GEOLOGICAL SURVEY OF CANADA

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CORRELATION OF QUATERNARY DEPOSITS AND EVENTS AROUND THE MARGIN OF THE BEAUFORT SEA:

CONTRIBUTIONS FROM A JOINT CANADIAN-AMERICAN WORKSHOP, APRIL 1984

J.A. Heginbottom, J-S. Vincent (editors)

June 1986

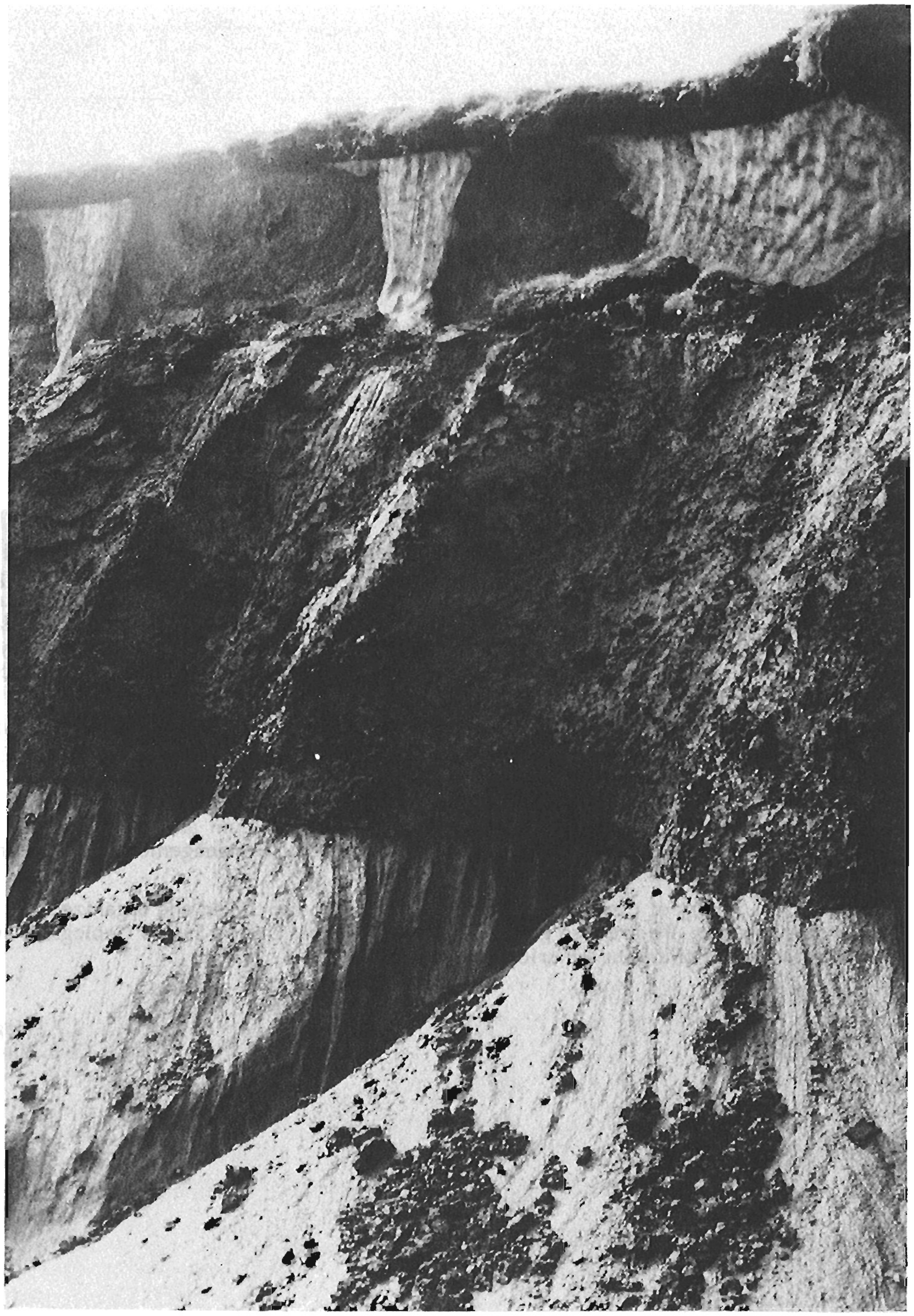
Preface

Among the many activities common to most national geological surveys, is a responsibility for the development of the correlation of geological deposits and events within and between regions and countries. This responsibility is discharged, both nationally and internationally, by various means, including meetings, field excursions and the publication of correlation charts, standards and definitions. This collection of extended abstracts and papers arose from just such an activity, and are the results of a joint Canadian/United States workshop on the correlation of Quaternary deposits and events in the western Arctic of North America.

Improving our understanding of the geological characteristics of the Quaternary in this region, will aid in the expansion of useful knowledge about the engineering geology and permafrost conditions, construction resources, geological hazards and environmental conditions of northern Alaska and northwestern Canada, in addition to the increase in basic scientific information. All this will contribute to the safe and rational development of the petroleum and other resources of this region, the development of the necessary infrastructure and wise management of the land within Canada and the United States.

The Geological Survey of Canada is grateful to those who conceived and organized this meeting, and to all the participants. We are also grateful to the Director, United States Geological Survey for facilitating the participation of our American colleagues.

J.A. Heginbottom
J-S. Vincent



Frontispiece

Ice slump, east of King Point, Yukon Coast

In the backwall of a large ice slump, are exposed:

- 4 m of lacustrine sands, silts and peat pierced by active ice wedges.
- 3 m of till deposited during the Buckland Glaciation (presumed Early Wisconsinan in age);
- over 4 m of icy sediments.

The Buckland Till records what is probably the all-time furthest west extent of continental (Laurentide) ice in northwestern Canada. (Photo by J-S. Vincent, GSC-204061-A).

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Abstract

A first approximation of a detailed correlation chart of Quaternary sediments for the Alaskan and Canadian sectors of the area adjacent to the Beaufort Sea has been compiled. The chart and contributions cover deposits and events ranging from Late Tertiary to Holocene in age. The region covered extends from the western Canadian Arctic Islands, across the Arctic Coastal Plain of Canada and Alaska and south into the Brooks Range and the mountains and basins of Yukon.

Résumé

L'ébauche d'un tableau détaillé de corrélation des dépôts quaternaires des régions canadiennes et américaines sises à proximité de la mer de Beaufort a été dressé pour la première fois. Le tableau ainsi que les diverses contributions traitent des dépôts et des événements depuis le Tertiaire supérieur jusqu'à l'Holocène. La région traitée comprend les îles de l'ouest de l'archipel Arctique canadien, la plaine côtière du Canada et de l'Alaska ainsi que les monts Brooks et les bassins et montagnes du Yukon.

Figure 1-1. Participants in the workshop. Front row, left to right: L.D. Carter, P.R. Hill, N.W Rutter, O.L. Hughes. Back row, left to right: S.E. Rawlinson, D.A. Dinter, C.E. Schweger, D.M. Hopkins, J.R. Mackay, J.G. Fyles, O.J. Ferrians, Jr., N.R. Catto, V.N. Rampton, J-S. Vincent, A.S. Judge. Missing: J.A. Heginbottom (photographer), S.M. Blasco, T.D. Hamilton.

1. INTRODUCTION

J.A. Heginbottom[1] and J-S. Vincent[1]

Canadian and American geologists concerned with the Quaternary have been studying the area of and around the Beaufort Sea in increasing detail over the last ten to twenty years. Although there has been considerable contact between individual scientists working on both sides of the international boundary, rather different pictures of the Quaternary geological history of the region have developed in Canada and Alaska. Given the continuing level of exploration and development activity in and around the Beaufort Sea, the need for a coherent picture of the Quaternary geology of the region is greater than ever, as a basis for interpreting other earth science data, as well as for its intrinsic scientific value.

Accordingly, the Terrain Sciences Division, Geological Survey of Canada, held a special workshop on this subject in Calgary, on 3 and 4 April 1984. The invited participants comprised seven scientists from the Geological Survey of Canada, six other Canadians, five scientists from the United States Geological Survey and one from the Alaska Division of Geological and Geophysical Surveys (Fig. 1-1).

The workshop was opened by J.G. Fyles (Chief Geologist, GSC), who charged the participants to attempt to develop a correlation chart for the Quaternary of the Beaufort Sea region. The first session was in the form of very short presentations by each of the participants. Each took approximately ten minutes to briefly summarize their knowledge of the region, within their area of expertise, to make suggestions regarding correlations, note areas where knowledge was lacking and recommend future research to resolve these problems. Only questions of clarification were accepted during these presentations.

The first four speakers described the surficial geology and Quaternary history of the Canadian sector: J-S Vincent (GSC) summarized the general framework of glacial limits and correlations of Quaternary deposits and events in northwestern Canada; V.N. Rampton (Terrain Analysis and Mapping Services Ltd.) described the history and geomorphology of the mainland Arctic Coastal Plain in Canada; O.L. Hughes (GSC) reviewed the limits of the Laurentide and Cordilleran ice sheets in the northern Cordillera; and N.R. Catto (University of Alberta) described Quaternary stratigraphy and chronology for the Richardson Mountains-Peel Plateau area. The next four speakers then presented similar information for the Alaskan sector: D.M. Hopkins (USGS) presented the general framework of glacial limits and correlations for northeastern Alaska; L.D. Carter (USGS) described the history and geomorphology of the Arctic Coastal Plain in Alaska; T.D. Hamilton (USGS) summarized the glacial stratigraphy of the Brooks Range; and S.E. Rawlinson (Alaska Geological Survey) reviewed the Quaternary geology of northeastern Alaska.

In a session on geochronology and paleoecology, C. Schweger (University of Alberta) and J.V. Matthews, Jr. (GSC), described the paleoenvironmental record of the Brooks Range and of the northern Yukon, respectively. Then N.W. Rutter (University of Alberta) reviewed the contribution of amino acid dating methods to the development of the chronology for the region. On the theme of "cryostratigraphy", J.R. Mackay (University of British Columbia) and O.J. Ferrians, Jr. (USGS) discussed the permafrost record for northwestern Canada and northeastern Alaska and considered the implications for an understanding of the Quaternary history of the area. Then A.S. Judge (Earth Physics Branch, Canada) presented information on deep ground temperatures and the implications with regard to the Quaternary history. The final group of presentations looked at the offshore geology and sea level history of the Alaskan and Canadian sectors of the Beaufort Sea, with presentations by D.L. Dinter (USGS), S.M. Blasco (GSC) and P.R. Hill (GSC).

These opening presentations were followed by animated periods of guided discussion. The first two were devoted to the chronology and limits of the Laurentide Ice Sheet, with T.D. Hamilton as discussion leader, and of the Cordilleran and Brooks Range glacial complexes, lead by J-S. Vincent. Two shorter sessions on the sea level history of the area (lead by J.R. Mackay) and the periglacial environment of the region (N.W. Rutter) followed.

These discussions on selected topics enabled the participants to familiarize themselves with the data, in the various regions, on which the chronologies and reconstruction of events were built. The strengths and weaknesses of the different frameworks as well as the converging elements of many of the frameworks became apparent. These discussions provided the basis for the final session, jointly lead by J.G. Fyles and D.M. Hopkins, which addressed the problem of creating for the first time a detailed correlation chart for the region (see Section 20).

The workshop concluded with consideration of possible future joint activities. Joint Canadian-American field excursions, to examine key sites in both Canada and Alaska were proposed. In discussing this, four potential field excursions or correlation trips were identified. The most important of these was seen to be a tour along the Arctic Coastal Plain, from southern Banks Island to at least as far west as Prudhoe Bay, and possibly as far as Skull Cliff, west of Point Barrow. Tentatively, a 10-day trip is planned for late July-early August 1985; the party will comprise two scientists each from USGS and GSC.

A second invitational workshop meeting, some time after this field tour, was also agreed on, to review the new knowledge obtained and to update and refine the correlation chart. This meeting is tentatively planned for Fall 1986, possibly in Anchorage, Alaska.

The Calgary meeting helped solve long standing problems of Quaternary chronology and correlation. It contributed in clearly defining critical problems that remain, and in producing information for inclusion in the forthcoming volume on the Quaternary Geology of Canada and Greenland. In addition it created an avenue through which continuing contacts, between Canadian scientists from different institutions and between Canadians and Americans, was made possible. Because of the oil and gas developments in the Beaufort Sea area, basic information on Quaternary deposits is essential. This information will help provide a better understanding of the engineering behaviour of soils, of geological hazards, and of the location of aggregate sources.

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[1] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada, K1A 0E8

2. WORKSHOP PROGRAM

CORRELATION OF QUATERNARY DEPOSITS AND EVENTS IN THE AREA AROUND THE BEAUFORT SEA

Tuesday, 3 April

08:30 Welcome and Introduction
- J.G. Fyles and J.A. Heginbottom

08:45 SESSION 1: BRIEF PRESENTATIONS
SESSION 1A: Quaternary Geology and Quaternary History

- CANADA -

- J-S. Vincent: General framework of glacial limits and correlation in northwestern Canada.
- V.N. Rampton: History and geomorphology of the Arctic Coastal Plain in Canada.
- O.L. Hughes: Limits of Laurentide and Cordilleran ice sheets in northwestern Canada.
- N. Catto: The McDougal Pass area.

- ALASKA -

- D.M. Hopkins: General framework of glacial limits and correlations in northeastern Alaska.
- D.L. Carter: History and geomorphology of the Arctic Coastal Plain in Alaska.
- T.D. Hamilton: Glacial stratigraphy of the Brooks Range.
- S.E. Rawlinson: Quaternary geology of northeastern Alaska.

10:15 SESSION 1B: Geochronology and Paleoecology
- C. Schweger: The paleoenvironmental record of the Brooks Range.
- J.V. Matthews, Jr.: The paleoenvironmental record of the northern Yukon.
- N.W. Rutter: Chronology as derived from amino acid studies.

10:45 SESSION 1C: Cryostratigraphy
- J.R. Mackay: The permafrost record and Quaternary history of northwestern Canada.
- O.J. Ferrians, Jr.: The permafrost record and Quaternary history of northeastern Alaska.
- A.S. Judge: Deep temperature records and Quaternary history.

11:15 SESSION 1D: Offshore geology and Sea Level History
- D. Dinter: The Alaskan sector of the Beaufort Sea.
- P. Hill/S. Blasco: The Canadian sector of the Beaufort Sea.

DISCUSSION

13:15 SESSION 2: Chronology and Limits of the Laurentide Ice Sheet
- T.D. Hamilton: (Discussion leader and reporter).

19:15 SESSION 3: Chronology and limits of the Cordilleran and Brooks Range glacial complexes
- J-S. Vincent: (Discussion leader and reporter).

Wednesday, 4 April

DISCUSSION CONTINUED

08:30 SESSION 4: Sea Level History: Onshore/Offshore Evidence
- J.R. Mackay: (Discussion leader and reporter).

10:30 SESSION 5: Periglacial Environments
- N.W. Rutter: (Discussion leader and reporter).

13:30 SESSION 6: Correlation of Quaternary Events
- D.M. Hopkins and J.G. Fyles: (Discussion leaders and reporters).

16:30 CONCLUSION: Future Activities, Joint Field Excursions, Publications
- J.A. Heginbottom: (co-ordinator).

17:30 FINISH

3. WORKSHOP PARTICIPANTS

S.M. Blasco
Geological Survey of Canada
Atlantic Geoscience Centre
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
Canada, B2Y 4A2

*J.K. Brigham-Grette
Department of Geology
University of Alberta
Edmonton, Alberta
Canada, T6G 2E3

L.D. Carter
Alaska Branch
United States Geological Survey
4200 University Drive
Anchorage, Alaska 99508
U.S.A.

N.R. Catto
Department of Geology
University of Alberta
Edmonton, Alberta
Canada, T6G 2E3

D.L. Dinter
United States Geological Survey
345 Middlefield Road
Menlo Park, California 94025
U.S.A.

O.J. Ferrians Jr.
United States Geological Survey
345 Middlefield Road
Menlo Park, California 94025
U.S.A.

J.G. Fyles
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario
Canada, K1A 0E8

T.D. Hamilton
Alaska Branch
United States Geological Survey
4200 University Drive
Anchorage, Alaska 99508
U.S.A.

J.A. Heginbottom
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario
Canada, K1A 0E8

P.R. Hill
Geological Survey of Canada
Atlantic Geoscience Centre
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
Canada, B2Y 4A2

D.M. Hopkins
Dept. of Geology
University of Alaska
Fairbanks, Alaska 99701
U.S.A.

O.L. Hughes
Geological Survey of Canada
3303 - 33rd Street N.W.
Calgary, Alberta
Canada, T2L 2A7

A.S. Judge
Earth Physics Branch
1 Observatory Crescent
Ottawa, Ontario
Canada, K1A 0Y3

J.R. Mackay
Department of Geography
University of British Columbia
Vancouver, British Columbia
Canada, V6T 1W5

J.V. Matthews, Jr.
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario
Canada, K1A 0E8

V.N. Rampton
Terrain Analysis & Mapping
Service Ltd.
Box 158
Carp, Ontario
Canada, K0A 1L0

S.E. Rawlinson
Division of Geological and
Geophysical Surveys
State of Alaska
794 University Avenue (Basement)
Fairbanks, Alaska 99701
U.S.A.

N.W. Rutter
Department of Geology
University of Alberta
Edmonton, Alberta
Canada, T6G 2E3

C. Schweger
Department of Anthropology
University of Alberta
Edmonton, Alberta
Canada, T6G 2E3

*P.A. Smith
United States Geological Survey
345 Middlefield Road
Menlo Park, California 94025
U.S.A.

J-S. Vincent
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario
Canada, K1A 0E8

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* J.K. Brigham-Grette and P.A. Smith were unable to participate in the workshop meeting.

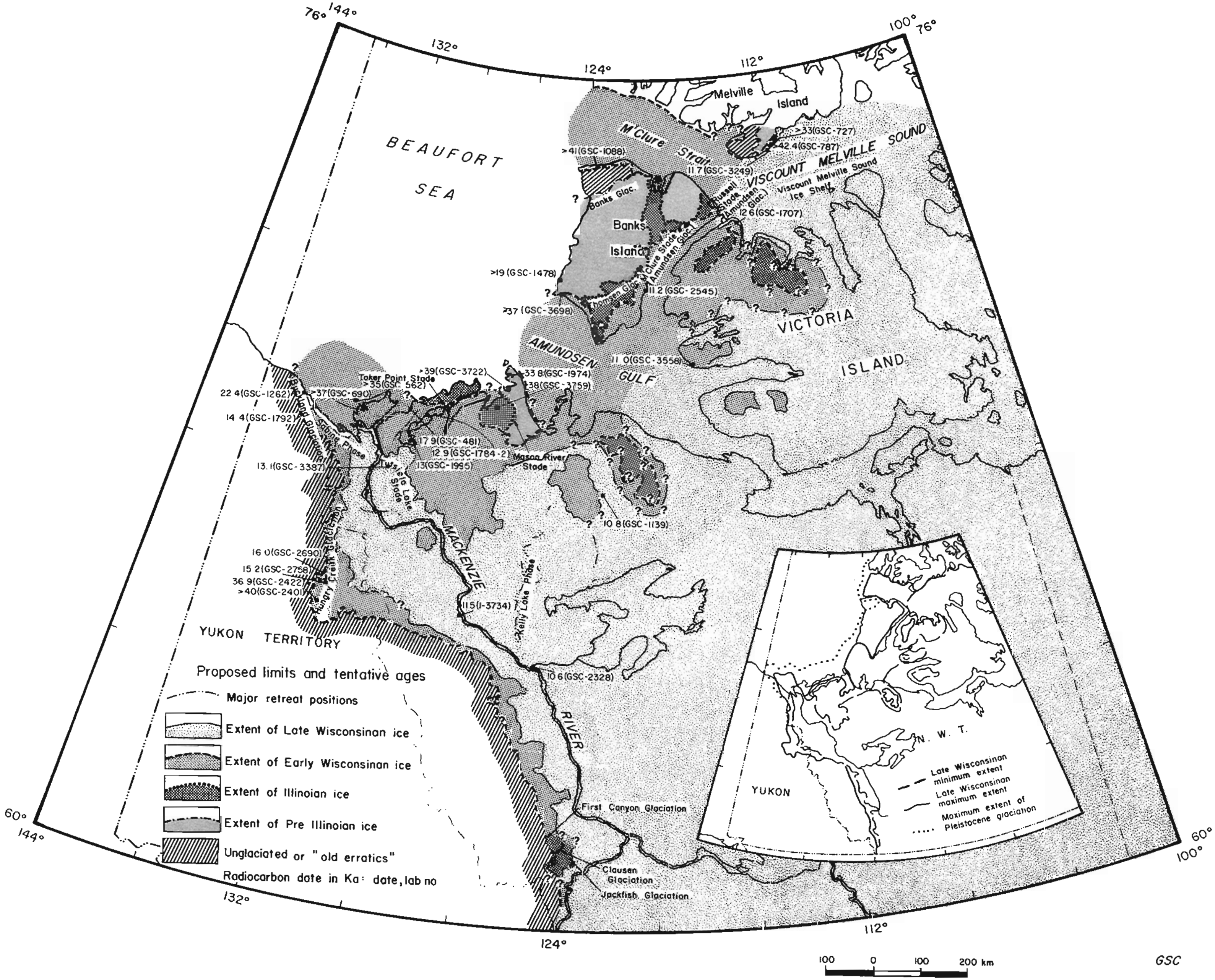

Figure 4-1. Proposed Quaternary limits of continental ice in northwestern Canada.

4. FRAMEWORK OF QUATERNARY EVENTS IN THE NORTHERN INTERIOR PLAINS OF CANADA

Jean-Serge Vincent[1]

Continental glaciers from west and northwest of Hudson Bay reached the Beaufort Sea on several occasions during the Quaternary. Glacial limits proposed by numerous authors are plotted and tentatively correlated on Figure 4-1. On the basis of limited radiometric data, ages are assigned on the limits. Sediments exposed in coastal cliffs and river bluffs provide an exceptional record, particularly on the Banks Island and Beaufort Sea coasts, of Quaternary preglacial, glacial, interglacial, and marine history. Events recorded in various areas of the western Canadian Arctic Archipelago and on the northern Interior Plains region of the Mainland are presented and correlated in Table 4-1. Pertinent radiometric age determinations are included. Suites of Quaternary sediments can be interpreted using a model in which interglacial periods, characterized by the deposition of organic bearing terrestrial and perimarine deposits, precede or follow glacial periods, characterized by transgressive marine (warping of the crust due to ice build-up), glacial per se, and regressive marine (glacio-isostatic recovery during ice retreat) events.

Preglacial Events

Sediments of organic, lacustrine, eolian, and fluvial origin, overlying the Miocene Beaufort Formation and underlying deposits of the earliest known glaciation, occur in the Worth Point and Duck Hawk bluffs sections of Banks Island and are assigned to the Worth Point Formation. The presence of macrofloral remains of larch and other plants indicate that the tree line was on Banks Island at the time. The beds are at least 730 ka old since they are magnetically reversed. Some of the pedimentation in the northern Yukon and fluvial erosion in the unglaciated portion of Banks Island may date from this period.

Early Quaternary Glaciation(s)

The oldest and most extensive advance of continental glaciers in northwestern Canada is recorded by the Banks Glaciation in the Western Arctic Archipelago. The Banks glacier is the only glacier which was strong enough to extend any distance into the Beaufort Sea and to cover at least part of the western Queen Elizabeth Islands. On Banks Island sediments of glacio-isostatic seas underlie and overlie the glacial deposits. Marine limit was lower than during the less extensive Middle Quaternary Thomsen Glaciation. The Banks Glaciation is >730 ka old since glacial and marine beds are magnetically reversed and it may correlate with Unit J of the central Arctic Ocean basin, the strongest coarse grained glaciomarine unit of Matuyama age. The "old erratics" found on surfaces lying outside the "Pre-Illinoian ice limit" may record a still older glaciation than the Banks Glaciation.

Middle Quaternary Interglaciation(s)

In five localities on Banks Island, organic bearing interglacial Morgan Bluffs Formation terrestrial (lacustrine, fluvial, eolian, and colluvial) and perimarine deposits overlie Early Quaternary Banks Glaciation deposits and underlie Middle Quaternary Thomsen Glaciation sediments. Larch may have been present on Banks Island but in most sites arthropod and plant remains indicate conditions only slightly warmer than today. The interglacial sea level was likely 30 m higher than at present. Aspartic acid racemization ratios of wood from this unit ranged from 0.32-0.35 in the Morgan Bluffs and bluffs east of Nelson River mouth, and 0.22-0.31 in the Duck Hawk Bluffs. Two uranium-thorium age determinations on wood provided non finite ages (>200 ka). The Brunhes-Matuyama boundary may lie within this interglaciation which is tentatively correlated with Unit K of the central Arctic Ocean basin, a unit considered to have been deposited during a time of reduced glacial ice activity.

Middle Quaternary Glaciation

A Middle Quaternary glaciation is recorded by glacial and marine deposits on Banks Island (Thomsen Glaciation) which overlie Morgan Bluffs Interglaciation deposits and underlie Cape Collinson Interglaciation deposits; and possibly by marine and fluvial deposits on the Yukon Coastal Plain and in the area east of the Mackenzie Delta. The western portion and northeastern plateau of Banks Island remained unglaciated. On this island extensive glacio-isostatically depressed areas were submerged by the Big Sea before, during, and after the ice advance. On eastern Banks Island marine limit was above 200 m while on the west coast it was at ca. 60 m. Total amino acid ratios of D-alloisoleucine to L-isoleucine in shells were around 0.19 in 3 samples including in situ shells. The latter were dated by the Uranium-Thorium method at 109 and 100 ka BP. On Victoria Island, Thomsen Glaciation till covers central Prince Albert Peninsula and possibly part of the Shaler Mountains while Big Sea sediments are found below Wisconsinan deposits along Prince of Wales Strait. The till on the high ground south of Melville Hills (Brock Upland) and on Bathurst Peninsula may also date from this glaciation.

Sangamonian Interglaciation

Sangamonian deposits (Cape Collinson Formation) are recognized in three localities on Banks Island where they overlie Middle Quaternary Thomsen Glaciation deposits and underlie Wisconsinan Amundsen Glaciation deposits. On the mainland, widespread, organic-bearing, bedded silts and sands and fluvial gravels with ice wedge casts on the Yukon Coastal Plain, and marine, deltaic, brown sands east of Mackenzie River on the Arctic Coastal Plain are tentatively assigned to the Sangamonian Interglaciation. On Banks Island, at the type section east of Nelson River, in situ tundra pond deposits with wood have been dated at >61 ka by the ^{14}C method and at 68 ka by the uranium-thorium method. The aspartic acid racemization ratio of the wood was 0.22. The environment on Banks Island was distinctly warmer than today as indicated by the dominant presence of birch and a few species of Coleoptera.

Wisconsinan Glaciation

Workers generally agree on what are Wisconsinan deposits in the area but disagree on the ages of events, within the Wisconsinan, responsible for their deposition. The minimalists believe that the maximum Wisconsinan advance occurred during the Early Wisconsinan and was followed by less extensive Late Wisconsinan ice. On the other hand maximalists believe the maximum Wisconsinan advance occurred in Late Wisconsinan and was followed in some areas by a readvance. The minimalists' point of view is followed in this presentation. Accordingly, maximalists would view the Early Wisconsinan limit as shown on figure 4-1 as being of Late Wisconsinan age and the Late Wisconsinan limit as a readvance. For example, Hughes, in a publication currently in preparation, refers the mainland's part of the Late Wisconsinan limit to the Tutsieta Lake Phase (Figure 4-1).

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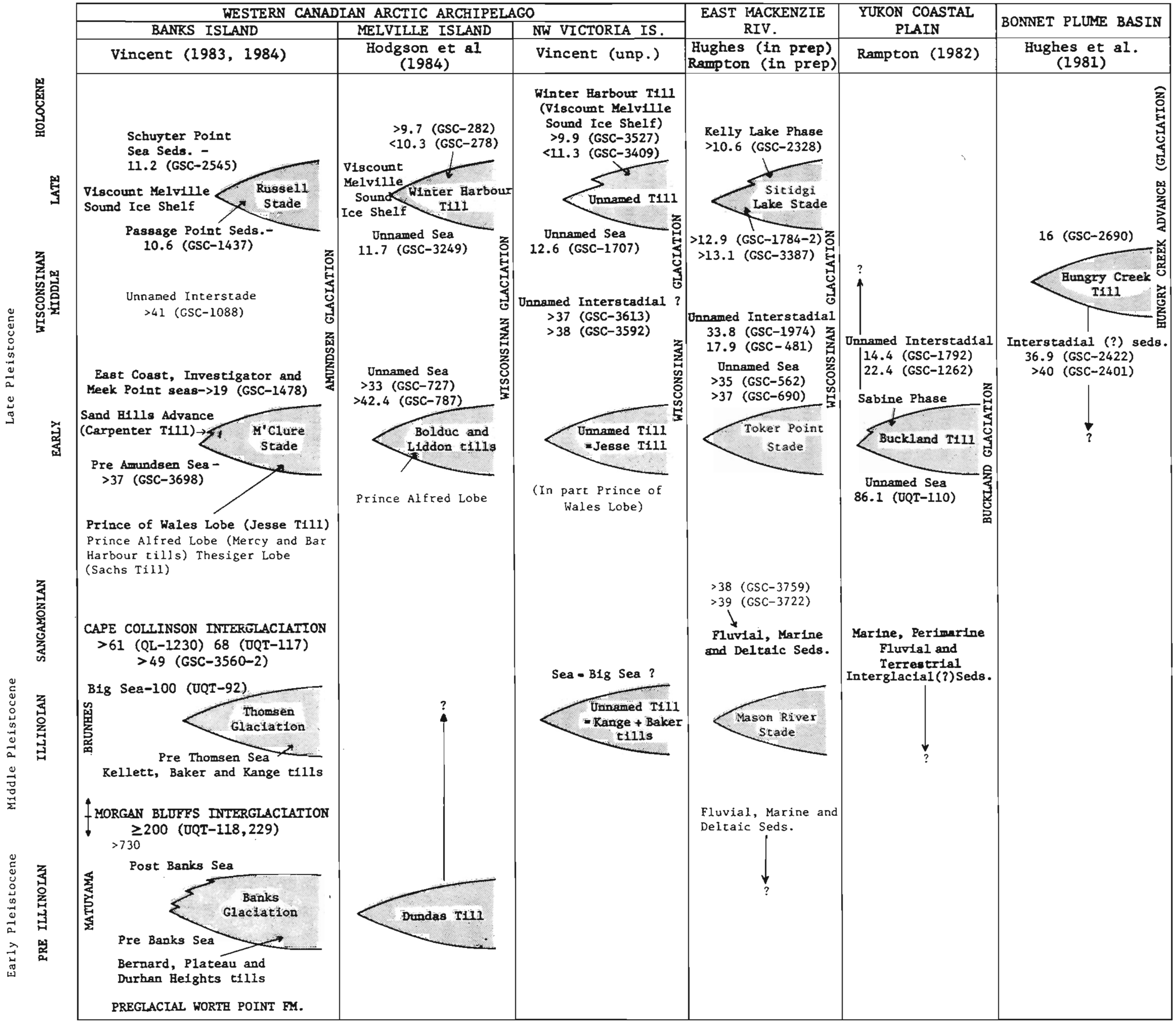
[1] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada, K1A 0E8

TABLE 4-1

CORRELATION OF QUATERNARY EVENTS - NORTHERN INTERIOR PLAINS OF CANADA



Early Wisconsinan Ice Advance

The limit of ice in Early Wisconsinan time is portrayed on Figure 4-1 and glacial events assigned this age are correlated on Table 4-1. Bathurst Peninsula, most of Banks and Melville islands, central Prince Albert Peninsula, and perhaps part of the Shaler Mountains, high ground south of Melville Hills (Brock Upland) and Tuktoyaktuk Peninsula escaped glaciation. Ice shelves likely existed in Amundsen Gulf and M'Clure Strait. Glacio-isostatic seas associated with the glaciation are recorded on Banks and Melville islands as well as on the Mainland Arctic Coastal Plain. Marine limit on the west coast of Banks Island was about 20 m and on the east coast 120 m. On the Arctic Coastal Plain it may have been as high as 45 m. On Banks Island in situ shells, in ice contact glaciomarine sediments gave a ^{14}C of >37 ka and a uranium-thorium age of 87 ka. Amino acid ratios of aIl:Ile (total) for **Hiatella arctica** shell fragments in a delta on the same Island, associated with the sea postdating the Early Wisconsinan advance, vary between 0.04 and 0.09 and gave a uranium-thorium age of 34 ka. On Melville Island and in the Mackenzie Delta area respectively, marine shells postdating the ice advance gave ages of >33 and >42.4 ka; >35 and >37 ka. Radiocarbon dates on in situ organic deposits of likely interstadial nature also provided limiting ages for the ice advance on Banks Island (>41 ka), Victoria Island (>37 ka), and on the Mainland's Arctic Coastal Plain (several dates shown on Table 4-1). A uranium-thorium date of 86.1 ka on shells in ice thrusted marine deposits on the other hand provide a maximum age for the Buckland Glaciation on the Yukon Coastal Plain and confirm its Wisconsinan age. The preceding data confirm the Early Wisconsinan age assignment for the glacial event. Assignment to the Late Wisconsinan of the all time ice limit in the Bonnet Plume basin and in the Richardson Mountain area, on the basis of the presence of 36.9 ka old wood below till, is difficult to reconcile with the evidence on the Arctic Coastal Plain. The position of clearly defined ice limits, the radiometric data, as well as the sea level history (absence of crustal depression in the Late Wisconsinan), permafrost history (thickness of offshore permafrost) and paleogeographic setting (elevation reached by the ice and symmetry on opposite sides of glacial lobes) all point towards restricted ice in the Late Wisconsinan.

Wisconsinan Interstadial

Organic bearing deposits which lie stratigraphically above the Early Wisconsinan glacial sediments are ikely present on Victoria Island and on the Arctic Coastal Plain. Both finite and non finite ^{14}C age determinations have been obtained on these (Table 4-1).

Late Wisconsinan Advance

The limit of extent of ice in Late Wisconsinan time is portrayed on Figure 4-1. Large portions of the Mainland Arctic Coastal Plain and northwestern Victoria Island, and most of Banks Island remained ice free. An ice shelf probably existed in eastern Amundsen Gulf and very likely in Viscount Melville Sound. The ice reached its maximum extent in the Mackenzie Delta area about 13 ka ago, in western Victoria Island about 11 ka ago and in Viscount Melville Sound about 10 ka ago. In these last two areas the ice came from the M'Clintock Ice Divide (Keewatin Sector) of the Laurentide Ice Sheet. By about 9.5 ka all the northern Interior Plains were ice free. The postglacial marine limit increases in altitude towards the southeast and east from elevations of a few metres a.s.l. north of the Melville Hills and about 25 metres, on the east coast of Banks Island. The Mainland Arctic Coastal Plain east of Parry Peninsula and the west coast of Banks Island both experienced continual submergence in postglacial time. Sea level in the southern Beaufort Sea was at least 100 m lower than today in Late Wisconsinan time. Thus large areas of the Continental Shelf were exposed.

Postglacial

Landscapes in the area evolved in postglacial time through the action of various geological, particularly fluvial and permafrost related processes. During the warmer and wetter period at the end of the Late Wisconsinan and in the Early Holocene, ground ice growth and thermokarst activity reached a peak.

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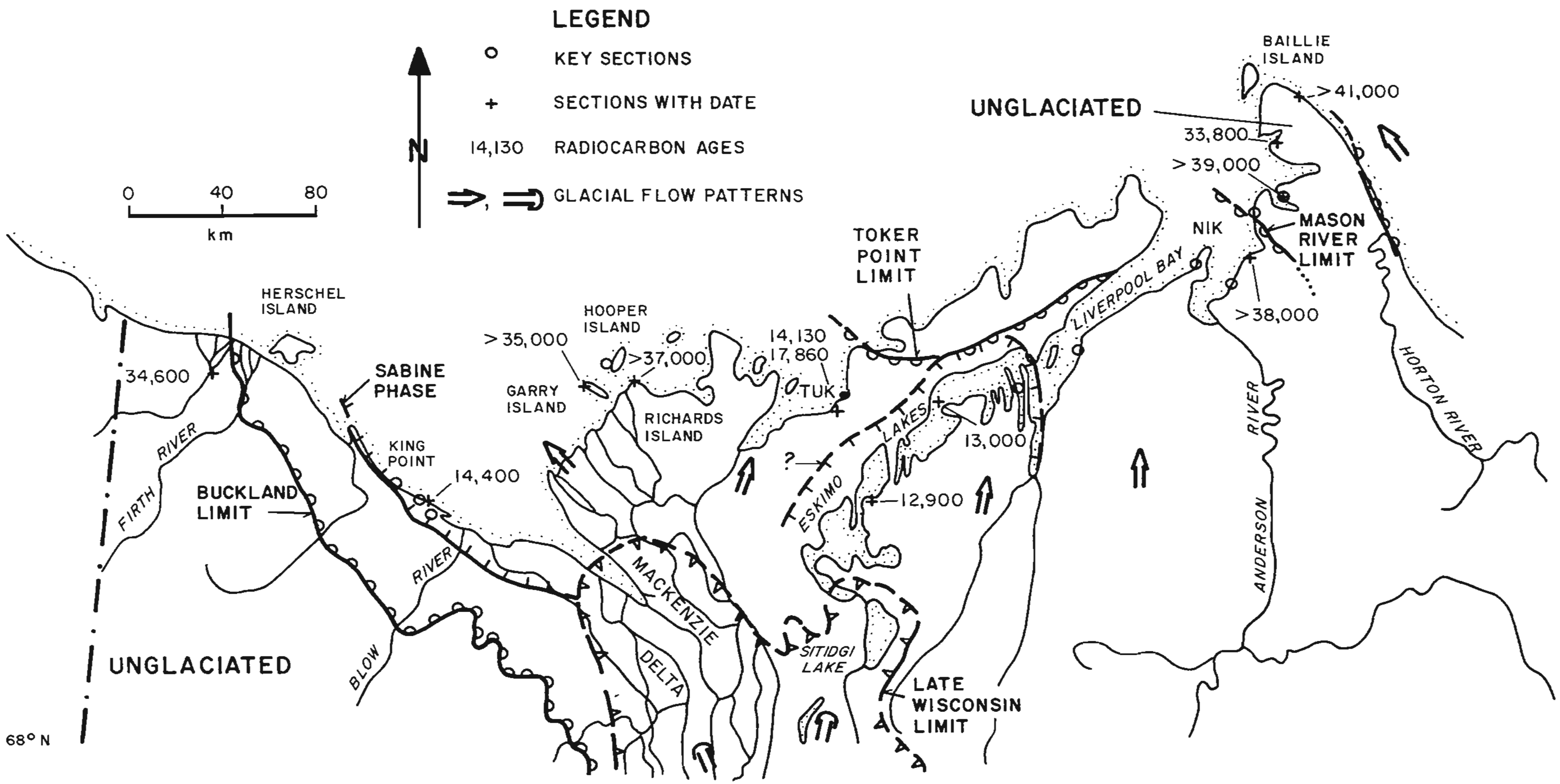

Figure 5-1. Locations of Quaternary phenomena, Arctic Coastal Plain, Canada.

5. QUATERNARY HISTORY OF THE ARCTIC COASTAL PLAIN IN CANADA

V.N. Rampton[1]

A number of glacial limits have been delineated on land around the Southern Beaufort Sea (Figure 5-1). The Buckland limit falls from over 900 m near 68° latitude North to sea level just west of Herschel Island. The Mason River limit approaches sea level near the northern end of Liverpool Bay. On the basis of the northernmost extent of the erratic boulders associated with till-like diamictons and the southern edge of a large outwash plain, the Toker Point limit has been extended across the Tuktoyaktuk Peninsula. Other glacial limits may lie farther north here, however (being buried by outwash). Along the Yukon Coast, an ice thrust ridge and associated outwash apron defines a glacial limit (Sabine). On the Tuktoyaktuk Peninsula a ridge of hummocky gravel down its axis and lobate ridges at the east end of the Eskimo Lakes may define a glacial limit. The ages of these glacial limits are problematic. The Mason River Glaciation has been assigned a pre-Sangamon age as lacustrine and perimarine sediments containing fossils having interglacial affinities and being beyond the range of radiocarbon dating are inset into terrain glaciated during the Mason River Glaciation. The Buckland and Toker Point limits are assigned to the Early Wisconsinan as: (1) plant material within a debris-flow east of King Point dates at 14.4 ka, and peaty silts within similar material near Tuktoyaktuk date circa. 14.1 and 17.9 ka; all dated materials are stratigraphically above tills presumably associated with these limits and all dates exceed the age of the regional Late Wisconsinan limit; (2) shells within late glacial (?) terraces northwest of Richards Island date at >35 and >36 ka; (3) ground ice believed to have been formed during the waning stages of the Buckland and Toker Point glaciations have never experienced an extended warm interval and completely thawed; (4) no known Pre-Wisconsinan sediments overlie glacial materials deposited during either the Buckland or Toker Point glaciations; and (5) the area shows no sign of Late Wisconsinan submergence. Near Sitidgi Lake, especially along its eastern edge, morainic ridges and outwash plains clearly define a glacial limit, which has been assigned a 13 ka age based on dates on grassy material found in cross-bedded outwash originating at this moraine.

Pond sediments and diamicton that cap most sections along the Yukon Coast and Richards Island-Tuktoyaktuk Peninsula area (Table 5-1) are Late Wisconsinan to Holocene in age. The general absence of Wisconsinan deposits on the glaciated surface is perplexing given the Early Wisconsinan age assignment of this surface.

Perimarine and alluvial deposits directly underlying glacial deposits along the Yukon Coast southeast of Herschel Island generally show no sign of oxidation and may have been deposited just prior to the Buckland Glaciation. Fossils from a peat horizon in a perimarine sequence on Herschel Island correlated with these deposits suggests that the landscape was covered by shrub tundra during their deposition. Perimarine and alluvial deposits underlying the above sediments generally show signs of oxidation and contain fossils indicative of a forest-tundra environment; ice-wedge casts indicate development and thawing of permafrost.

On the Tuktoyaktuk Peninsula and adjacent areas grey, horizontally bedded and cross-bedded sands both underlie tills and form terraces and outwash plains at the surface. Underlying these grey sands is a fine-grained, brown sand, generally showing large-scale foreset beds representative of a deltaic environment. Grey, cross-bedded sands with abundant woody detritus and clay underlie the brown sands. The sand is interpreted as fluvial in origin, the clay as marine; climate during their deposition is problematic.

East of Nicholson Point, a tripartite sequence of sediments can be extended from below a glaciated surface into unglaciated terrain. Brown sands and silts and locally gravels containing wood and bones and showing signs of erosional disconformities overlie; and brown silts and sands with ice-wedge casts and peaty horizons underlie grey, thinly bedded silts and fine sands with detrital, peaty layers. The brown sediments likely were deposited on a coastal plain in a nonglacial environment, whereas the grey, fine-grained sediments are tentatively interpreted as being deposited proglacially in deeper waters. Clays underlie the lower brown silts and sands. A sequence of pond sediments with wood and silts containing driftwood are believed to be inset into the above sequence. At a few localities at low elevations these inset sediments are covered by gravels and sands, presumably deposited during the Toker Point Stade.

Absolute dating and correlation of sediments pre-dating glaciation of the area will require utilization of techniques such as amino acid dating and paleomagnetic studies as all sediments lie beyond the range of radiocarbon dating. Tentative interarea correlations and correlations with Banks Island have been attempted, however, and are shown in Table 5-1.

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[1] Terrain Analysis and Mapping Services Ltd., Box 158, Carp, Ontario, Canada, K0A 1L0

Table 5-1. Correlation Chart of the Main Stratigraphic Units, Arctic Coastal Main, Canada

Banks Corralitives	Herschel Island	King Point	Sabine Point	Walking River	Blow River	Banks Corralitives
Holocene			Silty sediments (L)	Pebbly Sands (F)	Diamicton sandy sediments (L)	Holocene
	b·(M)	b·(M)	Till (M)	Gravels (G) Till (M)	Till (M)	
Pre-Amundsen Sea	Clays, silts (W); peat	Gravels, sands, silts, clays (FW & F) with much spruce wood and cones	Bedded silts & clays (FW); shell fragments toward top; ice-wedge cast	Clay (L) Gravels (F); ice-wedge casts	Thin gravels (F)	Pre-Amundsen Sea
Cape Collison Interglacial	Interbedded silts, sands, clays (FW)		Bedded silts, sand, clays; (FW) oxidized ice-wedge casts	Gravels (F); oxidized ice-wedge casts	Gravels (F); partly oxidized; ice-wedge casts; spruce wood	Cape Collison Interglacial
Big Sea	Clay; shells (W)					

Banks Corralitives	Hooper & Gary Islands	Eskimo Lake Fingers	Nicholson Point (NIK)	Stanton Shore	Maitland Point & Inlet	Banks Corralitives
Meek Sea?	Gravels (terrace with shells (G?))	Diamicton (L)	Diamicton (L)	Pond sands & silts, diamicton (L)	Pebbly sands (G?)	Meek Sea?
	b·(M)	b·(M)	b·(M)	Till (M)	Strandline & silts (L); with wood, ice-wedge casts	Cape Collison Interglacial
	Brown sand (deltaic - W)	Grey channel sands with clay layers at base (G?)	Clays, silts (FW)	Brown sandy silts (FW) soils	Brown sands & silts, locally gravels (FW); wood, bone	
	Grey sand (F)		Brown sands (?)			
Banks Sea	Clay (W); shells	Brown sand (deltaic - W)	Grey sands (F)	Thinly bedded silts (FW)	Thinly bedded silts (FW); detrital peat layer near base ↕ MR	Big Sea
		Grey sands; (F) much woody detritus	Clays (W)	Brown fine sand (FW); ice wedge casts; peat layer		
				Clay (W); peaty layer	Brown silts & sands (FW); peat layers; ice-wedge casts; gravels (thick?) over bedrock	Morgan Bluffs Interglacial
					Clay (W)	Banks Sea

F - fluvial, FW - perimarine, G - glaciofluvial, L - lacustrine or pond,
M - morainal, W - marine, b - boulder lag, MR - Mason River glaciation.

6. QUATERNARY CHRONOLOGY OF YUKON TERRITORY AND WESTERN DISTRICT OF MACKENZIE

Owen L. Hughes[1]

For convenience of description of Quaternary history, Yukon and adjacent parts of western District of Mackenzie can be divided into six regions: 1) an area in southern and central Yukon, comprising the western slopes of Selwyn Mountains, all of Yukon Plateau except for an elongate belt adjacent to the Alaska border, plus the Coast Mountains (Fig. 6-1). This large area was subjected to repeated advances of the Cordilleran Ice Sheet. 2) An area comprising the northeastern slope of St. Elias Mountains, the adjacent Shakwak Trench and a small part of Yukon Plateau lying to the northeast of Shakwak Trench; the area was subjected to repeated advances of montane glaciers originating in St. Elias Mountains that merged to form an extensive piedmont glacier in and beyond Shakwak Trench. During the successive advances the southern part of the St. Elias Piedmont glacier joined with the Cordilleran Ice Sheet. 3) Wernecke Mountains and Southern Ogilvie Ranges. These mountains were subjected to repeated advances of montane glaciers that were independent of the Cordilleran Ice Sheet, although discharge glaciers of the latter may have spilled northward across the lowest passes in Wernecke Mountains, being augmented by local glaciers. 4) Mackenzie Mountains. Virtually all of the major valleys of Mackenzie Mountains were occupied repeatedly by glaciers that flowed eastward and northward, locally extending as piedmont glaciers beyond the mountain front. 5) The Interior Plains and adjoining areas to the west, including the lower slopes of Richardson Mountains and Yukon Coastal Plain. The area lies within the maximum limit of Laurentide glaciation and, depending upon location, was glaciated one or more times. 6) Nonglaciated western and northern Yukon, comprising part of Yukon Plateau, northern Ogilvie Mountains, the Porcupine Plain and Plateau region, Richardson Mountains and the Arctic Ranges. This area is the eastern extremity of a vast nonglaciated area extending westward through Alaska, and is the largest nonglaciated area in Canada. A correlation chart for the events described below is presented in Table 6-1.

Cordilleran Ice Sheet and St. Elias Piedmont Glacier

In that part of central Yukon glaciated by the Cordilleran Ice Sheet, Bostock (1966) inferred four separate advances: Nansen (oldest), Klaza, Reid and McConnell, with each successive advance less extensive than the preceding one.

Landforms associated with the Nansen advance are very much subdued, so that the Nansen limit cannot be interpreted with confidence from air photos. The limit mapped by Bostock (1966, Fig. 1) and shown in this report (Fig. 6-1), is to a considerable degree based on field observations of glacial erratics.

In places, there are features suggestive of a glacial limit intermediate between the Nansen limit and the more readily identifiable limit of Reid Glaciation. Locally Bostock was able to link such features together to define a limit of Klaza Glaciation (1966, Fig. 1). However, there are extensive areas in which no distinction can be made on the basis of landform between Nansen and Klaza deposits. In this report, all glacial deposits beyond the limit of Reid Glaciation are grouped as "pre-Reid".

Moraines and other ice-marginal features marking the limit of the Reid Glaciation are subdued by comparison with features related to the McConnell Glaciation. Nevertheless, the highly digitate Reid limit can be traced, with interruptions, from the type locality near Reid Lakes southward then northwestward into Snag map area in southwestern Yukon where it joins with the limit of Mirror Creek Glaciation, as defined by Rampton (1969, 1972).

Well-preserved ice-marginal features related to the McConnell Glaciation can be traced from the type locality, 14 km southwest of Mayo, around the digitate margin of the northwestern part of the Cordilleran Ice Sheet during the McConnell maximum. The limit is traceable, with interruptions, into Snag map area, where it joins with the limit of McCauley Glaciation, as defined by Rampton (1969, 1971).

Montane Glaciation of Southern Ogilvie Ranges

Thick drift deposits of pre-Reid age deposited by the Cordilleran Ice Sheet occur along upper Lake Creek west of Willow Hills, along Stewart River downstream from where the river turns southwestward out of Tintina Trench, and northwestward along Tintina Trench. The gently undulating drift surface in Tintina Trench is continuous with the upper surface of Flat Creek Beds (McConnell, 1905) which comprise glaciofluvial gravel, till, and silt. Lithology of the gravel and till indicates that they were deposited by montane glaciers originating in Southern Ogilvie Ranges. To the west of Tintina Trench, glaciofluvial gravel, termed Klondike River Gravels or Klondike Gravels by McConnell (1907, p. 1 and 29) lie on a high bedrock terrace on the south side of Klondike River. At the mouths of Hunker and Bonanza creeks, the Klondike Gravels overlie White Channel Gravel of presumed Late Pliocene-Early Pleistocene age. The bedrock terrace and overlying Klondike Gravels merge at Yukon River with a terrace that continues northwestward beyond the mouth of Fortymile River. Flat Creek Beds and Klondike Gravels are the product of one or more "Old" glaciations during which large montane glaciers flowed both northward and southward from the axis of Southern Ogilvie Ranges (Vernon and Hughes, 1966). High terraces along Fortymile River east of the Yukon-Alaska boundary appear to be the downstream continuation of terraces thought by Weber (1983) to relate to the Early (?) Pleistocene Charley River glacial episode and probably also the Middle (?) Pleistocene Mount Harper glacial episode.

Modified but readily recognizable moraines and other ice-marginal features of Southern Ogilvie Ranges were assigned by Vernon and Hughes (1966) to an "Intermediate" glaciation. Glaciers in southward draining valleys such as North Klondike and Chandindu reached to the northeast side of Tintina Trench. Terminal deposits are inset within inner valleys that are incised some 200 m below the upper surface of the Flat Creek Beds, indicating a major erosional interval between "Old" and "Intermediate" glaciations of the area. The southward flowing glaciers had northward flowing counterparts that extended into Taiga Valley.

Moraines assigned to the "Last" glaciation of Southern Ogilvie Ranges (Vernon and Hughes, 1966) are mostly confined to tributary valleys, indicating a very restricted advance.

Laurentide Ice Sheet

Moraines and other ice marginal features marking the all-time limit of the Laurentide Ice Sheet are traceable around the arc of the Mackenzie Mountain front, around the periphery of Bonnet Plume Basin (the Hungry Creek Glaciation, Hughes et al., 1981) northward along the flanks of

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[1] Geological Survey of Canada, 3303-33rd Street NW, Calgary, Alberta, Canada, T2L 2A7

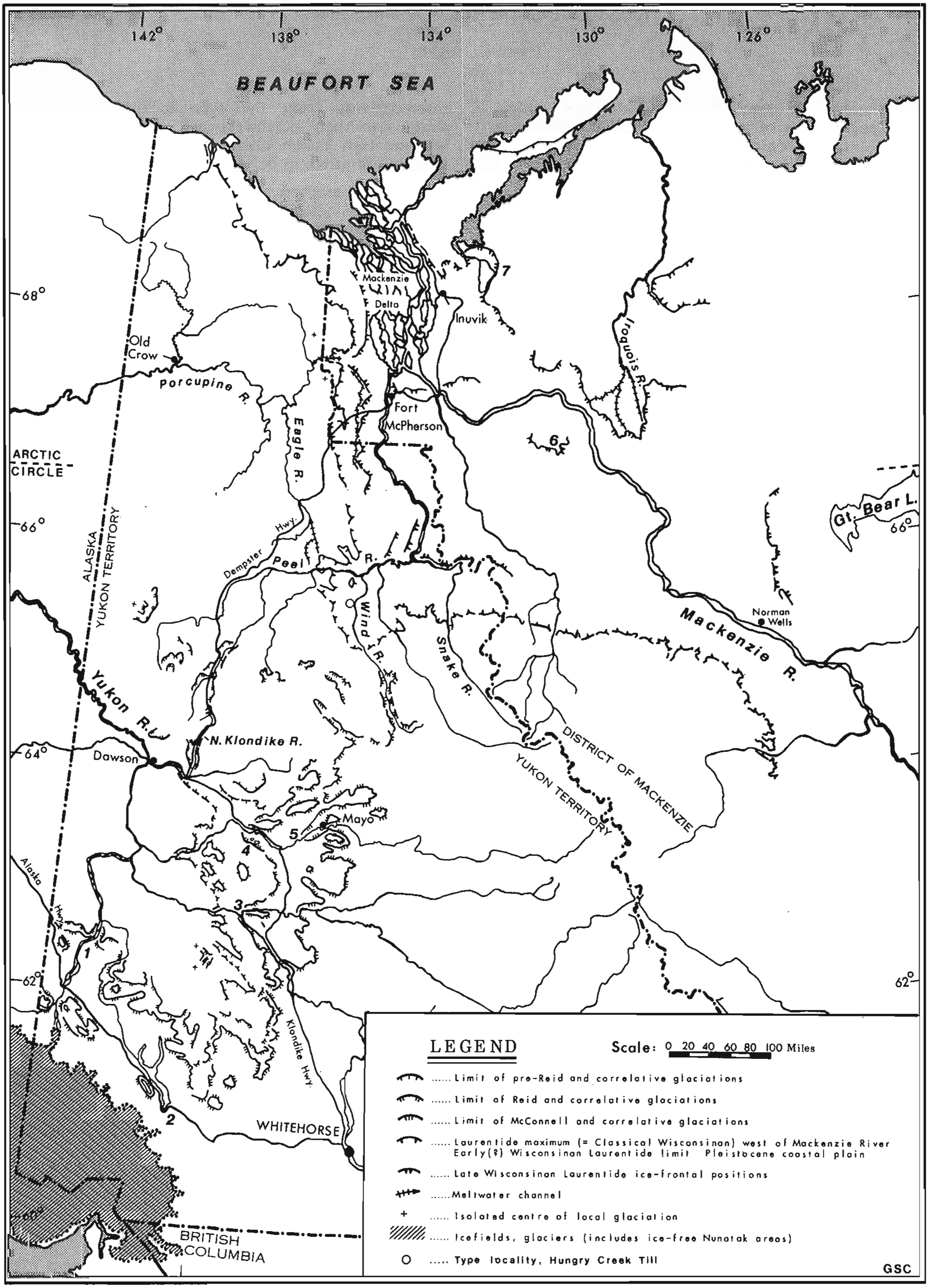

Figure 6-1. Glacial limits, Yukon and lower Mackenzie River Valley, Canada.

Richardson Mountains and northwestward to near Herschel Island (the Buckland Glaciation; Rampton, 1982). These features appear to mark the limit of a single Laurentide advance, although the possibility that more than one advance is involved cannot be totally dismissed. A single till of Shield origin overlies multiple tills of montane origin at several points along the Mackenzie Mountain front. At other points, the Laurentide limit truncates moraines associated with montane glaciers. The truncated moraines are judged from morphology to be of "Intermediate" (Reid) age.

At Hungry Creek section in Bonnet Plume Basin, Hungry Creek Till that was deposited during Hungry Creek Glaciation is underlain by organic sediments that in turn are underlain by glacial lake sediments that contain dropstones of Shield origin. The evidence indicates that the Laurentide Ice Sheet advanced close to the site impounding a glacial lake, retreated from the region during a nonglacial episode and then advanced beyond the site during the Hungry Creek Glaciation.

Three readvances or perhaps significant still-stands following the Hungry Creek maximum have been inferred from moraines and other ice-marginal features: the Sabine Phase (Rampton, 1982, p. 45) and the Tutsieta Lake and Kelly Lake phases (Hughes, in press).

Chronology

At Fort Selkirk, till of Nansen or possibly older age is overlain by tephra with fission-track ages of 0.84 ± 0.13 Ma to 0.94 ± .40 Ma (Naesser et al., 1982) and by basalt with a K/Ar age of 1.08 Ma (M.L. Silberman, personal communication to J.V. Matthews, Jr., 1981). A fission track age of 1.22 Ma for Mosquito Gulch Tephra from a terrace of Bonanza Creek near Dawson, is minimum for the Klondike Gravels.

There are no limiting dates for Klaza Glaciation. Reid drift is overlain by Sheep Creek Tephra, and bone associated with the tephra at Canyon Creek, Alaska, has produced uranium-thorium and uranium-protactinium dates of 78 and 73 ka years respectively (Hopkins, 1982). The apparently correlative Mirror Creek drift is overlain by Old Crow Tephra (Westgate, 1982) for which Schweger and Mathews (in preparation) suggest an age of 87-105 ka. Old Crow Tephra is also found below McCauley drift.

Wood from beneath till of McConnell age near the type locality has been dated as >46.48 ka (GSC-331; Dyck et al., 1966). At the Tom Creek section in Liard Plain of southeastern Yukon, organic sediments beneath till of the last advance of the Cordilleran Ice Sheet have produced dates ranging from >30 ka (GSC-2949) to 23.9 ± 1.140 ka (GSC-2811) (Klassen, in press). Only one finite date of 48 ± 1.3 ka (GSC-732) has come from beneath till of McCauley age and rootlet contamination of the sample is considered possible (Rampton, 1971, p. 294). However, at Silver Creek near Kluane Lake, organic sediments of the Boutellier nonglacial interval have yielded dates ranging from $37.7 \pm {}^{1.5}_{1.3}$ ka (Y-1356) to 29.6 ± .46 ka (GSC-769) (Denton and Stuiver, 1967; Lowdon and Blake, 1970, p. 76).

Pollen spectra from the Tom Creek and Silver Creek sections indicate former herbaceous tundra in areas now occupied by boreal forest (Klassen, in press; Schweger and Janssens, 1980). The nonglacial beds of these localities cannot therefore represent the whole of the Reid-McConnell nonglacial interval (Boutellier Interval of Hopkins, 1982), because that interval included a period with climatic conditions at least as warm as the present (C.E. Schweger and J.V. Matthews, Jr., personal communication). The beds may represent an interstade within the McConnell Glaciation, as suggested in Column 3b of Fig. 6-2 for the Silver Creek area.

The St. Elias piedmont glacier had begun retreat by 13.66 ± .18 ka (GSC-495, Lowdon et al., 1967, p. 20; Rampton, 1971, p. 295) and retreat following the last glaciation in Southern Ogilvie Ranges had begun by 13.74 ± .19 ka (GSC-515, Lowdon and Blake, 1968, p. 231; Hughes et al., 1968, p. 361). The Cordilleran Ice Sheet presumably began retreat at about the same time.

A date on wood from beneath Hungry Creek Till indicates that Hungry Creek Glaciation culminated after 36.9 ± .3 ka (GSC-2422; Hughes et al., 1981, Table 2). This maximum advance of the Laurentide Ice Sheet blocked eastward drainage of northern interior Yukon, causing inundation there of Bell, Bluefish, and Old Crow basins, beginning about 30 ka or slightly later (Hughes et al., 1981, p. 359). Retreat following the Hungry Creek Glaciation had begun by 16 ± .42 ka (GSC-2690; Ritchie, 1982, Table 15; Hughes et al., 1981, p. 358). On Yukon Coastal Plain where the last glaciation has been termed Buckland by Rampton, there had been considerable retreat by 22 ka (Rampton, 1982, p. 25).

The Sabine Phase is undated. The Tutsieta Lake Phase may have culminated about 13 ka ago and the Kelly Lake Phase culminated more than 10.6 ka ago (Hughes, in press).

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Table 6-1. Correlation chart for Yukon and western District of Mackenzie, Canada

Unglaciated Beringia	Cordilleran Ice Sheet	St. Elias Peidmont Glacier Snag-Klutlan	Silver Creek	Silver Creek	Alaska Range	Southern Ogilvie Range	Brooks Range	Laurentide Ice Sheet	Old Crow & Bluefish
		13,660	12,800	12,500		13,740		10,600 14,000 16,000	12,460
Duvanny Yar Interval	McConnell Glaciation	McCauley Glaciation	Kluane Glaciation	Kluane Glaciation Boutellier Nonglacial Icefields Glaciation	Donnelly Glaciation	Last Glaciation	Walker Lake Glaciation	Hungry Creek Glaciation	Upper Glaciolacust.
								36,900	36,400
Boutellier Interval	*Sheep Creek Tephra*	*Old Crow Tephra*	Boutellier Nonglacial	Silver Nonglacial			*Old Crow Tephra*		*Old Crow Tephra*
Happy Interval	Reid Glaciation	Mirror Creek Glaciation	Icefields Glaciation	Shakwak Glaciation	Delta Glaciation	Intermediate Glaciation	Itkillik Glaciation	'Deception' Glaciation	
			Silver Nonglacial						
	Klaza Glaciation	?	Shakwak Glaciation	?	Darling Creek Glaciation	Older Glaciation?	Sagavanirktok Glaciation		
			?						
	Ft. Selkirk Tephra 0.94 Ma					*Mosquito Gulch Tephra* 1.22 Ma			
	Nansen Glaciation Selkirk Group 1.0 Ma					Older Glaciation?	Anaktuvuk R. Glaciation		

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7. QUATERNARY STRATIGRAPHY AND CHRONOLOGY IN THE RICHARDSON MOUNTAINS-PEEL PLATEAU REGION, YUKON, NWT

N.R. Catto[1]

Investigation of the Richardson Mountains-Peel Plateau region has been concentrated on the sedimentology, stratigraphy, and palaeoecology of sections exposed along the principal rivers of the area. A total of 66 sections have been examined to date. The most informative of these sections are located along the lower and central portions of the Rat River, the Caribou River, the Peel River between the Trail and Caribou rivers, and the Snake River north of the Mackenzie Mountains.

Along the Lower Rat River, the sediments exposed consist of preglacial gravels that are overlain by several fluvial and lacustrine units, which are in turn overlain by a single till. The preglacial gravels are composed entirely of orthoquartzite, greywacke, siltstone, and other locally-derived clasts. The lower contact of this unit is approximately 50 m above the Rat River. These sediments are believed to be Tertiary.

Palynological, plant macrofossil, and arthropod analyses of the overlying fluvial sediments indicate that climatic conditions during their deposition varied from a cold, dry, open tundra environment to a boreal forest environment warmer and milder than that prevailing today. At section HH 62-107-81-2a (67°39'N, 135°29'W), the basal Quaternary fluvial sediments contain a palynological assemblage typical of southern boreal forest conditions, including **Picea** and minor amounts of **Pinus** and **Corylus** grains. A thin gravel layer separates the basal sediments from overlying fluvial overbank and back-bar channel sediments containing a tundra assemblage dominated by Cyperaceae and Gramineae grains. These sediments are directly overlain by till. Radiocarbon dating of the uppermost organic horizon at HH 62-107-81-2a, directly beneath the till, has yielded a date of >43 ka (GSC-3359).

At section HH 62-107-81-1, 800 m to the south, the preglacial gravels are overlain by cryoturbated fluvial (?) sediments containing a tundra palynological assemblage which persists throughout the section to the base of the till. In contrast, the sediment directly below the till at HH 62-107-81-3a, 1.4 km north of HH 62-107-81-2a, contains plant macrofossils indicative of a mild boreal forest environment. Material from this horizon has been submitted for radiocarbon dating. The till exposed at all three sections is apparently a single unit, although it is highly disturbed by slumping, flow, and cryoturbation, and is the uppermost inorganic sediment exposed throughout the lower Rat Valley.

In the central portion of the Rat River valley, lacustrine and fluvial sediments at section HHC 81-3 (67°43'N, 135°51'W), that formed after the withdrawal of glacial ice from the region have been dated at 21.3 ± .27 ka(GSC-3371). The elevation and sedimentology of these and correlated deposits indicate that the glacier was located to the east and was impounding the water of the Rat Valley. Detrital mineral and coal grains in the deposits indicate that the area was receiving discharge from the Bell Basin through McDougall Pass. The sediments are devoid of palynomorphs.

Transported wood from a gravel stratum near the base of the exposure at HHC 81-3 has been radiocarbon-dated at >42 ka (GSC-3565). This date, if accepted, implies that the central Rat River valley has not been glaciated since this time. In the McDougall Pass area, till and glaciofluvial sediments of the oldest glacial advance are overlain directly by Holocene sediments and peats. The subdued geomorphic expression of the Bell River moraine would suggest that the maximum advance occurred some time prior to 25 ka. However, no precise dating of this event is possible at the present time. The evidence suggests that the ice initially advanced to the Bell River moraine and had retreated to a position between HH 62-107-81-2a and HHC 81-3 by 21 300 B.P. HHC 81-3 was apparently not covered by glacial ice at any time since 42 ka.

Sections on the upper Caribou River suggest that the withdrawal of ice from this region occurred shortly before 12.4 ka. This date (GSC-3691) represents the first establishment of vegetation at location HH 72-49-82 (66°13'N, 135°11'W). The palynological succession reflects the development of an open evergreen/deciduous forest dominated by **Picea** and **Betula.** Till produced during the glacial event overlies organic sediments at HH 72-50-82 (66°15'N, 134°58'W). These organic sediments have been submitted for radiocarbon dating.

Along the lower Caribou River, fluvial sediments dated at 9.780 ± .11 ka (GSC-3573) are located at section HHC 82-1c (66°22'N, 134°20'W). This fluvial material lies stratigraphically above varved lacustrine silts and clays produced by the impounding of the Caribou River during deglaciation. The dated material was obtained from a bed located 109 m above the level of the present Caribou River. This indicates that the Caribou River was still dammed by glacial ice to the east at this time, and also that the Peel River had not yet established its modern drainage course. The date thus represents a maximum for withdrawal of ice from the eastern Peel Plateau. The palynological assemblages from the sediments suggest a scattered cover of **Picea, Alnus,** and **Betula.**

Along the Peel River, the oldest sediment exposed is a highly iron and manganese-oxidized gravel which contains granite, granodiorite, gneiss, and basalt clasts, many of which are disaggregated and extensively chemically weathered. These gravels show a higher degree of weathering than any other sediments in the Peel Plateau-Richardson Mountains region. They are tentatively correlated to the oldest Quaternary sediments exposed in the Rat Valley, and are associated with the development of glacially thrusted bedrock ridges east of the Peel River, near its confluence with the Trail River. The gravels are overlain by several successions of fluvial sediments, which are in turn overlain by till correlated to that exposed in the Caribou River sections and on the surface in the lower Rat Valley. These data suggest that the Peel-Caribou area was glaciated twice, once early in the Quaternary and a second time during the Late Quaternary. The ice retreated from the upper Caribou Valley before 12.4 ka, from the lower Caribou Valley by 9.78 ka, and from the Peel Plateau approximately 9.5 to 9 ka.

Along the Snake River, tills exposed at HH 62-71-82 (65°46'N, 133°16'W), and at HH 76-3-82 (65°48'N, 133°19'W), have been correlated and represent three glacial events. The oldest till, exposed at HH 62-71-82, is thought to represent an advance occurring prior to 39 ka. However, the degree of weathering of the granitic clasts is far less than that noted in the gravels exposed at the base of the Peel River sections. The second till is exposed at both sections. At HH 76-3-82, it is underlain by a fluvial complex of gravels, sands, silts, clays, and slump deposits. Wood from this complex has been dated at >39 ka (GSC-3697), and this is therefore considered to be the minimum age for the first glaciation. The till overlying the fluvial complex is tentatively correlated to the till described by Hughes et al. (1981) from the Hungry Creek

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[1] Department of Geology, University of Alberta, Edmonton, Alberta, Canada, T6G 2E3

section in the Bonnet Plume Basin, and to the sediments exposed along the Caribou and Peel rivers. The third till, exposed only at HH 76-3-82, is believed to represent a very local readvance from the major stillstand position located along the north and east margins of the Snake River valley.

In summary, the Richardson Mountains-Peel Plateau region was initially glaciated sometime before 42 ka. Sediments from this event are preserved in the McDougall Pass area and along the Peel River. A second glacial advance that covered the Caribou, Snake, and central Rat valleys occurred sometime after 36.9 ka as indicated by the data from the Bonnet Plume basin. By 21.3 ka, the ice had retreated to a position in the central Rat River valley between sections HH 62-107-81-2a and HHC 81-3. Continued retreat, with occasional minor local readvances, exposed the upper Caribou Valley and Snake Valley approximately 12.4 ka the lower Caribou Valley approximately 9.780 ka and the eastern Peel Plateau and lower Rat Valley approximately 9.5 to 9 ka.

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8. LATE CENOZOIC GEOLOGIC FRAMEWORK, ALASKAN ARCTIC COASTAL PLAIN AND BEAUFORT SEA SHELF

D.M. Hopkins[1]

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[1] Department of Geology, University of Alaska, Fairbanks, Alaska, 99701, U.S.A.

9. LATE CENOZOIC MARINE TRANSGRESSIONS OF THE ALASKAN ARCTIC COASTAL PLAIN

L. David Carter[1], Julie Brigham-Grette[2], and David M. Hopkins[3]

The Alaskan Arctic Coastal Plain is mantled by unconsolidated late Cenozoic marine, lacustrine, alluvial, glacial, and eolian deposits (O'Sullivan, 1961; Black, 1964; McCulloch, 1967; Sellmann and Brown, 1973). The marine deposits and the alluvial, lacustrine, and eolian deposits are commonly referred to as the Gubik Formation (Black, 1964), and glaciomarine deposits previously referred to as the Flaxman Formation (Leffingwell, 1919) recently have been reduced to member status within the Gubik Formation (Dinter, in press). The late Cenozoic deposits are thin (maximum measured thickness about 60 m) but they record a complex history spanning more than 3.5 Ma. Recent research on the eolian, fluvial, and glacial deposits has been discussed elsewhere (Carter, 1981, 1983a,b,c; Carter and Galloway, 1979, 1982; Carter et al., 1984). This paper considers only recent work on the marine deposits, and is based on fieldwork conducted west of the Kuparuk River and east of the Canning River (Fig. 9-1).

At least six and possibly seven or eight late Cenozoic marine transgressions are represented by deposits of the Gubik Formation. We correlate one of these transgressions with the Pelukian transgression of Hopkins (1967), and propose the following names (oldest to youngest) for transgressions which cannot be securely correlated with other transgressions defined by Hopkins: Colvillian, Bigbendian, Fishcreekian, Wainwrightian, and Simpsonian. Deposits of the Colvillian and Bigbendian transgressions are Pliocene (Carter and Galloway, 1985), and Fishcreekian beds may be Pliocene (Carter and Galloway, 1985) or Early Pleistocene (Brigham, 1985). The deposits of each of these three transgressions can be correlated across the coastal plain by comparing the extent of epimerization of isoleucine (Ile) to alloisoleucine (Alle) in fossil molluscs (Table 9-1) (Brigham, 1984, 1985). Deposits of the Wainwrightian transgression are not precisely dated, but are believed to be Middle Pleistocene. Deposits of the Pelukian and Simpsonian transgressions are Late Pleistocene and have been dated by thermoluminescence (TL).

The record of marine transgressions is most complete and has received the most study west of the Kuparuk River. Between the Kuparuk and the Canning rivers, deposits of only the Simpsonian transgression have been recognized, and these occur primarily in low coastal bluffs (Rawlinson, this volume, Section 11). From the Canning River east to the Canada-U.S. Border, only Colvillian, Fishcreekian, and Simpsonian beds have been recognized.

Between the Colville and Kuparuk rivers, late Cenozoic marine fossils have not been found south of a highly degraded bluff (Fig. 9-1) that truncates Tertiary gravel which is informally referred to as the Kuparuk gravel (Carter, 1983b). The break in slope at the base of this bluff occurs at an altitude of about 60 m and is inferred to mark the maximum altitude reached by late Cenozoic marine transgressions on this part of the coastal plain. Present data suggest that this limit relates to either the Colvillian or Bigbendian transgression, but are inconclusive as to which of these transgressions reached the highest altitude. On the far western part of the coastal plain the inner limit of marine deposits is also at an altitude of about 60 m (McCulloch, 1967), but the age of these deposits is unknown. The part of the coastal plain east of the Canning River has been affected by late Cenozoic tectonism, and the southern limit of marine deposition there has not yet been determined.

Colvillian

The Colvillian transgression is named for marine deposits that are well exposed in bluffs along the Colville River from the Kikiakrorak River north for about 10 km, and along the Kikiakrorak River from its confluence with the Colville River upstream for 5 km. These are the oldest marine deposits of the Gubik Formation that have been recognized on the Arctic Coastal Plain, and they contain marine mollusks **(Hiatella arctica)** which yield Alle/Ile values of 0.236 ± .022 (Table 9-1). These deposits generally consist of a basal gravelly sand as much as 1 m thick overlain by silty clay to clayey silt as thick as 2.5 m. They unconformably overlie Cretaceous or lower Tertiary strata throughout the extent of the exposures, and they generally are overlain by 11 to 12 m of unconsolidated fluvial and eolian deposits. In the northern part of the exposure along the Colville River, however, 1 to 1.5 m of Bigbendian deposits disconformably overlie the Colvillian beds and separate them from the fluvial and eolian deposits. Along this part of the bluffs, a femur of the North Atlantic harp seal **(Pagophilus groenlandica)** was found as float (Repenning, 1983), and could have been derived from either Colvillian or Bigbendian deposits. When Repenning's paper was written, the presence of marine deposits of two ages in the Colville River bluffs had not been established by amino acid geochemistry and it was assumed that the harp seal was from beds correlative with the Bigbendian deposits near Ocean Point.

Cobbles and boulders occur locally at the base of Colvillian deposits. Rock types present include well indurated sandstone and chert-pebble conglomerate which are common as similar sized clasts in the nearby Kuparuk gravel, and form resistant rock units in the Brooks Range to the south. Also present are clasts of metamorphic, intrusive, and volcanic rocks which do not occur in nearby parts of the Brooks Range but occur in Paleocene boulder-bearing beds that are exposed in the Colville River bluffs and underlie the Kuparuk gravel (Carter, 1983b; Carter and Galloway, in press). The simplest explanation for the occurrence of these clasts at the base of the Colvillian deposits is that they were incorporated by erosion of the Kuparuk gravel and Paleocene conglomerate during the Colvillian transgression. Some boulders derived from the Paleocene conglomerate occur several kilometres south of the nearest outcrop of these deposits, suggesting that the boulders were transported shoreward by sea ice.

Other deposits formed during the Colvillian transgression, as determined by amino acid geochemistry and superposition, are exposed east of the Colville River along the Miluveach River, on the north flank of the Marsh anticline on the eastern part of the coastal plain, and at Skull Cliff along the Chukchi Sea coast (Fig. 9-1). At Skull Cliff, deposits formed during the Colvillian transgression have been informally named the Nulavik beds by Brigham (1983). The deposits at Marsh anticline contain a distinctive ostracode fauna which includes an Atlantic form that does not live

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[1] Alaska Branch, United States Geological Survey, 4200 University Drive, Anchorage, Alaska, 99508, U.S.A.

[2] Department of Geology, University of Alberta, Edmonton, Alberta, Canada, T6G 2E3

[3] Department of Geology, University of Alaska, Fairbanks, Alaska, 99701, U.S.A.

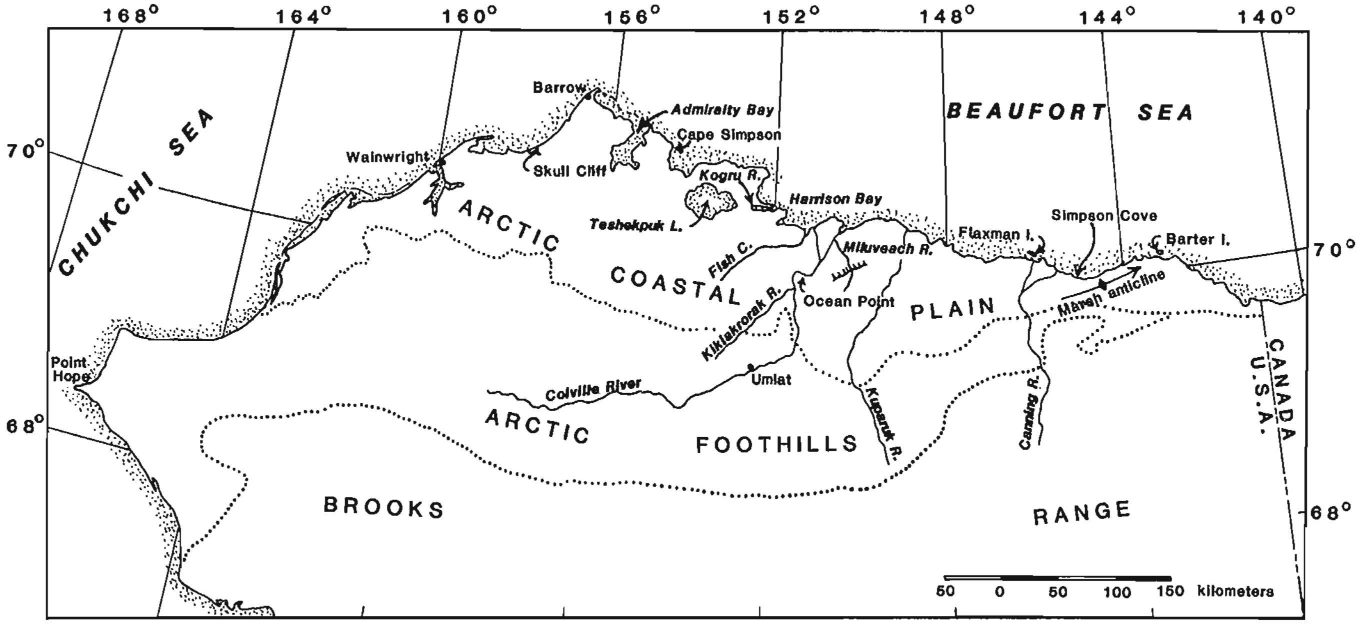

Figure 9-1. Location map, Arctic Coastal Plain and Arctic Foothills, Alaska. The hachured line denotes a degraded bluff that marks the southern limit of marine deposits between the Colville and Kuparuk rivers.

Table 9-1. Marine transgressions of the Alaskan Arctic Coastal Plain

			AIle/Ile[1]		
Transgression	Maximum Elevation Reached (m)	Age	Colville River/ Fish Creek Area	Chukchi Sea Coast Area[2]	Probable Correlation with Hopkins (1967)
Flaxman	7	70 Ka to 80 Ka	----------	----------	----------
Teshekpuk	10	120 Ka to 130 Ka	----------	.014 ± .002	Pelukian
Cape Simpson	20	210 Ka	----------	.038 ± .007	Kotzebuan
Fish Creek	>20, <60	----	.086 ± .004 (6)[3]	.086 ± .009	----------
Colville II	>35, <60	>2.19 Ma	.136 ± .014 (12)[3]	.15 ± .007	Anvilian
Colville I	>40, <60	<3.5 Ma	.236 ± .022 (8)[3]	.22	Beringian

[1] Ratios for the total fraction for Hiatella arctica.
[2] From Brigham, 1983 and 1984. A single value indicates that only one valve was analyzed.
[3] Number of analyses.

today in arctic water (E.M. Brouwers, personal communication, 1984). Although sea ice was perhaps seasonally present, climate during Colvillian time was apparently considerably warmer than now. Other localities contain similar ostracode faunas but cannot be confidently correlated with the Colvillian transgression. Evidence presented below indicates that climatic conditions during the next two transgressions were also warmer than today, and the faunas at these localities instead could be of Bigbendian or Fishcreekian age.

Faunas from deposits of the Colvillian transgression have not been studied in detail, but the mollusks form a diverse assemblage that includes the extinct whelk **Neptunia Lyrata leffingwelli** (L. Marincovich, Jr., written communication, 1984). The fauna includes taxa of Pacific origin and thus post-dates the opening of Bering Strait, which occurred between 3 and 3.5 Ma ago (Hopkins, 1972; Gladenkov, 1981). The Colvillian transgression may correlate with Hopkins' (1967) Beringian transgression as defined for the type locality at Nome.

Bigbendian

The Bigbendian transgression is named for deposits that are exposed in bluffs along the big bend of the Colville River from near Ocean Point and the Big Bend benchmark upstream for about 10 km. These beds generally consist of a basal, transgressive, gravelly beach sand about 1 m thick overlain by about 4 m of well-bedded sandy silt. **Hiatella arctica** from these deposits yield AIle/Ile values of 0.136 ± .014 (Table 9-1). The basal bed contains cobbles and boulders like those described for Colvillian deposits exposed in the Colville River bluffs. Bigbendian beds rest unconformably on Cretaceous and lower Tertiary strata, but in places are separated from them by a few centimetres of Colvillian deposits. The maximum altitude at which Bigbendian deposits have been identified is about 35 m.

Pollen spectra from Bigbendian beds indicate that nearby vegetation was probably coniferous forest dominated by spruce and with significant amounts of tree birch and minor pine and fir, somewhat similar to the modern Anchorage area (Nelson, 1981; Nelson and Carter, in press). A relatively mild climate is also suggested by the presence of sea otter remains (Repenning, 1983) and by the molluscan fauna. The mollusk fauna is richer than the Colvillian fauna and includes the gastropod **Littorina squalida,** whose modern northern limit is Bering Strait (L. Marincovich, Jr., personal communication, 1985). Modern sea otters cannot tolerate severe sea ice, and the presence of sea otter remains suggests that the Beaufort Sea may have been only seasonally frozen during the Bigbendian transgression.

Amino acid ratios indicate a correlation of Bigbendian deposits with Brigham's (1983) informally named Killi Creek beds of the Chukchi Sea coast and with deposits exposed on the Miluveach River east of the Colville River. Carter and Galloway (1982) proposed that the Bigbendian deposits correlate with Hopkins' Anvilian transgression, but Repenning (1983) referred them to Hopkins' second Beringian transgression. Both suggestions may be correct, inasmuch as D.M. Hopkins now believes that there was only one Beringian transgression, and that the marine deposits on St. George Island, which he proposed formed during a second Beringian transgression, were instead deposited during the Anvilian transgression. The marine deposits on St. George Island have a minimum age of 2.19 Ma. Repenning (1983) has suggested an age of between 1.7 and 2.2 Ma for the marine deposits near Ocean Point based on the stage of evolution exhibited by fossil sea otter remains. The paleontological evidence is not precise enough to preclude a greater age, however.

Fishcreekian

The Fishcreekian transgression is named for fossiliferous deposits south of Harrison Bay that are exposed along the north side of Fish Creek at the locality described by Carter et al. (1979). Amino acid ratios for marine mollusk shells from these deposits (Table 9-1) are statistically indistinguishable from those for shells from sandy beach deposits on the north flank of the Marsh anticline and from ratios for shells from the informally named Tuapaktushak beds (Brigham, 1983) on the Chukchi Sea coast. The Tuapaktushak beds unconformably overlie the Killi Creek beds which, as stated above, are correlated by amino acid ratios with the Bigbendian deposits at Ocean Point. Amino acid geochemistry and superpositional relationships thus indicate that the Fishcreekian transgression occurred after the Bigbendian transgression.

Deposits of the Fishcreekian transgression have yielded several species of extralimital mollusks, including **Natica janthostoma,** which today does not live north of the coast of Kamchatka, and **Littorina squalida,** which today does not occur north of Bering Strait (L. Marincovich, Jr., written communication, 1984). In spite of this evidence for warmth, the Tuapaktushak beds exhibit striated boulder pavements that D.M. Hopkins believes could have been produced by stranded icebergs.

The age of the Fishcreekian transgression is controversial. Brouwers et al. (1984) proposed that it occurred about 1.2 Ma ago, based on a very tenuous correlation with unfossiliferous marine deposits on the Pribilof Islands and a consideration of the possible long-term rates of the amino acid epimerization reaction, which was communicated to them by one of us (Brigham-Grette) and is described in Brigham (1985). Brigham (1985) assumed mean permafrost temperatures similar to those postulated for the past 125 ka (Brigham and Miller, 1983) and concluded that the Fishcreekian transgression most likely occurred between 1 and 1.5 Ma. However, Carter and Galloway (1985) have argued on the basis of faunal, palynological, and paleomagnetic data that the Fishcreekian transgression occurred between 1.5 and 2.48 Ma.

The Fishcreekian may correlate with the Anvilian transgression of western Alaska (Hopkins, 1967), but more likely is not correlative with any of the transgressions defined by Hopkins.

Wainwrightian

The Wainwrightian transgression is named for marine silty sand, sandy silt, and sandy clay exposed at Karmuk Point near Wainright. These deposits have been informally named the Karmuk beds by Brigham (1984). They disconformably overlie Fishcreekian beds and contain valves of **Hiatella arctica** which yield AIle/Ile values of .038 ± .007. A uranium-trend age of 540 ± 60 ka has been determined for Wainrightian sediments (J. Rosholt, written communication, 1984). Mollusk, foraminifera, and ostracode faunas from these sediments are similar to those of the modern Arctic shelf, and no extralimital taxa have been identified (Brigham, 1985).

Other deposits that may have formed during the Wainwrightian transgression are exposed at Cape Simpson, on both sides of Admiralty Bay, and along the south shore of Kogru River. The deposits at Cape Simpson are clayey silt and silty clay that have yielded a TL age of 209 ± 15 ka and are overlain by Pelukian and Simpsonian beds. Similar silty clay and clayey silt occurs beneath Pelukian deposits on the west side of Admiralty Bay. These pre-Pelukian sediments have not been examined in detail and amino acid analyses have not been performed to test a possible correlation with the Karmuk beds. The TL age is considerably younger than the uranium-series determination for the Karmuk beds and should be viewed with skepticism. The date agrees remarkably well with the age of the warmest peak of oxygen isotope stage 7a, however, suggesting the possibility that these pre-Pelukian sediments formed during the penultimate interglacial event.

Fine-grained marine sediments also occur beneath Pelukian deposits on the east side of Admiralty Bay and appear to be correlative with the fine-grained pre-Pelukian sediments directly across Admiralty Bay. The marine mud on the east side of the bay, however, contains erratic stones of Canadian provenance. Pre-Pelukian erratic-bearing mud also occurs at the base of bluffs along the south shore of Kogru River, and has been dated by TL as older than 158 ka. These glaciomarine deposits possibly represent a separate transgression. Less likely, they may be an offshore facies formed during the Fishcreekian transgression.

Pelukian

The Pelukian transgression was defined by Hopkins (1967) as occurring during the last interglacial interval and producing shoreline features and deposits a few metres above present sea level that can be traced discontinuously around the coast of western and northern Alaska. Beach deposits of last interglacial age on the Arctic Coastal Plain are exposed in bluffs along the north shore of Teshekpuk Lake and can be traced eastward to Harrison Bay and northwestward to near Barrow (Carter and Robinson, 1981), where they have been informally named the Walakpa beds (Brigham, 1983).

These deposits occur at altitudes that range from 1 m at their base to perhaps as much as 10 m at their top. At Teshekpuk Lake, they overlie marine mud and are disconformably overlain by lacustrine or deltaic deposits. Spruce driftwood is locally common in the deposits and the molluscan and ostracode faunas indicate more open water and warmer climatic conditions than presently prevail (Hopkins et al., 1981). Amino acid ratios determined for the bivalve **Hiatella arctica** are barely distinguishable from those determined for modern specimens (Brigham, 1983), and preclude an age greater than the last interglacial episode. Oxygen isotope analyses of the bivalve **Astarte borealis** show that their ^{18}O content is about the same as that of modern **A. borealis** shells (J.R. O'Neil, written communication, 1984), suggesting a correlation with oxygen isotope stage 5e. This correlation is supported by seven TL dates on the beach deposits and underlying muds that range from 108.5 to 140 ka and average 123.5 ka. The altitude of beach deposits formed during the Pelukian transgression is about the same as that estimated for the eustatic high-stand during isotope stage 5e based on evidence from oceanic islands and other continental shelves (Cronin et al., 1981), and suggests that this part of the western Arctic Coastal Plain has been tectonically stable for the past 125 ka.

Simpsonian

The Simpsonian transgression is defined as the transgression during which the Flaxman Member of the Gubik Formation was deposited. The Flaxman Member (Dinter, in press) consists of a few metres of erratic-bearing, glaciomarine silt, clayey silt, and silty sand, and occurs locally along the Beaufort Sea coast to altitudes of about 7 m. It is especially well exposed at Cape Simpson and at Simpson Cove. These deposits locally are overlain by regressive sand, beach, deltaic, or fluvial deposits. The erratic stones are of Canadian provenance (Rodeick, 1979) and rock types include dolomite, diabase, pyroxenite, granite, and quartzite (MacCarthy, 1958). Erratics occur to within a few hundred metres of the southern limit of the deposit, and so were being supplied at the peak of the transgression (Hopkins, 1982). Their transport to the Beaufort Sea coast by icebergs records the breakup of an ice sheet in the Canadian Arctic. Remains of Pacific marine mammals, including ribbon seal **(Histriophoca fasciata)** and gray whale **(Eschrichtius** sp.) (Repenning, 1983) indicate that a connection with the Bering Sea existed at this time. Mollusk faunas are depauperate and include no extralimital species (Hopkins et al., 1981). The Flaxman transgression was a brief event of a distinctly different character than the interglacial transgressions discussed above.

Eleven TL dates on sediment of the Flaxman Member range from 53 to 81 ka. Six of these are between 71 and 76 ka and uranium series date on whale bone from Flaxman deposits is 75 ka (J.L. Bischoff, written communication, 1984). Finite radiocarbon dates previously obtained for organic remains from Flaxman deposits (Carter, 1983b) are apparently erroneous, and the Flaxman transgression most probably occurred between 70 and 80 ka.

Because the western part of the Arctic Coastal Plain has been tectonically stable for at least the past 128 ka, the altitude of the Flaxman deposits cannot be attributed to tectonism. Furthermore, marine deposits exposed near sea level on the Atlantic Coastal Plain were deposited about 75 ka (Cronin et al., 1981; Cronin et al., 1984), suggesting that the Flaxman transgression was not a local event but represents a eustatic sea level higher than that of today. However, marine mollusk shells from Flaxman deposits are enriched in ^{18}O relative to modern specimens from the Beaufort Sea (J.R. O'Neill, written communication, 1984), indicating that more glacial ice was present during the Flaxman transgression than occurs today. Oxygen isotope data from deep sea cores for this time interval also indicate large volumes of glacial ice (Ruddiman and McIntyre, 1979).

Cronin et al. (1984) proposed that the paradox of high sea level 75 ka ago co-occurring with extensive glacial ice could be explained by large volumes of floating glacial ice in polar regions. The Flaxman Member does indeed document that floating glacial ice was present in the Arctic Ocean, but the discrepancy between the sea level and isotope records is so large that an extraordinary amount of floating glacial ice would be required to reconcile them.

A possible mechanism to provide an enormous amount of floating ice would be an ice-surge. Such a surge would cause a rapid rise in sea level (Wilson, 1964; Mercer, 1978; Hollin, 1982), and might lead to the catastrophic breakup of unstable marine-based ice over the central Canadian Shield (Denton and Hughes, 1983). Recent studies of amino acid geochemistry of fossil marine mollusk shells in the Hudson Bay region do indeed indicate that the Hudson Bay Lowlands were evacuated of Laurentide ice and inundated by marine waters about 75 ka (Andrews et al., 1983).

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10. GLACIATION OF THE BROOKS RANGE[1]

Thomas D. Hamilton[2]

Drift sheets and erratics within and adjacent to the Brooks Range form four major complexes that represent phases of glaciation separated by long-lasting intervals of weathering and erosion (Fig. 10-1). Each drift complex differs markedly from the others in the degree to which it has been modified by weathering, erosion, and mass wastage; each also exhibits a distinctive relation to the valley system from which it originated. Although each glacial phase probably consisted of multiple ice advances, these advances can be distinguished from each other only among the younger deposits.

Pre-Pleistocene (?) Glaciation

The oldest interval of glaciation is represented along the north flank of the Brooks Range by the informally named "Gunsight Mountain" erratics (Hamilton, 1979). These boulders of highly resistant rock types form a belt up to 25 km wide beyond the limits of recognizable drift sheets of Pleistocene age (Detterman et al., 1963). "Gunsight Mountain" erratics generally are found weathering out of alluvial gravel in which they were redeposited during a long-lasting interval of stream erosion and pedimentation when drainage courses north of the Brooks Range stood 50-100 m above modern stream levels. These erratics are restricted to piedmont zones and to uplifted plateaus along the mountain front, and cannot be traced to existing mountain valleys.

Erosion surfaces that formed following the "Gunsight Mountain" phase are related to extinct drainage systems north of the Brooks Range that were tributary to an ancient course of the Colville River. According to L.D. Carter (oral communication, 1982), the Colville River abandoned this course during or after a marine transgression that may be correlative with the Anvilian marine transgression, which took place sometime between 0.7 and 1.8 Ma ago (Hamilton and Hopkins, 1982). The extent of erratics north of the Brooks Range suggests that at least part of the precipitation that nourished the glaciers may have been derived from the north. Such a source would be consistent with the marine sedimentary record, which indicates that the Arctic Basin lacked a permanent sea-ice cover prior to about 0.7-0.9 Ma ago (Herman and Hopkins, 1980).

Early (?) Pleistocene Glaciation

The oldest recognizable drift sheet in the Brooks Range has been assigned to the Anaktuvuk River Glaciation (Detterman et al., 1958). This drift commonly overlaps erosion surfaces of post-"Gunsight Mountain" age.

Glaciers of Anaktuvuk River age flowed through mountain valleys at levels generally 100 m or more above their modern floors. Extensive moraines beyond the mountains are fairly continuous but subdued, with slope angles generally no greater than 1°-2°, mature drainage networks developed, and complex lake basins indicating repeated cycles of thaw-lake formation and drainage. Erratics generally are sparse ($<1/\text{km}^2$), large (1.5-2.0 m), and nearly completely buried. The drift sheets have been dissected by streams that flowed 40-65 m above modern levels and eroded valleys as wide as 10 km within the glacial deposits. Arcuate drainage courses separate subdued morainal ridges that could represent either individual ice advances or merely recession of a single glacier.

Middle Pleistocene Glaciation

A younger complex of drift sheets, assigned to the Sagavanirktok River Glaciation (Detterman et al., 1958; Hamilton, 1979), occurs on or close to modern valley floors. Its deposition followed a long interval of valley enlargement and pedimentation that took place after the Anaktuvuk River Glaciation.

Drift extends into valley centers, where it generally stands no more than 40 m above modern stream levels. Moraines retain much of their original morphology, and even the oldest deposits bear immature drainage networks. Deposits are deeply oxidized, subdued by mass wastage, and dissected by streams; they differ from older glacial deposits in their steeper (3°-6°) slope angles, greater abundance of surface erratics, and preservation of a few primary kettle depressions.

Two separate drift sheets of Middle Pleistocene age are present in some valley systems. These drift sheets provisionally are considered to be of early and late Sagavanirktok River age.

Late Pleistocene Glaciation

Glacial deposits of Late Pleistocene age occupy modern valley floors and generally are little eroded; they have stony surfaces that lack deep weathering. Deposits assignable to older and younger glacial advances within the complex are distinguishable from each other on the basis of soil development, solifluction cover, and sharpness of surface morphology.

Deposits of the older ice advance, termed the Itkillik Glaciation (Detterman et al., 1958), have been somewhat subdued by postglacial solifluction and patterned-ground formation. Better drained deposits are oxidized to depths of as much as 1 m. Moraine crests typically are 3-10 m wide, with flanking slopes up to 15°-20°. The Itkillik Glaciation formerly was assumed to be of Late Wisconsinan age (Porter, 1964; Hamilton and Porter, 1975), but subsequent studies have shown that this ice advance is older than 50 ka (Hamilton, 1979, 1982a). It probably took place during Early Wisconsinan time because some deposits remained ice cored until the Holocene and because glaciers evidently remained in at least some mountain valleys of the Brooks Range between the Itkillik and Walker Lake advances (Fig. 10-2).

The younger ice advance, termed the Walker Lake Glaciation (Fernald, 1964), has been dated at between 24 and 11.5 ka, with an early advance beginning perhaps 29 ka ago in some valleys (Fig. 10-3). Deposits of this age are morphologically fresh and still are ice cored in many places (Hamilton, 1982b). Moraine crests typically are narrow (1-3 m), and have flanking slopes as steep as 20°-25°. Solifluction cover is negligible.

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[1] Reprinted, with permission, from:

Hamilton, T.D. and Thorson, R.M. (editors)
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[2] Alaska Branch, United States Geological Survey, 4200 University Drive, Anchorage, Alaska, 99508, U.S.A.

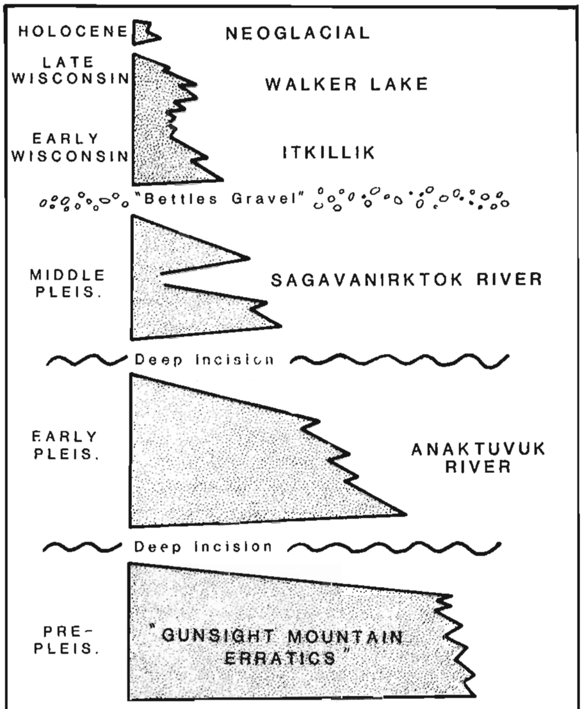

Fig. 1. LATE CENOZOIC RECORD, CENTRAL BROOKS RANGE

Figure 10-1. Time-distance diagram for late Cenozoic events and glacial deposits, central Brooks Range, Alaska.

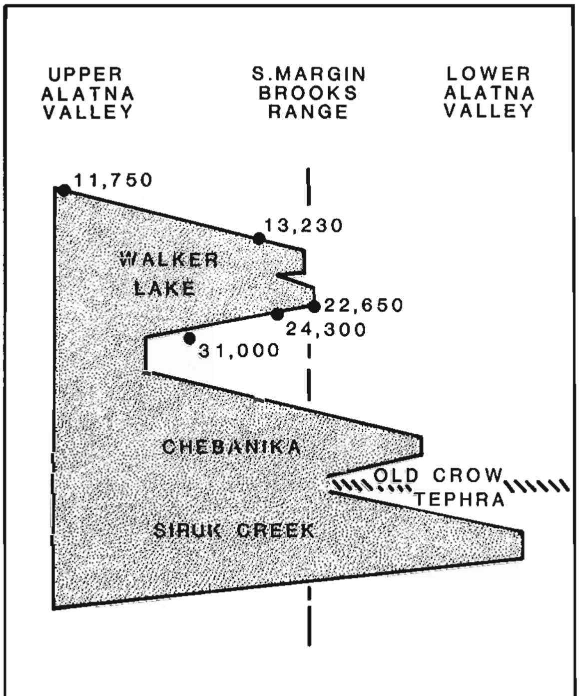

Fig. 2. ITKILLIK GLACIATION ALATNA VALLEY REGION

Figure 10-2. Time-distance diagram showing possibly relations between glacial advances at the head of Alatna Valley and at the south margin of the Brooks Range. Dates in radiocarbon years B.P. (from Hamilton and Brubaker, 1983).

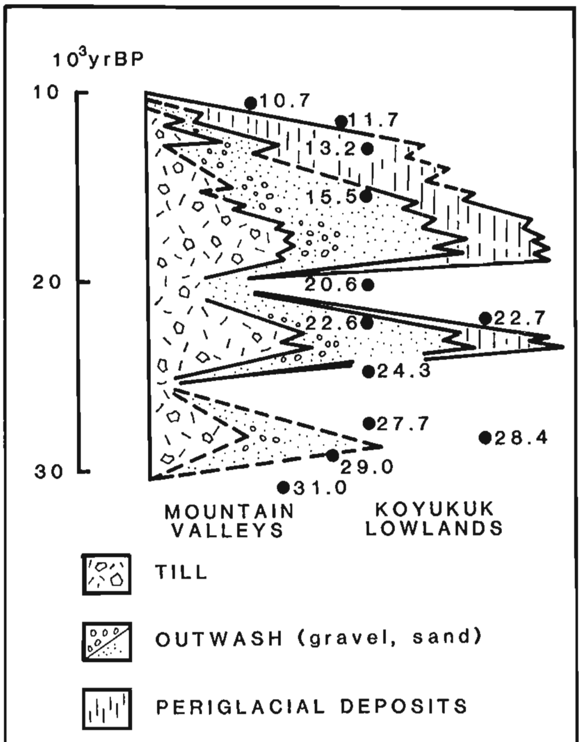

Fig. 3. GLACIAL AND PROGLACIAL DEPOSITS OF WALKER LAKE AGE

Figure 10-3. Time-distance diagram showing glacial and pro-glacial deposits of Walker Lake age in the south-central Brooks Range and adjoining Koyukuk basin. Radiocarbon dates (black dots) in thousands of years B.P. (from Hamilton, 1982a).

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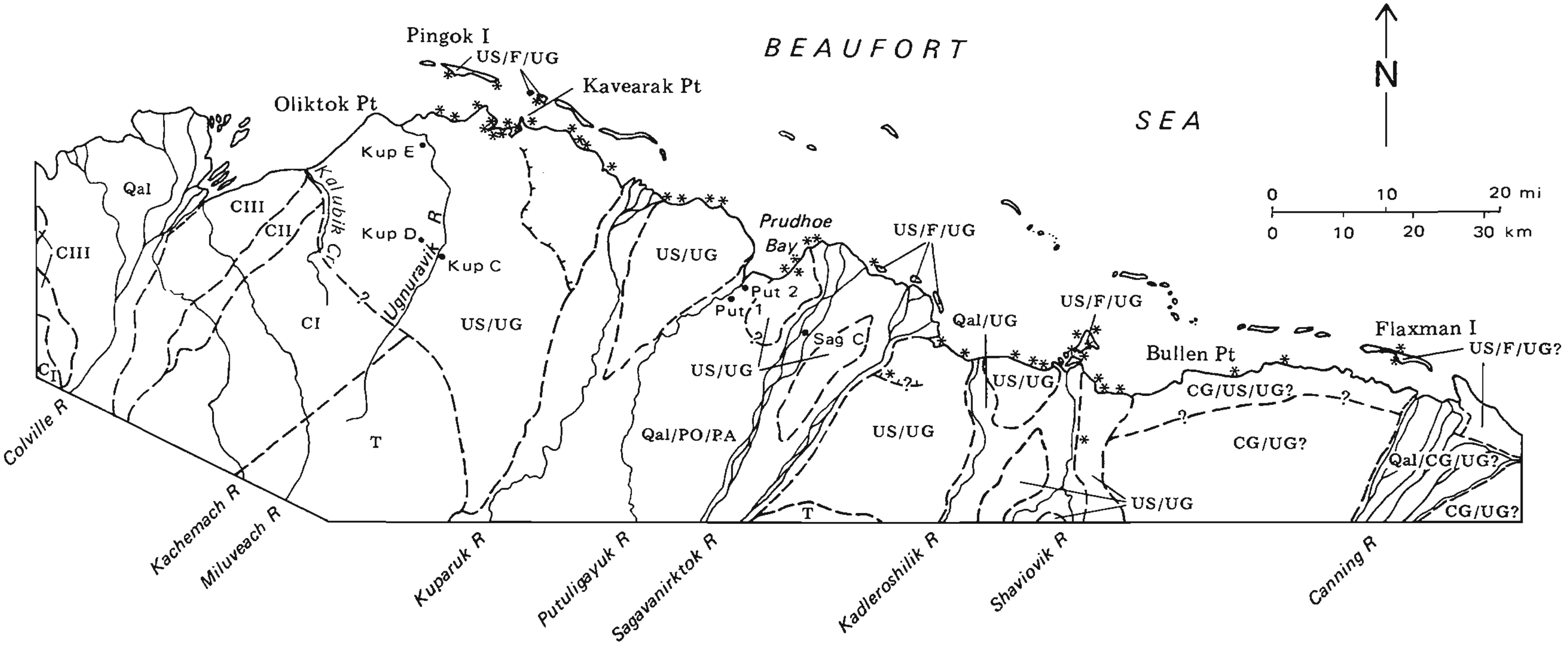

EXPLANATION

CI	Colville terrace I, late Pliocene-early Pleistocene
CII	Colville terrace II, middle Pleistocene
CIII	Colville terrace III, Sangamonian
US	Ugnuravik sand, middle-late Wisconsinan
UG	Ugnuravik gravel, Illinoian-Sangamonian
PO	Put outwash, late Wisconsinan
PA	Put alluvium, middle Wisconsinan
CG	Canning gravel, late Wisconsinan
F	Flaxman Fm., early Wisconsinan
T	Tertiary, undifferentiated
Qal	Flood-plain and terrace alluvium, undifferentiated
*	Known Flaxman lithology occurance
⊥⊥⊥	Possible Flaxman or older marine shoreline

Figure 11-1. Late Cenozoic deposits of the Arctic Coastal Plain between the Colville and Canning Rivers. Map units are separated by dashed lines. Stratigraphic units are shown in sequence downward, separated by a slash. Map-unit boundaries and stratigraphic units are queried where they are uncertain. Gravel pits are shown by a dot. Except where indicated, the Flaxman shoreline is not shown on the mainland because of its uncertainty.

11. LATE CENOZOIC GEOLOGY OF THE ARCTIC COASTAL PLAIN BETWEEN THE COLVILLE AND CANNING RIVERS

Stuart E. Rawlinson[1]

The Arctic Coastal Plain between the Colville and Canning rivers represents about one-third of the Alaskan Beaufort Sea coast. The coastal plain here consists chiefly of unconsolidated late Cenozoic fluvial, glaciofluvial, eolian, and lacustrine sediments. Marine sediments partially compose two terraces east of the Colville River and some coastal bluffs. Glacial deposits extend to about 30 km of the coast along the Canning River and may also overlie Tertiary deposits adjacent to the Colville River terraces.

Carter and Galloway (1982) described three terraces east of the Colville River and delta; the youngest and oldest of these terraces have counterparts west of the river and delta (Fig. 11-1). The youngest terrace, Terrace III, consists of sand, gravelly sand, and sandy gravel that are probably alluvium. **Alnus**, **Populus**, and **Picea** wood in this alluvium suggests deposition during an interglacial or warm interstadial. This wood has been dated at >48 ka; Carter and Galloway proposed that Terrace III most likely formed during the Sangamonian interglacial. Although the eastern terrace boundary can be followed northeastward with certainty only to about 5 km of Kalubik Creek, it probably continued to near the mouth of this creek. The next older terrace, Terrace II, occurs only east of the Colville River. Carter and Galloway (1982) traced the eastern boundary of this terrace northeastward almost to Kalubik Creek. Terrace II southwest of the Miluveach River consists of fluvial pebbly sand, gravelly sand, and sandy gravel. These deposits exposed along the Kachemak and Miluveach Rivers contain abundant marine mollusk fragments. Because the terrace has a nearly constant elevation northeast of the Miluveach River, Carter and Galloway (1982) presumed that the terrace here was formed during a single marine transgression, possibly the middle Pleistocene Kotzebuan transgression of Hopkins (1967).

The oldest and most extensive terrace, Terrace I, occurs on both sides of the Colville River. East of the Colville River, Terrace I abuts an upland composed of unconsolidated Tertiary till (Kuparuk gravel of Carter), fluvial sediments, and coal. Terrace I consists of nonmarine pebbly sand, sandy gravel, silt, and interbedded sand, gravelly sand, and silt overlying fossiliferous marine gravelly sand, sand, and silt. The marine deposits represent Carter's Colvillian I and II transgressions, which are currently thought to correspond to either the first and second episodes of Hopkins' (1967) Pliocene and early Pleistocene Beringian transgression or to one episode of the Beringian transgression (presumably the latest) and the early Pleistocene Anvilian transgression (Hopkins, personal communication, 1984).

The boundary between Terrace I and the Tertiary upland is straight and trends about 50 degrees. At the Miluveach River, the boundary is about 32 km southeast of the main Colville River channel. The boundary is easily recognizable along the Tertiary upland but is not recognizable northeast of the contact of the upland with younger coastal-plain sediments (a point about 30 km south of the Beaufort Sea coast).

Deep exposure of the coastal-plain lowland between the Colville River and a well-defined alluvial terrace scarp 2 to 5 km west of the Kuparuk River is visible only in four gravel pits. Three of these pits have been studied and are designated Kup C, D, and E (Fig. 11-1). Kup C pit is along the Ugnuravik River about 21 km from the coast; the coastal-plain surface here is 18.3 m above mean sea level. The pit exposes sediments to a depth of 16 m: from top to bottom, 0.5 m lacustrine peat and silt, 1.6 m eolian pebbly sand, 3.4 m fluvial or glaciofluvial interbedded pebbly sand and sandy gravel, and 10.5 m fluvial or glaciofluvial ice-rich sandy gravel. The latter two units are oxidized. A sand wedge is present at the top of the interbedded pebbly sand and sandy-gravel unit, and the sandy-gravel unit contains thin ice wedges, ice-wedge pseudomorphs, detrital wood, some of which is **Larix** (unidentified wood 8.6 m below the surface has been dated at >38.4 ka), and thin discontinuous fine-sand and silty-sand beds. These thin beds contain abundant detrital wood and mark changes of mode and maximum grain sizes in overlying and underlying sediments. One such bed 12.8 m below the surface fills cut-and-fill structures and has been determined by thermoluminescence to be 150.2 ± 11 ka old.

Kup D pit is about 3 km northwest of Kup C pit; the coastal-plain surface here is 15.2 m above mean sea level. The pit reportedly reached a maximum depth of 19 m (3.8 m below mean sea level). There are unsubstantiated reports of oil-field workers collecting shells from the bottom of the pit. At the time the stratigraphy was described, flooding of the pit had begun and only the top 11.5 m were exposed: from top to bottom, 0.6 m lacustrine peat and silt, 1.5 m eolian pebbly sand, 2.9 m fluvial or glaciofluvial interbedded pebbly sand, gravelly sand, and sandy gravel (top may be eolian), and 6.5 m fluvial or glaciofluvial interbedded sandy gravel and gravel. As in Kup C pit, the latter two units are oxidized and the interbedded sandy-gravel and gravel unit contains detrital wood, some of which is **Larix**. A peat- and sand-filled ice-wedge pseudomorph extends from the base of the lacustrine sediments into the underlying eolian sand near the top of the section.

Kup E pit is two adjacent pits along the Ugnuravik River about 5 km from the coast; the coastal-plain surface at the eastern pit is 5.8 m above mean sea level. The pit exposes: from top to bottom, 0.5 m lacustrine peat, 1.4 m eolian pebbly silty sand, 0.5 eolian sand, 0.4 fluvial pebbly sandy silt, 2.3 m covered, 3.0 m fluvial or glaciofluvial interbedded pebbly sand and sandy gravel, and 6.0 m fluvial or glaciofluvial interbedded sandy gravel and gravel. Similar to Kup C and D pits, the interbedded pebbly sand and sandy-gravel unit is oxidized. Sand-filled ice-wedge pseudomorphs are present near the center of the interbedded pebbly sand and sandy-gravel unit. The underlying interbedded sandy-gravel and gravel unit contains sand wedges, detrital wood, and a thin silty-sand bed that fills cut-and-fill structures and an ice-wedge pseudomorph, and contains abundant wood, some of which is **Salix** and **Larix**. This bed has been determined by thermoluminescence to be 221.4 ± 17 ka. Gravel below the silty-sand bed in Kup E pit is oxidized to a depth of about 1 m.

Eolian and fluvial or glaciofluvial deposits exposed in Kup C, D, and E pits are very similar in terms of unit thicknesses and boundaries, oxidation, composition, and sedimentary texture and structures including cut and fill, ice wedges, ice-wedge pseudomorphs, and sand wedges. Disparate ages of fine- and silty-sand beds within the basal one-third of the Kup C and E pits suggest a northward-thinning fluvial or glaciofluvial bajada.

Eolian deposits overlying fluvial or glaciofluvial deposits in Kup C, D, and E pits are herein termed the Ugnuravik sand. This designation is applicable to widespread eolian deposits on the coastal plain between the Colville River and the westernmost terrace scarp of the Kuparuk River, between the Sagavanirktok and Shaviovik rivers, and along the coast between the Shaviovik and Canning rivers.

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[1] Division of Geological and Geophysical Surveys, State of Alaska, 794 University Avenue (Basement), Fairbanks, Alaska, 93701, U.S.A.

The sand was derived from extensive flood plains of these rivers and deposited during the middle and late Wisconsinan, and perhaps the early Holocene. A maximum age of 36.8 ± 4 ka (determined by thermoluminescence) for the Ugnuravik sand is provided by a fluvial silt bed exposed 5.7 m below the surface in a section about 10 km inland along the eastern bank of the Sagavanirktok River main channel. The silt bed underlies the Ugnuravik sand and overlies regressive-marine deposits of the Flaxman or an earlier transgression. A near-minimum age of 11.9 ± 1.8 ka (determined by thermoluminescence) for the Ugnuravik sand is provided by a fluvial silt bed exposed 2.4 m below the surface in Kup E pit and by radiocarbon dates of basal peats on the coastal plain that range between 8 and 12 ka (Schell and Ziemann, 1983). The silt bed in Kup E pit is overlain by 1.9 m of the Ugnuravik sand and it is probable that the Ugnuravik sand also underlies this bed; except for 0.2 m of sand exposed below the silt bed, the section is covered to 5.1 m below the surface.

Fluvial or glaciofluvial deposits exposed in the Kup C, D, and E pits are herein termed the Ugnuravik gravel. This designation is applicable to widespread fluvial or glaciofluvial deposits on the coastal plain between the Colville River and the westernmost terrace scarp of the Kuparuk River and between the Sagavanirktok and Shaviovik Rivers. The gravel likely underlies younger glacio-fluvial deposits (discussed later) between the Shaviovik and Canning rivers. Its presence is queried in Figure 11-1. Thermoluminescence dates of 150.2 ± 11 and 221.4 ± 17 ka of sediments deep in Kup C and E pits indicate that the Ugnuravik gravel is Illinoian. Oxidation and inclusion of ice wedges, sand-filled ice-wedge pseudomorphs, and **Larix** wood suggest, however, deposition during an interglaciation with periodic freezing and thawing, most likely the Sangamonian. It is likely that deposition of the Ugnuravik gravel spanned both the Illinoian and Sangamonian.

Spatial and stratigraphic relationships of the Ugnuravik gravel with the Colville River terraces are unclear. Assuming that age assignments for the Ugnuravik gravel (Illinoian-Sangamonian) and Colville River Terrace I (Pliocene and early Pleistocene) and Terrace II (middle Pleistocene) are correct, marine deposits associated with these terraces either (1) were never deposited on the coastal plain where the gravel is now present, (2) underlie the gravel, or (3) were removed by fluvial processes and replaced by the gravel. Because the eastern boundary of Terrace II can be traced almost to Kalubik Creek, even where it crosses Terrace I, the latter alternative is most probable, although the unsubstantiated reports of shells in the bottom of Kup D pit warrant consideration. The Ugnuravik sand is exposed in 2- to 4-m high bluffs along Kalubik Creek and presumably overlies the northeastern edges of Terraces I, II, and perhaps III, but the full extent of the sand is not known.

Except for isolated areas near the coast that consist of Ugnuravik sand and gravel and marine deposits of the Flaxman transgression, the coastal plain between the western boundary of the alluvial terrace west of the Kuparuk River and the eastern bank of the Sagavanirktok River main channel is chiefly alluvium and outwash. The drainage history of this area is complex and is still being interpreted. It is clear that a major part of the Sagavanirktok River and perhaps the Kuparuk River once drained through the present Putuligayuk River drainage basin. Deep exposure of the coastal plain in this area is visible in two gravel pits along the Putuligayuk River and one pit on the Sagavanirktok River; another pit on the Putuligayuk River has since been converted to a landfill. The two accessible pits on the Putuligayuk River from south to north are designated Put 1 and Put 2, and the pit on the Sagavanirktok River is designated Sag C (Fig. 11-1).

Put 1 pit is 5.2 km up the Putuligayuk River from Prudhoe Bay; here the coastal-plain surface is 6.1 m above mean sea level. The pit exposes sediments to a depth of 14 m: 0.7 m peat and fluvial sandy silt overlying 13.3 m of fluvial and glaciofluvial interbedded pebbly sand, sandy gravel, and gravel; sandy gravel is dominant. Hopkins et al. (1981) reported more than 4 m of "Sagavanirktok River" alluvium below 0.9 m of bedded oxbow sediments in this pit. Detrital peat 0.9 m below the top of this alluvium (1.8 m below the surface) has been 5.420 ± .11 ka. Sandy-silt beds are present 7.5 and 10.5 m below the surface. These beds contain peat and detrital wood and likely correspond to organic horizons in the landfill pit that yielded ^{14}C dates of 26.3 ± .37 ka (Hopkins and Robinson, 1979) and 35.6 ± .55 ka (Hopkins et al., 1981). The lower sandy-silt bed overlies and often fills cut-and-fill structures; **Salix** wood within this bed has been dated at $37 \pm {}^{10}_{4.3}$ km years old. Sandy gravel below the bed is oxidized and coarser grained than sandy gravel higher in the section. Detrital wood also occurs in lenses of pebbly sand in the bottom half of the section.

Put 2 pit is 2.3 km northeast of Put 1 pit; here the coastal-plain surface is 3.0 m above mean sea level. The pit exposes sediments to a depth of 12 m: 0.5 m peat and fluvial sandy silt overlying 11.5 m fluvial and glaciofluvial interbedded pebbly sand, sandy gravel, and gravel; sandy gravel is dominant. A thin pebbly sand bed with abundant detrital wood overlies and infills cut-and-fill structures and ice-wedge pseudomorphs 8.3 m below the surface. This bed likely corresponds to the bottom sandy-silt bed in Put 1 pit because they differ only slightly in depth below sea level (4.2 m in Put 1 and 5.1 m in Put 2), and gravel below this bed is oxidized as in Put 1 pit. A counterpart to the upper sandy-silt bed in Put 1 pit was not observed in Put 2 pit and thin sand lenses with small detrital wood and peat are present in the middle one-third of the section. Detrital peat collected 6.6 m below the surface has been dated at 4.075 ± .115 ka old, indicating that at least half of the section consists of Holocene alluvium. Pebbly sand deposits that apparently had been dug from deep in the pit (below a lake presently in the bottom of the pit) and placed along side the lake showed salt efflorescence, the significance of which is unknown. Also a single cobble of pink quartzite similar to that common in Flaxman deposits and older marine deposits at Skull Cliff near Barrow was found at the bottom of the pit. Connotations of this cobble are unknown.

Deposits exposed in the Putuligayuk River pits are undoubtedly equivalent. The approximate bottom one-half of Put 1 pit is alluvium deposited primarily during the middle Wisconsinan nonglacial Boutellier interval and into the glacial Duvanny Yar interval of Hopkins (1982). This alluvium is overlain by outwash derived from the late Wisconsinan Walker Lake glaciation in the Brooks Range and by Holocene alluvium. The approximate bottom one-third of the Put 2 pit is alluvium deposited primarily during the Boutellier interval; little or no outwash overlies this alluvium. The older alluvium exposed in Put 1 and 2 pits, and in the landfill pit, is termed the Put alluvium. The overlying outwash exposed in Put 1 pit and the landfill pit is termed the Put outwash. Collectively, the older alluvium and the outwash are herein termed the Put gravel.

The Sag C pit is within the active flood plain of the Sagavanirktok River 11.2 km southeast of Put 1 pit and about the same distance up the river from the coast; the flood-plain surface at Sag C pit is 3.4 m above mean sea level. The pit exposes sediments to a depth of 16 m: from top to bottom, 5.1 m fluvial sandy gravel, 3.5 m fluvial or glaciofluvial sandy gravel, and 7.4 m fluvial sandy gravel with large lenses of pebbly sand. A pebbly sand bed with peat and some detrital wood is discontinuously present 5.1 m below the surface. Wood within this bed has been dated at 4.640 ± .09 ka old.

Deposits below this bed are oxidized and probably not part of the Holocene alluvium. There are no obvious counterparts in Sag C pit to the organic-rich sandy-silt beds in Put 1 pit. In the Sag C pit, beginning at the approximate corresponding depth below sea level of the bottom organic-rich bed in Put 1 pit, large (up to 1 m thick) wood-rich pebbly sand lenses in sandy gravel are present to the bottom of the pit. Wood present near the top of this unit 8.7 m below the surface (5.3 m below sea level) has been dated at >38.4 ka old. A wood-rich, pebbly sand bed is present 12.5 m below the flood-plain surface (9 m below mean sea level) in Sag C pit. This bed overlies and fills cut-and-fill structures and an ice-wedge pseudomorph. It also shows salt efflorescence like that observed in Put 2 pit. It is possible that the pebbly sand with salt efflorescence in Put 2 pit is equivalent to this pebbly sand.

Several key similarities between the Put 1 and 2 pits and the Sag C pit suggest that deposits in these pits are equivalent. The Put alluvium likely corresponds to the oxidized pebbly sand and sandy gravel in the bottom two-thirds of the Sag C pit. It is likely that the Put outwash is not present. Sandy gravel in the top one-third of the Sag C pit is Holocene alluvium.

The coastal plain between the Sagavanirktok and Shaviovik rivers is much like the coastal plain west of the westernmost Kuparuk River terrace. Deposits exposed along the east side of the Sagavanirktok River are representative of deposits elsewhere in this area which, except for near-coast Flaxman and perhaps older marine deposits and Holocene flood-plain and terrace deposits (undifferentiated), consist of Ugnuravik sand and gravel (Fig. 11-1). The Ugnuravik sand here was derived from flood plains and terraces of the Kadleroshilik, Shaviovik, and Canning rivers. The drainage chronology of flood plains and alluvial terraces associated with rivers that presently cross this area is being interpreted. The Ugnuravik sand is present in almost all exposures. The Ugnuravik gravel becomes increasingly exposed the farther the distance inland from the coast. A measured section about 21 km inland on the Sagavanirktok River exposes: from top to bottom, 0.9 m lacustrine peat and silt, up to 1.6 m eolian fine and medium pebbly sand, and 2.0 m fluvial gravelly sand.

The coastal plain between the Shaviovik and Canning rivers consists chiefly of Ugnuravik gravel (?) overlain by a large fan of glaciofluvial deposits. A measured section about 13 km south of Bullen Point, on the western flank of the fan, showed about 0.5 m eolian pebbly silty sand overlying about 1 m of glaciofluvial sandy gravel. The modal diameter of pebbles in the sandy gravel is about 5 cm and the diameter of the largest cobble observed was 20 cm. The gravel of the fan is not oxidized and has a coating of carbonate near the top of the section. Marine Flaxman deposits and overlying Ugnuravik sand along the coast are cut by glaciofluvial deposits of the fan, which restricts their age to post-Flaxman; the fan deposits are most likely late Wisconsinan. Thin eolian deposits overlying the fan deposits are also late Wisconsinan or Holocene, being derived from flood plains of the Canning River and other rivers to the east. Glaciofluvial deposits of this fan are herein termed the Canning gravel. Glacial deposits of the early Pleistocene Anaktuvuk River glaciation and subsequent Brooks Range glaciations are present south of the Canning gravel.

Coastal bluffs between the Colville and Canning rivers are rarely higher than about 3 m, and most are commonly 1 to 2 m high. Often all that is exposed are Holocene eolian, organic, and lacustrine deposits. Deposits of the early Wisconsinan Flaxman transgression also crop out near sea level along the coast and on tundra-covered nearshore islands (Fig. 11-1). The inland extent of the Flaxman transgression in this area is unclear, but it may correspond in part to a 3 to 15 km wide zone of relatively flat terrain along the coast. It is difficult to draw a precise boundary between this zone and more elevated and rolling terrain farther inland because there is no distinct break in topography except in a few areas. Older coastal plain deposits within the area of the Putuligayuk gravel and Holocene alluvium (between the Kuparuk and Sagavanirktok rivers) have low topographic expression. A distinct break in topography can be traced about 20 km from the westernmost alluvial terrace scarp of the Kuparuk River northwestward toward Kavearak Point. Another break in topography 10 km inland along the eastern bank of the Sagavanirktok River main channel can be traced a short distance eastward; Flaxman lithologies are present immediately north of this break in topography. Also, a boulder of Flaxman lithology is present in the Shaviovik River about 9 km inland from the coast. These inland occurrences of Flaxman lithologies may actually be deposits of a marine transgression older than Flaxman.

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12. WISCONSIN AGE PALEOCLIMATES OF ALASKA – A ONE HUNDRED THOUSAND YEAR RECORD FROM SOUTH-CENTRAL BROOKS RANGE

C.E. Schweger[1]

(Presented at Workshop but contribution unavailable for publication)

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[1] Department of Anthropology, University of Alberta, Edmonton, Alberta, Canada, T6G 2E3

13. SYNTHESIS OF ENVIRONMENTAL HISTORY AND STRATIGRAPHY OF THE NORTHERN YUKON

J.V. Matthews, Jr.[1]

(Presented at Workshop but contribution unavailable for publication)

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[1] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E9

14. AMINO ACID DATING – BEAUFORT LITTORAL AREA

N.W. Rutter[1]

Amino acid analysis of marine and freshwater shells, bone and wood have been made on samples collected at various localities along the Arctic Coastal Plain of northern Alaska; the Yukon Coastal Plain; Old Crow-Bluefish Basins, Yukon; Banks Island, NWT; and Epigurik Bluff, Alaska. Most of the shells have been analysed at the University of Colorado laboratory whereas investigations of wood and shells have been carried out at the University of Alberta. The following discussion focuses mainly on wood because of the great number of wood samples that have been analysed from various stratigraphic positions and sections.

Wood

The D/L ratios of over 400 wood samples have been determined to evaluate the usefulness of wood as an aid in correlating equivalent units, determine relative ages, estimate absolute ages of units, and to determine variations in D/L ratios of similar age but from different geographical areas subjected to varying climatic histories. The total amounts of amino acid were determined using a gas chromatograph equipped with a chirasil-val capillary column. Although aspartic acid has proved the most useful, leucine and glutamic acids have shown promise. Computer analysis and graphics have been utilized to analyse trends.

The following overall conclusions can be drawn on Wood data analysed so far from the Beaufort Littoral area.

1. Aspartic and glutamic acid D/L ratios are the most useful.
2. Correlation and relative age dating of Pleistocene deposits can be made within certain geographical-climatic regions whereas comparing with other regions is questionable.
3. Comparing results to the generic level does not appear to improve results.
4. There appears to be no trend of higher or lower ratios of wood of the same age when compared region by region that have experienced different climatic (temperature) histories.
5. D/L ratios of aspartic acid (total) in modern samples in all regions vary usually from .02 to .04. The racemization of modern samples is attributed to heating during analytical procedures.
6. In all regions, D/L ratios of aspartic acid (total) in Holocene samples vary between .01 and .08, with most averaging about .07.
7. With a few exceptions, Late Wisconsinan-Mid Wisconsinan age samples can be separated from those of Early Wisconsinan-Sangamon age.
8. The greatest problems lie with older samples where accurate results are difficult to obtain. Results are commonly erratic and ratios lower than expected. The explanation for this is elusive but probably centers on diagenetic changes since burial involving such things as mineralization, selective leaching of acids, bacterial attack and racemization rate variations.

Banks Island

Vincent (1983) has been successful in correlating various units utilizing wood and shells from Banks Island. D/L ratios of aspartic acid (total) of wood vary between 0.22 and 0.35 in the Morgan Bluffs Interglacial sediments, 0.12 to 0.22 in the younger Cape Collinson Interglacial sediments, and 0.08 in post-glacial sediments. D/L ratios vary according to location. The ratio of the older sediments, as low as 0.08 are less than what they should be for a projected age of Late Tertiary. Although there is little data, subdividing wood to the generic level may improve accuracy.

Yukon Coastal Plain

Over 45 wood samples collected by V. Rampton from various localities along the Yukon Coastal Plain have been analysed. Interpretation is not complete, but first indications are that D/L ratios of aspartic acid of samples analysed from the same unit or sections are consistent and increase with increasing age. Overall, ratios appear to be low, not unlike what is found along the Arctic Coastal Plain of northern Alaska. Samples compared between units of the same age at widely spaced sections do not appear to be consistent or comparable.

Old Crow-Bluefish Basins

By far the greatest number of wood samples analysed are from the Old Crow-Bluefish basins. There is an abundance of wood in a variety of stratigraphic positions. Four age intervals have been separated by D/L ratios of aspartic acid (total). Modern samples vary from 0.02 to 0.04, Holocene samples from 0.01 to 0.08, Late to Mid-Wisconsinan 0.14 to 0.24, Early Wisconsinan to Sangamon 0.24 to 0.36. Older samples pose a problem. However, ratios of 0.50 have been obtained from a few (Early Quaternary-Late Tertiary). D/L ratios of leucine and glutamic acid offer promise. A minimum of five individual wood samples from each stratigraphic horizon is usually necessary for accurate interpretation. When averages of the D/L ratios of aspartic acid are calculated for various intervals and plotted against time, Late Wisconsinan sediments can usually be separated from Middle Wisconsinan sediments and Early Wisconsinan sediments from Sangamon sediments.

Arctic Coastal Plain of northern Alaska

Very little data are available from wood found along the Alaska coast. D/L ratios of aspartic acid (total) of spruce for relative age dating are encouraging, however. One post-glacial ratio obtained is 0.05, Pelukian ratios vary between 0.13 and 0.16, and Mid Pleistocene from 0.18 to 0.29. These ratios are lower than equivalent aged ratios from other areas but are consistent (with some variations) from within the same region. In addition, although little data are available, glutamic acid and leucine give consistent results.

Epigurik Bluff, Alaska

D/L ratios of aspartic acid of several ^{14}C dated samples of **Salix** consistently increase with increasing age. Ratios (total) vary from 0.09 for 4 ka old samples to 0.17 for 24 ka old samples. Ratios of older samples have not been consistent. Preliminary results, however, indicate that when samples are separated according to similar diagenetic histories there is a consistent trend.

Marine Shells

Marine molluscs are the most successful materials utilized in amino acid dating techniques. **Hiatella arctica** has been widely used with consistent results from many parts of

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[1] Department of Geology, University of Alberta, Edmonton, Alberta, Canada, T6G 2E3

the north, especially the eastern Arctic. Results are limited for the Beaufort Littoral zone and those that have been obtained are mostly from Julie Brigham of the University of Colorado.

Banks Island

D-alloisoleucine and L-isoleucine ratios of **Hiatella arctica** have been used widely on Banks Island to separate deposits of the Amundsen Glaciation from those of the older Thomson Glaciation (Vincent, 1983). Free ratios of 0.42 to 0.51 and total ratios of 0.04 to 0.09 have been obtained for the former, whereas free ratios of 0.44 to 0.73 and total ratios of .12 to .21 have been obtained for the latter.

Arctic Coastal Plain of northern Alaska

Smith and Brigham (1982) have done extensive work with marine shells in this area. Using **Eliphidium clavatum** or **E. orbiculare**, results so far show: (1) D-alloisoleucine/L-isoleucine ratios (total hydrolysate fraction) consistently in the range 0.072-0.078 for Sangamon (Pelukian) samples; (2) ratios of 0.053 ± for the early Wisconsinan-late Sangamon samples, and (3) ratios of 0.096 and 0.140 to 0.158 for three of the deepest samples. In addition, Brigham (1982) has been able to recognize five major depositional sequences of contrasting age in the Gubik Formation by detailed stratigraphic study and extent of amino-acid diagenesis of several mollusc species.

Fresh Water Shells and Bones

Fresh water molluscs such as **Valvata** and **Pisidium** have been analysed from sections in the Old Crow Basin. Although data are limited because of the paucity of samples, they offer promise. At the generic level they can be used to correlate units within the Old Crow Basin provided units are of widely varying age. Vertebrate fossils from the Old Crow Basin have also been analysed. The fragmented nature of a variety of bones from many species has resulted in little consistency from unit to unit of the same age or from the same unit.

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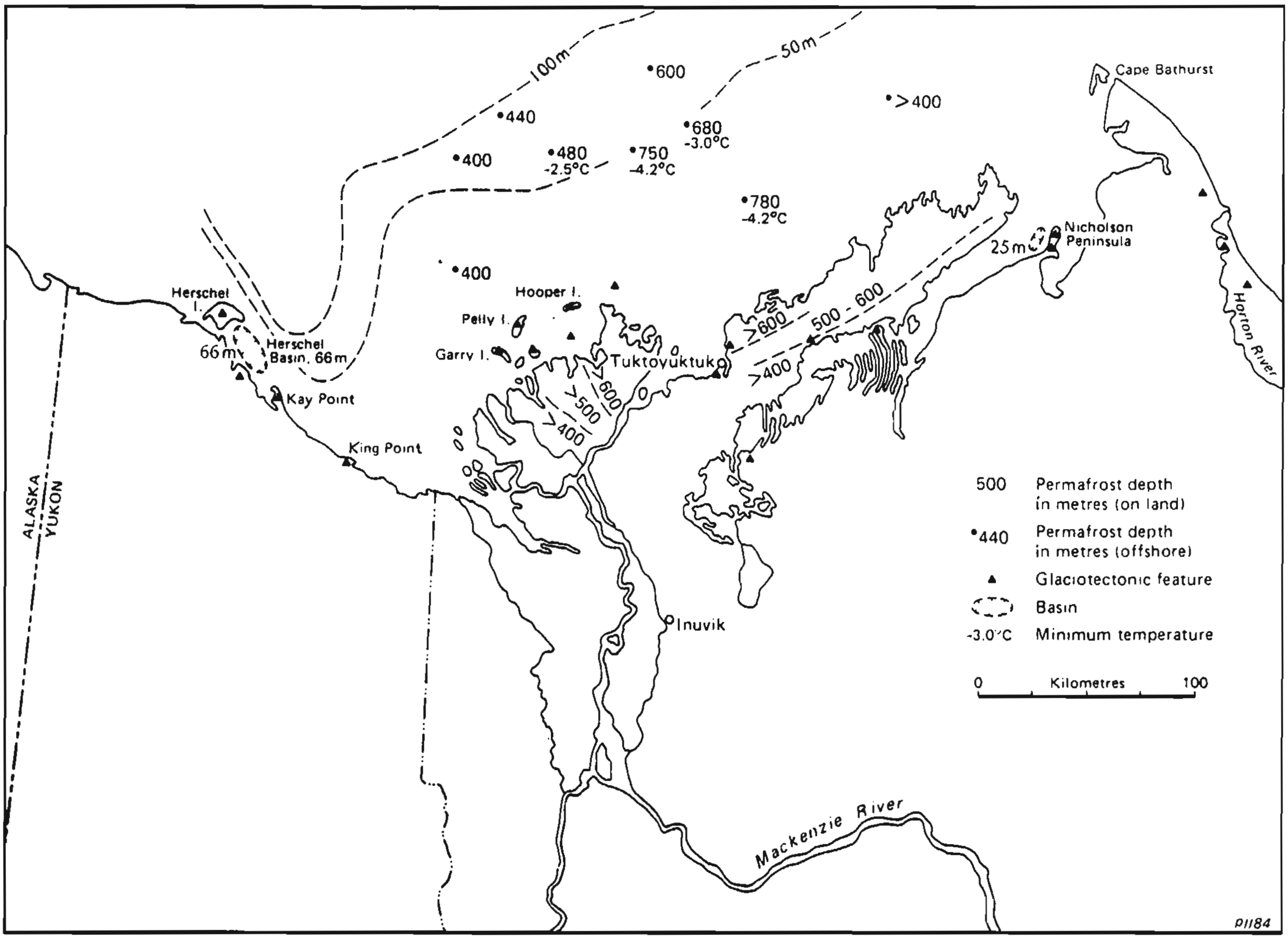

Figure 15-1. Permafrost conditions of the Beaufort Sea Continental Shelf and adjacent Arctic Coastal Plain, Canada.

15. THE PERMAFROST RECORD AND QUATERNARY HISTORY OF NORTHWESTERN CANADA

J.R. Mackay[1]

Onshore Permafrost

Sangamon and earlier

Pre-Wisconsinan interglacial and glacial deposits have been identified in many areas of Northwestern Canada, but the direct evidence for pre-Wisconsinan permafrost, as given by ice-wedge pseudomorphs and other permafrost related features, is limited. For example, an ice-wedge pseudomorph, overlain by sediments preserving a record of three major glacial periods, has been reported for southeastern Yukon (Klassen, 1978). In central Yukon, sand wedges, presumably indicative of permafrost conditions, developed beyond the limit of the Reid (Early Wisconsinan or Illinoian) Glaciation (Foscolos et al., 1977). Ice-wedge pseudomorphs along the Yukon Coast that underlie Buckland (Early Wisconsinan) till are considered to be Sangamon or of early Wisconsinan age (Rampton, 1982).

Early Wisconsinan

Most of the Yukon Coastal Plain was glaciated by the Buckland Glaciation, presumably of Early Wisconsinan age (Rampton, 1982). Glaciotectonic structures formed by the over-riding of ice extend 400 km along the Beaufort Sea coast (Fig. 1) (Mackay, 1956, 1959; Mackay et al., 1972). Because the deformed sediments are locally ice-rich, permafrost growth predated the ice advance that deformed the sediments, and permafrost has been present continuously since then. Permafrost prior to deformation was probably at least 100 m thick at Herschel Island in the west. At Nicholson Peninsula in the east, the deformation extended to a depth of some "hundreds of feet below sea level" (industry data) but there is no proof that there was permafrost to that depth. East of Nicholson Peninsula, westward moving ice from Amundsen Gulf may have been the cause of the extensive Early Wisconsinan (?) or earlier deformation of bedrock in the Cape Bathurst area.

Early to Mid-Wisconsinan

Eskers, kames, and outwash presumably deposited during the retreat of the Buckland (Early Wisconsinan) Glaciation lie beyond the Late Wisconsinan limit in the western part of the Tuktoyaktuk Peninsula area. Extensive drilling by industry has shown that abundant clean, white, bubbly ice as much as 17 m thick lies beneath the sands and gravels and above the underlying pre-glacial sediments. Unfortunately no study has yet been made of the ice, but since permafrost has been preserved continuously from at least the Early Wisconsinan, the ice might be buried glacier ice.

Unglaciated estuarine terraces 12 to 14 m above sea level dated at >40 000 years rest unconformably on glacially deformed sediments at Garry Island. This suggests a relatively higher sea level in Middle Wisconsinan or earlier (Forbes, 1980; Mackay and Matthews, Jr., 1983).

Undeformed horizontal sheets of nearly pure ice as much as 40 m in thickness are widespread along the Beaufort Sea coast (Mackay, 1971). The massive ice probably postdates the Buckland Glaciation, for otherwise the ice would likely have been deformed. Although some of the ice could be buried glacier ice, the evidence favors a segregational or locally a segregational-injectional origin because: 1) the ice fabrics suggest segregated ice; 2) the concentration of dissolved solids in the ice (water) are very much higher than that typical of glacier ice; 3) massive ice is present in marine sediments; 4) massive ice is often interbedded with sand and gravel as is common in areas where the ice has grown in silty laminae; 5) the material beneath the massive ice is 80 to 90% sand and gravel, rarely a till; 6) vertical profiles of oxygen isotope ratios show a general continuity downward from the massive ice into the underlying sands, thus indicating a common water source; and 7) the massive ice tends to exist in topographic highs where burial of glacier ice would be least expected. The origin of the ice is puzzling, because if it is segregated ice, then as ice grew in situ the underlying sand must have been unfrozen to permit flow of water to the freezing plane. But the widespread preservation of Early Wisconsinan deformed high ice content beds within a few metres of the ground surface indicates minimal thaw since the Early Wisconsinan. The oxygen isotope ratios for the massive ice fall in the range of -28 to -35‰, an indication of a very cold (glacier ?) source of the water (Mackay, 1983). Growth in association with a nearby glacier (Rampton, 1974) is a possibility.

Late Wisconsinan

Widespread permafrost.

Holocene

Prior to 8500 years BP, ice wedges fully equal in size to modern ice wedges of the Beaufort Sea coast had grown at Garry, Pelly, and Hooper islands and by inference, elsewhere. During the Hypsithermal the active layer thickened and the wedges were truncated. The depth of thaw is easily recognized where tilted and deformed icy sediments were truncated by a thaw unconformity.

The last episode appears to be recent submergence (Forbes, 1980). Some geomorphic evidence (e.g. a "missing" Horton River delta) supports this conclusion.

Offshore Permafrost

Permafrost is known to be widespread in the southern Beaufort Sea. Ice of terrestrial origin has been recovered by industry from drill cores (Mackay, 1972). Beaufort Sea permafrost depths and minimum permafrost temperatures are plotted in Fig. 15-1, the data coming from Weaver and Stewart (1982). The thermal disturbance caused by submergence of land beneath the sea has been analyzed in a number of papers (e.g. Judge, 1974; Lachenbruch et al., 1982). Using the approach of Lachenbruch et al. (1982) after a period exceeding one time constant (λ), which is about 2 ± .5 ka for the southern Beaufort Sea, all of the subsea permafrost in water depths of more than 50 m should have temperatures no colder than the freezing point of sea water, about -1.8°C. This analysis assume that the pore water in permafrost was initially fresh. Therefore, as submergence at the 50 m depth has probably been for at least 10 ka (Forbes, 1980; Hopkins, 1982), or at least three time constants (λ), all subsea permafrost temperatures should be at or above -1.8°C, but this is at variance with the much colder minimum temperatures shown in Fig. 1. Furthermore, again using the approach of Lachenbruch et al. (1982), after submergence for a period in excess of one time constant (λ), a basal thaw of permafrost would amount to about 15 ± 5 m per thousand years (1 ka). Assuming 10 ka for submergence at the 50 m depth and a time constant of 2 ka, basal thaw would have been about 120 m to give pre-submergence depths in excess of 850 m. In addition, even if mean annual ground

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[1] Department of Geography, University of British Columbia, Vancouver, British Columbia, Canada, V6T 1W5

temperatures along the coast in the Wisconsinan were as much as 8°C colder than now (Brigham et al., 1983), a rough calculation suggests that it would take much longer than 30 ka to grow 850 m of permafrost, and such a time span does not appear present in many sea level curves for depths exceeding 50 m. The subsea permafrost history is unclear, but if permafrost grew in sediments with saline pore water, rather than fresh pore water, the phase change would be shifted to temperatures below -1.8°C and this, in turn, would delay warming of the subsea permafrost, in agreement with the calculations presented above.

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16. PERMAFROST DISTRIBUTION AND THE QUATERNARY HISTORY OF THE MACKENZIE-BEAUFORT REGION: A GEOTHERMAL PERSPECTIVE

Alan Judge[1]

The base of permafrost for each of 161 exploratory wells was determined using conventional well-logs as outlined by Walker and Stuart (1976), Hnatiuk and Randall (1977), Hatlelid and Macdonald (1979), and D&S Petrophysics (1983). The values determined are strictly the base of ice-bearing permafrost as revealed by changes in the physical properties, in particular the electrical and acoustic properties. In coarse-grained sediments the base may coincide closely with the 0°C isotherm, the difference depending on depth and pore-water salinity alone. In fine-grained soils the freezing characteristics of the soil predominate and the base of ice-bearing permafrost may be up to 100 m above the 0°C isotherm with a transition layer below (Osterkamp and Payne, 1981; Taylor and Judge, 1982). The bottom of the ice-bearing sediments is actually determined by a very complex set of soil characteristics, both static and dynamic, whose relationships remain poorly understood.

Deep temperature observations were collected and collated from 172 exploratory wells in the Mackenzie Delta, Arctic Coastal Plain and Beaufort Shelf (Geotechnical Assoc. Ltd., 1983). Three primary sources were used: (1) bottom-hole temperature information from the headers of well-logs, together with relevant information on depth and time since the end of circulation in the wells, and on mud temperature; (2) drill-stem test determinations of formation temperature with information on the depth of measurement and (3) industry-run downhole temperature surveys together with relevant information on the time of last circulation of the well, and the survey accuracy. Probable equilibrium temperatures were calculated for each type of data and plotted by depth. Such information extends to depths of 4 km.

Over the past decade, through the cooperation of industry and other government agencies, temperature measurements have been made in 45 wells drilled for hydrocarbon exploration (Taylor et al., 1982). Precise temperatures have been measured at successive times since completion of the wells to depths in excess of 600 m. The base of ice-bearing permafrost, the 0°C isotherm, and indications of zones of high ice content as derived from this data set were used to calibrate the interpretation of the geophysical well-logs. Mean surface temperatures, temperature gradients within and below the permafrost and other characteristics of the temperature curves have been used to regionalise the nature of the permafrost distribution.

The drilling of some 100 shallow holes on- and offshore have enabled an examination of the current nearsurface permafrost characteristics and active processes through the precise monitoring of temperatures (MacAulay et al., 1977; Burgess et al., 1982). In the offshore such temperature results have been integrated with seismic reflection and refraction studies, as outlined by Hunter et al. (1976) and Neave et al. (1978).

Thicknes of Permafrost

In Figure 16-1, the picks of the base of permafrost have been plotted and the values roughly contoured at 100 m intervals where the data permits. The greatest depths, as much as 740 m, to the base of permafrost on land are in the northern part of the Mackenzie Delta on northern Richards Island, but exceed 500 m in the northern half of the entire Tuktoyaktuk Peninsula between the East Channel of the Delta and the northeastern tip of the Tuktoyaktuk Peninsula. In the offshore, depths to the permafrost base are as much as 700 m beneath the sea-floor. Almost the entire shelf between longitude 129°W and 136°W is characterized by thick occurrence of permafrost below the sea-bed. The seaward boundaries of permafrost determined from the well-log analysis coincide closely with the boundaries of permafrost inferred from seismic refraction velocities on the upper permafrost table. Seismic interpretation suggests an additional portion of the northeastern shelf, extending southwesterly in a belt 15-20 km wide, to be without this frozen substrate. Lack of well information in the area prevents confirmation of the total absence of permafrost throughout the belt.

The thickness of permafrost decreases in the southern portion of the Mackenzie Delta, along the Eskimo Lakes in the east, east of a line through the west side of the Mackenzie Delta and possibly on the Yukon Coastal Plain. The offshore west of 136°W is largely characterized by thin or absent permafrost. A few limited observations onshore to the east of the study region again indicate thick permafrost; e.g. >300 m at 68°51'N, 126°47'W and 450 m at 67°44'N, 126°50'W (Taylor et al., 1982). Similar increases in permafrost thickness might be expected west of the Mackenzie Delta with a boundary either in or to the south of the Yukon coastal areas. Well data is not available to confirm this, however. West of the Mackenzie Trough, permafrost in the offshore may again thicken although again the little well data that is available does not confirm the supposition. Sediment characteristics are akin to those encountered in the Alaskan Beaufort where thick permafrost is encountered in the offshore (Osterkamp and Payne, 1981).

Deep Temperature Observations

The deep temperatures calculated from industry data were plotted and contoured isotherm maps were generated for depths of 1, 2, 3 and 4 km utilising a 10°C contour interval. As shown in Figure 16-2, the individual data points are often sparse and so the individual contours are speculative. The maximum and minimum temperatures recorded for the given depth zones are 44/14°C at 1 km, 66/33°C at 2 km, 97/46°C at 3 km and 128/83°C at 4 km. Differential temperatures between the maximum and minimum range from 30 K at 1 km to 50 K at 4 km, consistent with regions of varying geothermal gradient. The heat sources and sinks are not well-defined because, for example, the number of individual data points has fallen to 50 at 5 km. However, the higher temperature zones consistently occur around the Eskimo Lakes region east of Tuktoyaktuk, along the west coast of Mackenzie Bay and offshore between latitudes 69°40'N and 70°N around longitude 136°W. A low temperature zone follows a general northeast-southwest trend west of Tuktoyaktuk, centered over northern Richards Island and the western Tuktoyaktuk Peninsula.

Deep geothermal gradients are quite uniform compared with other geological regions and indicate an area of normal heat flow, i.e., gradients generally in the range of 20 to 30°C/km (Fig. 16-3). A 40°C/km gradient region occurs to the northwest of the area around latitude 70°N and longitude 136°W. Gradients appear to decrease towards the eastern edge of the area.

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[1] Earth Physics Branch, 1 Observatory Crescent, Ottawa, Ontario, Canada, K1A 0Y3

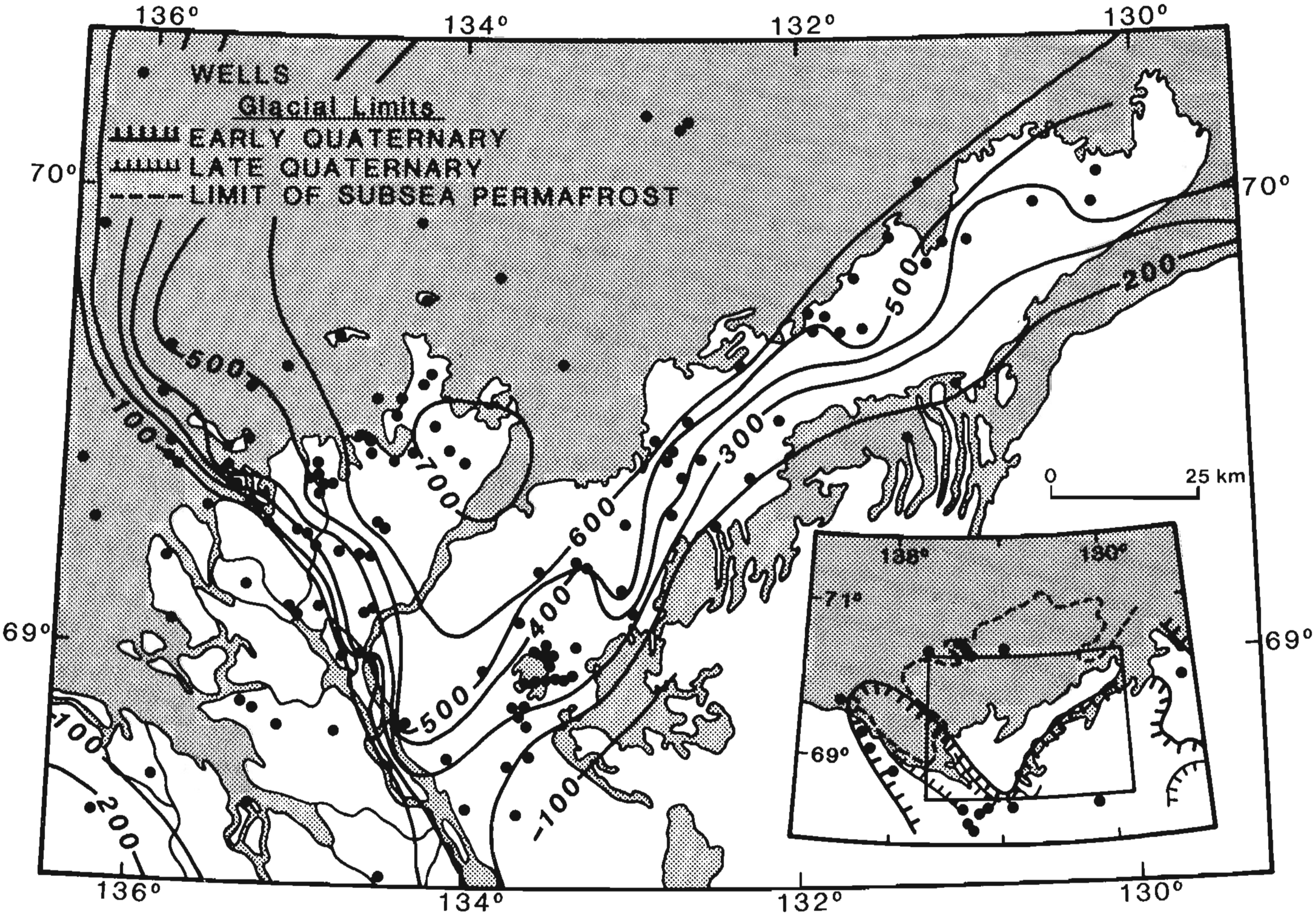

Figure 16-1. Thickness of permafrost (m), Beaufort Sea Continental Shelf and adjacent Tuktoyaktuk Coastlands, Canada.

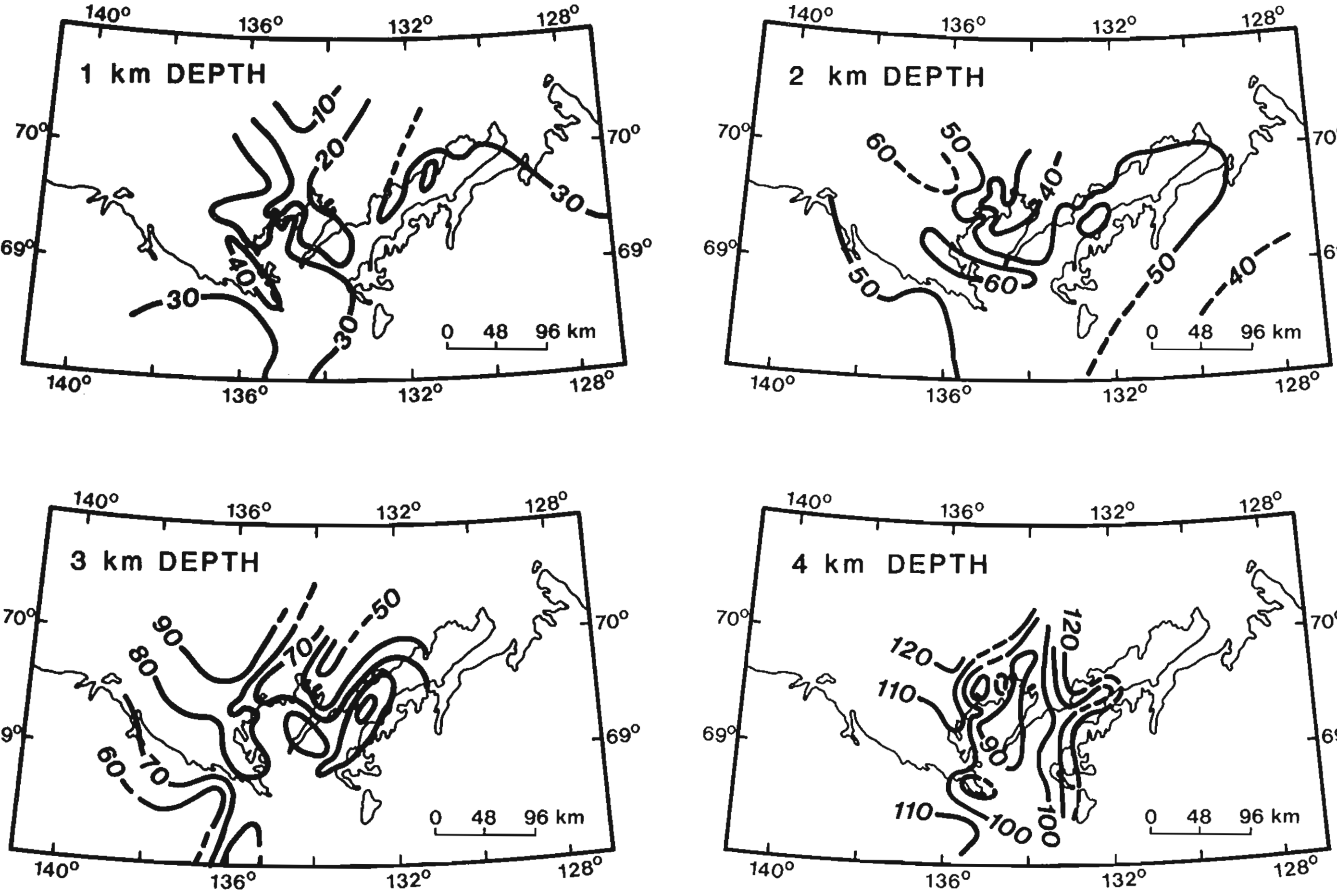

Figure 16-2. Isotherms of deep ground temperatures (°C), Beaufort Sea Continental Shelf and adjacent Arctic Coastal Plain, Canada.

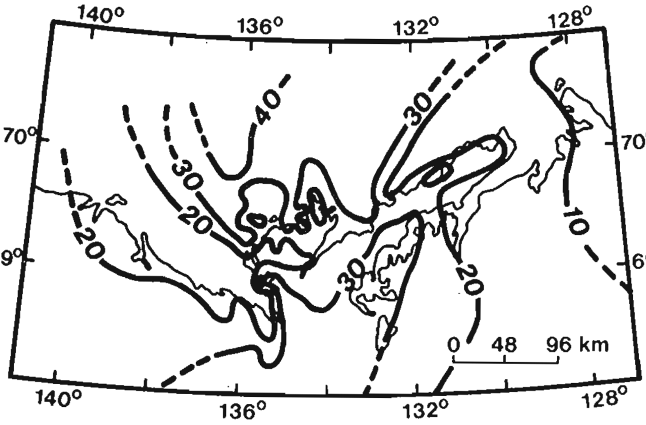

Figure 16-3. Geothermal gradients (°C/km), Beaufort Sea Continental Shelf and adjacent Arctic Coastal Plain, Canada.

Precise Well Temperature Data

Deep temperature measurements are available at 45 sites in the region, primarily onshore. The coverage is not uniform in distribution; 30 sites are in the old delta where permafrost thickness, as revealed by the 0°C isotherm, ranges from 272 to 670 m with a median value of 370 m. This is a factor of four to five times thicker than the permafrost at nine sites in the modern delta (65 to 175 m; median 85 m). Ground temperatures, extrapolated to the surface from measurements in the upper 100 m at these sites, lie in the range -4.4 to -9.5°C (old delta) and -1.4 to -4.9°C (modern delta). A similar range was found by Mackay (1974) from measurements in seismic shot-holes. Little difference in present day air temperatures is observed in the region as recorded at three stations (Environment Canada, 1973). In most instances the temperatures increase reasonably linearly with depth below 100 m indicating a quasi-equilibrium state, although above 100 m indications do exist of surface warming in the old delta wells and cooling at the modern delta sites. An exception to this distribution of temperature with depth is very pronounced in five wells to the west and south of Big Lake in the central delta. Although Mackay (1963) placed the region in the modern delta, thick permafrost in excess of 500 m places it in the old delta while the essentially isothermal nature of the temperatures through the permafrost are most akin to the thermal characteristics of the offshore.

Shallow Thermal and Seismic Studies in the Offshore

As described by Hunter et al. (1976) and Neave et al. (1978), high seismic velocities encountered on the eastern half of the Beaufort Shelf are interpreted as relict ice-bonded permafrost. The velocity data east of 135°W is divisible into an upper velocity group with a top 60-100 m below sea-level and a lower group 130-200 m below sea-level. West of 135°W and to the edge of the Mackenzie Trough a more complex structure is present probably representing partially ice-bonded or ice-bearing sediments. Shallow drilling to depths of 60 m below the sea-floor has revealed the profound nature of the edge of the Mackenzie Trough north and east of Garry Island and a very complex shallow thermal regime to the east (MacAuley et al., 1977, 1978). These observations are indicative of relict conditions at depth, possible seasonal aggradation of frost in the upper 3 to 4 m of sediments and non-conductive processes of heat transfer above the top of the main permafrost body.

Permafrost and Quaternary History

The zones of thick and thin permafrost appear to show a strong relationship to the limits of Wisconsin Glaciation. The relatively shallow permafrost of the modern delta and the Late Wisconsinan glacial limit (Mackay et al., 1972) are in close agreement; the deeper permafrost has been measured in northern Richards Island and along the north west Tuktoyaktuk Peninsula which does not correlate well with the proposed limit of the Early Wisconsinan maximum. In fact the thickest permafrost might be predicted to be to the north-east of Tuktoyaktuk, north of the northern limit of glaciation where in fact values average several hundred metres less than on Richards Island. In a general sense the existence of the ice tongues or ice sheets in the region served to insulate the soil from sub-zero air temperatures which characterized the climate during the period of Wisconsin Glaciation, thus inhibiting the growth of deep permafrost. In the northern and central part of the Mackenzie Delta, along the Beaufort Coastal zone of the Tuktoyaktuk Peninsula and on the shelf adjacent to both areas, the presence of deep permafrost suggests an absence of glacial ice or sea-water cover, and a direct exposure of the land to the colder air temperatures occurring in an ice age.

Permafrost thickness in the modern delta is relatively shallow although the thickness has been further limited by proximity to seasonal flooding and to major river channels that have shifted over the past few thousand years. Intercept temperatures generally suggest cooling of the land surface over the period which is consistent with an aggradation of permafrost in an aggrading modern river delta.

Observations of permafrost distribution are accompanied by temperature measurements at 10 sites in the Parsons Lake area. In the morainic hills adjacent to the lake permafrost thickness ranges from 294 to 386 m. Mackay et al. (1972) position the Late Wisconsinan limit directly through the area; a site 10 km west of the lake has very deep permafrost (550 m), suggesting it may lie outside of the Wisconsinan advance. Alternatively, since a recent geophysical survey has shown Parsons Lake not to be underlain by permafrost (Geophysicon, 1983), the lake may be an old feature and the glacial limit lie further east.

The deep permafrost and temperature results add to the definition of the boundary between the modern and old deltas. Mackay (1963) places it at the base of the Caribou Hills and the Pleistocene area further north, towards the sea. This definition results in a loop extending east to include the Taglu gas field in the modern delta. Recently obtained deep temperature observations and the well-log interpretations in this field, however, have shown permafrost thicknesses to be in excess of 500 m, values that are more similar to permafrost thicknesses in the old delta. Furthermore, permafrost depths in the Taglu field suggest that the area was unglaciated during the Late Wisconsinan, adding confirming evidence to the ice limit proposed by Mackay et al. (1972). The present data suggests the boundary between old and modern deltas follows a linear extension north-west from the Caribou Hills. Several logged wells are located very close to this lineament; the deep permafrost (502 m) at Sun Garry P-04 would suggest the boundary passes to the west of that site and of Garry Island further north, as shown in Figure 16-1.

Contiguity of the permafrost distribution and history on and offshore is well illustrated by logs from the Taglu gas field, where onshore is found a region of thick warm permafrost similar to that found offshore and newly emergent in the past 1000 years or less. Consequently the permafrost is degrading at the base and aggrading in the upper 120 m.

Unfortunately although shallow temperature observations to 60 m below the sea-bottom confirm the degradational character of offshore permafrost and the well-log interpretations reveal the wide regional variations in permafrost thickness, the lack of precise temperature observations taken over a period of time preclude at present detailed thermal modelling of the shelf history.

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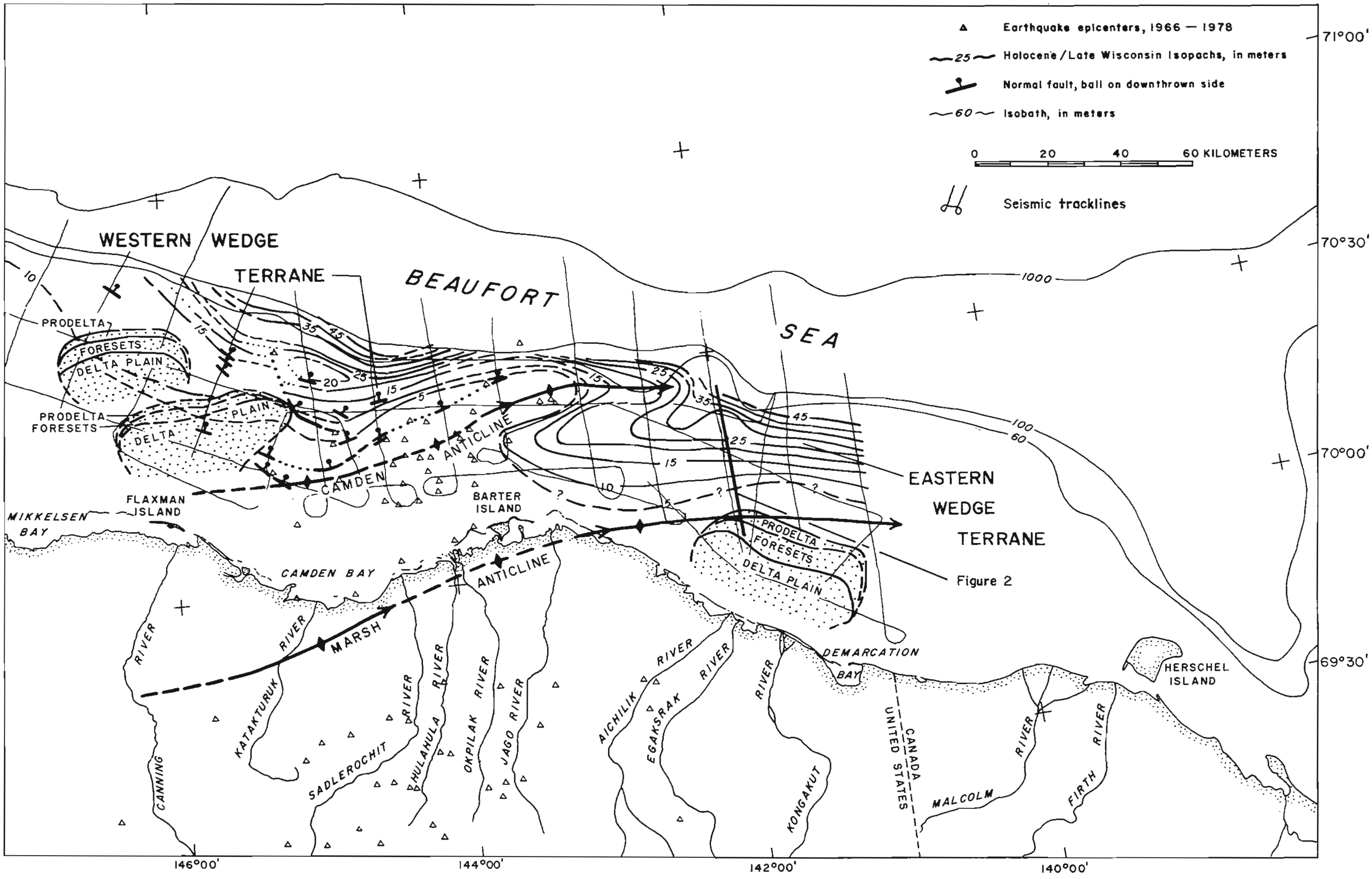

Figure 17-1. Quaternary geologic features of the eastern Beaufort shelf, north of Alaska. Earthquake epicenters, active folds and faults, late Wisconsinan/Holocene sediment isopachs, pre-late Wisconsinan deltas, and high-resolution seismic reflection tracklines are shown.

17. LATE QUATERNARY STRATIGRAPHY OF THE ALASKAN BEAUFORT CONTINENTAL SHELF NEAR THE CANADIAN BORDER

David A. Dinter[1]

During the summer of 1977 the U.S. Geological Survey acquired high-resolution reflection seismic profiles (Uniboom and 3.5 kHz bathymetry) on lines approximately perpendicular to the shelf break traversing most of the Alaskan Beaufort shelf seaward of the 25-meter isobath at line spacings of about 20 km (Fig. 17-1). The six most easterly of these profiles and their cross ties cover the Alaskan portion of a geologic terrane that exhibits a uniform style of Late Quaternary deposition and deformation. In this area – designated here as the Eastern Wedge Terrane – the Quaternary sedimentary section beneath the middle and outer shelf is composed mainly of wedge-shaped marine(?) strata, the youngest of which, composite Unit A, is as thick as 45 m near the shelf break. These units thin towards the inner shelf, where they interfinger with probable fluvial, deltaic, and nearshore marine deposits (Fig. 17-2). Trends of the wedge strata north of Demarcation Bay suggest that they extend onto the Canadian Beaufort shelf. They may persist as far east as Herschel Island, beyond which the shelf is inundated by still younger sediments debouched from the Mackenzie River. At the northwestern boundary of the Eastern Wedge Terrane the wedges thin or wedge out over Camden Anticline, an east-plunging, northeast-trending, seismogenic structural arch (Fig. 17-1), beyond which extends the Western Wedge Terrane (Dinter, in press).

Transgressive Marine(?) Wedges

Unit A

Isopachs of Unit A, the youngest composite marine(?) wedge of the Eastern Wedge Terrane, revised from Dinter (1982), are provided in Figure 17-1. Details of its stratigraphic character are shown in Figure 17-2, a cross-section drawn from a reflection seismic profile. The base of Unit A is the uppermost strong, laterally persistent, subbottom reflector observed beneath the middle and outer shelf. In the Eastern Wedge Terrane this reflector terminates seaward near the shelf break at depths ranging from about 100 to 120 m below present sea level. The coincidence of this range with Late Wisconsinan sea level minima measured on other continental shelves (e.g., Curray, 1965; Dillon and Oldale, 1978; Cronin, 1983) suggests that the basal reflector is a disconformity recording a subaerial exposure of the shelf during the last glacial drawdown of sea level. If this interpretation is correct, the seaward termination of the disconformity approximates the position of the Late Wisconsinan beach, and all overlying deposits, i.e. Unit A, must be younger than the onset of the post-glacial rise in sea level about 17 ka ago.

The deposits of Unit A are most commonly acoustically translucent and quite homogeneous laterally. Sparse internal bedding is weakly reflective, usually subparallel to the seafloor, and laterally persistent. Surficial samples of Unit A from the Western Wedge Terrane are marine mud and silt containing, in places, abundant sand and striated, ice-rafted pebbles and cobbles (Rodeick, 1979). For these reasons, Unit A is interpreted to be dominantly marine. Its provenance and its environment and period of deposition still present a problem, however, inasmuch as depositional rates on the middle and outer shelf are presently negligible and yet deposits thicker than 40 m in some places have apparently accumulated there during the past 17 ka or so.

A substantial proportion of Unit A may have been transported to its depositional site by ice-rafting. This mechanism has long been suggested to account for the origin of certain Quaternary deposits of the Alaskan North Slope. Leffingwell (1919) proposed that large boulders lying along the Beaufort coastline had been carried there by ice originating in Canada. More recently, Rodeick (1979) studied the lithologies of shelf and coastal gravel samples from the Alaskan Beaufort Sea area and concluded that his "dolomite facies" was dominantly ice-rafted and that the most likely provenance was the Coronation Gulf region of the Canadian Arctic Islands, where a similar lithologic suite is exposed in bedrock. Dinter (1983) extended this notion to suggest that much of Unit A may have been rafted to the Alaskan Beaufort shelf from the Canadian Arctic Islands some 14 to 9 ka during the retreat of the Amundsen Gulf and McClure Strait lobes of the Laurentide Ice Sheet, when large volumes of sediment-laden ice were likely shed into the Arctic Ocean (Prest, 1969), and carried westward by the Beaufort Gyre. He also suggested that sedimentation rates in the Eastern and Western Wedge Terranes may have dropped to near zero when those sources were depleted.

Figure 17-2 shows that Unit A is actually a composite of several thinner units, A_1, A_2, and A_3. Unit A_3 is wedge-shaped, acoustically translucent and homogeneous, and may be a transgressive, offshore marine facies. The lower part of Unit A_2 is a hummocky stratum about 1 to 5 m thick that has no analog in the Western Wedge Terrane. It may represent an interval of accelerated sediment flux from the Romanzof Mountains, perhaps during the early part of the period from approximately 12 to 8 ka, when the Alaskan Arctic climate was warmer and probably wetter than at present (Carter et al., 1984). The upper part of A_2 is a thin, seaward-thickening wedge that terminates near the shelf break in a poorly defined foreset sequence, which also may have resulted from an increased terrigenous sediment influx at some time during the warm period. The surficial deposits of composite Unit A, designated Unit A_1, are a succession of lens-shaped marine(?) layers that may record the infilling of an actively subsiding middle shelf depression discussed below.

Older Wedges

In the Western Wedge Terrane Unit A is underlain by at least two additional composite marine(?) wedges of similar thickness and depositional character, Units E and I (Dinter, in press). If the interpretation of Unit A presented in the previous section proves correct, that is, if Unit A records an increased supply of sediment from both local and exotic sources during the early phases of the transgression following the Late Wisconsinan glacial maximum, then the underlying wedges probably represent similar phases of previous deglaciations.

Seismic penetration is insufficient beneath the middle and outer shelf in the Eastern Wedge Terrane to distinguish the geometry of any strata underlying Unit A. However, Unit E, at least, is inferred to exist there, and to be represented by acoustically translucent deposits underlying Unit B on Figure 17-2.

Fluvial, Deltaic, and Nearshore Deposits

Unit B

Unit B is a discontinuous, acoustically complex, hummocky-topped layer that commonly underlies Unit A in both Beaufort wedge terranes (Dinter, 1982). It is tentatively interpreted as a regressive nearshore, beach and fluvial deposit formed prior to and during the late Wisconsin

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[1] United States Geological Survey, 345 Middlefield Road, Menlo Park, California, 940525, U.S.A.

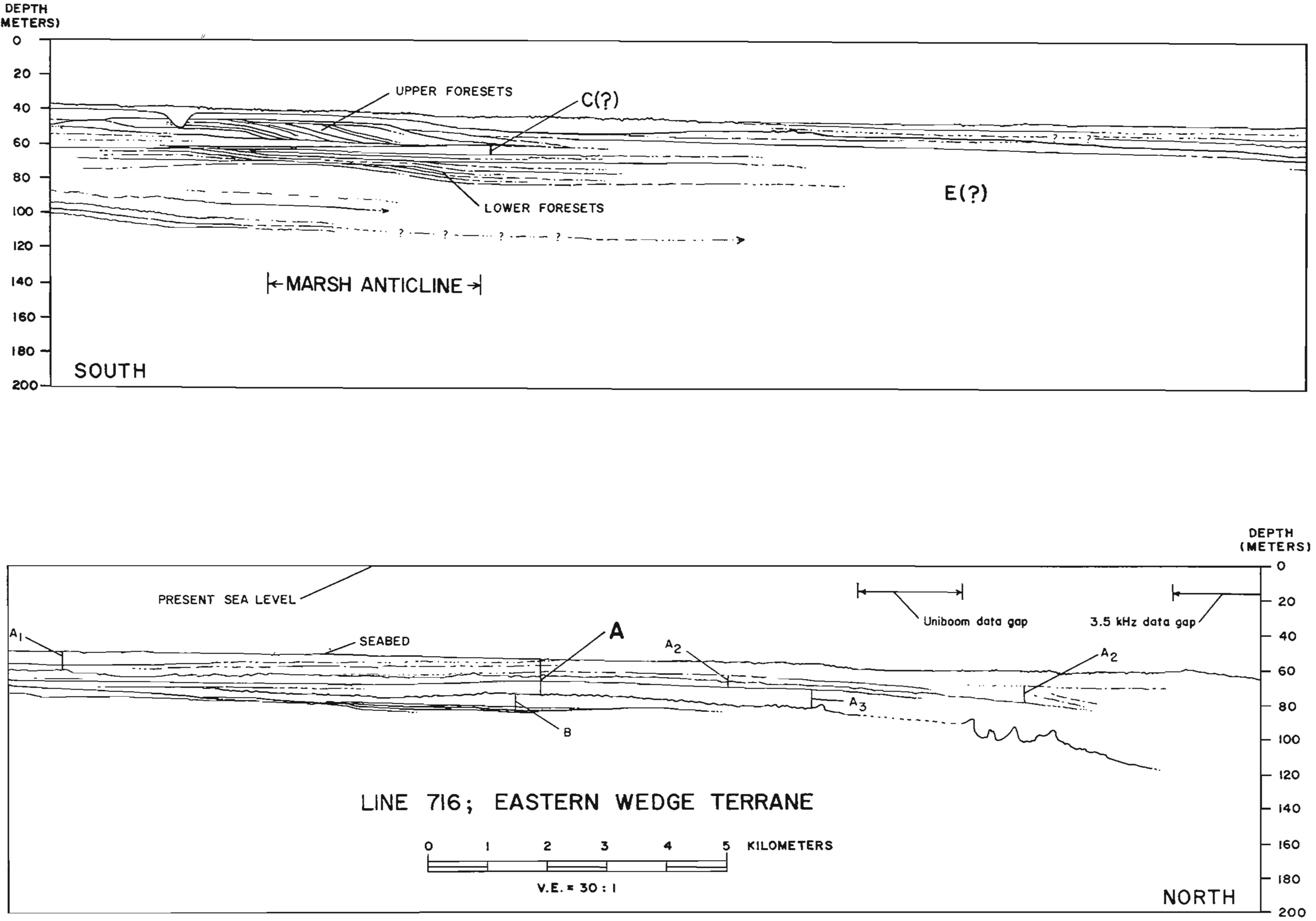

Figure 17-2. Cross section showing late Quaternary sedimentary units of the Eastern Wedge Terrane, Beaufort Sea, Alaska. See Figure 17-1 for location.

glacial maximum. In the wedge terranes Unit B commonly terminates seaward in a ridge of sediment at least 1 km wide and about 10 km thick that may be the remnant of a barrier island chain.

Foreset deposits

On the middle shelf, off the Aichilik, Egaksrak and Kongakut rivers, the shoreward wedge-edges of Unit A and/or Unit B are underlain by the upper foresets, a sequence about 10 m thick with a strongly reflective top at 46 to 49 m below present sea level (Fig. 17-2). This unit is interpreted to be a delta of one or several of the rivers just mentioned. Older deltas are represented by the lower foresets, actually composed of two foreset sequences, each approximately 8 m thick. The older, lower sequence has a top at about -70 m, and the younger sequence at -62 m.

In the Western Wedge Terrane a foreset unit that is probably analogous to the lower foresets of Figure 17-2 overlies a transgressive marine(?) wedge interpreted on the basis of a tentative correlation to cores obtained nearshore to have an age in the vicinity of 125 ka (Dinter, in press), which can thus be taken as a likely maximum age for the deltaic deposits. Given the interpretation of Units A and B above, the upper foresets of Figure 17-2 must be older than Late Wisconsinan. A better minimum age may be about 36 ka, since from that time through most of the Late Wisconsinan desert conditions prevailed across most of the Alaskan North Slope (Carter, 1983). Extensive deltaic deposition might be likelier to have occurred when wetter conditions prevailed in the source terrane prior to 36 ka.

Quaternary Structures

Isopachs of Unit A show the Eastern Wedge Terrane to be a scoop-shaped basin widening and thickening to the east. It owes this shape to its position between two active, east-plunging folds, Camden and Marsh Anticlines (Fig. 17-1). Modern tectonic activity along these features is evidenced by the clustering of earthquake epicenters beneath their southern flanks. Through much of Quaternary time, continuing subsidence of the syncline between these two folds appears to have created a persistent topographic depression that has been intermittently filled during periods when sedimentation rates on the shelf were high. There is presently a slight topographic depression along the axis of the syncline. Profiles obtained using a multichannel reflection seismic array show that these folds overlie similar structures developed in older rocks.

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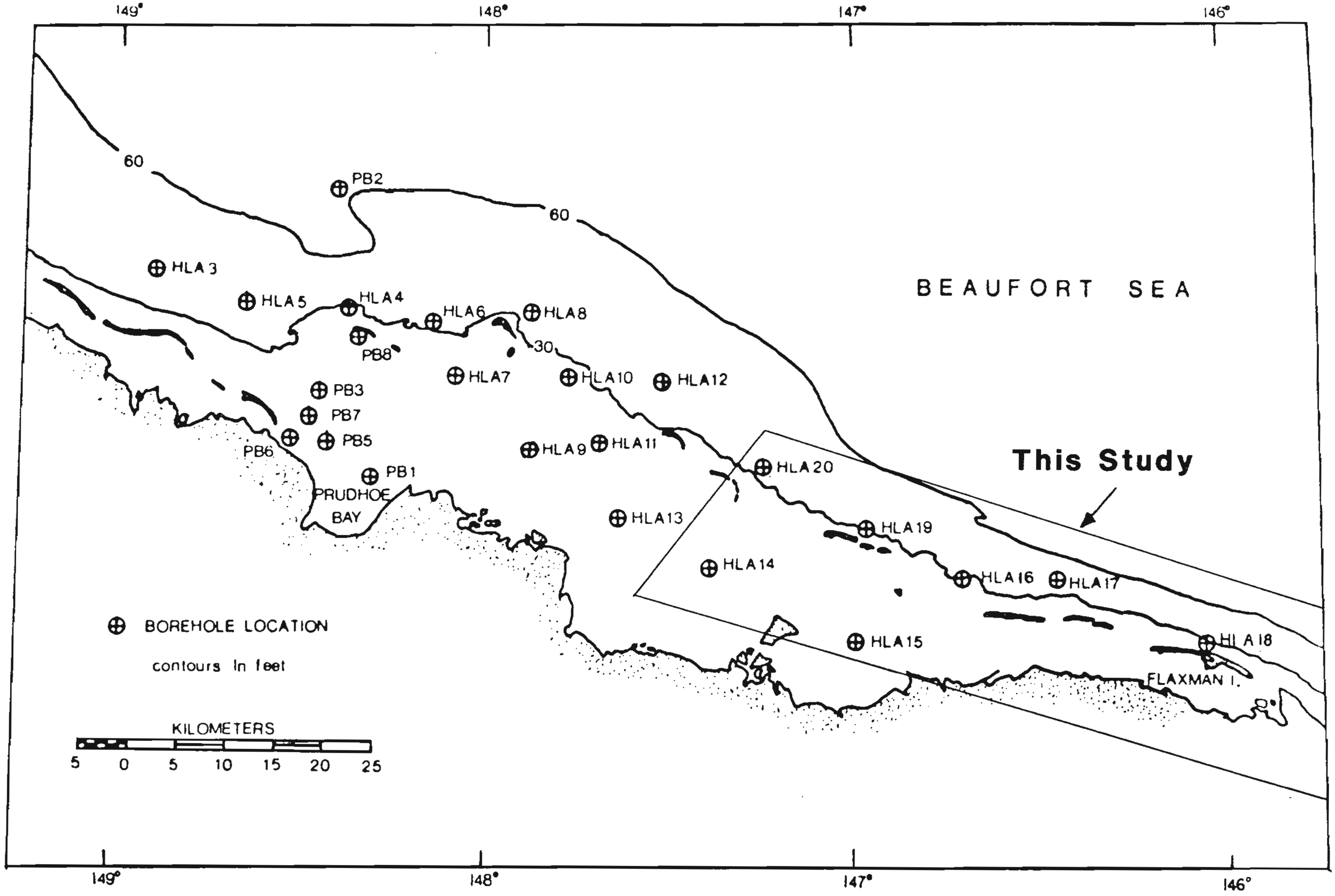

Figure 18-1. Borehole location map, Canning River Delta region, Beaufort Sea Continental Shelf, Alaska.

18. THE LATE PLEISTOCENE-HOLOCENE STRATIGRAPHIC RECORD, CANNING RIVER DELTA REGION, NORTHERN ALASKA

Peggy A. Smith[1]

A detailed study of seven boreholes situated in shallow water (<20 m) near Prudhoe Bay, Alaska, (Figure 18-1) has provided a record of three pre-Holocene marine units, as well as a deltaic sequence primarily non-marine in nature. High resolution seismic surveys in the area document two prominent reflectors resembling erosional surfaces. The borehole studies confirm the erosional nature of the surfaces, and provide some indication of the possible age of the features. Sediments which can be called Holocene without much doubt are found only in the two boreholes closest to shore. Figures 18-2a & b are cross-sections through the five outer and the two in-shore boreholes, showing generalized stratigraphic relations.

The oldest of the three marine units is present in the five outer boreholes, and is here designated as the Leffingwell Lagoon Unit. The unit ranges in thickness from 10 to 18 m, thickest in hole 16 and thinning both to the east and west. Its base consists of marine silt and clayey silt overlying gravelly beach deposits, while the top is marked by an erosional surface. Microfossil assemblages in the lower half of this unit indicate mid-neritic (20-40 m) water depths, with some reworking of sediments near the base. Boreal and arcto-boreal (?) foraminifers present in the lower half of this unit indicate the influence of warmer Atlantic water masses near the start of the transgression. Microfossil assemblages in the upper half of the unit, however, reflect a shallowing and cooling trend and are similar to the present day arctic fauna of the Alaskan Beaufort. The thinly-bedded nature and the absence of reworking in the mid-neritic portion of this unit suggests that ice-gouging, which presently is most active in exactly this water depth, was either non-existent, or was most active at some other, presumably greater, water depth during the time in which the Leffingwell Lagoon Unit was deposited. The influence of the Atlantic water mass (which presently sits at a depth of about 200 m along the Alaskan Beaufort) at mid-shelf depths suggests that perhaps the Beaufort water column was not as well-stratified as it is today. If the ice-cover during this time was less extensive than it is today, then the increasing fetch would lead to greater wave activity and corresponding mixing of the water column.

The middle unit, here designated the Maguire Islands Unit, represents an environment transitional from shallow marine to deltaic. In HLA-17 beach or possibly barrier island sand and sandy gravel overlying clayey silt of the Leffingwell Lagoon Unit is interpreted as the base of the Maguire Islands Unit. In HLA-18 and 16 a gravelly mud is chosen as the base, while in HLA-20 the base is a silty clay with detrital peat, shells, and sand. In general, sediments in the Maguire Islands Unit coarsen slightly up-section from silty clay and silt to sandy silt and silty sand. Microfossil assemblages throughout the unit are characterized by small populations, low diversity, and species suggesting frigid to subfrigid, low salinity, shallow marine conditions. Samples from the coarser-grained upper part of the unit are either barren or very depauperate, and may represent a non-marine deltaic environment into which marine elements have been reworked, either by erosion of older sediments or by washing in during storms. Seismic profiles from the area also show a considerable amount of cut and fill within the upper part of the unit, suggesting subaerial exposure. In fact, HLA-19 is located within a large filled channel apparent on the seismic records.

The Maguire Islands Unit is overlain by yet another shallow marine transgression, here designated the Cross Island Unit. The unit ranges in thickness from 0 to 7 m, is primarily clayey silt to silty sand, and contains microfaunal assemblages indicative of cool, low to variable salinity, inner-neritic water depths.

In HLA-18, 17, and 16 the uppermost 1 to 2.5 m of sediment is composed of sandy silt with pebbles and shells or shell fragments, suggestive of shoal deposits or ice-gouged material. This interpretation is supported by the microfossil assemblages, which reflect a great deal of reworking. In HLA-19 the interbedded silty clay and sandy gravel at the top of the borehole again represents a mechanical mixing of sediments, perhaps related to the passage of a barrier island. Unlike the five outer boreholes, HLA-14 and 15 are in a relatively protected area much closer to shore. The uppermost sediments in these two holes are lagoonal in character – black organic-rich silt and clayey silt with shallow marine/estuarine faunas. These uppermost sediments have not been assigned to a unit, but they are presumed to be Holocene in age.

There are some definite problems in trying to define the age of these three units, and the boundaries are still open to question in places, but at least it is a start. A strong reflector (No. 3) correlates very well with the base of the Leffingwell Lagoon Unit, probably showing the velocity contrast between the clayey marine silt and the underlying gravel and gravelly sand interpreted as beach and/or basal transgressive layers. This reflector is very widespread on this part of the shelf, and is thought to represent an erosional surface because it truncates underlying reflectors. Reflector No. 4, though not as strong nor as widespread, also truncates underlying reflectors and is thought to represent an erosional surface. A reflector at about the base of the Cross Island Unit in HLA-20 is less prominent than the underlying No. 3 and No. 4, but it has been traced a short distance out on the shelf where it is being destroyed by ice-gouging.

The degree of epimerization of isoleucine in fossil foraminifers in the Leffingwell Lagoon and Maguire Islands Units has been used in an attempt to distinguish their ages. Total Alle/Ile values in the Leffingwell Lagoon Unit range from 0.073 to 0.089, while those in the Maguire Islands Unit range from 0.053 to 0.075. (These two groups of amino acid ratios are the same as those reported as Pelukian and Flaxman, respectively, in Smith and Brigham, 1982. Unit boundaries have been revised since then, and informal names have been applied to the units instead of trying to force-fit them into existing, formally named units.) Some of the overlap may be due to the inadvertent choice of reworked material, but it also suggests that the two units are fairly close in age. An attempt was then made to integrate the probable sea level and paleoclimatic history of the area into a thermal model to be used for determining possible ages from the raw amino acid ratios. Figure 18-3 shows both the generalized sea level curve of Shackleton and Opdyke (with two "mid-Wisconsin" data points from New Guinea and Barbados included), and the thermal model which reflects postulated conditions during alternating exposure and inundation of the sampled horizons. Using this model, a ratio of 0.086 = 195 ka, 0.075 = 122 ka, and 0.053 = 90 ka. If temperatures during intervals 4 and 6 are colder than those used in the model, then the ratios must reflect greater age. Conversely, warmer temperatures would yield a younger age.

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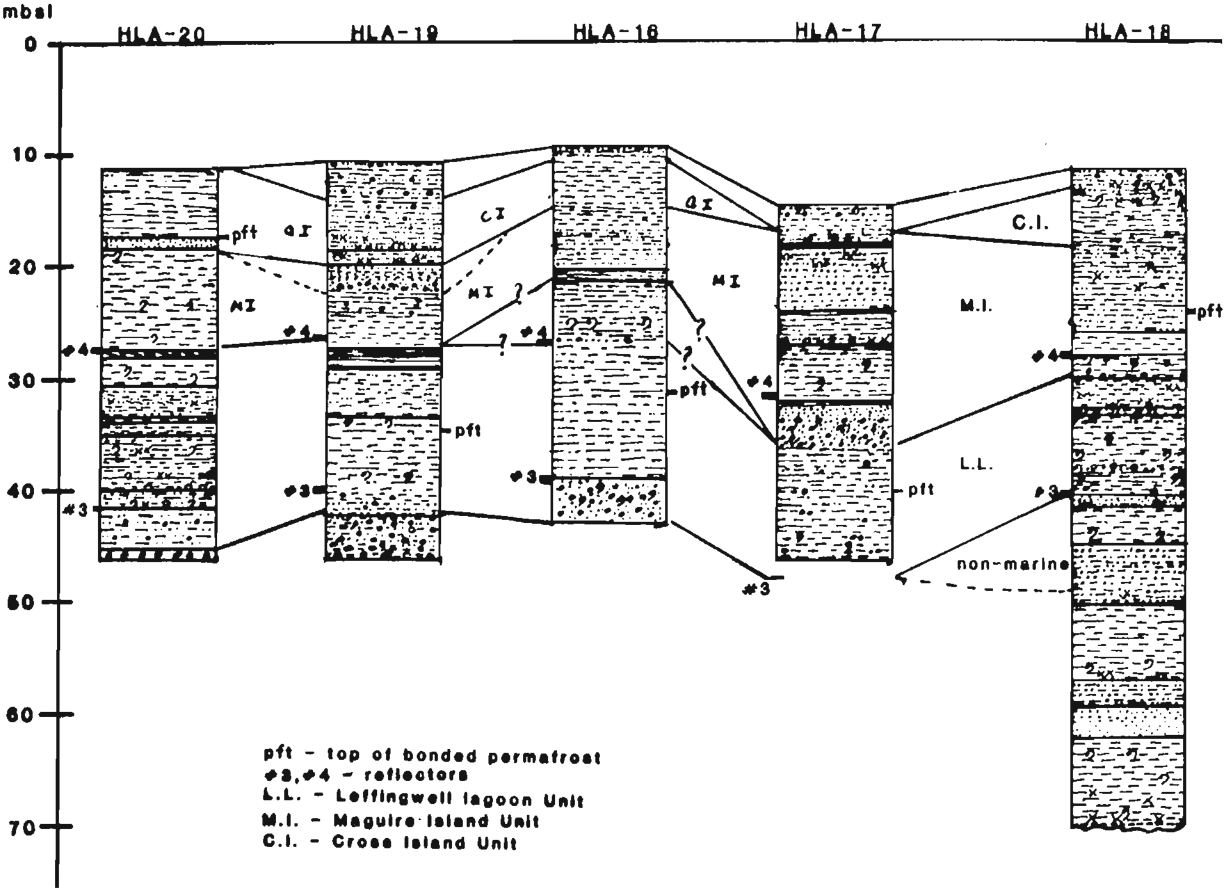
[1] United States Geological Survey, 345 Middlefield Road, Menlo Park, California, 94025, U.S.A.



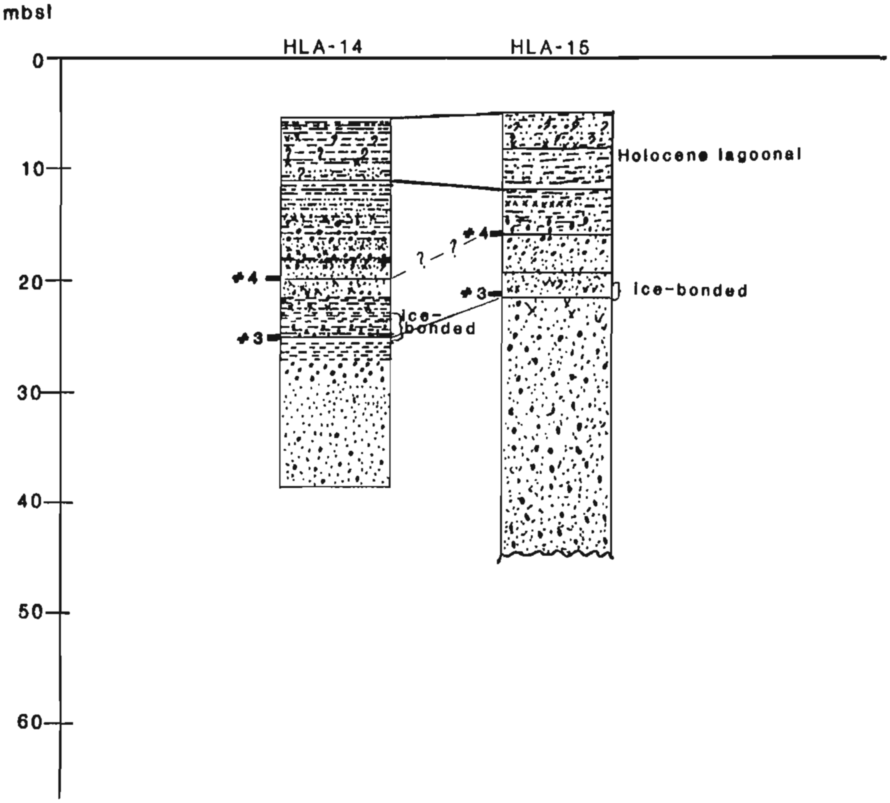
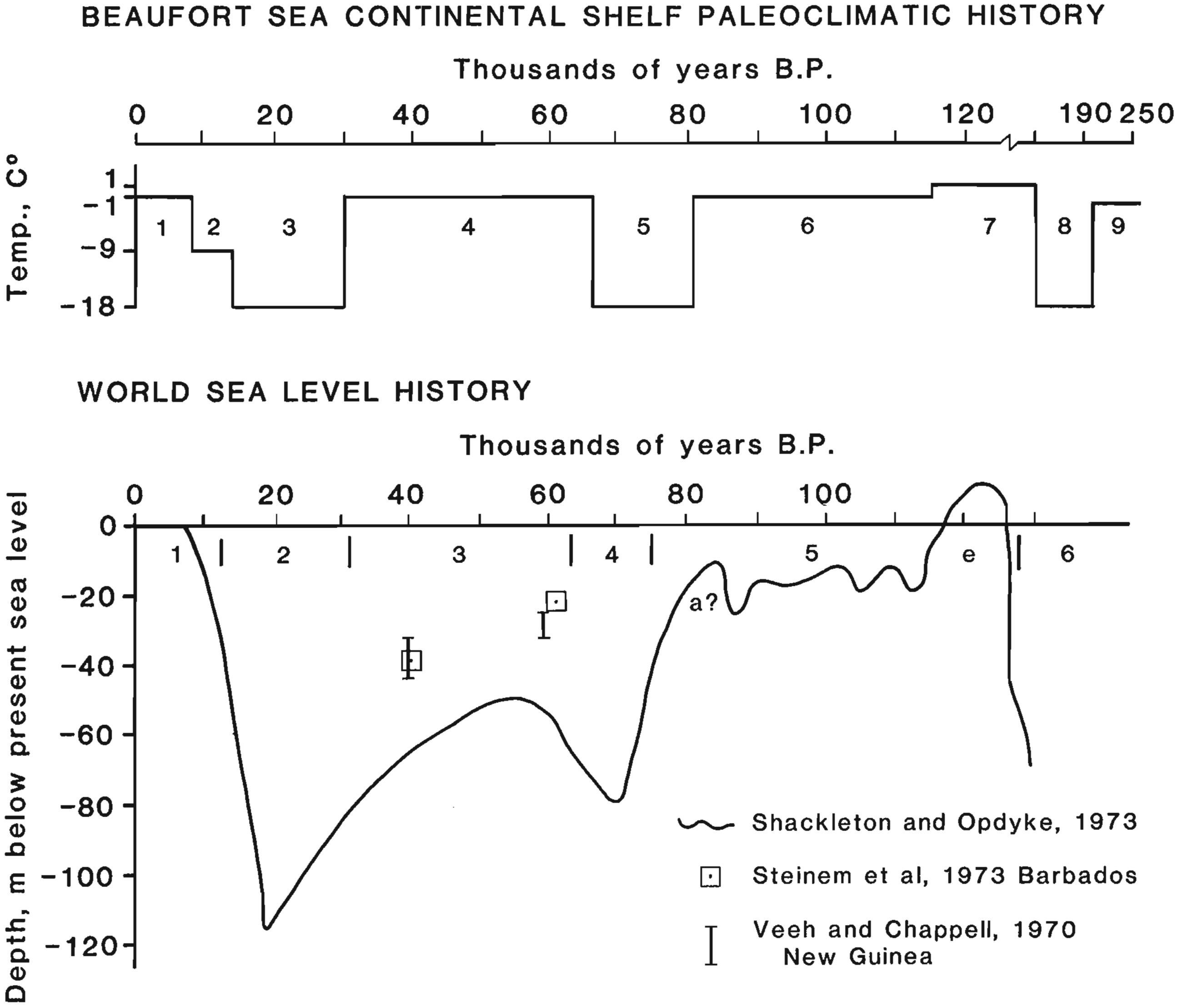


Figure 18-2

Lithostratigraphic correlation of boreholes, Canning River Delta region, Beaufort Sea Continental Shelf, Alaska.



BEAUFORT SEA CONTINENTAL SHELF PALEOCLIMATIC HISTORY

WORLD SEA LEVEL HISTORY

Figure 18-3. Correlation of paleoclimatic history, Beaufort Sea Continental Shelf, Alaska, and world sea-level history.

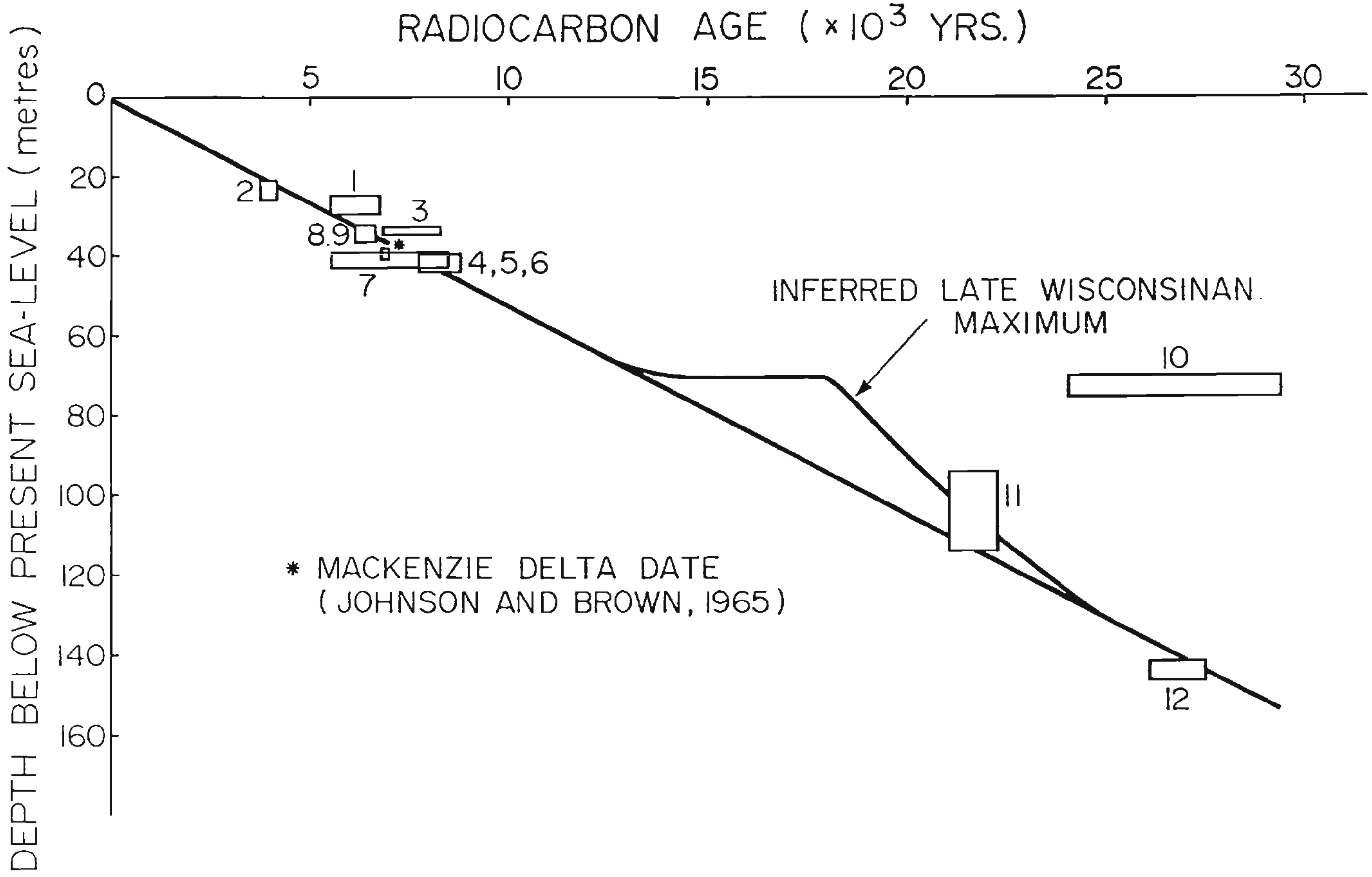


Figure 19-1. Relative sea-level curve, Beaufort Sea Continental Shelf, Canada.

20. CORRELATION OF QUATERNARY DEPOSITS AND EVENTS IN THE AREA ADJACENT TO THE BEAUFORT SEA – A FIRST APPROXIMATION

Workshop Participants

As mentioned in the Introduction, the workshop participants addressed the problem of creating for the first time a detailed correlation chart for the region. The first draft of this chart is shown in Table 20-1. We cannot overemphasize the preliminary, embryonic nature of the chart. The age relationships of the data shown in some of the columns are uncertain; the relationship between the columns is therefore very tentative. While none of us were completely satisfied with the document, we agreed that it was a reasonable first attempt at such a chart. A long and complex Quaternary record exists in both northwestern Canada and Alaska. Clearly, as more fieldwork is done in the region and as more radiometric and other geochronologic data become available, revisions will be necessary.

Some column authors have provided nomenclatural and bibliographical notes to accompany their column in the chart. These are reproduced below.

Yukon Cordilleran Ice Sheets (no notes provided).

Yukon Basins (J.V. Matthews, Jr.)

Upper glaciolacustrine: Listed ages bracket a glaciolacustrine clay unit that represents meltwater ponded by diversion of the regional drainage during the last advance of Laurentide ice to the east flank of the Richardson Mountains. Although the clay unit occurs near the top of most exposures in the Old Crow and Bluefish basins, it is usually poorly exposed due to thawing. Thus it may represent a more complex sequence of lake level fluctuations than is indicated. Meltwater ponding events may have occurred during isotope stage 3 (see Thorson and Dixon, 1983), but if so are not clearly portrayed by the stratigraphy of the "interlacustrine unit" in the Bluefish and Old Crow basins.

Hanging Lake interval: A short phase of warmer climate presumed to have occurred around 19 ka, during isotope stage 2. In the Yukon it is apparently represented by slight increase of percentage and influx values of spruce, birch, and alder pollen in zone HL1B at Hanging Lake, a small basin on the northeast margin of the Old Crow Basin (Cwynar, 1982, p. 15).

Koy-Yukon thermal event: A period of very warm summer climate that occurred across east Beringia sometime prior to the onset of isotope stage 2 but after deposition of Old Crow tephra (Schweger and Matthews, 1984). Pollen, macro-fossils of insects and plants, and thaw structures suggest that the Koy-Yukon thermal event was characterized by a summer climate warmer than that of the present.

Old Crow tephra: A distinctive distal tephra horizon that occurs across east Beringia and which was deposited during an "instant" of time within the interval 87 to 105 ka (Schweger and Matthews, 1984).

Interlacustrine alluvium: The most complete exposures of the "interlacustrine alluvial unit" are at sections in the Old Crow Basin, but even there it contains numerous unconformities and at some exposures probably represents most of Quaternary time.

Little Timber tephra: Exposed near the base of the "interlacustrine alluvial unit" at two Old Crow Basin exposures. It is associated with significant finds of small mammal fossils (R.E. Morlan, National Museum of Man, personal communication) as well as fossils of insects, plant macrofossils and pollen. The date is based on a Fission-track analysis conducted by J.A. Westgate (Scarborough College, Scarborough, Ont.).

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

Brooks Range and Basins to South (T.D. Hamilton)

Geologic-climate units (glaciations, interglaciations, stades, and interstades), defined in the previous stratigraphic code (American Commission on Stratigraphic Nomenclature, 1970, p. 31), have been abandoned by the North American Commission on Stratigraphic Nomenclature (1983, p. 849) and are now recognized as informal units.

The WALKER LAKE GLACIATION was named by Fernald (1964) and correlated through the southern Brooks Range by Hamilton (1982).

The unnamed paleosol has been radiocarbon-dated at Epiguruk bluff in the central Kobuk Valley (Ashley and Hamilton, 1984).

The ITKILLIK GLACIATION was named by Detterman (1953; Detterman et al., 1958) and later was redefined by Porter (1964) and Hamilton and Porter (1975). The separate stadial advances shown on the chart were recognized by Hamilton (1969) and Westgate et al. (1983).

The Old Crow Tephra and interstadial forest beds in the Koyukuk basin were described by Westgate et al. (1983).

The SAGAVANIRKTOK RIVER and ANAKTUVUK RIVER GLACIATIONS were termed the Sagavanirktok and Anaktuvuk Glaciations by Detterman (1953; Detterman et al., 1958). They later were renamed to avoid confusion with previously named rock-stratigraphic units (Keroher et al., 1966, p. 91 and 3379).

High terraces along the north flank of the Brooks Range were described and mapped by Hamilton (1980).

The Gunsight Mountain erratics were described and mapped by Hamilton (1979, 1980).

CORRELATION OF QUATERNARY DEPOSITS AND EVENTS IN THE AREA ADJACENT TO THE BEAUFORT SEA – A FIRST APPROXIMATION[1]

(COMPILED by J-S. VINCENT, -from data provided by S.M. Blasco, J.K. Brigham-Grette, L.D. Carter, N. Catto, D.A. Dinter, T.D. Hamilton, P.R. Hill, D.M. Hopkins, O.L. Hughes, J.V. Matthews, Jr., S.E. Rawlinson, N.W. Rutter, V.N. Rampton, C. Schweger, P.A. Smith and J-S. Vincent)

GENERAL CHRONOSTRATIGRAPHY (age in ka)			OXYGEN ISOTOPE STAGES	YUKON CORDILLERAN ICE SHEETS (O.L. Hughes)	YUKON BASINS (O.L. Hughes J.V. Matthews, Jr., N.W. Rutter and C. Schweger)	BROOKS RANGE AND BASINS TO SOUTH (T.D. Hamilton)	ALASKAN ARCTIC COASTAL PLAIN (J.K. Brigham-Grette, L.D. Carter, D.A. Dinter, D.M. Hopkins, S.E. Rawlinson and P.A. Smith)	YUKON COASTAL PLAIN AND MACKENZIE DELTA AND VALLEY (N. Catto, O.L. Hughes, V.N. Rampton and J-S. Vincent)	MACKENZIE DELTA OFFSHORE (P.R. Hill and S.M. Blasco)	WESTERN ARCTIC ISLANDS (J-S. Vincent)
LATE PLEISTOCENE	WISCONSINAN STAGE 115	LATE 23	2	McCONNELL GLACIATION = MACAULEY GLACIATION	Upper glaciolacustrine (12-30ka-^{14}C) Interstadial fluctuation? Hanging Lake interval (at about 18-20 ka-^{14}C)	WALKER LAKE GLAC. (13-24 ka-^{14}C)	Put River outwash and alluv. (9-15 ka-^{14}C); UNIT A marine wedge on middle and outer shelf (9-15 ka-^{14}C) Ikpikpuk sand sea Canning gravel	Sitidgi Lake stade = Tutsieta Lake phase (13 ka-^{14}C) HUNGRY CREEK GLAC. (16-25 ka-^{14}C)	*Sea level drop or standstill-Mackenzie Delta progradation in west and outwash plain in east (8.8 to 21.6 ka-^{14}C)* *Sea level rise from mid or early(?) Wisconsinan minimum* *Delta progradation in west (21.6 to 27.4 ka-^{14}C)*	AMUNDSEN GLACIATION (RUSSELL STADE) = PRINCE OFWALES FM (incl. SCHUYTER POINT SEA SEDS-12.6 to 9 ka-^{14}C; and PASSAGE POINT SEDS)
		MIDDLE 64	3	THOM CREEK INTERSTADIAL (28 ka-^{14}C) BOUTELLIER NONGLACIAL INTERVAL (29, >37 ka-^{14}C)	*Alternating warm and cold intervals within stage 5d to 3 and including*	*Unnamed paleosol* (24-34 ka-^{14}C)	Paleosols in Put River outwash and alluvium (24 and 43 ka-^{14}C); Ugnuravik sand marine UNIT B on middle and outer shelf	*Nonglacial beds* (33.8 and 36.9 ka-^{14}C)	*Outwash plain in east. off Tuktoyaktuk Peninsula*	*Unnamed interstadial* (>41 and >49 ka-^{14}C)
		EARLY	5d-4	Sheep Creek Tephra (>42 ka-^{14}C, 73, 78 ka-U/Th) Old Crow Tephra MIRROR CREEK GLACIATION = REID GLACIATION	Koy-Yukon Thermal Event Old Crow Tephra	ITKILLIK GLACIATION (Chebanika advance) *Forest beds* (>55 ka-^{14}C) Old Crow Tephra ITKILLIK GLACIATION (maximum advance)	SIMPSONIAN TRANSG. = FLAXMAN MEMBER of GUBIK FM (75 ka-Tl) = Cross Island Unit on inner shelf? = mid shelf deltas = UNIT C marine wedge (?)	Deception glaciation = BUCKLAND GLACIATION[2] = Toker Point stade (>35 and >39 ka-^{14}C) *Deformed ground ice* *Sabine grey member?*		AMUNDSEN GLACIATION (M'CLURE STADE) = PRINCE OF WALES FM (incl. MEEK POINT SEA SEDS. and EAST COAST SEA SEDS-51 ka-U/Th; CARPENTER, BAR HARBOUR, MERCY, SACHS and JESSE TILLS; and PRE AMUNDSEN SEA SEDIMENTS-106 ka-U/Th)
	SANGAMONIAN STAGE 128		5e			Bettles gravel	PELUKIAN TRANSG. (125 ka-Tl) = Walakpa Member of GUBIK FM = MCGUIRE ISLAND UNIT on inner shelf = UNIT E marine wedge = Ugnuravik gravel	*Sabine oxidized member?;* *Mason River driftwood (>38 and >39 ka-^{14}C)* *Maitland brown sand?* *Peel fluvial deposits?*		CAPE COLLINSON INTERGLAC. = CAPE COLLINSON FM (>61 ka-^{14}C and 83.3 ka-U/Th)
MIDDLE PLEISTOCENE 730					*Interlacustrine alluvium with multiple paleosols*	SAGAVANIRKTOK RIVER GLACIATION *Long interglacial*	WAINWRIGHTIAN TRANSG. (210 ka-Tl) = Karmuk Member of GUBIK FM (500 ka-Aa) = KOTZEBUAN TRANSG. = LEFFINGWELL LAGOON UNIT on inner shelf (?) = UNIT I marine wedge (?)	Mason River Glaciation Maitland thinly bedded silts? Maitland lower brown sands and silts? Peel gravels? Maitland clay		THOMSEN GLACIATION = NELSON RIVER FM (incl. BIG SEA SEDS. 116 and 118 ka-U/Th; KELLETT, BAKER and KANGE tills; and PRE THOMSEN SEA SEDS) MORGAN BLUFFS INTERGLAC. = MORGAN BLUFFS FM (>300 ka-U/Th)
EARLY PLEISTOCENE				KLAZA GLACIATION Fort Selkirk Tephra (.94 ma-Ft and 1.08 ma-KAr) NANSEN GLACIATION Klondike gravels Flat Creek beds White Channel gravels	Little Timber Tephra (~ 1.2 ma-Ft) Lower lacustrine (in Old Crow Basin) *Sands containing permafrost structures (in Bluefish Basin)*	ANAKTUVUK RIVER GLAC. *High terraces*	FISHCREEKIAN TRANSG. = Tuapaktushak Member of GUBIK FM(-?) BIGBENDIAN TRANSG. = Killi Creek Member of GUBIK FM(+) (1.7-2.2 ma-Aa, mammals) = ANVILIAN TRANSG. = OLDUVAI GEOMAGNETIC EVENT?			BANKS GLACIATION = DUCK HAWK BLUFFS FM (incl. POST BANKS SEA SEDS.; BERNARD, PLATEAU and DURHAM HEIGHT TILLS; and PRE BANKS SEA SEDS-*magnetically reversed in Duck Hawk Bluffs)* *Old erratics* ?
LATE TERTIARY					*Paleosol with extinct Larix minuta type. Picea and Pinus?*	Gunsight Mountain erratics	COLVILLIAN TRANSG. (<3.5 ma. -Pacific mollusks) = BERINGIAN TRANSG.? = Nulavik Member of GUBIK FM Erratics in Kuparuk gravel NUWOK FM = Papigak Clay			WORTH POINT FORMATION (*preglacial*) BEAUFORT FORMATION

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[1] a) Names in upper case letters are published and in the Alaskan columns are formal names that are published and/or have the approval of the USGS Geologic Names Committee.

b) Names in lower case are informal and in the Alaskan column, if formal, have not yet been published and do not have the approval of the USGS Geologic Names Committee.

c) Names and comments in italics are quite informal and are included for the sake of completeness of the chart.

d) It should be stressed that the correlation chart is a working document. Readers will note the lack of consistency in the nature of the units discussed. Few formally defined names of lithological units are used. Geologic-climate units (glaciations, interglaciations, stades, and interstades) are used even though these have been abandonned by the North American Commission on Stratigraphic Nomenclature, and are now recognized only as informal units.

[2] According to Hughes, the Buckland Glaciation is correlative with the Hungry Creek Glaciation.

Aa age estimate from amino acid analyses
^{14}C age estimate from radiocarbon analyses
Ft age estimate from fission track analyses
Tl age estimate from thermoluminescence analyses
U/Th age estimate from Uranium-Thorium analyses
(+) magnetically normal
(-) magnetically reversed

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Alaskan Arctic Coastal Plain (D.M. Hopkins)

Formal names in upper case are published or have the approval of the United States Geological Survey Geologic Names Committee (GNC). Names in lower case are informal or, if formal, have not yet been published and do not have the approval of the GNC.

Outwash, alluvium, and paleosols in Put River (= Putuligayuk River) gravel pits near Prudhoe Bay are described by Hopkins et al. (1980).

Marine wedges A and B on the outer Beaufort Sea shelf are described by Dinter (in press).

The Ikpikupuk sand sea (new name) is described in Carter (1981, 1983a).

The GUBIK FORMATION was redefined most recently by Black (1964). Although Black considered the GUBIK FORMATION to be entirely of Quaternary age, the lower part is now known to be at least 2 Ma (Repenning, 1983) and thus is of Pliocene age.

The FLAXMAN MEMBER was originally described as "The FLAXMAN FORMATION" by Leffingwell (1919), and is redefined as the FLAXMAN MEMBER of the GUBIK FORMATION by Dinter (in press).

The Walakpa, Karmuk, Tuaptushak, Killi Creek, and Nulavik members of the GUBIK FORMATION are proposed and defined by Brigham (in prep.).

The MCGUIRE ISLAND and LEFFINGWELL LAGOON units are named by Smith (in press).

The PELUKIAN, KOTZEBUAN, ANVILIAN, and BERINGIAN TRANSGRESSIONS are defined by Hopkins (1967).

The Teshekpuk, Cape Simpson, Fishcreekan, Colvillean II and Colvillean I transgressions are named by Carter and Brigham-Grette (this volume, Section 9).

The erratics in the informally-named Kuparuk gravel are reported in Carter (1983b).

The NUWOK FORMATION was named by MacNeil (1957).

The Papigak Clay is named by Brigham (in prep.).

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– Late Quaternary geology of the Beaufort inner shelf near Prudhoe Bay; in United States Geological Survey in Alaska: Accomplishments during 1983; U.S. Geological Survey Circular (in press).

Yukon Coastal Plain and Mackenzie Delta and Valley (V.N. Rampton)

Sitidgi Lake Stade, Toker Point Stade, Mason River driftwood, Maitland brown sand, Mason River Glaciation, Maitland thinly bedded silts, Maitland lower brown sands and silts, and Maitland clay are being described in a Geological Survey of Canada publication on the Tuktoyaktuk Coastlands by V.N. Rampton (in press). In this document the Maitland brown sand is equivalent to the Upper Sandy Member of the Stanton Sediments; the Maitland thinly bedded silts are equivalent to the Thinly Bedded Member of the Stanton Sediments; the Maitland lower brown sands and silts are equivalent to the Lower Complex Member of the Stanton Sediments; the Maitland clay is equivalent to the Basal Clay Member of the Stanton Sediments or the informally named Baillie clay.

The Buckland Glaciation is defined in Rampton (1982) as are other elements of the Yukon Coastal Plain stratigraphy. The Sabine grey member and Sabine oxidized member are informal units that are based on an unpublished review of the coastal stratigraphy by J.V. Matthews, Jr., J-S. Vincent and V.N. Rampton in 1983.

The Tutsieta Lake phase is defined in Hughes (in preparation). The Hungry Creek Glaciation is defined in Hughes et al. (1981). The Deception glaciation, Peel fluvial deposits and Peel gravels are defined by Catto (in preparation) on the basis of stratigraphy east of the Richardson Mountains, exposed along the Peel River and its tributaries.

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Mackenzie Delta Offshore (no notes provided).

Western Arctic Islands (J-S. Vincent)

The names used in this column have all been proposed by Vincent (1983). Both geologic-climate unit and lithostratigraphic unit names are used.

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Energy, Mines and
Resources Canada

Énergie, Mines et
Ressources Canada