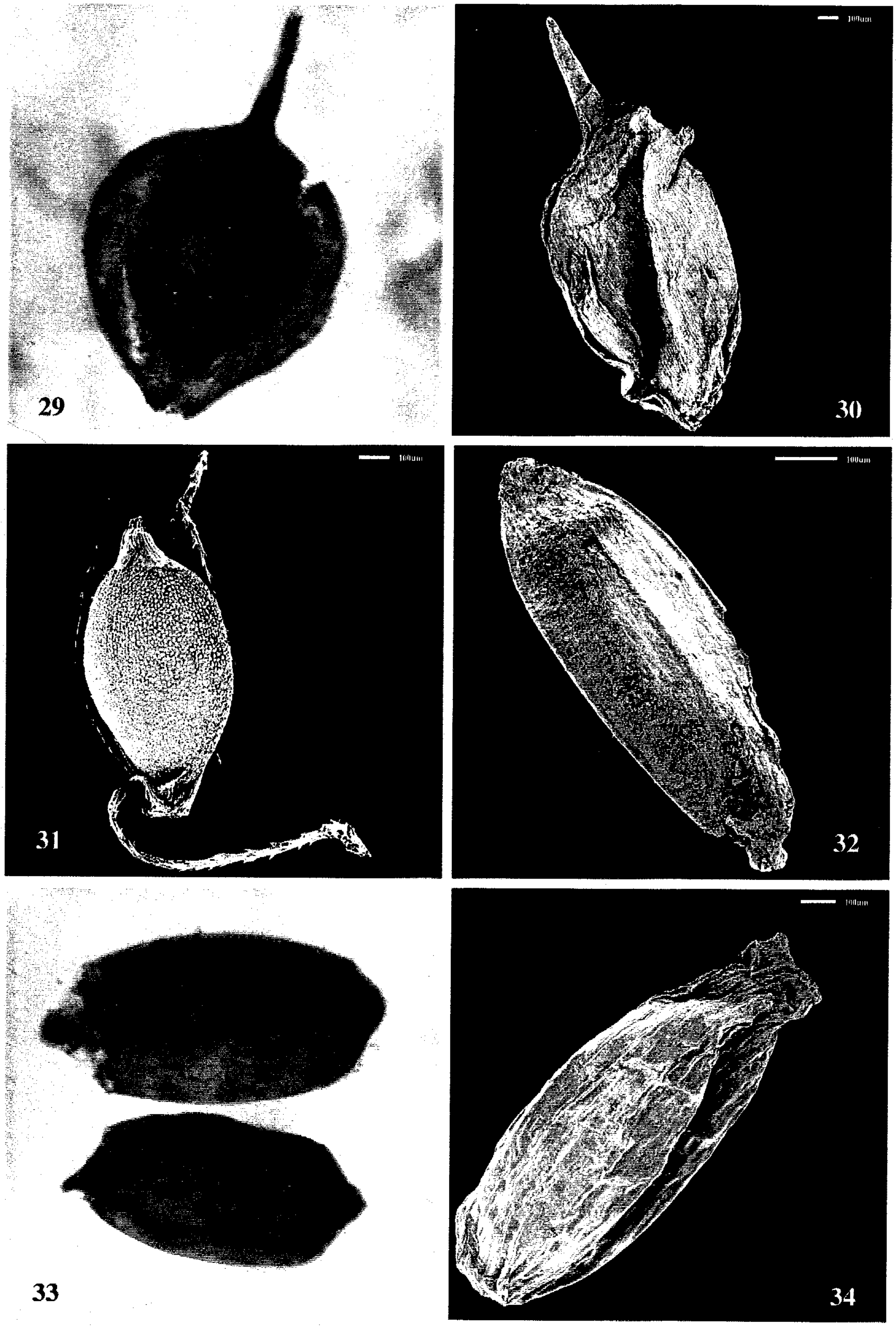


Plate 29) *Carex aquatilis/bigelowii* type achene; 30) *Kobresia* sp. achene; 31) *Scirpus* cf. *validus* achene (SB = 100 $\mu$m); 32) *Juncus* sp. seed (SB = 100 $\mu$m); 33) Two *Juncus* sp. seeds; 34) cf. *Luzula* sp. seed (SB = 100 $\mu$m);

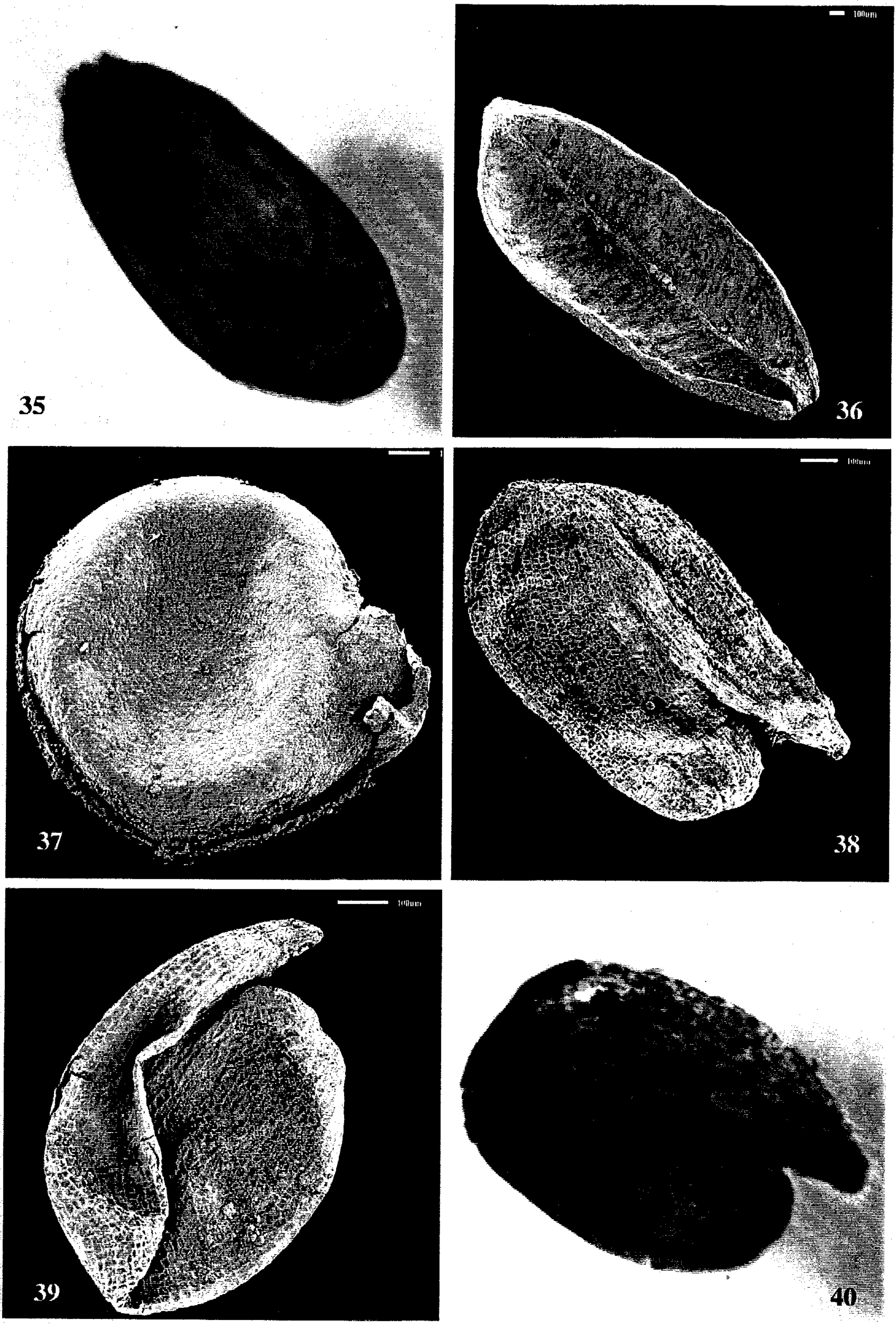


Plate 35) cf. *Luzula* sp. seed; 36) *Juncus/Luzula* sp. silique fragment (SB = 100 μm); 37) *Chenopodium* sp. seed; 38) Brassicaceae undet. seed (SB = 100 μm); 39)*Draba* type seed (SB = 100 μm); 40) *Draba* type seed

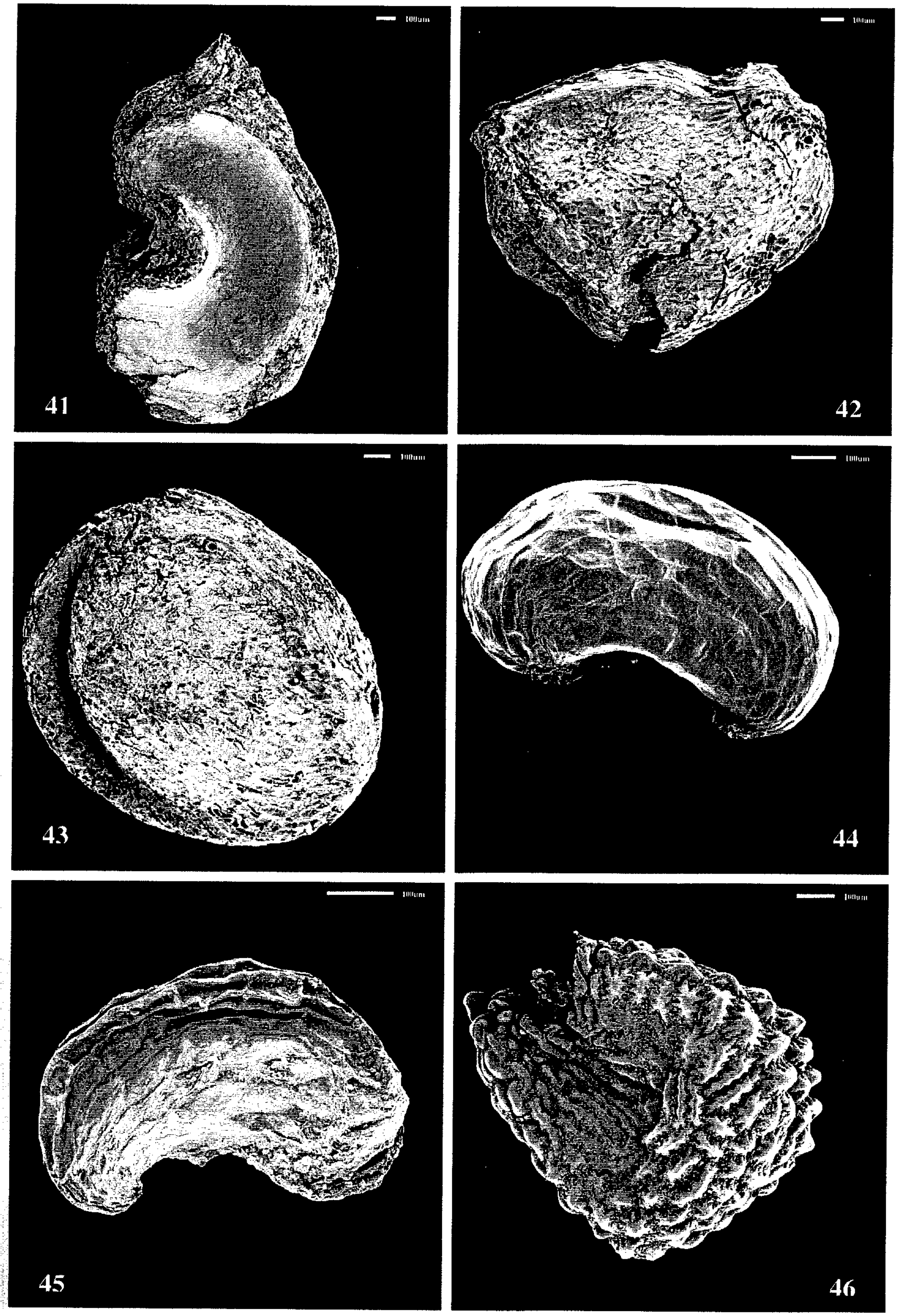
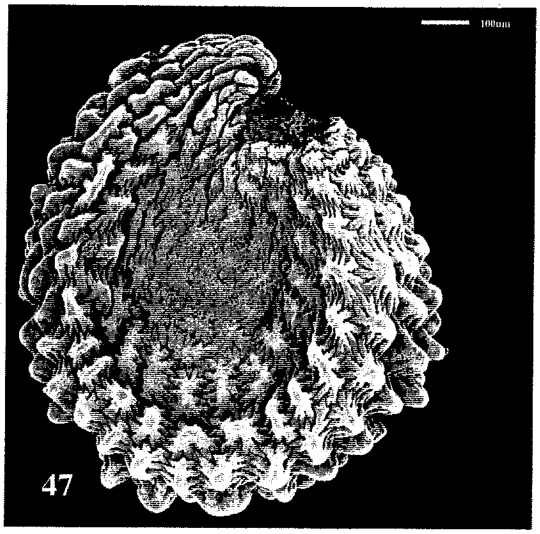
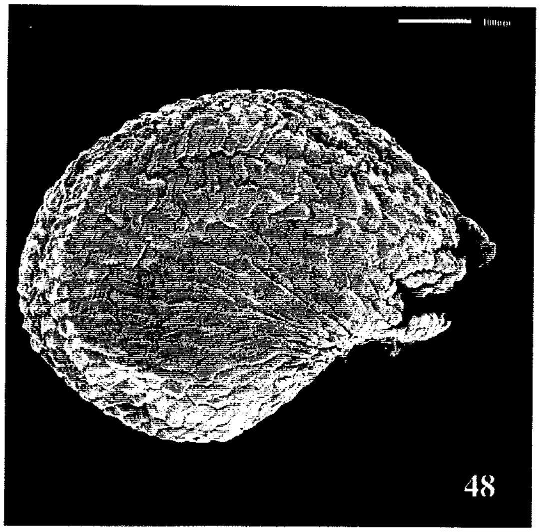
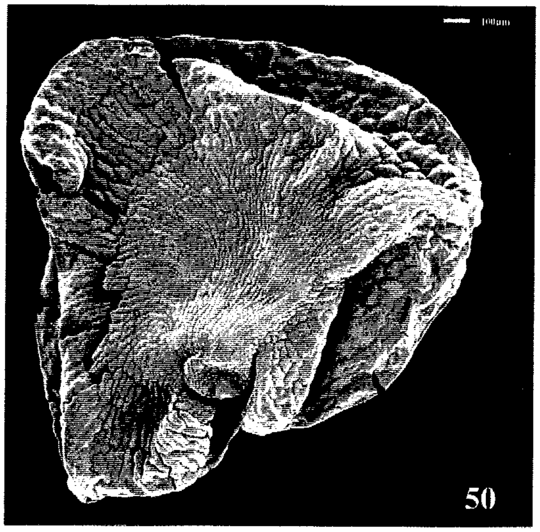
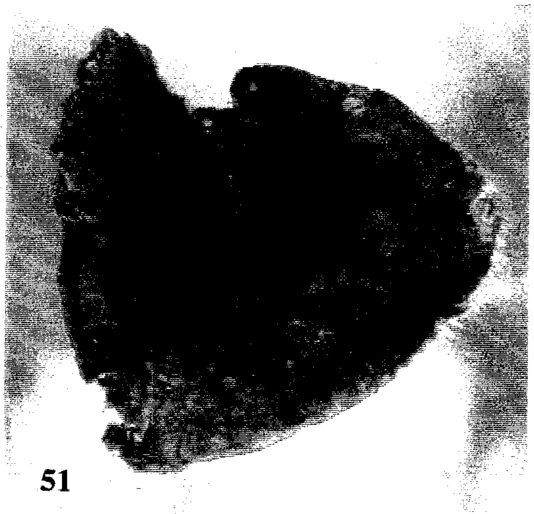


Plate 41) *Potamogeton* sp. endocarp (SB = 100 µm); 42) *Ranunculus* cf. *nivalis* achene (SB = 100 µm); 43) *Ranunculus* cf. *sceleratus* achene (SB = 100 µm); 44-45) *Papaver* sect. *Scapiflora* seed (SB = 100 µm); 46) *Cerastium* cf. *arvense* seed (SB = 100 µm)









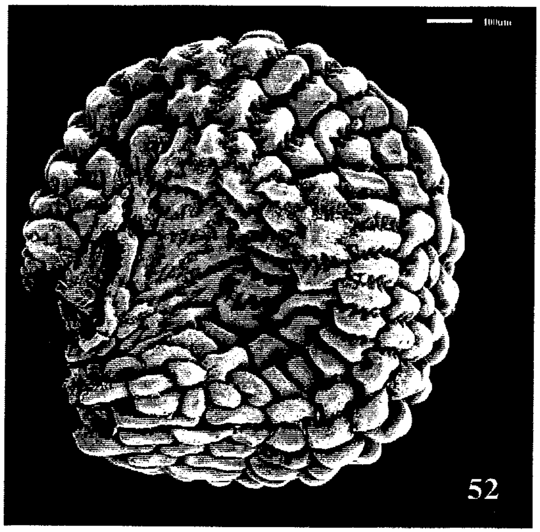
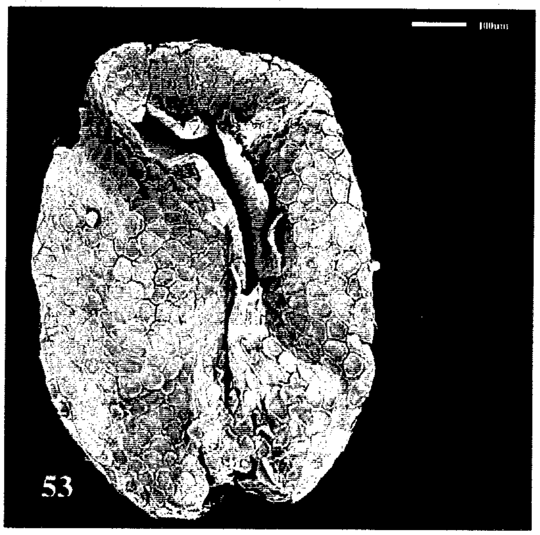
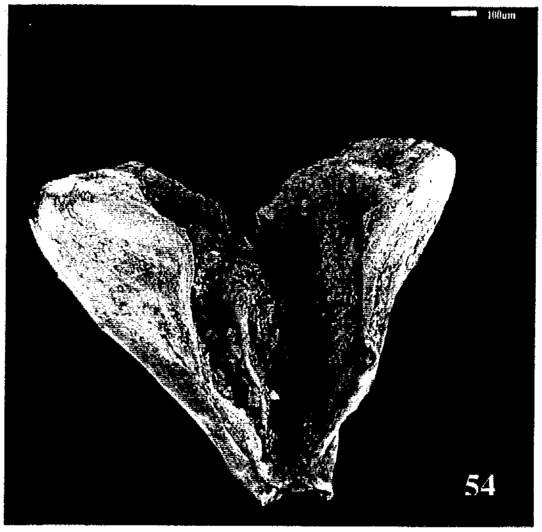
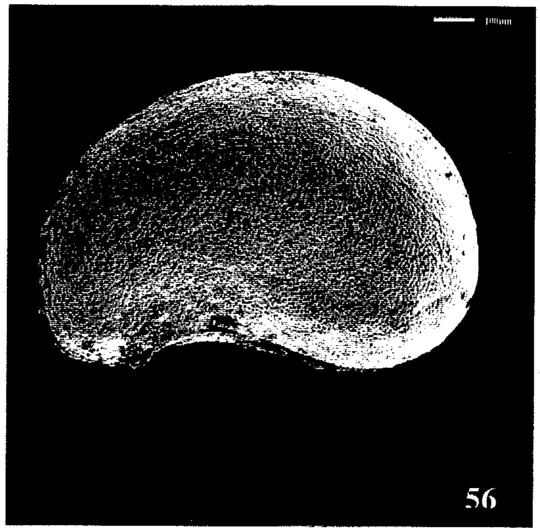


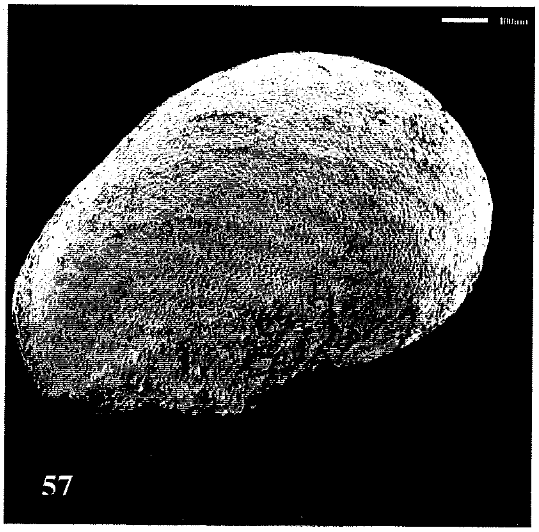
Plate 47) *Cerastium* cf. *beeringianum* seed (SB = 100 µm); 48) *Minuartia rubella* seed; 49) *Silene involucrata* seed (SB = 100 µm); 50-51) *Silene uralensis* seed (SB = 100 µm); 52) *Stellaria* sp. seed (SB = 100 µm)


53


54


55


56


57

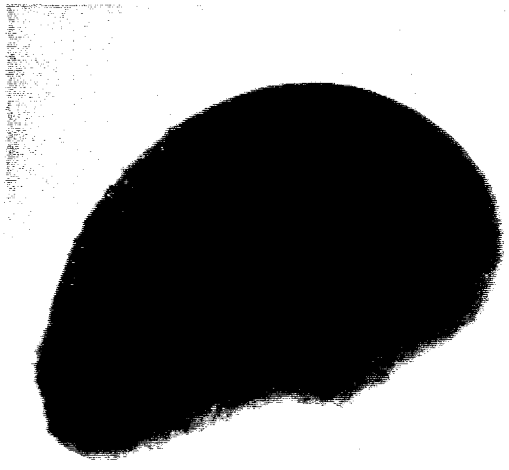

58

Plate 53) *Androsace septentrionalis* seed (SB = 100 μm); 54-55) *Saxifraga oppositifolia* leaf pair (SB = 100 μm); 56-58) *Potentilla* sp. achenes (SB = 100 μm)

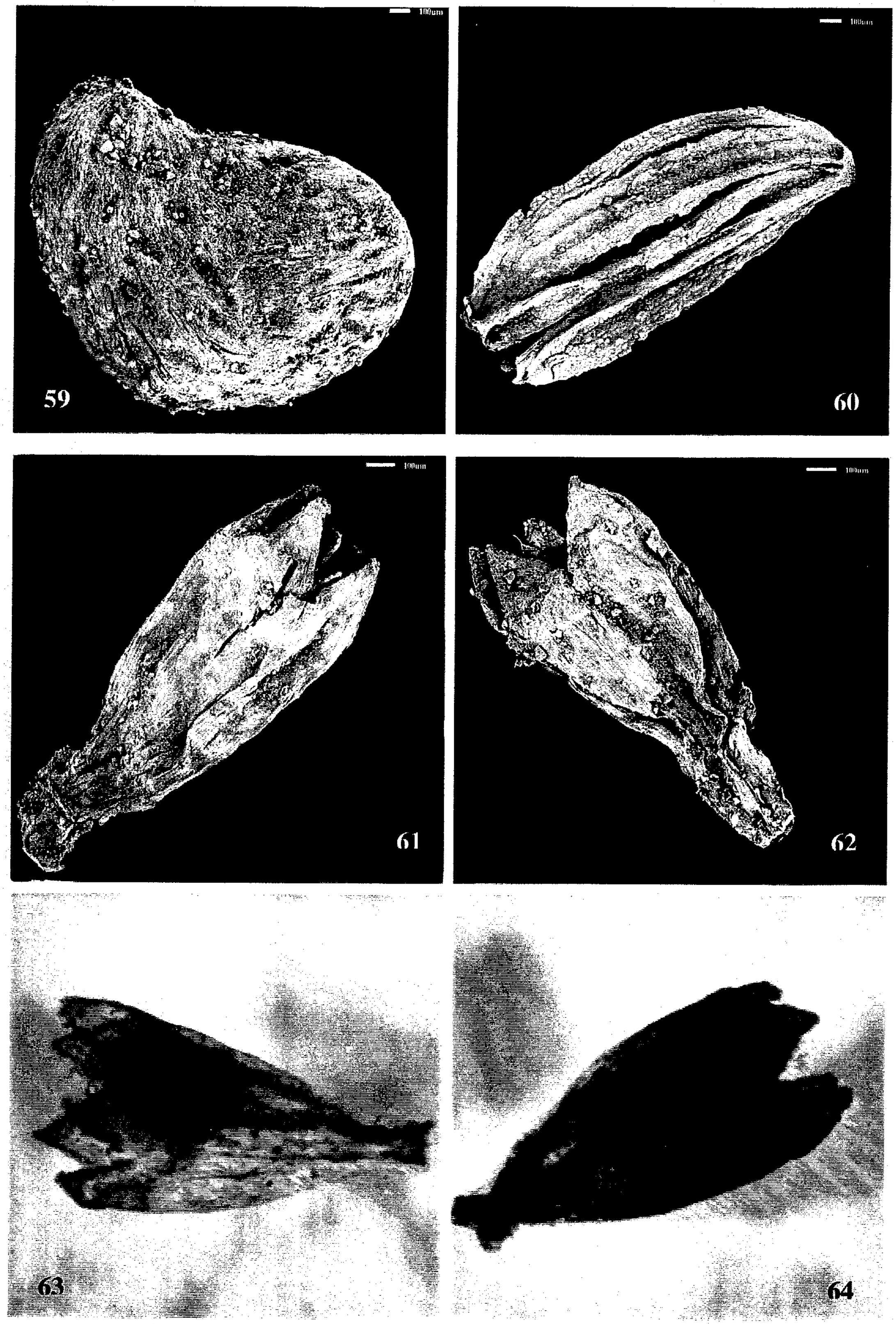


Plate 59) *Rubus idaeus* achene (SB = 100 µm); 60) *Achillea* sp. achene (SB = 100 µm); 61-64) *Artemisia frigida/campestris* type flowers (SB = 100 µm)

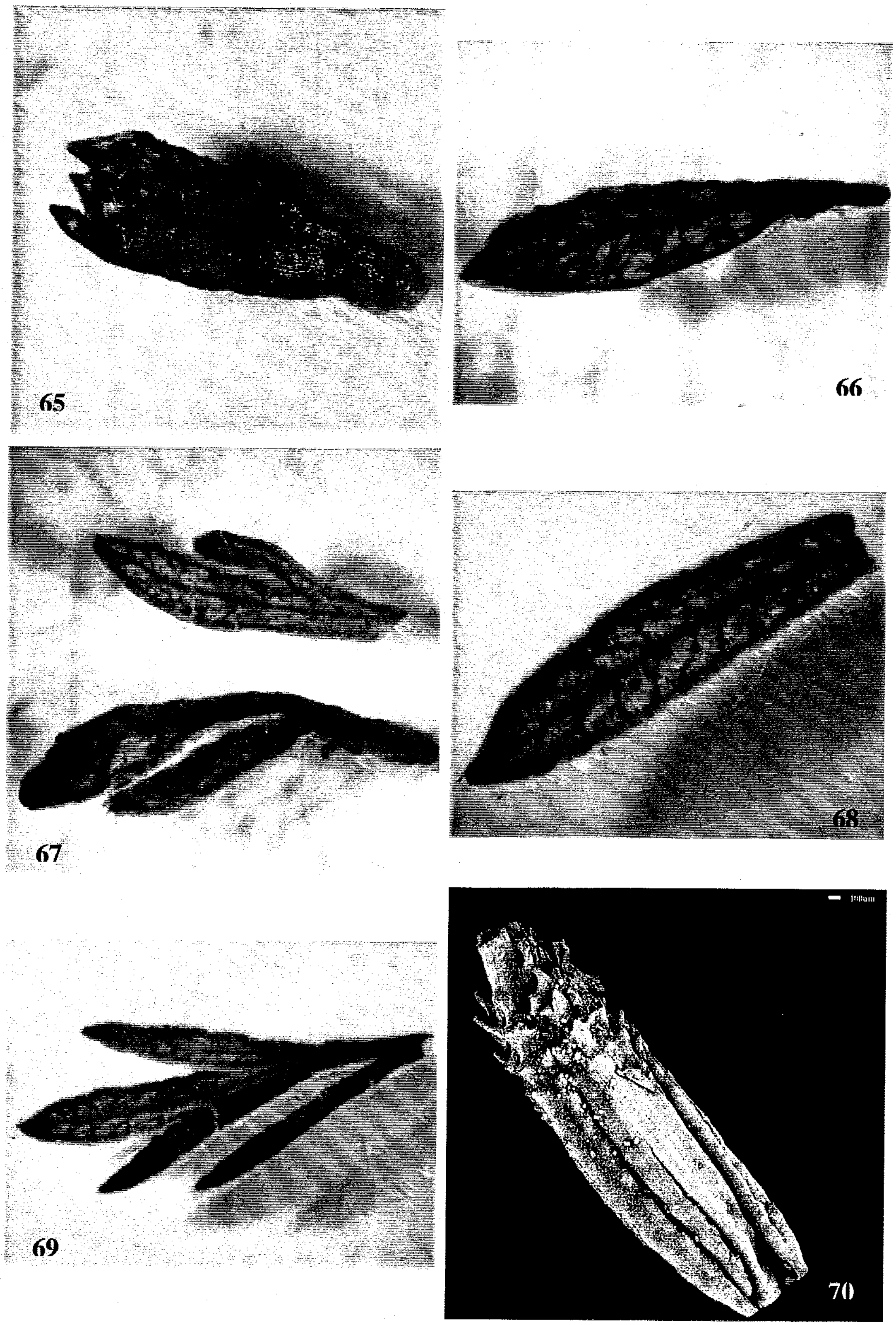


Plate 65) Modern *Artemisia frigida* flower; 66-67) Subfossil *Artemisia frigida* leaves; 68-69) Modern *Artemisia frigida* leaves 70) *Taraxacum ceratophorum* achene (SB = 100 µm);

Plate 71) *Thymallus arcticus* scale (SB = 100 $\mu$m).

# Appendix B: Glossary

This is a glossary of some terms used in this thesis; after (Viereck *et al.* 1992).

**Acrocarpic –** mosses with an upright growth form.

**Biome –** A continental-scale ecosystem characterized by similarities in plant life-form and environment, including all plants and animals in that area.

**Bryophyte** – A plant of the phylum Bryophyta, which includes mosses, liverworts, and hornworts.

**Community** – A general term for an assemblage of plants or animals living together and interacting among themselves in a specific location.

**Ecosystem** – Totality of an environment plus its included organisms, or habitat and community as an interacting unit; including all component organisms, together with the environment forming an interacting system.

**Ecotone** – A transition zone between two well-defined plant communities or units of vegetation.

**Extrazonal** – Disjunct localities that are characterized by vegetation types that are compositionally, and physiognomically different from the regional zonal vegetation; this vegetation is often a result of physical variables such as slope, elevation, and aspect. For example, steppe vegetation occurs on extrazonal, south-facing, slope sites within the boreal forest zonal vegetation of the subarctic.

**Fellfield** – A type of tundra ecosystem characterized by very stony soil, and low, widely spaced vascular plants.

**Fen** – A mire (peat forming ecosystem) with little or no *Sphagnum* spp. and with a source of water and minerals outside the limits of a mire. Fens, in comparison to bogs, are less acidic or even alkaline and mineral rich.

**Floodplain** – An alluvial plain bordering a stream and subject to periodic flooding unless protected.

**Forb** – An herbaceous plant other than grass, sedge, or other grasslike plant.

**Graminoid** – Grass-like in appearance with leaves mostly narrow or linear; members of the Poaceae, Cyperaceae, and Juncaceae families.

**Habitat** – The natural abode of a plant or animal; refers to the kind of environment a plant or animal normally lives in as opposed to the range or geographical distribution.

**Herb** – Flowering plants with no significant woody tissue above the ground; includes forbs and grasses.

**Hygric** – Sites characterized by wet conditions.

**Litoral** – That portion of a lakeshore subject to alternate submergence and emergence.

**Loess** – Sediment transported and deposited by wind and consisting of predominantly silt-sized particles.

**Meadow** – A closed herbaceous vegetation, commonly in stands of limited extent. Often used to denote stands of grasses and sedges.

**Mesic** – Sites of habitats characterized by intermediate moisture conditions; that is, neither wet (hygric) nor dry (xeric).

**Moss** – A plant in the class Musci of the phylum Bryophyta; usually.

**Physiognomy** – The general outward appearance of a plant community, determined by the life-form of the dominant species; for example, forest or scrub.

**Pioneer** – Plant capable of invading bare sites and persisting there.

**Pleurocarpic** – Mosses that form relatively flat carpets.

**Riparian** – Pertaining to streamside environment.

**Shrub** – A woody perennial plant differing from a tree by its low stature and by generally producing several basal stems instead of a single bole, and from a perennial herb by its persistence and woody stem(s).

**Steppe** –Vegetation type dominated by sagebrush, perennial graminoids and forbs, in zonal or extrazonal areas that are too dry for the establishment of natural forests; characterized by dry soils and relatively high proportions of bare ground.

**Sub-shrub** – A perennial plant with a woody base whose annually produced stems die back each year.

**Tundra** – A cold-climate landscape having vegetation without trees. The absence of trees is caused by a complex of conditions that ultimately related to cold and short growing season.

**Vascular plant** – Fern or seed plant having an internal system of vascular tissue for transport of food (via phloem) and water (via xylem).

**Vegetation type** – The kind of vegetation, or the kind of community of any size, rank, or stage of succession.

**Watershed** – A drainage basin including all areas within, that contributes runoff and discharge to a stream or river.

**Xeric** – a dry habitat or site.

**Xerophyte** – A plant capable of surviving periods of prolonged moisture deficiency; a plant that grows on dry sites.

**Zonal** – term applied to vegetation unit that reflects a close relation to current climatic conditions of a large region on soils with nonextreme properties. Zonal plant communities correspond more or less to a climatic climax community.

**Zone** – An area characterized by similar flora and/or fauna; a belt or area that certain species are limited to.

# Appendix C: Scientific and Common Plant Names

Plant names mentioned in thesis text. Nomenclature and habitat information descriptions for mosses follow Janssens (1981) and vascular plants follow Cody (1996).

| **Scientific Name** | **Common Name** | **Habitat** |
|---|---|---|
| | | |
| **Sphagnaceae** | | |
| *Sphagnum* | | often acidic bogs, wet |
| **Dicranaceae** | | |
| *Dicranum* | | moist calacareous substrates, heaths, mesic tundra |
| **Pottiaceae** | | |
| *Didymodon rigidulus* var. *icmadophila* Hedw. | | on open, calcareous soil, earth covered boulders, rocks in streams |
| *Tortula* | | calcareous soils and rocks |
| **Bryaceae** | | |
| *Bryum* | | on moist calcareous soils, above water table |
| **Amblystegiaceae** | | |
| *Calliergon giganteum* (Schimp.) Kindb. | | shallow pools, rich fens, edges of springs and streams |
| *Calliergon stramineum* (Brid.) Kindb. | | shallow pools, rich fens |
| *Drepanocladus vernicosus* (Lindb. *Ex* C. Hartman) Warnst. | | moist or wet calcareous soil, rich fens |
| *Scorpidium scorpioides* (Hedw.) Limpr. | | moist or wet calcareous soil, rich fens |
| **Brachytheciaceae** | | |
| *Tomenthypnum nitens* (Hedw.) Loeske. | | moist or wet calcareous soil, rich fens, muskeg, tundra |
| **Selaginellaceae** | Spike-moss family | |
| *Selaginella selaginoides* (L.) Link | | moist banks and shores, bogs |
| *Selaginella sibirica* (Milde) Hieron. | | dry exposed rocks and ridges |
| **Equisetaceae** | Horsetail family | |
| *Equisitum arvense* L. | Field horsetail | open woods, meadows |
| **Cupressaceae** | Cypress family | |
| *Juniperus communis* L. s.l. | Shrub juniper | clearings, wooded areas, lowlands |
| **Pinaceae** | Pine family | |
| *Picea* A. Dietr. | Spruce | |
| *Picea glauca* (Moench) Voss s.l. | White spruce | well-drained, exposed situations, alluvial |
| *Picea mariana* (Mill.) B.S.P. | Black spruce | poorly-drained lowlands, muskeg |
| *Pinus* L. | Pine | well-drained sandy soils |
| *Larix* | Larch | poorly drained, muskeg |
| **Typhaceae** | Cattail family | |
| *Typha* L. | Cattail | shallow water, marshes |

| | | |
|---|---|---|
| **Potamogetonaceae** | Pondweed family | |
| *Potamogeton* L. | Pondweed | shallow water, lake shores |
| **Poaceae** | Grass family | |
| *Calamagrostis purparescens* R. Br. | Reed bent grass | well-drained calcareous soils |
| *Calamgrostis canadensis* (Michx.) Beauv. | Blue-joint | meadows, riverbanks |
| *Deschampsia* Beauv. | Hair-grass | often riparian |
| *Deschampsia caespitosa* (L.) | Tufted hair-grass | wet-meadows, lakeshores, gravel bars |
| *Elymus* L. | Wild rye | open areas |
| *Elymus innovatus* (Beal) | | calcareous slopes, sandy soils, dunes |
| *Festuca* L. | Fescue | open areas |
| *Festuca altaica* Trin. | Northern rough fescue | open woods, alpine grassland, tundra |
| *Glyceria* R. Br. | Manna grass | shallow water, wet meadows, lakeshores |
| *Poa* L. | Blue grass | open, well-drained locales |
| *Poa glauca* Vahl. | | dry slopes, well-drained soils |
| *Puccinellia* Parl. | Goose grass | marshes, wet meadows |
| **Cyperaceae** | Sedge family | |
| *Carex* L. | Sedge | |
| *Carex aquatilis* Wahlenb. | | wet meadows, periodic flooding |
| *Carex bigelowii* Hultén | | bogs, wet meadows |
| *Carex maritima* Gunn. | | sandy, turfy places, dunes, floodplains |
| *Carex podocarpa* R. Br. | | subalpine herbmats |
| *Carex scirpoidea* Michx. | | dry turfy places, calcareous |
| *Eriphorum* L. | Cotton-grass | wet, peaty |
| *Eriphorum angustifolium* Honckn. | | wet bogs, bordering ponds |
| *Eriphorum vaginatum* L. | | wet peaty places |
| *Kobresia* Willd. | | dry, open, tundra |
| *Kobresia myosuroides* (Vill.) Fiori & Paol. | | dry, calcareous. ridges |
| *Scirpus validus* Vahl | Bulrush | shallow water, lakeshores |
| **Juncaceae** | Rush family | |
| *Juncus* L. | Bog rush | moist, riparian |
| *Luzula* DC. | Wood rush | alpine, tundra, riparian |
| **Liliaceae** | Lily family | |
| **Salicaceae** | Willow family | |
| *Populus* L. | Poplar | |
| *Populus tremuloides* Michx. | Trembling aspen | dry slopes, recent burns, well-drained riparian |
| *Salix* L. | Willow | |
| *Salix reticulata* L. | Net-veined willow | tundra turf, meadows, montane forests |
| **Myricaceae** | Wax-myrtle family | |
| *Myrica* | Sweet gale | marshes, bogs, borders of lakes |

| | | |
|---|---|---|
| **Betulaceae** | Birch family | |
| *Alnus* Mill. | Alder | riparian, disturbed |
| *Alnus crispa* (Drylander ex Ait.) | Green alder | stream banks, mountain slopes, tundra |
| *Alnus incana* (L.) Moench | Thinleaf alder | riverbanks, lake shores |
| *Betula* L. | Birch | |
| *Betula glandulosa* Michx. | Shrub birch | low arctic tundra, muskeg |
| **Polygonaceae** | Buckwheat family | |
| *Oxyria* J. | Mountain sorrel | |
| *Oxyria digyna* (L.) J. Hill | *Oxyria digyna* | moist alpine tundra, near snowbeds |
| *Polygonum alaskanum* Wight ex Hultén | Alaskan knotweed | pioneer on freshly exposed surfaces |
| *Polygonum amphibium* L. | Water smartweed | borders of shallow ponds |
| *Polygonum bistorta* L. | Bistort | moist peaty tundra |
| *Rumex* L. | Dock, sorrel | moist alpine, disturbed, marshy |
| **Chenopodiaceae** | Goosefoot family | |
| *Chenopodium* L. | Goosefoot | disturbed areas |
| **Amaranthaceae** | Amaranth family | |
| *Amaranthus* L. | Pigweed | disturbed areas |
| **Caryophyllaceae** | Pink family | |
| *Cerastium arvense* L. | Mouse-ear chickweed | gravel slopes, open thickets, meadows |
| *Cerastium beeringianum* Cham. & Schlecht. | Beringian chickweed | tundra, meadows, heath, woodlands |
| *Minuartia rubella* (Wahlenb.) Graebn. Ex Asch. & Graebn. | Sandwort | dry sandy, rocky slopes |
| *Silene acaulis* L. | Moss campion | alpine tundra |
| *Silene involucrata* (Cham. & Schlecht.) Bocquet | Campion | moist stony, gravelly, sandy places |
| *Silene uralensis* (Rupr.) Bocquet | Campion | alpine slopes, meadows, dunes |
| *Stellaria* L. | Chickweed | open, slopes, tundra, meadows |
| **Ranunculaceae** | Buttercup family | |
| *Aconitum* L. | Monkshood | tundra, meadows, slopes |
| *Ranunculus* L. | Buttercup, crowfoot | wet meadows, moist places |
| *Ranunculus nivalis* L. | Snow buttercup | moist herbmats, snow patch, streams |
| *Ranunculus sceleratus* L. | Celery-leaved buttercup | wet peaty, by streams, lakes |
| *Thalictrum* L. | Meadow rue | alpine herbmats, meadows |
| **Papaveraceae** | Poppy family | |
| *Papaver* sect. *Scapiflora* Reichenb. | Arctic poppy group | tundra, open slopes, alpine meadows, often calcareous, rocky |
| **Brassicaceae** | Mustard family | |
| *Arabis* L. | Rock cress | open slopes, alpine, disturbed |
| *Draba* L. | | open slopes, tundra, sandy riverbanks |
| *Draba cana* Rybd. | | open calcareous slopes |
| *Draba cinerea* Adams | | calcareous cliffs |
| *Draba nemorosa* L | Wood whitlow-grass | dry, disturbed situations |

| | | |
|---|---|---|
| *Draba nivalis* Liljeble. | | dry, gravelly areas |
| **Saxifragaceae** | Saxifrage family | |
| *Ribes* L. | Currant, gooseberry | moist woods |
| *Saxifraga hieracifolia* Waldst. & Kit. | | moist turfy, calcareous |
| *Saxifrage hirculus* L. | Yellow saxifrage | wet mossy tundra |
| *Saxifraga nelsoniana* D. Don | | moist open hillsides |
| *Saxifraga oppositifolia* L. | Purple mountain saxifrage | broken calcareous gravels |
| *Saxifraga tricuspidata* Rottb. | Prickly saxifrage | dry rocky and gravelly places |
| **Rosaceae** | Rose family | |
| *Dryas* L. | Mountain avens | |
| *Dryas integrifolia* M. Vahl | | pioneer on rocky, gravelly places, river flats, tundra |
| *Dryas octopetala* L. | | alpine tundra |
| *Potentilla* L. | Cinquefoil | open meadows |
| *Potentilla fruticosa* L. | Shrubby cinquefoil | open muskeg, moist tundra |
| *Potentilla gracilis* Dougl. | Slender cinquefoil | open woods, grassland |
| *Potentilla nivea* L. | | open gravelly slopes |
| *Potentilla palustris* (L.) Scop. | Marsh cinquefoil | wet marshes and bogs |
| *Potentilla pensylvanica* L. | | dry prairies, bluffs, dunes, slopes |
| *Rosa* L. | Rose | riverbanks, clearins, dry slopes |
| *Rubus chamaemorus* L. | Cloudberry | moist peaty, turf |
| *Rubus idaeus* L. s.l. | Wild red raspberry | clearings |
| **Fabaceae** | Pea family | |
| *Hedysarum* L. | Licorice-root | |
| *Hedyasarum mackenzii* (Richards.) | | calcareous clays and gravels |
| *Lupinus arcticus* Wats. | | moist alpine tundra, grassy slopes |
| *Oxytropis* DC. | Locoweed | rocky, gravelly, tundra, ridges |
| *Oxytropis campestris* (L.) DC. | Late yellow locoweed | tundra, rocky ridges, riverbanks |
| **Eleagnaceae** | Oleaster family | |
| *Shepherdia canadensis* Nutt. | Soapberry | riverbanks, clearings, subalpine and alpine slopes |
| **Onagraceae** | Evening primrose family | |
| *Epilobium* L. | Willowherb | often pioneer on burned areas, meadows, disturbed |
| **Apiaceae** | Parsley family | |
| **Ericaceae** | Heath family | |
| *Arctostaphyos rubra* (Rehd. & Wils.) Fern. | Bearberry | open coniferous woodland, tundra |
| *Ledum decumbens* (Ait.) Lodd. | Labrador-tea | moss-lichen heath |
| *Oxycoccus microcarpus* Turcz. | Cranberry | muskeg |
| *Rhododendron lapponicum* (L.) Wahlenb. | Lapland rhododendron | dry rocky tundra, heathland |
| *Vaccinium* L. | Blueberry, cranberry | acidic soils, heath, moist tundra |

|  |  |  |
|---|---|---|
| **Primulaceae** | Primrose |  |
| *Androsace chamaejasme* Host | Rock-jasmine | calcareous sand and gravel, rocky tundra slopes |
| *Androsace septentrionalis* L. | Fairy-candelabra | dry calcareous sandy or gravelly |
| **Gentianaceae** | Gentian family |  |
| **Polemoniaceae** | Phlox family |  |
| *Phlox* L. | Phlox | open, stony, dry, prairie |
| *Phlox hoodii* Richards. | Moss phlox | dry prairies and foothills |
| *Polemonium* L. | Jacob's-ladder | alpine tundra, meadows, peaty |
| **Labiatae** | Mint family |  |
| *Galeopsis* L. | Hemp-nettle | waste places |
| **Scrophulariaceae** | Figwort family |  |
| *Pedicularis* L. | Lousewort | tundra, meadows, rocky slopes |
| **Plantaginaceae** | Plantain family |  |
| *Plantago* L. | Plantain | open slopes, disturbed, meadows, alkaline |
| **Rubiaceae** | Madder family |  |
| *Galium* L. | Bedstraw | riverbanks, floodplain, dry open slopes, meadow |
| **Asteraceae** | Composite family |  |
| *Achillea* L | Yarrow |  |
| *Achillea millefoilium* L. |  | riverbanks, open, gravelly, sandy |
| *Antennaria* Gaertn. | Pussytoes | arctic and alpine tundra, rocky |
| *Artemisia* L. | Sage, wormwood |  |
| *Artemisia alaskana* Rydb. |  | gravelly, slopes, hillsides, floodplain |
| *Artemisia campestris* L.s.l. |  | riverbeds, prairie, open slopes |
| *Artemisia frigida* L. | Prairie sagewort | open slopes, prairie, dry, disturbed |
| *Artemisia furcata* Bieb. |  | arctic and alpine tundra |
| *Artemisia tilesii* Ledeb. s.l. |  | river flats, heath, alpine tundra |
| *Taraxacum ceratophorum* (Ledebl) DC. s.l. | Dandelion | woodland, heath to tundra |

# Appendix D: Macrofossil Quantitative Data

Identified vascular plant macrofossil taxa refer to the following codes.

1) *Picea* sp. needles
2) *Betula* sp. nutlets
3) *Potamogeton* sp. seeds
4) Poaceae undet. caryopses
5) Poaceae undet. florets
6) cf. *Festuca* sp. caryopses
7) *Deschampsia* sp. caryopses
8) *Elymus* sp. caryopses
9) *Poa* type caryopses
10) *Carex* spp. achenes
11) *Carex aquatilis/bigelowii* type achenes
12) *Carex maritime* type achenes
13) *Kobresia* sp. achenes
14) *Scirpus* cf. *validus* achenes
15) *Juncus/Luzula* silique fragments
16) *Juncus* sp. seeds
17) cf. *Luzula* sp. seeds
18) *Chenopodium* sp. seeds
19) *Cerastium* cf. *beeringianum* seeds
20) *Cerastium* cf. *arvense* seeds
21) *Minuartia rubella*
22) *Silene involucrata* seeds
23) *Silene uralensis* seeds
24) *Stellaria* sp. seeds
25) *Ranunculus* cf. *sceleratus* achenes
26) *Rancunculus* cf. *nivalis* achenes
27) *Papaver* sect. *Scapiflora* seeds
28) *Brassicaceae* undet. seeds
29) *Draba* type seeds
30) *Saxifraga oppositifolia* leaf fragments
31) *Dryas octopetala* leaves
32) *Potentilla* spp. achenes
33) *Rubus idaeus* achenes
34) *Androsace septentrionalis* seeds
35) *Achillea* sp. achenes
36) *Taraxacum ceratophorum* achenes
37) *Artemisia campestris/frigida* flowers
38) *Artemisia frigida* leaves

Below are the macrofossil count spreadsheets. Sample GZ.07.14.99.01 is the stratigraphically lowest sample at Station 2 and GZ.07.16.99.31 is the highest. At Station 3, GZ.07.17.99.00 is found at the base of Unit 10. Samples with * represent a second 25 ml sample that was analyzed. Taxa 38 (*Artemisia frigida* leaves) were not counted. Their frequency was recorded with qualitative ordinal values; / = absent, R = Rare (least frequent), O = Occasional, F = Frequent, A = Abundant (most frequent).

| | *Station 2 Samples* | GZ.07.14.99.01 | GZ.07.14.99.02 | GZ.07.14.99.03 | GZ.07.14.99.04 | GZ.07.14.99.05 | GZ.07.14.99.06 |
|---|---|---|---|---|---|---|---|
| *Taxa* | | | | | | | |
| *1* | | | | | | | |
| *2* | | | | | | | |
| *3* | | | | | | | |
| *4* | | 1 | | | | | |
| *5* | | | | | 1 | | |
| *6* | | | | | | | |
| *7* | | | | | | | |
| *8* | | | 1 | | | | |
| *9* | | | | | | | |
| *10* | | | | | | | |
| *11* | | 2 | 1 | | | | |
| *12* | | 4 | | | 1 | | 1 |
| *13* | | | | | | | |
| *14* | | | | | | | |
| *15* | | | | | | | |
| *16* | | | 1 | | | | |
| *17* | | | | | | | |
| *18* | | | | | | | |
| *19* | | | | | | | |
| *20* | | | | | | | |
| *21* | | 1 | | 1 | | | |
| *22* | | | | | | | |
| *23* | | | | | | | |
| *24* | | | | | | | |
| *25* | | | | | | | |
| *26* | | | | | | | |
| *27* | | | 2 | | | | |
| *28* | | | | | | | |
| *29* | | 2 | 2 | 1 | 1 | | 1 |
| *30* | | | | | | | |
| *31* | | | | | | | |
| *32* | | 3 | 1 | | | | |
| *33* | | | | | | | |
| *34* | | | | | | | |
| *35* | | | | | | | |
| *36* | | | | | | | |
| *37* | | | | | | | |
| *38* | | / | / | / | / | / | / |

|  | GZ.07.14.99.07 | GZ.07.14.99.08 | GZ.07.14.99.08* | GZ.07.14.99.09 | GZ.07.14.99.10 | GZ.07.14.99.11 | GZ.07.14.99.12 |
|---|---|---|---|---|---|---|---|
| *Taxa* |  |  |  |  |  |  |  |
| *1* |  | 2 | 1 | 1 |  |  |  |
| *2* |  |  |  |  |  |  |  |
| *3* |  |  |  |  |  |  |  |
| *4* |  | 38 | 11 | 21 |  |  | 5 |
| *5* | 4 | 6 | 41 | 37 |  |  |  |
| *6* |  |  |  | 1 |  |  |  |
| *7* | 1 | 13 | 9 | 11 |  |  |  |
| *8* |  | 2 | 5 | 4 |  |  |  |
| *9* | 4 | 66 | 54 | 105 |  |  |  |
| *10* |  |  | 4 |  |  |  |  |
| *11* | 4 | 10 | 7 | 4 | 1 |  |  |
| *12* | 1 | 5 | 1 | 1 |  |  |  |
| *13* |  |  |  | 6 |  |  |  |
| *14* |  |  |  |  |  |  |  |
| *15* | 3 | 13 | 38 | 30 |  |  | 1 |
| *16* | 1 |  | 2 | 1 |  |  |  |
| *17* |  |  | 4 | 4 |  |  |  |
| *18* |  | 1 |  | 2 |  |  |  |
| *19* |  |  | 3 | 3 |  |  |  |
| *20* |  |  | 1 |  |  |  |  |
| *21* |  | 9 | 1 |  |  |  |  |
| *22* |  |  | 1 | 1 |  |  |  |
| *23* |  | 2 | 2 | 1 |  |  | 1 |
| *24* |  | 3 | 2 | 1 |  |  |  |
| *25* |  |  | 3 |  |  |  |  |
| *26* |  |  |  |  |  |  |  |
| *27* | 1 | 8 | 1 | 5 |  |  | 3 |
| *28* |  |  |  | 7 |  |  |  |
| *29* | 19 | 117 | 59 | 71 |  |  | 18 |
| *30* |  |  |  |  |  |  |  |
| *31* |  |  |  | 1 |  |  |  |
| *32* | 4 | 12 | 5 | 3 |  | 1 | 4 |
| *33* |  |  |  |  |  |  |  |
| *34* | 1 | 1 |  | 3 |  |  | 1 |
| *35* |  | 1 | 1 |  |  |  |  |
| *36* |  | 2 | 5 | 1 |  |  |  |
| *37* |  | 13 | 17 |  |  |  |  |
| *38* | / | Frequent | Frequent | Frequent | / | / | / |

|  | GZ.07.16.99.13 | GZ.07.16.99.14 | GZ.07.16.99.15 | GZ.07.16.99.16 | GZ.07.16.99.16* | GZ.07.16.99.17 | GZ.07.16.99.18 |
|---|---|---|---|---|---|---|---|
| *Taxa* |  |  |  |  |  |  |  |
| *1* |  |  |  | 2 | 4 |  |  |
| *2* |  |  |  | 1 | 1 |  |  |
| *3* |  |  |  |  |  |  |  |
| *4* |  | 1 | 2 | 37 | 52 | 32 | 1 |
| *5* |  |  | 5 | 219 | 397 | 71 |  |
| *6* |  |  |  | 1 |  |  |  |
| *7* |  |  | 1 | 27 | 20 | 18 |  |
| *8* |  |  |  | 1 | 2 | 1 |  |
| *9* |  |  | 7 | 319 | 482 | 157 |  |
| *10* |  |  |  |  |  |  |  |
| *11* |  |  |  | 5 | 12 | 3 |  |
| *12* |  |  |  | 6 | 4 | 3 |  |
| *13* | 1 |  | 1 |  |  |  |  |
| *14* |  |  |  |  |  |  |  |
| *15* |  |  | 1 | 61 | 94 | 80 |  |
| *16* |  |  |  | 2 |  | 2 |  |
| *17* |  |  | 2 | 6 |  |  |  |
| *18* |  |  |  |  |  |  |  |
| *19* |  |  | 1 | 6 | 8 | 2 |  |
| *20* |  |  |  | 2 | 2 |  |  |
| *21* | 1 |  | 1 | 14 | 5 | 2 |  |
| *22* |  |  |  | 3 |  | 2 |  |
| *23* |  |  | 1 | 2 | 7 | 2 |  |
| *24* |  |  |  | 2 | 2 |  |  |
| *25* |  |  |  | 1 | 5 |  |  |
| *26* |  |  |  |  |  |  |  |
| *27* |  | 1 | 2 | 33 | 24 | 16 |  |
| *28* |  |  |  | 7 | 10 |  |  |
| *29* | 1 |  | 27 | 219 | 193 | 91 | 2 |
| *30* |  | 1 | 1 | 2 | 4 |  |  |
| *31* |  |  |  |  |  |  |  |
| *32* |  | 1 | 3 | 11 | 13 | 9 |  |
| *33* |  |  |  | 1 |  | 1 |  |
| *34* |  |  |  | 13 | 7 | 1 |  |
| *35* |  |  |  |  |  |  |  |
| *36* |  |  |  |  | 2 |  |  |
| *37* |  | 1 | 7 | 225 | 234 | 104 | 1 |
| *38* | Rare | / | Occasional | Abundant | Abundant | Abundant | Rare |

|  | GZ.07.16.99.19 | GZ.07.16.99.20 | GZ.07.16.99.21 | GZ.07.16.99.22 | GZ.07.16.99.23 | GZ.07.16.99.24 | GZ.07.16.99.25 |
|---|---|---|---|---|---|---|---|
| *Taxa* |  |  |  |  |  |  |  |
| *1* |  |  |  |  |  |  |  |
| *2* |  |  |  |  |  |  |  |
| *3* |  |  |  |  |  |  |  |
| *4* | 2 | 6 |  |  |  | 1 |  |
| *5* |  |  |  |  |  |  |  |
| *6* |  |  |  |  |  |  |  |
| *7* |  |  |  | 1 |  | 2 |  |
| *8* |  |  |  |  |  |  |  |
| *9* |  | 1 |  |  | 1 |  | 1 |
| *10* |  |  |  |  |  |  |  |
| *11* |  |  |  | 1 | 6 | 4 | 1 |
| *12* |  |  |  |  | 2 | 4 |  |
| *13* |  |  |  |  |  |  |  |
| *14* |  |  |  |  |  |  |  |
| *15* |  | 7 |  |  |  |  |  |
| *16* |  |  |  |  |  |  | 1 |
| *17* |  |  |  |  |  |  |  |
| *18* |  |  |  |  |  |  |  |
| *19* |  |  | 1 |  |  |  |  |
| *20* |  |  |  |  |  |  |  |
| *21* | 1 |  |  |  |  |  |  |
| *22* |  |  |  |  |  |  |  |
| *23* |  |  |  | 2 |  |  |  |
| *24* |  |  |  |  |  |  |  |
| *25* |  |  |  |  |  | 1 |  |
| *26* |  |  |  |  |  |  |  |
| *27* |  | 1 |  |  |  |  |  |
| *28* |  |  |  |  |  |  |  |
| *29* | 1 | 10 |  | 1 | 2 |  |  |
| *30* |  |  |  |  |  |  |  |
| *31* |  |  |  |  |  |  |  |
| *32* |  | 1 |  |  |  |  |  |
| *33* |  |  |  |  |  |  |  |
| *34* |  |  | 1 |  |  |  | 1 |
| *35* |  | 1 |  |  |  |  |  |
| *36* |  |  |  |  |  |  |  |
| *37* |  |  |  |  |  |  |  |
| *38* | / | Rare | / | / | / | / | / |

|  | GZ.07.16.99.26 | GZ.07.16.99.27 | GZ.07.16.99.28 | GZ.07.16.99.29 | GZ.07.16.99.30 | GZ.07.16.99.31 |
|---|---|---|---|---|---|---|
| *Taxa* |  |  |  |  |  |  |
| *1* |  |  |  |  |  |  |
| *2* |  |  |  |  |  |  |
| *3* |  |  |  |  |  |  |
| *4* | 1 |  |  |  | 1 |  |
| *5* |  |  |  |  | 1 |  |
| *6* |  |  |  |  |  |  |
| *7* |  |  | 1 |  |  | 1 |
| *8* |  |  |  |  |  |  |
| *9* |  |  |  |  | 2 |  |
| *10* |  |  |  |  |  |  |
| *11* | 2 |  |  |  |  |  |
| *12* | 1 | 1 | 1 |  | 2 |  |
| *13* |  |  |  |  |  |  |
| *14* |  |  |  |  |  |  |
| *15* |  |  |  |  |  |  |
| *16* |  |  |  |  |  |  |
| *17* |  |  |  |  |  |  |
| *18* |  |  |  |  |  |  |
| *19* |  |  |  |  |  |  |
| *20* |  |  |  |  |  |  |
| *21* |  |  |  |  |  |  |
| *22* |  |  |  |  |  |  |
| *23* |  |  |  |  |  |  |
| *24* |  |  |  |  |  |  |
| *25* |  |  |  |  |  |  |
| *26* |  |  |  |  |  |  |
| *27* |  |  |  |  |  |  |
| *28* |  |  |  |  |  |  |
| *29* |  |  |  |  |  |  |
| *30* |  |  |  |  |  |  |
| *31* |  |  |  |  |  |  |
| *32* |  |  |  | 1 | 1 |  |
| *33* |  |  |  |  |  |  |
| *34* |  |  |  |  |  |  |
| *35* |  |  |  |  |  |  |
| *36* |  |  |  |  |  |  |
| *37* |  |  |  |  |  |  |
| *38* | / | / | / | / | / | / |

|  | *Station 3 Samples* | GZ.07.17.99.00 | GZ.07.17.99.4 | GZ.07.17.99.14 | GZ.07.17.99.15 | GZ.07.17.99.16 |
|---|---|---|---|---|---|---|
| *Taxa* |  |  |  |  |  |  |
| *1* |  | 2 | 2 |  |  |  |
| *2* |  |  |  |  | 1 |  |
| *3* |  |  | 1 |  |  |  |
| *4* |  | 3 | 13 | 18 | 20 | 22 |
| *5* |  | 21 | 36 | 87 | 5 | 78 |
| *6* |  | 2 |  |  | 1 | 1 |
| *7* |  | 14 | 16 | 7 | 4 | 5 |
| *8* |  | 1 | 2 |  | 1 |  |
| *9* |  | 39 | 82 | 96 | 40 | 135 |
| *10* |  | 1 |  |  |  |  |
| *11* |  | 7 | 5 | 3 | 2 | 5 |
| *12* |  | 17 | 1 | 6 | 1 |  |
| *13* |  | 1 |  |  |  |  |
| *14* |  |  |  |  |  | 1 |
| *15* |  | 19 | 26 | 43 | 23 | 26 |
| *16* |  |  |  | 2 |  |  |
| *17* |  |  |  |  | 5 | 9 |
| *18* |  |  |  |  | 1 |  |
| *19* |  | 4 |  | 2 |  | 2 |
| *20* |  | 1 |  |  |  | 1 |
| *21* |  | 7 | 5 |  | 2 | 5 |
| *22* |  |  |  |  |  |  |
| *23* |  | 3 |  | 1 | 1 | 5 |
| *24* |  |  | 2 | 3 |  |  |
| *25* |  | 1 | 1 | 2 | 2 |  |
| *26* |  | 1 |  |  |  |  |
| *27* |  | 6 | 16 |  | 2 | 14 |
| *28* |  | 1 | 2 | 4 |  | 10 |
| *29* |  | 108 | 74 | 89 | 49 | 106 |
| *30* |  |  | 3 | 2 |  |  |
| *31* |  |  |  |  |  |  |
| *32* |  | 20 | 9 | 21 | 5 | 4 |
| *33* |  |  |  |  |  |  |
| *34* |  | 4 | 1 | 5 | 2 | 8 |
| *35* |  | 1 |  |  |  |  |
| *36* |  | 2 |  | 1 |  | 2 |
| *37* |  | 18 | 25 | 31 | 13 | 48 |
| *38* |  | Occasional | Frequent | Frequent | Occasional | Frequent |