14TH ARCTIC WORKSHOP
ARCTIC LAND-SEA INTERACTION

6-8 November, 1985

Bedford Institute of Oceanography,
Dartmouth, Nova Scotia, Canada

G.S.C. OPEN FILE 1223

November, 1985

SPONSORED BY:

Arctic Institute of North America (AINA)
Centre for Cold Ocean Resources Engineering (C-CORE)
Geological Survey of Canada (GSC)
Institute of Arctic and Alpine Research (INSTAAR)
Norske Polar Institutt (NPI)
Ocean Science and Surveys (OSS)
Scott Polar Research Institute (SPRI)

STEERING COMMITTEE:

G. Vilks, Chairman
J.P.M. Syvitski, Technical Program
I.A. Hardy, Social Events/Secretary
E.P.W. Horne, Treasurer
D.H. Loring, Posters
R.B. Taylor, Field Excursions
R.W. Trites, Publications

TABLE OF CONTENTS

INTRODUCTION

On a cold blustery September day, in 1983, a group of scientists sat casually around the conference room on board the C.S.S. HUDSON. The ship had just retrieved its two Boston Whalers that had been used to ferry survey teams ashore and another two profiling/sampling launches. The mood in the room was good as the ship rock 'n rolled its way to the next fjord up the Baffin Island coast. As icebergs streamed across the porthole windows, the theme of Arctic Land-Sea Interactions was conceived as a possibility for the 14^{th} Arctic workshop.

Normally sponsored and hosted by the Institute of Arctic and Alpine Research (INSTAAR), Boulder, CO, past workshops have promoted communication among scientists and students engaged in a wide range of scientific activity in the cold regions. This, the 14^{th} workshop, deviates in a number of ways. First, by being held at BIO, the workshop continues the recent alternation of meeting locations between INSTAAR and other arctic institutes. Second, the timing of the meeting was changed to allow maximum participation of marine scientists, who at other times may still be riding the high seas. Third, this workshop is in one sense more focussed through the implementation of a theme, yet in another sense is broadened through the joint sponsorship with other international arctic establishments and associations.

The theme reflects research activity in the arctic nearshore zone in response to exploitation pressures and associated environmental concerns. The workshop organizers felt that by the fall of 1985 a number of activities on the Beaufort Shelf, Baffin Island fjords, Labrador shelf, Spitsbergen and the Canadian Arctic Archipelago would have reached a reporting stage on the workshop theme. This volume substantiates our hopes with ≈ 90 abstracts covering a menagerie of arctic land/seascapes. Topics range from marine geology, glaciology, paleontology, archeology and marine biology.

We gratefully acknowledge the financial support of the Department of Energy, Mines and Resources and the Bedford Institute of Oceanography, and the Arctic Petroleum Operators Association.

Cheers

Gustavs Vilks and James Syvitski

PROGRAM SCHEDULE

WEDNESDAY, November 6, 1985 AM

0830-0840 DR. A.R. LONGHURST, Director-General OSS Atlantic Region WELCOMES PARTICIPANTS

Permafrost Deltas and Shelves

Chaired by: S.M. Blasco and H.J. Walker

TIME	Page	
0840-0900	18	NATURE AND PRESERVATION OF SUPERPOSED TRANSGRESSIVE/ REGRESSIVE SEQUENCES ON THE NW COAST OF ALASKA Julie Brigham-Grette
0900-0920	22	HIGH SEA LEVEL ALONG THE ALASKAN ARCTIC COAST ABOUT 70 OR 80 KA: EVIDENCE FOR AN ANTARCTIC ICE-SURGE? L.D. Carter, J.R. O'Neil and J.J. Stipp
0920-0940	25	LATE CENOZOIC STRATIGRAPHY OF THE BEAUFORT SEA INNER SHELF NEAR PRUDHOE BAY, ALASKA Peggy A. Smith
0940-1000	29	RECORDS OF QUATERNARY SEA LEVEL LOWSTANDS PRESERVED BENEATH THE ALASKAN BEAUFORT SHELF David A. Dinter
1000-1020	33	SEISMIC STRATIGRAPHY OF THE LATE QUATERNARY INNER- SHELF FROM PRUDHOE BAY TO DEMARCATION POINT, ALASKA S.C. Wolf, Erk Reimnitz and P.W. Barnes
1020-1040	37	SEDIMENT REWORKING, TRANSPORT AND DEPOSITION ON THE ALASKAN BEAUFORT SHELF: THE ROLE OF ICE, IN RELATION TO WAVES, CURRENTS AND INFAUNA Peter W. Barnes and Erk Reimnitz
1040-1100	41	PALEOGEOGRAPHIC SIGNIFICANCE OF TEXTURES OF COLVILLE DELTAIC SEDIMENTS, NORTH ARCTIC ALASKA A. Sathy Naidu

WEDNESDAY, November 6, 1985 AM

Permafrost Deltas and Shelves

TIME	Page	
1100-1120	42	THE ROLE OF ICE IN CONTROLLING SEDIMENTATION ON THE YUKON DELTA William R. Dupré
1120-1140	44	LAND EVIDENCE FOR LATE CENOZOIC SEA LEVEL FLUCTUATIONS IN AREAS ADJOINING THE BEAUFORT SEA IN THE WESTERN CANADIAN ARCTIC Jean-Serge Vincent
1140-1200	48	A PRELIMINARY ASSESSMENT OF THE OCCURRENCE AND DISTRIBUTION OF SUBSEA PERMAFROST IN NORTON SOUND T.E. Ostercamp, W.D. Harrison and D.M. Hopkins

WEDNESDAY, November 6, 1985 PM

Arctic Fjords

Chaired by: G. Boulton

TIME	Page	
1340-1400	51	ON THE ORIGIN OF HIGH ARCTIC FIORDS J. England
1400-1420	54	OCEANOGRAPHIC RECONNAISSANCE OF SELECTED BAFFIN ISLAND FJORDS Ron Trites
1420-1440	58	DETRITAL CARBONATE ACCUMULATION ON THE SHELF AND IN THE FIORDS, BAFFIN ISLAND, EASTERN CANADIAN ARCTIC J.T. Andrews
1440-1500	59	GEOCHEMICAL INDICATORS OF DEPOSITIONAL ENVIRONMENT IN BAFFIN ISLAND FIORDS D.E. Buckley and R.A. Fitzgerald
1500-1520	60	SUBAQUEOUS SLOPE FAILURES WITHIN SESMICALLY ACTIVE ARCTIC FJORDS J.P.M. Syvitski
1520-1540	64	CONTRASTS IN SEDIMENT MASS TRANSPORT AND DEPOSITIONAL PROCESSES IN TWO BRITISH COLUMBIA FJORDS David B. Prior and Brian D. Bornhold
1540-1600	68	INTERTIDAL SEDIMENTATION IN HIGH ARCTIC FIORDS, EAST-CENTRAL ELLESMERE ISLAND M.T. Krawetz and S.B. McCann
1600-1620	72	CONTRASTS IN FORM AND SEDIMENT DISTRIBUTION BETWEEN SOME GLACIOMARINE FJORDS - SPITSBERGEN AND BAFFIN ISLAND I.J.M. Van der Meer and G. Boulton
1620-1640	73	DISTRIBUTION AND DYNAMICS OF SUSPENDED PARTICULATE MATTER IN BAFFIN ISLAND FJORDS G.V. Winters, J.P.M. Syvitski and L. Maillet

WEDNESDAY, November 6, 1985 PM

Arctic Coastal Lakes

Chaired by: Bruno D'Anglejan

TIME	Page	
1640-1700	78	AEOLIAN PROCESSES, CONTROLS AND FEATURES IN THE EASTERN CANADIAN ARCTIC Cheryl McKenna-Newman and Robert Gilbert
1700-1720	82	LAKE LINNEVATNET, SVALBARD, A POSSIBLE 40,000 YEARS CONTINUOUS RECORD OF LACUSTRINE AND MARINE SEDIMENTATION Jan Mangerud, Jon Landvik, Otto Salvigsen and Gifford Miller
1720-1740	86	ISOTOPIC COMPOSITION OF LACUSTRINE BRINES IN COASTAL AREAS OF THE CENTRAL CANADIAN ARCTIC Pierre Pagé
1740-1800	88	STRATIGRAPHY AND SEDIMENTOLOGY OF HIGH ARCTIC COASTAL LAKE BASINS NORTHERN ELLESMERE ISLAND, NORTH WEST TERRITORIES Michael J. Retelle

THURSDAY, November 7, 1985

Tidewater Glaciers and Iceberg Dynamics

Chaired by: A. Elverhoi and D. Drewry

TIME	Page	
0840-0900	90	ICEBERG PITS: DESCRIPTION AND POSTULATED ORIGIN J.V. Barrie and W.T. Collins
0900-0920	91	ICEBERG SCOURING IN HUDSON BAY S. Whittaker, B. Chevelier & Hawk Geerlott
0920-0940	92	DIGS-85: DYNAMICS OF ICEBERG GROUNDING AND SCOURING: OBSERVATIONS OF ICEBERG SCOUR MARKS BY MANNED SUBMERSIBLE H.W. Josenhans, J.V. Barrie, C.M.T. Woodsorth, A. Lynas and D.R. Parrott
0940-1000	93	DIGS-85: DYNAMICS OF ICEBERG GROUNDING AND SCOURING; ICEBERG AND SEABED MAPPING OBSERVATIONS C.F.M. Lewis, D.R. Parrott, J.H. Lever, D. Diemand, M. Dyke, W.J. Carter and A.F. Stirbys
1000-1020	94	PUMPING AWAY TIDE WATER GLACIERS AND ICE SHELVES E.L. Lewis
1020-1040	97	SEDIMENTARY AND MORPHOLOGICAL FEATURES OF A LATE WEICHSELIAN SHALLOW GLACIOMARINE SEQUENCE IN THE CENTRAL NORTH SEA A.J. Bent
1040-1100	101	ICEBERG CALVING AND ITS INFLUENCE ON ICE-PROXIMAL SUBAQUEOUS GLACIGENIC LITHOFACIES Ross D. Powell

THURSDAY, November 7, 1985 AM

Tidewater Glaciers and Iceberg Dynamics

Chaired by: A. Elverhoi and D. Drewry

THURSDAY, November 7, 1985 PM

Beaches and Coasts

Chaired by: E.H. Owens and S.B. McCann

TIME	Page	
1320-1340	110	MORPHOLOGY AND PROCESSES OF THE CANADIAN BEAUFORT SEA COAST John R. Harper, Arene Collins and P. Douglas Reiner
1340-1400	112	AN INTEGRATED APPROACH TO STUDIES OF THE PHYSICAL ENVIRONMENT OF THE NEARSHORE ARCTIC COAST OF ALASKA William G. Benjey
1400-1420	115	GROUND ICE SLUMPS, BEAUFORT SEA COAST, YUKON TERRITORY David G. Harry
1420-1440	118	THE ERODING COAST OF THE ALASKAN BEAUFORT SEA, ITS SEDIMENT SUPPLY AND SINKS E. Reimnitz, S.M. Graves and P.W. Barnes
1440-1500	121	ARCTIC AIR QUALITY STUDY IN THE BEAUFORT REGION F. Fanaki, B. Martin and J. Markes
1500-1520	125	COASTAL DUNE FORMATION - AN EFFECT OF THE LAND-SEA INTERACTION UNDER THE NEW GLACIAL ARCTIC CLIMATE Ying Wang and Da-Kuei Zhu
1520-1800		**POSTER SESSION** Chaired by: D. Loring

FRIDAY, November 8, 1985 AM

Archeology

Chaired by: W.W. Fitzhugh

TIME	Page	
0840-0900	128	ARCHAEOLOGICAL IMPLICATIONS OF ISOSTATIC ADJUSTMENT IN NORTHERN LABRADOR J. Peter Johnson, Jr.
0900-0920	129	CLIMATIC CONDITIONS IN SOUTHEASTERN LABRADOR-UNGAVA DURING THE EARLY HOLOCENE George A. King

FRIDAY, November 8, 1985 AM

Transgression - Regression of Sea Level

Chaired by: J.T. Andrews and D.J. Mangerund

TIME	Page	
0920-0940	131	CORRELATION OF LATE QUATERNARY EVENTS: TORNGAT MOUNTAINS AND LABRADOR SHELF Peter Clark, Heiner Josenhans and W.D. McCoy
0940-1000	133	LATE QUATERNARY ONSHORE/OFFSHORE STRATIGRAPHIC CORRELATION AND GLACIAL RECONSTRUCTION, SOUTHERN BAFFIN ISLAND, ARCTIC CANADA Jay A. Stravers
1000-1020	136	ONSHORE-OFFSHORE CORRELATION - NORTHERN LABRADOR H.W. Josenhans, A. Jennings, P. Clark, T. Bell and R. Rodgerson
1020-1040	137	EVIDENCE FOR A LATE WISCONSINAN LOW SEA LEVEL STAND OF 100-200M FROM THE SCOTIAN SHELF OF THE GRAND BANKS OF NEWFOUNDLAND Gordon Fader
1040-1100	139	LATE WEICHSELIAN AND HOLOCENE RELATIVE SEA LEVEL HISTORY OF BROGGERHALVOYA, SPITSBERGEN Steven L. Forman, Darriel H. Maun and Gifford H. Miller
1100-1120	140	SEA LEVEL CHANGE AND THE LATE WISCONSINAN GREENLAND ICE SHEET Svend Funder
1120-1140	144	LAND-SEA INTERACTIONS IN AN ARCTIC MARINE LOW ENERGY ENVIRONMENT, NORTHERN ELLESMERE ISLAND, N.W.T., CANADA Lorenz King

FRIDAY, November 8, 1985 AM

Transgression - Regression of Sea Level
Chaired by: J.T. Andrews and D.J. Mangerund

TIME	Page	
1140-1200	145	THE INFLUENCE OF SEA-LEVEL FLUCTUATIONS, DISCHARGE VARIATIONS AND SEA CONDITIONS ON ARCTIC DELTA FORMATION: EXAMPLES FROM BAFFIN ISLAND J.P.M. Syvitski
1200-1220	150	GLACIO-MARINE OUTWASH DELTAS, ICE RETREAT AND STABLE ICE FRONTS IN THE NORTH EASTERN COASTAL REGIONS OF UGAVA James Gray, Bernard Lauriol and Jean Ricard
1220-1240	154	PAST, PRESENT, AND FUTURE RELATIVE SEA LEVEL CHANGE IN HUDSON BAY Harvey Thorleifson

FRIDAY, November 8, 1985 PM

Climate-water circulation interactions

Chaired by: C.T. Schafer and T.B. Kellogg

TIME	Page	
1340-1400	155	THE FORMATION OF ARCTIC OCEAN HALOCLINE PROPERTIES BY CONTINENTAL SHELF PROCESSES Peter Jones and L.G. Anderson
1400-1420	157	FACTORS AFFECTING THE EXTENT OF THE FAST ICE COVER IN SOUTH-EASTERN HUDSON BAY P. Larouche and P. Galbraith
1420-1440	160	DIATOMS AS SEA-ICE INDICATORS? Kerstin M. Williams
1440-1500	161	GLACIAL-INTERGLACIAL CHANGES IN GLOBAL DEEP-WATER CHARACTERISTICS Thomas B. Kellogg
1500-1520	162	LATE QUATERNARY PALEOCEANOGRAPHY OF BAFFIN ISLAND CONTINENTAL SHELF: BENTHIC FORAMINIFERAL EVIDENCE Lisa Osterman
1520-1540	164	LATE QUARTERNARY HISTORY OF A FIORD/SHELF TRANSECT, NORTH EASTERN BAFFIN ISLAND Anne E. Jennings
1540-1600	166	GLACIAL STYLE AND OCEANIC CONTROLS ON GLACIATION OF WESTERN SPITSBERGEN, SWALBARD ARCHIPELAGO Gifford H. Miller, Hans Petter Sejrup, Scott Lehman and Steven Forman

FRIDAY, November 8, 1985 PM

Climate-water Circulation Interactions

Chaired by: C.T. Schafer and T.B. Kellogg

TIME	Page	
1600-1620	168	ISOTOPIC EVIDENCE REGARDING THE NATURE OF THE LAST THREE DEGLACIAL HEMI-CYCLES ON WEST SPITSBERGEN, SALBARD S.J. Lehman, H.P. Sejrup and G.H. Miller
1620-1640	173	DINOFLAGELLATE AND POLLEN STRATIGRAPHY IN EASTERN CANADA WITH SPECIAL EMPHASIS ON THE MIDDLE WISCONSINAN EPISODE A. de Vernal and C. Hillaire-Marcel

FRIDAY, November 8, 1985 PM

Terrestrial and Marine Ecosystem Interactions

Chaired by: S. Short

TIME	Page	
1640-1700	177	ANIMAL-SEDIMENT RELATIONSHIPS ON AN ARCTIC TIDAL FLAT: PANGNIRTUNG, BAFFIN ISLAND, N.W.T. Alec E. Aitken, M.J. Risk and J.D. Howard
1700-1720	178	COMPARISON OF MODERN AND SUBFOSSIL MYA TRUNCATA FROM PANGNIRTUNG, N.W.T. Alec E. Aitken and M.J. Risk
1720-1740	179	USE OF STABLE ISOTOPES OF CARBON AND NITROGEN TO ASSESS IMPORTANCE OF TERRESTRIAL DETRITUS TO A MARINE FOOD WEB: INTERTIDAL FLATS AT PANGNIRTUNG, BAFFIN ISLAND, N.W.T. James P. Magwood, M.J. Risk and H.P. Schware
1740-1800	180	PHYSICAL AND BIOLOGICAL ZONATION OF INTERTIDAL FLATS AT FROBISHER BAY, N.W.T. Janis E. Dale

POSTERS

Chaired by: D. Loring

PAPER ABSTRACTS

NATURE AND PRESERVATION OF SUPERPOSED TRANSGRESSIVE/REGRESSIVE SEQUENCES ON THE NW COAST OF ALASKA

Julie Brigham-Grette

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

The Gubik Formation across the western Arctic Coastal Plain of Alaska consists, in large part, of lagoon, beach, and inner to central shelf marine sediments that record six high sea level events that occurred during late Pliocene and Pleistocene time (Brigham, 1985). The oldest of these events occurred shortly after the mid-Pliocene submergence of the Bering Straits and the youngest event records a high sea stand some 70-80 ka (Carter and Brigham-Grette, in press). Sediments of the Gubik Formation are best known along the Chukchi coast between Peard Bay and Barrow where sea bluffs up to 23 m asl and over 70 km in length expose the most complete sequence of unconsolidated marine deposits known on the North Slope. Moreover, these bluffs are now recognized as the only area in Alaska, and probably in northwestern North America where all of the known Pliocene, early and middle Pleistocene marine transgressive units are present and exposed in superposition. Study of the character and preservation of these transgressive/regressive marine sequences in an area of little tectonic activity provides invaluable insight into the nature and complexity of similar sequences now being cored and mapped by seismic methods on the continental shelf of the Alaskan and Canadian Beaufort Seas (e.g., Dinter, 1985).

Sediments of the Gubik Fm. can be subdivided into eight primary depositional environments that are independent of chronology: 5 are of marine or marginal marine and 3 are of non-marine origin. Each depositional environment is distinguished on the basis of broad textural characteristics and primary sedimentary structures, in concert with paleontological information assembled concerning the habitat requirements of the enclosed micro- and macrofaunas and analogues with the modern beach, nearshore, and shelf environments. These environments include:
(1) basal gravel/cobble lag deposits composed of sandy silty gravel or cobble gravel formed by migrating shoreface erosion during transgression. Lag deposits commonly include erratic clasts;
(2) inner to central shelf deposits most commonly composed of fine interbeds of moderately well-sorted medium to fine sand, silty sand, clayey silt, and silty clay locally supporting dropstones. These deposits represent deposition offshore in water generally more than 10 m deep. Evidence of secondary folds and contorted beds is common;
(3) beach, longshore bar, and barrier island deposits composed of well cross-bedded coarse, cobbly gravel and coarse to medium sand. These deposits mark the peak of the transgression and are preserved by abandonment during sea level regression;

(4) lagoonal deposits composed of horizontal to finely rippled silty sand and silt, commonly containing Macoma balthica, that accumulated behind barrier island systems and in protected bays;
(5) tidal delta deposits composed of large-scale bidirectionally planar cross-bedded to trough cross-bedded fine pebbles, coarse to medium sand, and detrital coal thought to represent storm and/or wave-induced sediment exchange between barrier islands;
(6) eolian deposits preserved as thin sand sheets and small dunes of medium to fine-grained sand that accumulated predominately during cooler, drier glacial periods (cf, Carter, 1981);
(7) thaw lake deposits consisting of sand and silty sand containing fresh water ostracodes and interbedded with stringers and clots of detrital peat, in places commonly crosscut by ice wedge pseudomorphs formed subsequent to lake drainage; and finally
(8) fluvial deposits of gravel and sand deposited by rivers draining the western arctic coastal plain.

As a result of the late glacial/Holocene transgression, unconsolidated sediments on the open shelf adjacent to the Chukchi sea coast today are thin and limited to less than a few meters thickness within 10 km of shore (Phillips and others, 1984). Only in areas of divergent currents or eddy systems where velocities diminish, e.g., off Point Franklin or Icy Cape, does sediment accumulate to thicknesses of 10 to 15 m. Similarly, unconsolidated sediments inland across the western Arctic Coastal Plain are also thin, in places preserved only as linear patches of beach gravel or a veneer of eolian sand. In exposures along Skull Cliff between Barrow and Peard Bay, the Gubik Fm. reaches a maximum thickness of only 17.5 meters over Cretaceous bedrock where as many as three transgressive episodes are recorded in superposition. More typical are sediment thicknesses of 8 to 10 m representing one or two transgressions, in turn overlain by 0.5 to 2 m of eolian sand or thaw lake deposits. The erosional capacity of the late glacial/Holocene transgression probably provides a suitable analogue to the amount of shoreface erosion that took place during previous transgressions, leaving at best only a thin veneer of older sediments preserved over the undulating bedrock surface. Moreover, this transgression demonstrates that the inital sediment cover following submergence can be extremely thin and limited to a lag gravel or sand on scoured bedrock.

Where several transgressions are found superimposed, the vertical sequence most commonly consists of a basal unconformity or shoreface erosional surface upon which is found a gravel or sandy gravel lag that grades vertically into interbedded shelf deposits that range from one to several meters in thickness. These beds can be locally deformed and contorted either by grounded ice or soft sediment deformation and may support large clasts thought to be dropstones. These sediments are in turn truncated by an second basal unconformity or shoreface erosional surface upon which are deposited lag deposits and shelf sediments of a younger transgression. Pockets of marine shells found on unconformities or scattered shells incorporated into lag deposits always yield amino acid ratios similar to those determined on shells enclosed within the overlying shelf deposits. This observation indicates that major erosional unconformities do not exist within shelf sediments of the same age. Unconformities between marine shelf deposits in some sections can be limited to a scattering of pebbles or abrupt to gradational changes in lithology, depending upon the erodibility of the underlying sediment or bedrock. Lateral tracing of these unconformities and amino acid data determined on mollusks from the marine sediments confirm that the variable depth of erosion during subsequent transgressions was sufficent to remove locally all evidence of the deposits recording one or several older marine events. For example in some sections, shelf sediments of the middle Pleistocene Karmuk Mbr. lie directly on bedrock or shelf sediments of the late Pliocene Killi Creek Mbr. and the intervening Tuapaktushak Mbr. is missing. Such stratigraphic incision along Skull Cliff has removed most of the evidence of beach or barrier island lithosomes or other regressive deposits that may have accompanied past transgressive/regressive migrations of the Chukchi shoreline. Exceptions include beach, barrier island, and lagoon deposits of the last interglacial Walakpa Mbr. and the younger Flaxman Mbr. that have not been subsequently submerged, in addition to tidal delta sediments that at one location form part of the middle Pleistocene Karmuk Mbr. In general, beach, barrier island, and barrier bar lithosomes form part of the transgressive stratigraphic record of the Gubik Formation only where they are preserved by abandonment following the peak of the sea level rise (cf, Demarest and Kraft, 1984; Belknap and Kraft, 1985).

Only in a few places has it been possible to identify remnants of a former tundra surface (such as eolian sand, sand wedges, ice wedge pseudomorphs, and thaw lake deposits) between marine units. At one location along the Kokolik River, some 140 km southwest of Skull Cliff, several ice wedge pseudomorphs are found preserved in fluvial deposits where they are overlain by lagoonal deposits that help delineate the inland extent of the middle Pleistocene Karmuk Mbr. at 20 to 23 m asl. These fluvial deposits escaped shoreface incision when sea level subsequently dropped about 500 ka and has not since reoccupied this level.

The stratigraphy of the deposits and associated discontinuities observed in the Gubik Fm. west of Barrow generally conforms to preservation models proposed for areas along the U.S. Atlantic and Gulf coasts (cf, Belknap and Kraft, 1981; Penland and others, 1985; Synder and others, 1985). Differential preservation of the inner and central shelf sequences exposed at Skull Cliff and elsewhere was dependent upon the depth of erosion and incision along the migrating shoreface which in most cases, <u>but not all</u>, exceeded the depth of the former land surface developed on older marine units and/or bedrock during low sea level stands. It remains to be understood how differences in sediment supply, the rate of sea level rise, and other factors allowed shelf sediments to accumulate during earlier high sea level events in contrast to conditions on the open shelf of the Chukchi Sea today.

REFERENCES:

Belknap, D.F., and Kraft, J.C., 1985, Influence of antecedent geology on stratigraphic preservation potential and evolution of Delaware's barrier systems, Marine Geol., 63, 235-262.

______________________________, 1981, Preservation potential of transgressive coastal lithosomes on the U.S. Atlantic Shelf, Marine Geol., 42, 429-442.

Brigham, J.K., 1985, Marine stratigraphy and amino acid geochronology of the Gubik Formation, NW Arctic Coastal Plain, Alaska, [PhD Dissertation], University of Colorado, Boulder, 316p.

Carter, L.D., 1981, A Pleistocene sand sea on the Alaskan Arctic Coastal Plain, Science, 211, 381-383.

____________, and Brigham-Grette, J., in press, Late Cenozoic marine transgressions on the Alaskan Arctic Coastal Plain, GSC paper "Correlation of Quaternary deposits and events around the margin of the Beaufort Sea", Contibutions from the Joint Canadian-American Workshop, April 3-4, Calgary, Alberta.

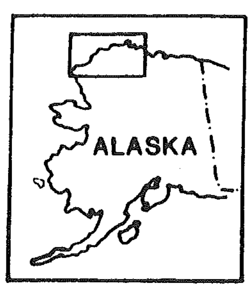
Demarest, J.M., and Kraft, J.C., 1984, Stratigraphic record of Quaternary sea levels: implications to more ancient strata, SEPM Annual Meetings, Abst.,p. 25.

Dinter, D.A., 1985, Quaternary sedimentation of the Alaskan Beaufort Shelf: influence of regional tectonics, fluctuating sea levels, and glacial sediment sources, Tectonophysics, 114,133-161.

Penland, S.,Suter, J.R., and Boyd, R., 1985, Barrier island arcs along abandoned Mississippi River deltas, Marine Geol., 63, 197-233.

Phillips, R.L., Reiss, T.E., Kempema, E., Reimnitz, E., 1984, Nearshore marine geologic investigations, northeast Chukchi Sea, Wainwright to Skull Cliff, U.S. Geological Survey Open-File Report 84-108, 33p.

Synder, S.W., Hine, A.C., and Belknap, D.F., 1984, Stratigraphic consequences of an erosional transgression: A Holocene model applied to the Quaternary record, SEPM Annual Meetings, Abst., p.76.



HIGH SEA LEVEL ALONG THE ALASKAN ARCTIC COAST ABOUT 70 OR 80 KA: EVIDENCE FOR AN ANTARCTIC ICE-SURGE?

CARTER, L.D., U.S. Geological Survey, 4200 University Drive, Anchorage, AK, USA 99508-4667; O'NEIL, J.R., U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025; and STIPP, J.J., Department of Geology, University of Miami, Miami, FL 33124

Two late Pleistocene marine transgressions of contrasting character are recorded by deposits of the Alaskan Arctic Coastal Plain. Shoreline deposits of the older transgression provide a datum for the interpretation of sea level during the younger transgression.

The older deposits extend from Harrison Bay westward to near Barrow. They formed during interglacial conditions as documented by a fauna that indicates more open water and warmer climatic conditions than exist at present (Hopkins and others, 1981). Amino acid ratios determined for shells of the bivalve *Hiatella arctica* collected from these deposits are barely distinguishable from those determined for modern specimens (Brigham and Miller, 1983), and preclude an age greater than the last interglacial episode. Oxygen isotope compositions of shells of the bivalve *Astarte borealis* are about the same as those of modern *A. borealis* shells suggesting a correlation with oxygen isotope stage 5e. This correlation is supported by 8 thermoluminescence (TL) dates on the sediments that average 125 ka. Sedimentary structures characteristic of the surf and swash zones occur at altitudes within the commonly accepted range (6 +/- 4 m) for eustatic sea level at that time (Cronin and others, 1981), showing that this part of the coastal plain has been tectonically stable for the past 125,000 years.

Deposits of the younger transgression are glaciomarine sediments that contain ice-rafted erratics of Canadian provenance (Rodeick, 1979). They compose the Flaxman Member of the Gubik Formation and occur along the Beaufort Sea coast and inland to altitudes of about 7 m. Locally, they disconformably overlie deposits of the older transgression. Erratics occur to within a few hundred meters 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) collected from these deposits indicate that a connection with the Bering Sea existed at this time. The mollusk fauna is depauperate and includes no extralimital species (Hopkins and others, 1981). A near-absence of shoreline features suggests that this transgression was much briefer than the interglacial transgression described above. Ten TL dates on sediment samples of the Flaxman Member average 72.4 ka and a uranium-series date on whale bone found in the Flaxman deposits is 75 ka (J. L. Bischoff, written communication, 1984).

Because the western part of the Arctic Coastal Plain has been tectonically stable for the past 125,000 years, the altitude of the Flaxman deposits cannot be attributed to tectonism. Furthermore, marine deposits exposed near sea level on the Atlantic Coastal Plain also were deposited about 75 ka (Cronin and others, 1981; Cronin and others, 1984; Szabo, 1985), suggesting that high sea level on the Arctic Coastal Plain was not a result of local factors but represents a global eustatic sea level that was 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, indicating that there was more glacial ice during this transgression than there is today. Oxygen isotope data from deep sea cores for this time interval also indicate large volumes of glacial ice (Ruddiman and McIntyre, 1979).

Cronin and others (1984) proposed that the paradox of high sea level 75 ka contemporaneous 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. A possible mechanism to provide a large volume of floating glacial ice would be an Antarctic 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 marine-based ice over the central Canadian Shield (Denton and Hughes, 1983). Recent studies of the amino acid geochemistry of fossil marine mollusk shells in the Hudson Bay region suggest that the Hudson Bay Lowlands were evacuated of Laurentide ice and inundated by marine waters about 75 ka (Andrews and others, 1983).

References

Andrews, J.T., Shilts, W.W., and Miller, G.H., 1983, Multiple deglaciations of the Hudson Bay Lowlands, Canada, since deposition of the Missinaibi (last Interglacial?) Formation: Quaternary Research, v. 19, no. 1, p. 18-37.

Brigham, J.K., and Miller, G.H., 1983, Paleotemperature estimates of the Alaskan Arctic Coastal Plain during the last 125,000 years: Fourth International Conference on Permafrost, Fairbanks, July 18-22, 1983, Proceedings, Washington, D.C., National Academy Press, p. 80-85.

Cronin, T.M., Szabo, B.J., Ager, T.A., Hazel, J.E., and Owens, J.P., 1981, Quaternary climates and sea levels of the U.S. Atlantic Coastal Plain: Science, v. 211, p. 233-240.

Cronin, T.M., Ager, T.A., Szabo, B.J., Rosholt, John, and Shaw, E.G., 1984, Cold climates - high sea level: Interglacial deposits of the North Carolina Coastal Plain: American Quaternary Association Eighth Biennial Meeting, Program and Abstracts, August 13-15, 1984, p. 28.

Denton, G.H., and Hughes, T.J., 1983, Milankovitch theory of ice ages: Hypothesis of ice-sheet linkage between regional insolation and global climate: Quaternary Research, v. 20, p. 125-144.

Hollin, J.T., 1982, Rapid transgressions and cooling in isotope stage 5: Program and Abstracts, Seventh Biennial Conference, American Quaternary Association, June 28-30, 1983, Seattle, Washington, p. 44-46.

Hopkins, D.M., 1982, Abortive glaciaions at high latitudes indicated by glaciomarine deposits, Gubik Formation, northern Alaska: Geological Society of America Abstracts with Programs, v. 14, no. 7, p. 518.

Hopkins, D.M., McDougall, Kristin, and Brouwers, Elizabeth, 1981, Microfossil studies of Pelukian and Flaxman deposits, Alaska coast of the Beaufort Sea, <u>in</u> Smith, P.A., Hartz, R.W., and Hopkins, D.M, Offshore permafrost studies and shoreline history as an aid to prediciting offshore permafrost conditions: U.S. National Oceanic and Atmospheric Administration, Environmental Assessement of the Alaskan Continental Shelf, Annual Report, Task D-9, Research Unit 204 and 473, April 1979 to March 1980, Appendix G, p. 64-71.

Mercer, J.H., 1978, West Antarctic ice sheet and CO_2 greenhouse effect: a threat of disaster: Nature, v. 271, p. 321-325.

Repenning, C.A., 1983, New evidence for the age of the Gubik Formation, Alaskan North Slope: Quaternary Research, v. 19, p. 356-372.

Rodeick, C.A., 1979, The origin, distribution, and depositional history of gravel deposits on the Beaufort Sea continental shelf, Alaska: U.S. Geological Survey Open-File Report 79-234, 87 p., 31 figs.

Ruddiman, W.F., and McIntyre, A., 1979, Warmth of the subpolar North Atlantic Ocean during northern hemisphere ice-sheet growth: Science, v. 204, p. 173-175.

Szabo, B.J., 1985, Uranium-series dating of fossil corals from marine sediments of southeastern United States Atlantic Coastal Plain: Geological Society of America Bulletin, v. 96, p 398-406.

Wilson, A.T., 1964, Origin of ice ages: an ice shelf theory for Pleistocene glaciation: Nature, v. 201, p. 147-149.

LATE CENOZOIC STRATIGRAPHY OF THE BEAUFORT SEA INNER SHELF NEAR PRUDHOE BAY, ALASKA

Smith, Peggy A., U. S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025

The sedimentary sequence recorded in seven boreholes on the innermost shelf east of Prudhoe Bay, Alaska (fig. 1) can be divided into twelve stratigraphic units representing deposits of seven and perhaps eight late Pliocene through Holocene marine transgressions, as well as intervening fluvial and glaciofluvial deposits recording episodes of lowered sea level. Cores were taken in water depths ranging from 5.5 to 11.3 m, and were terminated at depths between 37.2 and 103.7 m. The units recognized from the cores have been given informal names, and represent subdivisions of the Gubik Formation. Unit boundaries have been revised and a new unit recognized since the publication of an earlier description of the younger units in the study area (Smith, 1985). Textural and microfaunal characteristics allow paleoenvironmental interpretation of core samples, and presence of characteristic microfossils provides age control. Data from nearshore seismic profiling allow two of the units to be confidently correlated between boreholes, but the oldest units in the sequence lie at depths below the resolution capacity of the survey. The extent of isoleucine epimerization in foraminiferal samples has been analyzed, and the results have been used to strengthen correlations and to postulate possible ages of the units as well. Finally, Holocene sediments are distinguished from older sediments by their lack of consolidation, recognizable on seismic lines as well as in engineering tests performed on core samples.

In addition to establishing correlations between core samples, an attempt was made to reconcile the shelf record with the record of transgresions on the Arctic Coastal Plain. The following paragraphs very briefly summarize the physical characteristics of each of the 12 units, as well as speculations on the age of deposits.

Camden Bay Unit

The oldest unit described in the present study, the Camden Bay unit, is present only in HLA-18, where it consists of 0.9 m of shallow marine silt at the base of the hole. It is tentatively correlated with deposits of the late Pliocene Colvillian transgresion of Carter and Brigham-Grette (in press). The dominance by *Elphidium* in the foraminiferal fauna restricts the age of this unit to late Pliocene or younger. The ostracode fauna is more comparable to Neogene faunas that to modern faunas, and suggests an age of late Pliocene (E. Brouwers, U. S. G. S., personal communication, 1982). An ice-free Arctic Ocean or a major change in the circulation pattern in the Beaufort Sea is suggested by the presence of *Cytheropteron simplex*, an ostracode now found only in the frigid to subfrigid North Atlantic.

Brownlow Point Unit

The Brownlow Point unit, the second oldest unit described in this study, is present only in HLA-18, where it consists of 14.8 m of shallow to mid-shelf marine silt overlying beach deposits. This unit is correlated with deposits of the late Pliocene Bigbendian transgression of Carter and Brigham-Grette (in press). The microfauna is similar to that of the Camden Bay unit, but also contains the extinct ostracode Rabilimis paramirabilis, known only from late Pliocene and early Pleistocene marine deposits in Alaska.

North Star and Newport Sands

The North Star sand in HLA-18 and the possibly correlative Newport sand in HLA-15 consist of 18 to 20 m of silty sand, interpreted as floodplain alluvium. The North Star sand overlies the Brownlow Point unit, while the Newport sand overlies 4.1 m of outwash gravel. Both sands are unfossiliferous and can not be positively correlated with any deposits described thus far on the Arctic Coastal Plain. An age of early Pleistocene is assigned, because of the position of the North Star sand between late Pliocene and early Pleistocene marine units.

Staines River Unit

Overlying the North Star sand in HLA-18 is the Staines River unit, 21.7 m of shallow marine silty sand and clayey silt. This unit is tentatively correlated with deposits of the Fishcreekian transgression of Carter and Brigham-Grette (in press). Rabilimis paramirabilis, present near the top of the unit, restricts its age to early Pleistocene or older. Atlantic affinity ostracodes are present throughout the unit, and in general the fauna is similar to fauna from marine deposits of the Gubik Formation overlying Miocene Nuwok Formation at Carter Creek, south of Camden Bay (D. M. Hopkins, unpublished field notes, 1980; E. Brouwers, written communication, 1984).

Shaviovik Gravel and Duchess Sand

The Shaviovik gravel, 46.9 m thick in HLA-15 and 11.6 m thick in HLA-14, is tentatively assigned an age of middle Pleistocene, and may be correlative in part to the Ugnurovik gravel of Rawlinson (in press). The unit represents a complex of outwash - non-glacial alluvium - outwash in HLA-15, while the section in HLA-14 is thought to correspond to the younger outwash in HLA-15. The Duchess sand, 6.8 m of silt and silty fine sand in HLA-18, was deposited at the same time as the Shaviovik gravel, but their relationship is not entirely clear.

Leffingwell Lagoon Unit

The Leffingwell Lagoon unit has been recognized in cores from HLA-16 through 20. It ranges in thickness from 10.0 to 15.7 m, and consists of a complex of deposits ranging from nearshore sand to mid-shelf clayey silt. A correlation with deposits of the middle Pleistocene Kotzebuan transgression of Hopkins (1967) or Wainwrightian transgression of Carter and Brigham-Grette (in press) is suggested. The microfauna of the Leffingwell Lagoon unit is the oldest fauna in this study that looks modern.

Maguire Islands Unit

The Maguire Islands unit is the oldest unit encountered in all seven of the boreholes in this study. It ranges in thickness from 2.1 to 20.4 m, and is represented primarily by shallow shelf and delta front deposits. This unit is correlated with deposits of the late Pleistocene Pelukian transgression of Hopkins (1967). Foraminifera now found associated with Bering Sea water on the mid to outer shelf of the Beaufort Sea are present near the base of the unit in HLA-16 and 20, and indicate sea level and temperature as high as or greater than modern values. The thickness of the deltaic sediments indicates an abundant supply of water to the Canning River during a lengthy interglacial.

Cross Island Unit

The Cross Island unit is absent in HLA-15 and 19, and ranges in thickness between 0.8 and 7.0 m in the remainder of the cores. The presence of Flaxman-like dolomite and red granite in the unit and the similarity of the pebbly silt and clay of the unit to exposures of the Flaxman Member of the Gubik Formation on the coastal plain make a correlation with that member very strong.

Mikkelsen Bay Unit

The Mikkelsen Bay unit, an 11.0 m thick channel fill deposit present only in HLA-19, is younger than the Cross Island unit, as Flaxman-like red granite and dolomite are present in the channel lag gravel at its base. Whether it represents a mid-Wisconsinan transgression or is a late-Wisconsin to early Holocene deposit is uncertain. The microfauna are compatible with either age, and the sediments are relatively soft, unlike the sediments of the older units.

Stefansson Sound Unit

The Stefansson Sound unit is present at the top of the core in HLA-14 and 15, where it ranges in thickness from 4.9 to 13.1 m. The sediments are very soft, ice-bonded permafrost is absent in the unit, and the microfauna is very abundant and diverse, suggesting very strongly that the unit is Holocene in age. The lower 6.4 m of the unit in HLA-15 represents a transition from late Wisconsinan fluvial to early Holocene deltaic deposition, while the upper part of the unit in HLA-15 and the entire unit in HLA-14 represent estuarine conditions similar to those existing in the area today.

References Cited

Carter, L. D., and Brigham-Grette, J. K., in press, Late Cenozoic marine transgressions of the Alaskan Arctic Coastal Plain: Geological Survey of Canada Paper.

Hopkins, D. M., 1967, Quaternary marine transgressions in Alaska, in Hopkins, D. M., ed., The Bering land bridge: Stanford, California, Stanford University Press, p. 47-90.

Rawlinson, S. E., in press, Late Cenozoic geology of the Arctic Coastal Plain between the Colville and Canning Rivers: Geological Survey of Canada Paper.

Smith, P. A., 1985, Late Quaternary geology of the Beaufort Sea inner shelf near Prudhoe Bay, in Bartsch-Winkler, Susan, and Reed, K. M., eds., The United States Geological Survey in Alaska -- accomplishments during 1983: U. S. Geological Survey Circular 945, p. 100-103.

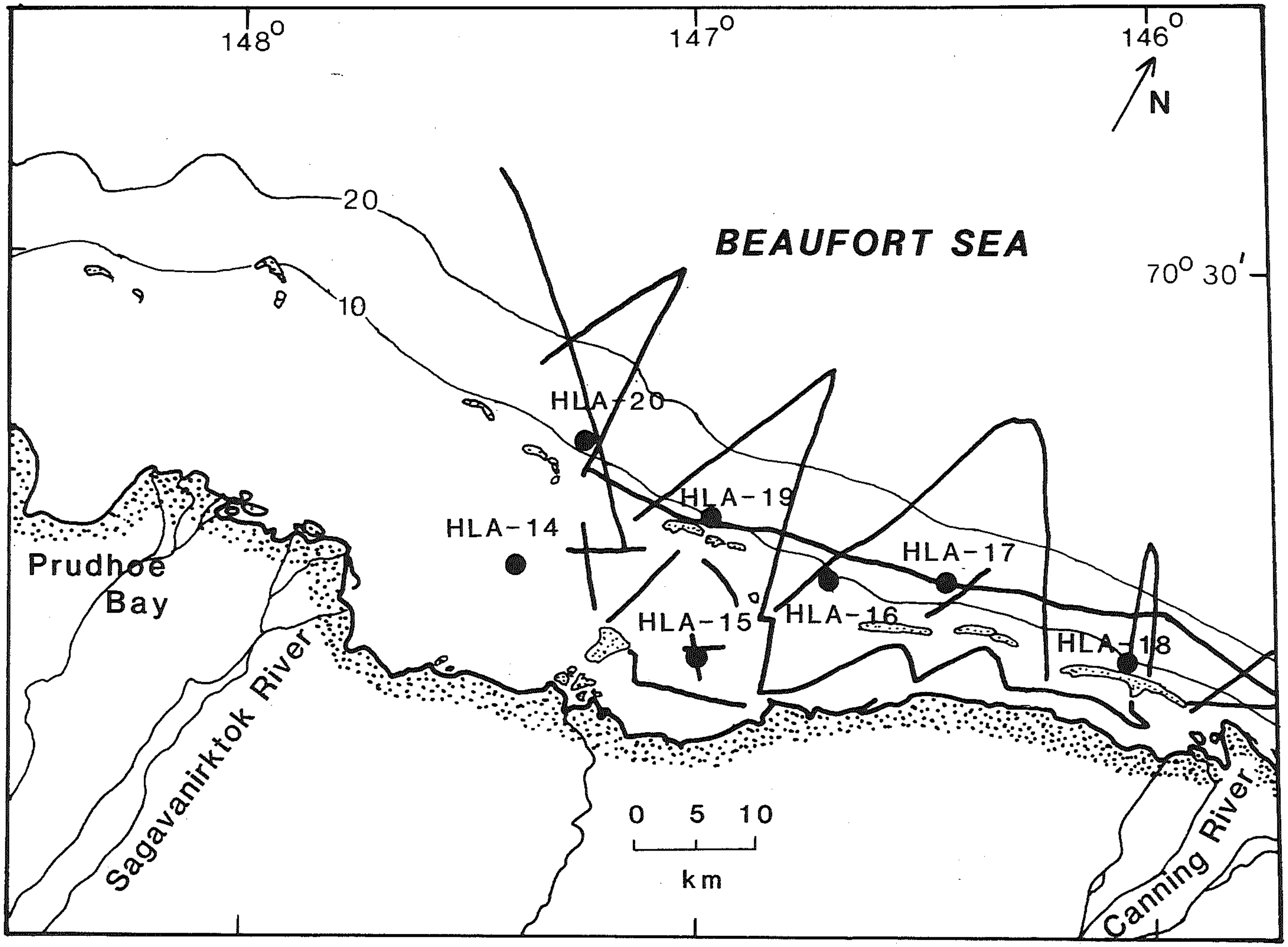


Figure 1. Map showing locations of boreholes (heavy dots) and high resolution seismic reflection tracklines (heavy lines). Depth contours are in meters.

Records of Quaternary sea level lowstands preserved beneath the Alaskan Beaufort shelf

By

David A. Dinter, U.S. Geological Survey
345 Middlefield Road, Menlo Park, California 94025

Beneath the Alaskan Beaufort shelf north and northeast of Camden Bay, there are two zones of active structural subsidence. These zones have been called the Eastern and Western Wedge Terranes, because high-resolution reflection seismic profiles reveal each to be filled by a progradational stack of offshore-thickening, wedge-shaped strata. The wedges are inferred to be Quaternary in age based on correlations with known Quaternary strata in nearby, nearshore boreholes.

The depositional rate on the outer Alaskan Beaufort shelf is presently low, and yet the youngest wedge deposit, which has apparently accumulated since the last glacial lowstand of sea level at approximately -100 meters some 17,000 years ago, is locally as thick as 40 m near the shelf break. To account for this, depositional rates on the outer shelf must have been much higher during the early phases of the post-glacial transgression than they are now. The likely source of so much sediment at such a time is the Laurentide Ice Sheet, specifically debris-laden icebergs, shed into the Arctic Ocean as the ice margins retreated, and then rafted downdrift by the Beaufort Gyre to ground and melt on the Alaskan Beaufort shelf as sea level rose. This depositional scenario is corroborated by the lithology of a suite of ice-striated gravels collected from the surface of the youngest wedge. The dolomite- and red granite-dominated assemblage is similar not to any known

Brooks Range rocks, but rather to a suite of shield rocks exposed along the southern shore of Coronation Gulf in the Canadian Arctic Islands (Rodeick, 1979).

A useful result of this early post-glacial blanketing of the outer shelf with glaciomarine sediment is the apparent preservation of the maximum glacial lowstand shoreface--i.e., the seaward termination of the disconformity at the base of the youngest wedge deposit--at about 100 meters below present sea level. This value merely corroborates estimates of maximum late Wisconsin global sea level lowering measured on other continental shelves, but the implication of the depositional scenario described for the youngest wedge is that underlying wedges may have been deposited in similar conditions during previous early post-glacial transgressions, and so preserve--as their basal disconformities--records of earlier glacial sea level minima, records which have been routinely destroyed by erosion on most shelves of the world.

Based on this hypothesis, an attempt has been made to extract the sea level lowstand information from the Beaufort shelf deposits, and compare it for consistency with other data sets bearing on Quaternary sea level fluctuations. The most continuous such record is the ^{18}O-enrichment curve of Shackleton and Opdyke (1973). Many of the enrichment minima peaks in this curve--believed to represent minima in global ice volume and, thus, interglacial periods--have been calibrated back through stage 7 (about 250,000 y.B.P.) as sea level highstands, using information from dated, uplifted coral reefs in Papua New Guinea (e.g. Bloom et al., 1974; Chappell, 1974; Aharon et al., 1980) and Barbados (e.g. Broecker et al., 1968; Fairbanks and Matthews, 1978). Only one ^{18}O-enrichment peak, however, the stage 2 extremum at approximately 17,000 y.B.P., has so far been reliably calibrated as a sea level minimum (c. -100 m). In an effort to examine the magnitudes of earlier sea level minima, a tentative age scheme and subsidence history are proposed for the Beaufort Sea wedge deposits, and used to establish a preliminary succession of late Quaternary sea level lowstand magnitudes, which is then compared qualitatively with the lowstand magnitudes implied by the oxygen isotope curve.

To obtain the succession of lowstand magnitudes from the Beaufort Sea data, termination depths of basal disconformities were measured for all profiled wedges, and corrected for offsets along all visible faults. No compaction estimates were made because the wedges are progradational, and were deposited in such a way that the thickness of deposits overlying each measured disconformity termination is less than 120 m.

Two major tie points are the basis for a provisional correlation scheme which allows a comparison between the two data sets. The basal disconformity beneath the youngest Beaufort wedge, Unit A (Dinter, 1985), likely represents the late Wisconsin sea level lowstand approximately 17,000 y.B.P. (oxygen isotope stage 2), as implied above. The basal disconformity beneath composite wedge Unit E is tentatively correlated with the Illinoian glacial lowstand (c. 150,000-160,000 y.B.P., late oxygen-isotope stage 6), because Unit E is thought to correlate with Sangamonian Interglacial (oxygen-isotope stage 5) deposits cored nearshore (Dinter, 1985). Interpolating and extrapolating from these tie points yields a correlation scheme in which the Beaufort Sea and oxygen isotope curves agree remarkably well in both numbers and magnitudes of implied lowstands. Direct testing of the correlation awaits coring in the Beaufort wedge terranes.

References

Aharon, P., Chappell, J. and Compston, W., 1980. Stable isotope and sea-level data from New Guinea support Antarctic ice-surge theory of ice ages. Nature, 283: 649-654.

Bloom, A.L., Broecker, W.S., Chappel, M.A., Matthews, R.K. and Mesolella, K.J., 1974. Quaternary sea level fluctuations on a tectonic coast: New $^{230}Th/^{234}U$ dates from the Huon Peninsula, New Guinea.

Broecker, W.S., Thurber, D.L., Goddard, J., Ku, T., Matthews, R.K. and Mesolella, K.J., 1968. Milankovitch hypothesis supported by precise dating of coral reefs and deep-sea sediments. Science, 159: 297-300.

Chappell, J., 1974. Geology of coral terraces, Huon Peninsula, New Guinea: a study of Quaternary movements and sea-level changes. Geol. Soc. Am. Bull., 84: 553-570.

Dinter, D.A., 1985. Quaternary sedimentation of the Alaskan Beaufort shelf: Influence of regional tectonics, fluctuating sea levels, and glacial sediment sources. Tectonophysics, 114: 133-161.

Fairbanks, R.G., and Matthews, R.K., 1978. The marine oxygen isotope record in Pleistocene coral, Barbados, West Indies. Quat. Res., 10: 181-196.

Rodeick, C.A., 1979. The origin, distribution and depositional history of gravel deposits on the Beaufort Sea continental shelf, Alaska. U.S. Geol. Surv., Open-File Rep., 79-234: 87 pp., 31 figs.

Shackleton, N.J. and Opdyke, N.D., 1973. Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotope temperatures and ice volumes on a 10^5 and 10^6 year scale. Quat. Res., 3: 39-55.

SEISMIC STRATIGRAPHY OF LATE QUATERNARY INNER-SHELF FROM PRUDHOE BAY TO DEMARCATION POINT, ALASKA

by

S.C. Wolf, Erk Reimnitz, and P.W. Barnes
U.S. Geological Survey

We have interpreted high-resolution seismic-reflection records collected during 14 field seasons over the inner shelf between Prudhoe Bay and the United States-Canadian border at Demarcation Point. West of mid-CAmden Bay, seismic horizons correlate well with stratigraphic interpretations of more than 20 offshore boreholes. From mid-Camden Bay to abot 20 km east of Barter Island, tectonism has deformed the section, trackline coverage is sparse, and so continuity is lost. From there eastward to the border, however, the seismic stratigraphy appears to be so similar to that of the western region that correlations can be drawn with considerable certainty. Two of the major seismic horizons are unconformities marked by several cut-and-fill channels, as much as 10-m deep. These two horizons, which dip gently north, are interpreted to be the result of erosion during the last two major glaciations and lowered sea levels. These episodes were followed by deposition of at least 10 to 20 m of shallow-water marine sediment on the inner shelf to midshelf, grading to deltaic and fluvial outwash deposits near the coast. The two seismic units are thought to correlate with the Sangamonian and Pelukian interglacial transgressions (Smith, 1985). Except for the tectonically deformed section near Barter Island, the lobate configuration of these two units agrees well with the positions of the present major North Slope drainage systems and sediments sources. Evidence for major offshore paleovallleys previously thought to exist was not seen in the geophysical data. The glaciomarine Flaxman Member (of the Gubik Formation), laid down during a short Wisconsinan transgression about 80,000-70,000 yr B.P. (Carter, 1983; Dinter, 1985), has been eroded away in the offshore, as evidenced by only a thin lag deposit of Flaxman rock types mantling the inner-shelf surface. The modern shelf surface is also eroding into underlying, offshore-dipping pre-Flaxman units. From Prudhoe Bay eastward to the border at Demarcation Point, the entire inner shelf is an erosional surface devoid of Holocene sediment accumulations. Erosion here is clearly facilitated by ice keels digging into the sea floor, continually excavating successively older underlying materials and mixing these with materials supplied by coastal erosion and upland sources. The "Rototilled" unit thus produced is transient and is not accreting but, instead, maintains a thickness corresponding to the maximum ice-gouge-incision depth, as the level of the shelf surface is being lowered by erosion. Sediment supply to any particular area is balanced by removal through normal marine and ice-related processes. Areas where Holocene sediment possibly continues to accrete are entirely restricted to bays, lagoons, barrier islands and beaches, and offshore shoals, as shown for the west half of the study area in figure 1.

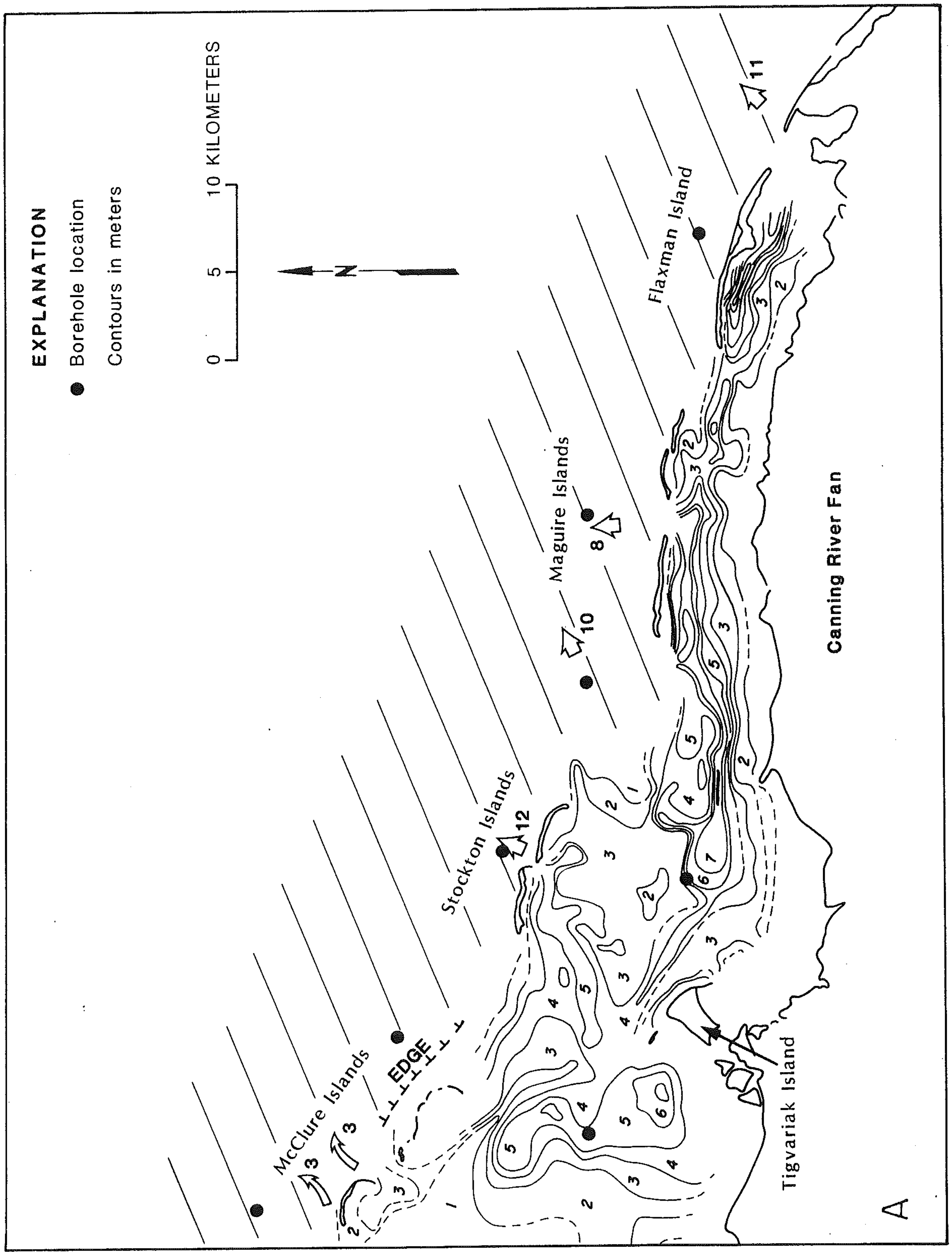
REFERENCES

Carter, David L., 1983, Cenozoic glacial and glaciomarine deposits of the central north slope, Alaska, in Glaciation in Alaska: extended abstracts from a workshop, Robert N. Thorson, Thomas D. Hamilton (eds.): Alaskan Quaternary Center, University of Alaska Museum, Fairbanks, Alaska.

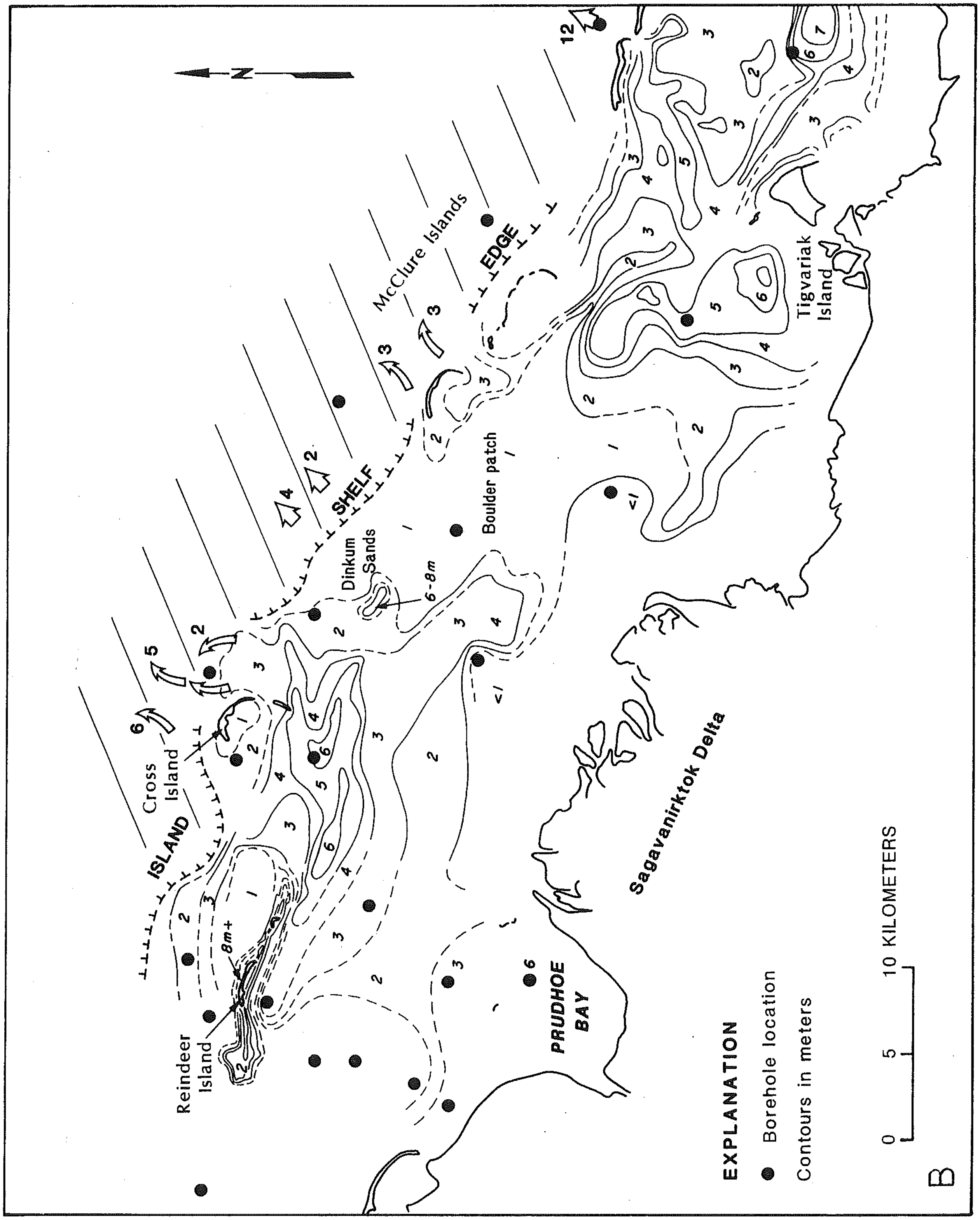
Dinter, C.A., 1985, Quaternary sedimentation of the Alaskan Beaufort shelf: influence of regional tectonics, fluctuating sea levels, and glacial sediment sources: Tectonophysics, v. 14, p. 133-161.

Smith, Peggy, 1985, Late Quaternary geology of the Beaufort Sea inner shelf near Prodhoe Bay, in U.S. Geological Survey Circular 945, Accomplishments during 1983, S. Bartch-Winkler, and K.M. Reed (eds.), p. 100-103.

Figure 1A and 1B. Isopach maps of Holocene marine-sediment accumulations in western part of the study area, showing locations of available boreholes. Arrows denote locations of cut-and-fill channels; adjacent numbers show depth of channel fill (in meters).



EXPLANATION
Borehole location
Contours in meters
0
5
10 KILOMETERS
N
Flaxman Island
Maguire Islands
Stockton Islands
McClure Islands
Tigvariak Island
Canning River Fan
EDGE
A


N
Reindeer Island
8m+
Cross Island
ISLAND
SHELF
EDGE
McClure Islands
Dinkum Sands
6-8m
Boulder patch
Tigvariak Island
PRUDHOE BAY
Sagavanirktok Delta
EXPLANATION
Borehole location
Contours in meters
0
5
10 KILOMETERS
B

Sediment reworking, transport, and deposition on the Alaskan Beaufort shelf; the role of ice, in relation to waves, currents, and infauna.

by Peter W. Barnes and Erk Reimnitz
U.S. Geological Survey
Marine Geology
Menlo Park, CA 94025

The sediments of high-latitude shelves are subject to reworking by ice in addition to the temperate-latitude processes of waves, currents, and bioturbation (Reimnitz and Barnes, 1974). This adds a complexity to the processes themselves and to the depositional records of high-latitude sediments. Here we document the character of sediment reworking on the arctic shelf of the Alaskan Beaufort Sea and assess the likely stratigraphy of high-latitude sedimentary deposits involving ice.

PROCESSES

Wave and current reworking

Wind-driven waves and currents are limited to the open-water season, and even then they are influenced by remnant ice blocks and ice fields on the shelf. Nevertheless, wave reworking and current transport dominate the sediment-transport regime inshore of 10 meters water-depth. On the extensive delta-front platforms river-born sediments are temporarily deposited early in the summer, only to be resuspended and transported in the fall when storms and extensive open water are most common. Bedload transport has been measured at 9 cubic meters per meter per year on the platform due to the infilling of strudel scours (Reimnitz and Kempema, 1983). The latter are scour depressions formed when spring flooding overflows the sea ice and subsequent drainage through strudel creates scour pits on the seafloor. Thus, high-latitude delta deposits might be characterized by discontinuous lenses of scour infill.

Tidal and barotropic currents impact the seafloor in winter when flow is constricted by the overlying ice canopy. These constrictions are most pronounced on the delta-front platforms and in the stamukhi zone, the zone of grounded ice ridges that seperates the landfast ice from the moving polar ice pack. Inshore of 2m water depth the winter growth of the ice canopy decreases the water column cross section through which the tidal prism must pass and increases the current velocities an order of magnitude over the ambient winter currents resulting in the deposition of coarse well sorted sediments along the seaward edge of the platform. In the stamukhi zone a discontinuous curtain of ice extends downward, contacting the seafloor at an unknown number of points. The curtain acts to constrict currents near the seafloor and thus increases their velocities. As a result, shoals marked by ripples and sand waves are common at the inner edge of the stamukhi zone.

Waves and currents on the shelf are further influenced by seabed roughness resulting from ice processes. In areas of ice gouging, strudel-scour, and ice-wallow seabed roughness is markedly increased and the energy absorbed by the seafloor is similarly increased. As a result, sediment reworking and transport are enhanced and the wave climate along the coast is mitigated.

Ice reworking

Repetitive sidescan sonar and precision bathymetric survey corridors indicate that the seafloor area annually impacted by ice keels increases seaward to the offshore limit of the surveys at 25m water depth. Total seafloor disruption in a 1-km segment ranged as high as 60 % to a depth of 1.4 m, while as much as up to 7.4 % disruption occurred in a single year for an entire corridor (Barnes and Rearic, 1985 and Figure 1). High gouge densities are associated with wide,

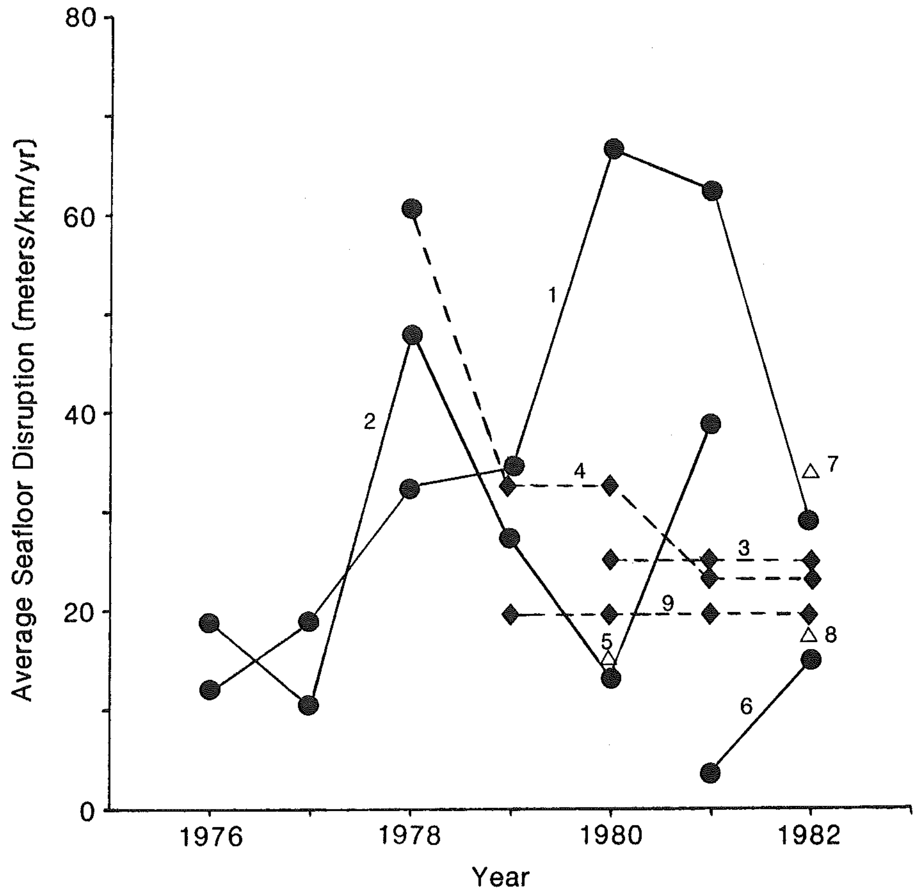


Figure 1. Time variability of seafloor distruption from ice gouging. Numbers refer to different study corridors, while diamonds show data averaged over 2 to 4 years. See Barnes and Rearic (1985) for further explanation.

shallow "multiplet" gouging events, where long sections of pressure-ridge keels raked the bottom. Small annual variations in the amount and intensity of new gouges indicate consistent reworking of the inner shelf.

Repetitive observations helped to develop developed a detailed description of storm-altered seabed conditions. Reworked seabed sediments obliterated seabed ice gouges to a water depth of 13m and ponded soupy sediments in deeper ice gouges
(Barnes and Reimnitz, 1979). The ponded sediments are underlain by overconsolidated materials which, where exposed between ponds, exhibit a surface with finer ice gouge texture than seen regionally. These observations and ongoing repetitive surveys indicate that rates of inner-shelf sediment reworking from storms are apparently an order of magnitude greater than from other processes. As sedimentation during these events preferentially infilled gouge troughs, a series of characteristic interfingering shoestring deposits are developed, defining the stratigraphy where currents and ice gouging interact. However, the specific hydraulic mechanisms of sediment redistribution, ponding, and compaction are poorly understood.

Over a period of many years ice gouging, repetitively plows the seabed, creating a rototilled layer that elsewhere has been called an ice turbate. In the Beaufort Sea, where the shelf surface is apparently a surface of erosion, the thickness of the ice turbate represents the depth to which the deepest ice keels penetrate the seafloor. On the Alaskan shelf this thickness has been determined from deep vibracoring. Where sediments are presently accumulating, as on parts of the

Canadian shelf, the thickness of ice turbate can not be used to determine the maximum keel-penetration depths.

Biologic reworking

Underwater observations, box cores, bottom photographs, and vibracores from the shelf were examined for biologic structures. Few were seen on the central and inner shelf at water depths of less than 50 m. Along the outer shelf box cores reveal burrowing and bioturbation in the upper 20 cm of sediment (Barnes and Reimnitz, 1974). Inshore, biological sediment reworking is overshadowed by wave and current activity and ice gouging. Biologic reworking is also limited by the presence of an overconsolidated sediment on the inner shelf. As a result, biologic structures are expected to be unusual in sediments from high-latitude inner shelves.

INTERACTIONS

The stamukhi zone occurs in about the same location year after year. Here, a major portion of the atmospheric energy imparted to the arctic ocean is expended against the continent. At the inner boundary of the zone, consolidated gravelly mud of pre-Holocene age is being gouged by ice to form a 2-m-high bench (Barnes and Asbury, 1985). Subsequent ice motion and current erosion generate lag gravels which are bulldozed into 2- to 3-m-high shoals atop the bench. Ice gouging seaward of the inner boundary is markedly more intense and characterized by multiplet gouging, reflecting the local formation of grounded ridges. The bench effectively mitigates ice forces on the seabed inshore of the boundary, and favors ice-ridge nucleation at the inner edge of the stamukhi zone. The bench is created by repetitive ice gouging along the inner boundary of the stamukhi zone at roughly the same location year after year. We do not understand the link between the ice canopy and the seafloor, and the factors causing the stamukhi zone to form within the same approximate boundaries each year. This bench boundary in the stratigraphic record would clearly mark a specific ice regime and depth.

Transient ice and current-related bottom morphologies are created in nearshore regions with non-cohesive sediments. Repeated surveys with accurate navigation and close trackline spacing reveal many closed depressions and mounds 50-100m in diameter and 2-3m in relief (Reimnitz and Kempema, 1982). Over the course of three years some features were obliterated while others were formed. The depressions resemble kettles but are formed by intensified current flow around semi-stationary ice blocks aided by pulsating currents generated by vertical oscillations and rocking motions in a seaway. The resulting depressions are much larger than the ice-block footprint. The stratigraphy of ice wallow deposits would appear as discontinuous overlapping units of non-cohesive sediments.

Anchor ice is a more subtle agent of sediment reworking and transport. This agent is well known from high-latitude fresh water streams and lakes, where anchor ice is shown to transport large amounts of sediment, and to raise 30 kg boulders off the bottom. In contrast, little is known about the role of anchor ice in the ocean. However, recent underwater observations during fall storms in the Beaufort Sea have documented the formation of sediment-laden anchor ice and ice-bonded surface sediments. The frozen seabed does not last into the winter. Anchor ice affects sediment by forming a protective cover for the sea floor, particularly in the surf zone, thereby arresting previously mobile bedforms. In addition, underwater ice is sticky during its formation, adhering to any particles within the water column and on the bottom. Where the substrate is fine grained, sediment particles are too light to overcome the buoyancy of ice crystals in turbulent flow and are carried away, many becoming part of the ice canopy. Large volumes of sediment included in the seasonal ice can be transported to the central arctic basin to form a component of the particulate sediment rain. We suspect that the structures generated by anchor-ice processes are overwhelmed by subsequent reworking by ice gouge and currents.

CONCLUSIONS

Along a shelf transect from the coastline to the shelf break waves and currents, ice and infauna each dominate the sediment-reworking regime in turn and thereby affect the character of resultant deposits. Inshore, waves and currents dominate sediment transport and depostion but are tempered by strudel-scour formation and infilling, anchor-ice processes, and reworking of the nearshore zone by ice wallow. At the 10 to 15m water depth ice-gouging processes begin to dominate, resulting in a series of random shoestring deposits in an ice turbate packet. Current processes again become important at depths of 50-60 m but are tempered by an active biologic community within the upper 20 cm of sediments.

SELECTED REFERENCES

Barnes, P.W., and Asbury, J., 1985, Detailed morphology of the seafloor at the inner edge of the stamukhi zone, Beaufort Sea, Alaska; proceeding Arctic Workshop, Dept. of Energy, Morgantown Energy Technology Center Morgantown, West Virginia, p.68-78.

Barnes, P.W. and Rearic, D.M., 1985, Rates of sediment disruption by sea ice as determined from characteristics of dated ice gouges since 1975 on the inner shelf of the Beaufort Sea, Alaska, U.S. Geological Survey Open File Report No. 85-463, 43p.

Barnes, P.W., and Reimnitz, Erk, 1974, Sedimentary processes on arctic shelves off the northern coast of Alaska, in, Reed, J.C. and Sater, J.E. eds, The Coast and Shelf of the Beaufort Sea, The Arctic Institute of North America, Arlington, VA, p. 439-476.

Barnes, P.W., and Reimnitz, Erk, 1979, Ice gouge obliteration and sediment redistribution event; 1977-1978, Beaufort Sea, Alaska: U.S. Geological Survey Open-File Report 79-848, 22 p.

Reimnitz, Erk, and Barnes, P.W., 1974, Sea ice as a geologic agent on the Beaufort Sea shelf of Alaska, in, Reed, J.C., and Sater, J.E., eds., The Coast and Shelf of the Beaufort Sea, The Arctic Institute of North America, Arlington, Virginia p. 301-351.

Reimnitz, Erk, Kempema, E.W., 1982, Dynamic ice-wallow relief of northern Alaska's nearshore - a dynamic bed- form: Journal of Sedimentary Petrology, v. 52, n. 2, p. 451-462.

Reimnitz, Erk and Kempema, E.W., 1983, High rates of bedload transport measured from infilling rate of large strudel-scour craters in the Beaufort Sea, Alaska: Con- tinental Shelf Research, v. 1, no. 3, p. 237-151.

PALEOGEOGRAPHIC SIGNIFICANCE OF TEXTURES OF COLVILLE DELTAIC SEDIMENTS, NORTH ARCTIC ALASKA

A. Sathy Naidu

Institute of Marine Science
University of Alaska
Fairbanks, Alaska 99775-1080

ABSTRACT

In the ice-stressed Colville Delta, north Alaska, a number of subenvironments can be delineated based on geomorphology. However, with a few exceptions, sediment textures — as defined by statistical grain-size parameters — are of limited use in differentiating the subenvironments. The exceptions pertain to the coastal beaches and barriers (predominantly constituted of poor- to medium-sorted sands with proportions of gravel), and the coastal plain (with poorly-sorted silty-sands, minor gravel and preponderance of tundra debris). Grain-size analysis of beach deposits do not generally display the mesokurtic and coarse-skewed distributions. These and C-M plots do not conform to the typical patterns displayed by deltaic beach deposits worldwide. It is suggested that the general lack of textural differences in the arctic deltaic sediments are related to the predominant role of ice in the reworking, transport and deposition of sediments. Hydraulic processes are relatively less active and, therefore, are not an efficient agent to sediment sorting.

Preliminary results suggest that sediment structures provide a better criterion to differentiate depositional subenvironments in the Colville Delta. The implications of the above studies in the recognition of paleodeltaic sediments are discussed.

THE ROLE OF ICE IN CONTROLLING SEDIMENTATION ON THE YUKON DELTA

William R. Dupre', Department of Geosciences, University of Houston - University Park, Houston, TX 77004

The Yukon Delta provides an excellent example of an "ice-dominated" delta in a sub-arctic environment. The climatic extremes of this high latitude depositional system play a significant role in controlling 1) weathering products in the source area, 2) seasonal variability of the river flow, 3) patterns of sediment dispersion along the margin of the delta, and 4) modification of the delta plain due to the incipient development of permafrost.

The role of ice is particularly significant as it affects the pattern of sediment and water discharge at the river mouth. Most studies of deltaic sedimentation emphasize the applicability of jet flow theory in describing river mouth processes and resultant geomorphology. Theoretical, experimental, and field studies all suggest that rapid sedimentation occurs at an offshore distance equal to 4-8 times the width of the river mouth, typically resulting in the formation of a distributary mouth bar. Lateral expansion of the sediment plume and resultant patterns of sedimentation effectively limit the distance that channelized flow can extend offshore.

The Yukon Delta is a significant exception to this model, however, as distributary channels can be traced beyond the shoreline up to 25 km, (i.e. distances equivalent to 20-30 times the width of the distributaries at the shoreline). In addition, these channels cross a broad, flat delta front platform (or "sub-ice platform"), typically less than 3 m deep, which results in an offshore profile which differs from previously described deltas in more temperate climates. These offshore (or "sub-ice") channels are typically 0.5 to 1 km wide, an 5 to 15 m deep. They are locally floored with seaward migrating megaripples up to 1 m high. They are slightly meandering (sinuosity ranges from 1.25-1.55) and can be shown to have migrated laterally (up to 50 m/yr) during the past century. These channels are clearly zones of active sediment transport via channelized flow far beyond the shoreline for at least a portion of the year. Additional evidence for active sediment transport in these channels is provided by a comparison of 1898 and 1978 bathymetry, which show the areas of active deltaic progradation is largely restricted to the areas coincidant with the seaward termination of these offshore channels. Vertical accretion up to 6 m and seaward progradation of up to 7 km has occurred associated with the largest of the major distributaries during this 80 year period.

The unusual characteristics of the offshore channels of the Yukon Delta (as well as a broad "sub-ice" platform), are related to the presence of the extensive shorefast ice that fringes the delta during breakup. The subaqueous levees adjacent to the river mouths are covered with bottomfast ice to a depth of 1-1.5 m at this time, whereas the channels are covered with a ribbon of floating fast ice. As the rapid increase in water and sediment discharge during breakup begins to flow through these channels, the floating fast ice lifts, with water (and some sediment) spilling over the adjacent bottomfast ice. This allows the river to maintain its channelized flow beyond the shoreline, because the bottomfast ice on top of the subaqueous levees acts to temporarily raise the margins of the channel to an elevation at or even above sea level. It is during this relatively short period of time that the river can actually extend itself beyond the shoreline, with active sedimentation occurring beyond the influence of the bottomfast ice.

When the ice melts, the channels remain, however much of the subsequent sedimentation is probably more typical of other deltas as it is during this time that sedimentation near the shoreline favors the formation of distributary mouth bars. This may be a time when sediment is temporarily stored in the channel near the shoreline, to be subsequently flushed farther offshore during breakup in the following Spring.

In summary, the presence of shorefast ice around the Yukon Delta provides a mechanism by which most of the sediment effectively bypasses the shoreline, to be deposited tens of kilometers farther offshore. Relatively small deltas (such as those along the North Slope of Alaska), appear to have a large portion of their sediment dispersed by over-ice flow during breakup. However larger rivers such as the Yukon may have most of their sediment bypass the nearshore via sub-ice flow in channels during breakup.

LAND EVIDENCE FOR LATE CENOZOIC SEA LEVEL FLUCTUATIONS IN AREAS ADJOINING THE BEAUFORT SEA IN THE WESTERN CANADIAN ARCTIC

Jean-Serge Vincent, Geological Survey of Canada,
601 Booth Street, Ottawa, Ontario, K1A 0E8

Sediments and landforms, adjacent to the Beaufort Sea, record fluctuations of Late Cenozoic sea levels associated with both glacio-isostatic depression related to northwesterly flowing continental ice advances and interglacial eustatic transgressions. Table 1 presents the sea level data and Figure 1 portrays glacial limits in the area. The evidence is particularly good on Banks Island whereas on the mainland Arctic Coastal Plain it has in many places been destroyed by widespread ice-thrusting, intensive thermokarst activity, and extensive coastal erosion.

Late Tertiary(?)

Preglacial marine sediments which have been documented to be equivalent to Beaufort Formation or younger have only been found on Meighen Island. Fine grained shell bearing sediments at least 25 m thick which underlie the oldest glacial deposits on eastern Banks Island may however be of Late Tertiary age. If this is the case, then they probably correlate with one or other of the well documented Tertiary Alaskan Coastal Plain transgressions.

Early Pleistocene

Sediments from this period are recognized on the basis of their magnetically reversed properties. During this time, the Banks Glaciation, which was the strongest of the recorded continental ice advances, covered most of Banks Island and extended well into the Beaufort Sea. A marine submergence following this glaciation covered the glacio-isostatically depressed coastal areas to at least 33 m on the east coast and to more than 50 m on the west coast. It is tempting to link the Banks Glacier with an ice free Arctic Ocean (source of moisture to build the largest of the recorded ice sheets) and with Clarks unit J of the Arctic Ocean basin, the coarsest glaciomarine unit of Matuyama age. On Bathurst Peninsula, on the mainland coast, a marine wave cut platform up to 75 m high may be equivalent in age to the Post Banks Sea.

Middle Pleistocene

On Banks Island, during the long Middle Pleistocene nonglacial period, characteristic of the northwestern margin of North America, marine waters transgressed to more than 30 m above present sea level. This is documented by perimarine sediments on the southwestern, southern, and eastern portion of the island that were laid down during a period that was warmer than both the Sangamonian and the present day interglaciation. In the latter part of the Middle Pleistocene, continental ice advanced again toward the Beaufort Sea as the Thomsen Glaciation on Banks Island and the probably correlative Mason River Glaciation on the mainland. Its extent was less than that of the Banks Glaciation. At this time the glacio-isostatic Big Sea flooded the depressed eastern Banks Island to more than 200 m and the western portion of the Island to 60 m. On Bathurst Peninsula the Harrowby Sea covered land areas to about 40 m as ice of the Mason River Glaciation retreated.

Late Pleistocene

Sangamonian Stage

Although terrestrial deposits dating from the last interglaciation have been found on Banks Island, no marine deposits or shorelines of that age have been identified. On Bathurst Peninsula, however, up to 2 m thick driftwood mats, between 6-8 m above sea level, have recently been identified. These deposits are assigned to the last interglaciation because of their stratigraphic position in relation to younger glacial deposits and because they imply that the Mackenzie River basin was ice free in order to produce the driftwood.

Early Wisconsinan Stade

Continental ice, less extensive than during the preceeding glaciations, advanced again towards the Beaufort Sea in the Early Wisconsinan. Banks Island was isostatically depressed and marine waters flooded the west coast to 20 m (Meek Point Sea) while the east coast was covered to 120 m during the deglaciation (East Coast Sea). On the mainland, Toker Point Stade ice (=Buckland Glaciation) extended locally into Beaufort Sea but there is little evidence for the extent of crustal depression and marine invasion. Features on outer Mackenzie Islands and Darnley Bay indicate that marine waters may have flooded up to at least 10 m. Ice shelves were present in Amundsen Gulf and M'Clure Strait during this glacial event. These were probably responsible for the floating ice which deposited the erratics found in the widespread glaciomarine sediments (Flaxman Member) of the Alaskan Arctic Coastal Plain. This past summer's investigation indicates that the Flaxman deposits extend east to Kay Point on the Yukon Coastal Plain. They overlie till of the Buckland Glaciation which therefore must be Early Wisconsinan or older.

Late Wisconsinan Stade and Holocene

Laurentide Ice again advanced into the area during Late Wisconsinan but this advance was less extensive than that of Early Wisconsinan. Associated glacio-isostatic marine overlap is recorded on eastern Banks Island by a transgression called the Schuyter Point Sea which covered the land up to 25 m. However, no submergence is recorded on western Banks Island or on the mainland coast west of the Brock Upland. Offshore investigations in the Beaufort Sea reveal a marine shoreline below -100 m. It is considered to be the Late Wisconsinan and is correlated with the emerged Schuyter Point shoreline. From its low level it has risen to its present position by a combination of eustatic rise and modern subsidence.

Although much new information has been gathered from the land area around the Beaufort Sea, the inferred timing and correlation of events, as well as the cause of sea level fluctuations (whether glacio-isostatic or eustatic or tectonic origin), remains speculative. Nevertheless, collaborative onshore/offshore studies would be mutually beneficial because the long land record of major glaciations provides information on the agent responsible for much of the sediments in the Arctic Ocean basin.

Fig. 1. Proposed Quaternary limits of continental ice in northwestern Canada

Table 1 GLACIAL AND SEA LEVEL RECORD IN THE AREA ADJACENT TO THE BEAUFORT SEA

General Chronostratigraphy (age in Ka)			Banks Island: Glaciations and Interglaciations	Banks Island Sea Level (m): West Coast Transgression	West Coast Regression	East Coast Transgression	East Coast Regression	Mainland Coast: Glaciations and Interglaciations	Mainland Coast Sea Level (m): Transgression	Regression
Late Pleistocene	Holocene 10		Postgalcial	<0			0 +8	Postglacial	<0	
Late Pleistocene	Wisconsinan Stage	Late (23)	Russell Stade (Amundsen Glac.)	<0			+25 (Schuyter Point Sea)	Sitidgi Stade	-140	
Late Pleistocene	Wisconsinan Stage	Middle (64)								
Late Pleistocene	Wisconsinan Stage (115)	Early	M'Clure Stade (Amundsen Glac.)		+20 (Meek Point Sea)		+120 (East Coast Sea)	Toker Point Stade = Buckland Glaciation	in the west +8 ("Flaxman Sea")	in the east >+8
Late Pleistocene	Sangamonian Stage (128)		Cape Collinson Interglaciation					Liverpool Bay Interglaciation	+8 to ?16	
Middle Pleistocene (730)			Thomsen Glaciation Morgan Bluffs Interglaciation	+30		+60 (Big Sea) +38	+60 to +215 (Big Sea)	Mason River Glaciation		+40 (Harrowby Sea) ↑
Early Pleistocene			Banks Glaciation		>+51 (Post Banks Sea)		>+33 (Post Banks Sea)			+75 (Horton Sea) ?
Late Tertiary			Worth Point Formation? ↑			>+25				

A PRELIMINARY ASSESSMENT OF THE OCCURRENCE AND DISTRIBUTION OF SUBSEA PERMAFROST IN NORTON SOUND

*T. E. Osterkamp *W. D. Harrison +D. M. Hopkins

There is considerable uncertainty in our knowledge of the parameters and conditions needed to assess the occurrence and distribution of subsea permafrost in Norton Sound. This uncertainty centers around the sparsity of data, the long time scales involved in the problem and includes the spatial variations in this region. In addition, the existence of subsea permafrost in the general area of the Bering Sea appears to be a near borderline case so that any assessment of its potential presence is especially difficult and depends strongly on the assumptions made in that assessment. However, recent efforts to develop the petroleum resources of the continental shelf of the Bering Sea establish the need for such an assessment. This paper reports the results of a reconnaissance drilling program in Norton Sound and uses these results to make a preliminary assessment of the occurrence and distribution of subsea permafrost in Norton Sound.

Five holes were drilled in Norton Sound during March, 1980; one near Nome and four on the south side of the Sound and north of the Yukon River delta (Table 1). The holes were logged to determine the temperature of the subsea sediments which are primarily silts deposited by the Yukon River (Nelson and Hopkins, 1972). Methods of drilling, temperature measurements and data reduction are given by Osterkamp and Harrison (1982). These temperature data show that the sediments are relatively warm, above 0°C, to the depths penetrated and that the temperature gradients appear to be positive in the two deeper holes which suggests that subsea permafrost is absent at these sites.

If these conditions prevailed over all of Norton Sound then the occurrence of subsea permafrost there would be very unlikely. However, Muench and Coachman (1980) found that the eastern portion of Norton Sound contained a two-layer water structure during the summers of 1976, 1977 and 1978, where the bottom layer was colder, more saline and denser than the upper layer. Bottom temperatures on the north side of Norton Sound were colder than on the south side and, during July, 1977, near Cape Darby, bottom temperatures < 0°C were observed, which warmed to 2-3°C by late August. This observation suggests that the mean annual sea bed temperature (MASBT) could be < 0°C in this area. Bottom temperatures on the south side of Norton Sound were several degrees or more warmer which agrees with our observations. The persistence of this cold bottom layer over time scales of decades to millennia is unknown.

An assessment of the occurrence of subsea permafrost requires information on a number of controlling factors that include:

*Geophysical Institute and +Quaternary Center, University of Alaska, Fairbanks, AK, 99701.

1. The initial permafrost conditions prior to submergence (especially thickness, thermal regime, thermal parameters, ice content, salt content, etc.).

2. Sea level history and bathymetry.

3. Oceanographic conditions during submergence (especially water temperature and salinity, timing and duration of the ice cover, presence of rivers, oceanographic currents, etc.).

4. Geologic conditions (especially sediment types, geothermal heat flow, shoreline erosion, sedimentation rates etc.).

This information must be incorporated into physical and mathematical models which are used to determine the freezing and thawing of the permafrost over geological time and, thus, to predict its presence or absence at the present time.

There are several factors that tend to preclude the presence of subsea permafrost in Norton Sound. For example, the presence of the Kaltag fault along the south side of Norton Sound, recent lava flows east of St. Michael, active icings, early break-up of lakes, and the presence of hot springs suggest that heat flow may be greater-than-normal. Therefore, the initial permafrost thickness would be smaller and basal melting of the permafrost after submergence would be greater.

It is concluded, on the basis of very sparse data and a preliminary analysis, that subsea permafrost does not occur at Nome nor on the south side of Norton Sound. Possible exceptions to this conclusion would be in nearshore areas of rapid coastal retreat as suggested by Hopkins (1980). In the Cape Darby area, ice-bonded subsea permafrost is also probably absent except in nearshore areas of rapid coastal retreat. These conclusions are based on assumptions of the maximum expected permafrost thickness ($\approx$ 125 m) at the time of submergence ($\approx$ 10,000 years before present), a geothermal heat flow capable of melting $\approx$ 2-3 cm per year at the permafrost base and that there will be some salt in the sediment pore water.

References

Hopkins, D. M., 1980. Likelihood of encountering permafrost in submerged areas of Northern Bering Sea, In: Smith, P., Hartz, R. and Hopkins, D. M., NOAA-OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Ann. Repts., Vol. 4, p. 187-193.

Muench, R. D. and Coachman, L. K., 1980. Energy balance in a highly stratified embayment: Norton Sound, Alaska, Second Int. Symp. on Stratified Flows, June 24-27, 1980, Norwegian Inst. of Techn., Trondheim, Norway.

Nelson, C. H. and Hopkins, D. M., 1972. Sedimentary processes and distribution of gold in the northern Bering Sea. U.S. Geological Survey, Prof. Paper 689.

Osterkamp, T. E. and Harrison, W. D., Temperature measurements in subsea permafrost off the coast of Alaska, Roger J. E. Brown Mem. Vol., Proc. of the Fourth Canadian Permafrost Conf., Calgary, Alberta, March 2-6, 1981, H. M. French (ed.) NRC, Ottawa, Canada, 1982.

TABLE 1

Norton Sound Drilling Data

Hole Designation	Location or Distance Offshore	Water Depth (m)	Sea Ice Thickness (m)	Drilling Method	Approx. Depth. Below Sea Bed (m)
Nome	N208°E from bench-mark on Anvil Mt., 326 m from shore along this line, 299 m offshore.	3.70	0.82	driving	6.8
St. Michael River	About 8.7 km SW of mouth of St. Michael River	2.00	1.10	jetting	25
Charley Green Creek hole 630 (hole 1)	Near the mouth of Charley Green Creek, about 630 m from shore	2.44	1.16	jetting	6
hole 610 (hole 2)	Same, but about 610 m from shore	1.69	1.16	jetting	7
Yukon Delta	63°27.2'N; 163°36.7W, 28 km from shore	10.30	1.05	jetting	18

On the origin of high arctic fiords

J. England, Department of Geography
University of Alberta, Edmonton, T6G 2H4

During the past three decades it has been widely assumed that the fiords and interisland channels of the Queen Elizabeth Islands represent an ancient, dendritic river system developed during the Tertiary on a contiguous landmass. This landmass would have included mainland Canada and Greenland which may have been the source areas for the streams. It was proposed further that these Tertiary channels were overdeepened by subsequent glacial erosion during the Quaternary. Indeed, not only are the channels assumed to be the result of glacial overdeepening but, in turn, they are used to support the presence of an Innuitian Ice Sheet occupying the Queen Elizabeth Islands during the last glaciation. On the other hand, research on northern Ellesmere Island provides an alternative model for the nature of the last glaciation in the eastern Queen Elizabeth Islands and, together with related observations, this warrants a reconsideration of the origin of these high arctic fiords (Fig 1).

During the last glaciation of northern Ellesmere Island the ice limit was only 10-40 km beyond present ice margins due to the aridity of the region. In most cases, where glaciers contacted fiords, they calved and terminated in a high, full glacial sea within 10-20 km of present coastlines. Extensive glaciomarine silts and ice-contact deltas were deposited along these ice margins whereas in the more distal parts of the full glacial sea the lack of sediment resulted in poorly developed beaches and washing limits. The limit of the full glacial sea is now 100-140 masl and its initial emergence began ca. 8000 to 11,000 BP.

Prior to the last glaciation, evidence that glaciers once filled the fiords and overtopped intervening highlands is based largely on high-elevation erratics. Furthermore, in such areas as northern Nares Strait, the retreat of the Greenland Ice Sheet from northeast Ellesmere Island is marked by an older and higher shoreline at 285 masl (>80,000 BP). The subsequent and most extensive Ellesmere Island glaciation is marked by shorelines up to 175 m asl (>35,000 BP). Nonetheless, as one enters Archer Fiord-Lady Franklin Bay, northeast Ellesmere Island, which leads inland (westward) from Nares Strait, sea levels associated with these older glaciations have not been observed above the limit of the full glacial sea. This is also true of other fiords such as Clements Markham Inlet to the north and Greely Fiord to the west. It seems unlikely that all of these marine sediments would have been removed by erosion or buried by subsequent weathering because they have been well preserved in the <u>older</u>, more distal locations (i.e. Nares Strait). Also, their removal from stable environments, such as topographic depressions, seems implausible.

Greely Fiord, north-central Ellesmere Island, is a major channel 180 km long, up to 25 km wide and 600 m deep. Recent observations around this fiord suggest an alternative interpretation regarding its origin. During the last glaciation, Greely Fiord was occupied principally by a full glacial sea. Above its marine limit one immediately encounters deeply weathered bedrock (residuum and tors) that reflects the underlying sedimentary structures. Although sparse erratics occur amongst this weathered bedrock, moraines and till sheets were not observed which is noteworthy if pervasive ice not only eroded this fiord but also crossed the intervening uplands. Also above marine limit, older shorelines were not observed which is noteworthy if a large trunk glacier retreated up-fiord in contact with the sea during greater glacioisostatic loading (than the last glaciation).

An alternative interpretation explaining the presence of the high elevation erratics around Greely Fiord involves deposition by Tertiary rivers and/or glaciers crossing a contiguous landscape. This deposition would have occurred prior to the faulting of the Queen Elizabeth Islands during the Eurekan Rifting Episode whose final phase involved extension of the crust at least as late as the Miocene or Pliocene. Prior to this faulting, the late Tertiary Beaufort Formation was deposited by streams crossing a continental landscape with a boreal forest as far north as Ellef Rignes Island. Such a contiguous landscape, under a more temperate climate, may have been favourable, both climatically and dynamically, for regional glaciation. Such a regional glaciation could disperse erratics independent of the present day fiords and its retreat would not result in glaciomarine sedimentation within those areas.

Subsequently, faulting of the Queen Elizabeth Islands resulted in fiords and channels that terminated the regional fluvial drainage and possibly regional glaciation. This faulting is known to have truncated Tertiary stream channels on Somerset Island which have counterparts displaced on the bottom of Barrow Strait. It is proposed that such channels as Greely Fiord and Archer Fiord - Lady Franklin Bay are not the result of Tertiary rivers because their substantial size and parallel, cliffed-sides are incompatible with river lengths of only 80 km! Also, these channels served to terminate the very regional drainage invoked for their original development. Consequently, it is proposed that these fiords are not the product of fluvial and glacial erosion but rather the product of faulting that has, in turn, permanently prevented the ice from subsequently covering the landscape it once crossed. If so, it is incorrect to invoke massive outlet glaciers filling fiords solely to explain high elevation erratics. Additional considerations concerning the distribution of Greenland erratics on northeast Ellesmere Island and, subsequently, the relatively small isostatic adjustment from the maximum Ellesmere Island ice advance also suggest that these ice sheets may have crossed a more subdued topography involving less ice than would be required by the present landscape.

Geologic questions that arise from this hypothesis include: (1) whether the fiords are tectonic rather than erosional; (2) if tectonic, what was the duration of their formation and how recently did the sea invade them; (3) is their a hierarchy of ages within the fiords such that northern Nares Strait was occupied by the sea during earlier glaciations while other areas, coinciding today with Greely Fiord and Archer Fiord - Lady Franklin Bay, were not; and (4) what is the relationship between the Beaufort Formation and the onset of glaciation (of Pliocene age in the Arctic Ocean cores). At present it is assumed that the Beaufort Formation is the youngest unconsolidated sediment cross-cut by the late Tertiary faulting. Although this provides a miximum age for the faults, it is also possible that they cross-cut the penultimate dispersal of glacial erratics in this region. It is recommended that where the sedimentary rocks are horizontally-bedded along both sides of Greely Fiord, seismic profiles could determine whether the intervening bedrock has been removed by erosion or simply displaced vertically.

Glacial geological questions that arise include: (1) whether the oldest glaciations predate the faulting; and (2) if so, whether glaciers have ever been capable of filling the fiords subsequently. Sampling of the unconsolidated sediments in the fiords should be persued to determine their origin and age. If regional glaciation of the high arctic predates the faulting of the channels then this will change our understanding of past ice sheet dynamics in high latitudes. This may also apply to the northward advance of the Laurentide Ice Sheet across what are now the southern arctic islands.

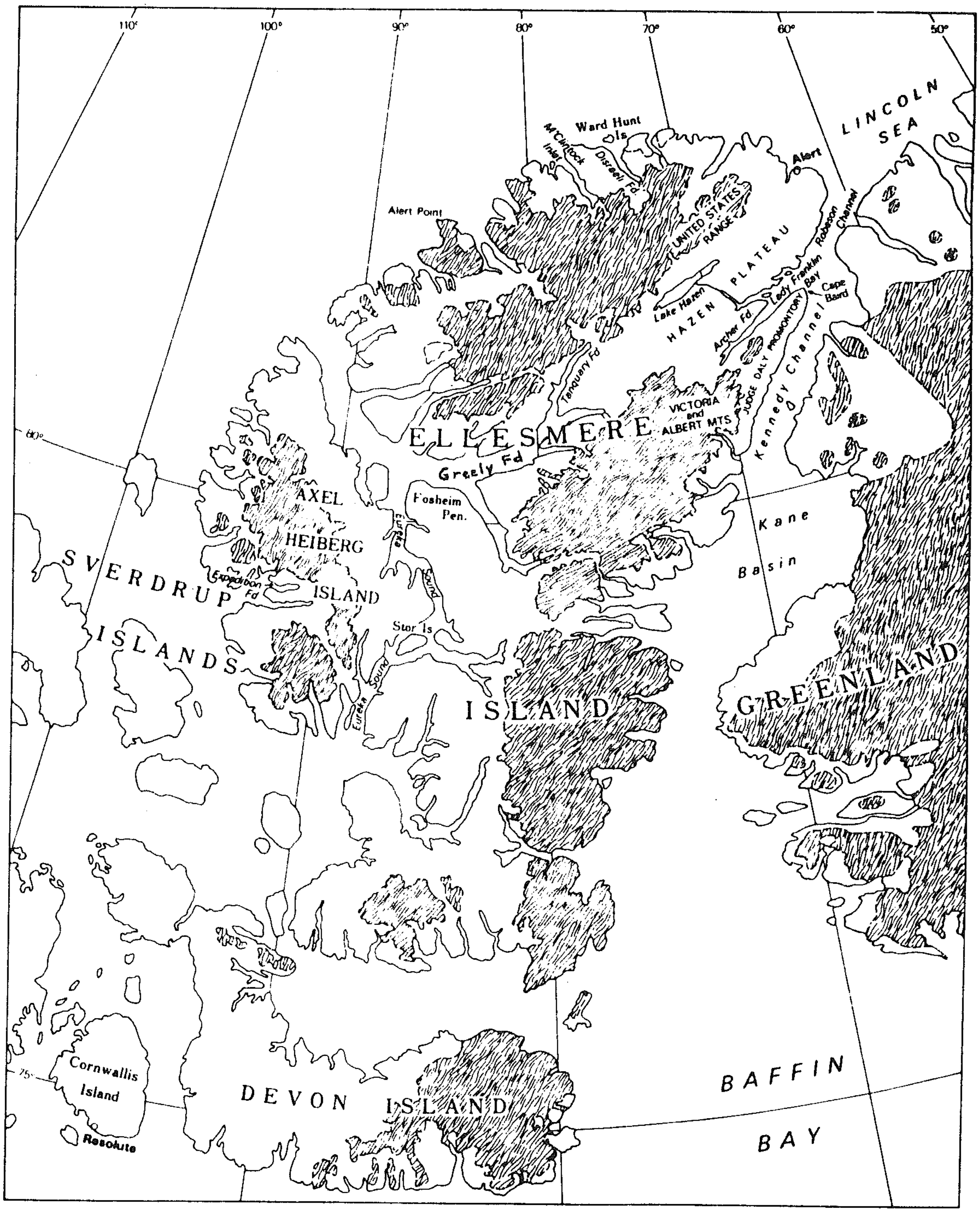


FIG. 1. Location map of the eastern Queen Elizabeth Islands, existing upland icefields (shaded areas) and prominent place names associated with the Archer Fiord – Lady Franklin Bay field area, northeastern Ellesmere Island.

OCEANOGRAPHIC RECONNAISSANCE OF SELECTED BAFFIN ISLAND FJORDS

by

R. W. Trites
Department of Fisheries & Oceans
Marine Ecology Laboratory
Bedford Institute of Oceanography
P. O. Box 1006
Dartmouth, Nova Scotia
CANADA B2Y 4A2

As part of the Geological Survey of Canada's project SAFE (Sedimentology of Arctic Fjords Experiment) the CSS Hudson undertook two multidisciplinary cruises into selected Baffin Island fjords (Fig. 1a), one in the period 6-24 Sept, 1982 and the second in the period 19 Sept - 5 Oct, 1983. The objective of the synoptic physical oceanographic program was to provide a broad general description of the distribution of temperature, salinity, density, dissolved oxygen and nutrients by making measurements at a series of stations from near the head of a fjord to a point seaward of its mouth (e.g. Fig. 1b). During the 1982 survey, measurements were taken in nine fjords: Sunneshine, Coronation, Maktak, Tingin, Itirbilung, McBeth, Inugsuin, Clark, and Cambridge (Fig. 1a). In 1983 measurements were confined to just three fjords: Itirbilung, McBeth, and Cambridge. Data from these two surveys have been compiled (Syvitski and Blakeney 1983; Syvitski 1984) but as yet only limited oceanographic analysis and interpretation have been undertaken.

Although each fjord displays its own unique features, there are, nevertheless, broad common features. At the time of the surveys the freshwater discharge into the fjords was rapidly decreasing to the near-zero winter levels. Autumn cooling was underway as well, so that maximum temperatures in the surface layer often occurred at 10-20 M depth rather than at the sea surface (Fig. 1c). Thermally, the fjords, at this period of the year, are comprised of three layers (Fig. 1c), - a relatively warm surface layer ($\sim$0-3^{o}C) of varying thickness ($\sim$5-60M), a cold intermediate layer (less than -1^{o}C) of varying thickness (0-325 m) with its axis (i.e., minimum temperature) located at a depth ranging from 40-400 M, and where depth permits, a warmer deep layer with temperatures that may exceed 1^{o}C. Salinity increases monitonically with depth (Fig. 1d) with surface values generally in the 25-30 ^{o}/oo range, and reaches values close to 34.5 ^{o}/oo in the deepest water near the mouth. Density stratification (Fig. 1e) is primarily controlled by salinity.

A vertical-longitudinal section of Cambridge Fjord (Fig. 1b) displays features generally present in all fjords visited. The lack of shallow sills near the mouth of the fjords allows deeper offshore water to penetrate into the fjord (Fig. 2). Thus below the surface layer properties bear close similarity to those observed in Baffin Bay by other researchers (Coote and Jones 1982). One of the shallowest sills (depth approx 100 M) encountered in the nine fjords, is located in Cambridge Fjord not far from its head, and does signficantly restrict ventilation in the basin above it where the depth reaches 325 M. Dissolved oxygen concentrations (2.82 ml/L) near the bottom of this basin in 1983 (Fig. 2d) had diminished from 3.45 ml/L measured in 1982 and was the lowest value measured in any of the fjords. Phosphate (Fig. 2e), nitrate (Fig. 2f), and silicate (Fig. 2g) concentrations near the bottom of this basin displayed the highest values seen in any of the fjords. From

1982 to 1983 values of phosphate, nitrate, and silicate near bottom (Station 2) increased by 0.06, 0.65 and 2.46 µg-at/L respectively. Although oxygen consumption and nutrient regeneration rates are unknown, it appears that only limited renewal of the deepest water in the basin took place over the 12-month period.

From the limited data available, the upper portion of the water column (less than 100 M) in the fjords appears to be subject to important short-period variations (hours-days), reaching maximum amplitudes at the head of a fjord. For example, in Inugsuin Fjord, in 1982, a surface layer with a temperature of about 2-3°C and a thickness of 30 M was observed in the lower reaches of the Fjord. At the head of the Fjord, initial measurements revealed an almost absent surface layer, but measurements taken a few hours later showed the surface layer had become largely re-established. Two vertical-longitudinal sections taken in McBeth Fjord in 1982 likewise showed a thinning of the surface layer at the head of the Fjord from about 50 M to 25 M over a time period of less than two days. In both these instances it is believed that local winds were largely responsible for inducing the observed changes.

References

Coote, A.R., and E.P. Jones. 1982. Nutrient distributions and their relationships to water masses in Baffin Bay. Can. Jour. Fish. Aquat. Sci. 39(8): 1210-1214.

Syvitski, J.P. 1984. Sedimentology of Arctic Fjords Experiment: HU83-028 Data Report, Volume 2. Can. Data Rep. Hydr. and Ocean Sciences. No. 28.

Syvitski, J.P., and C.P. Blakeney. 1983. Sedimentology of Arctic Fjords Experiment: HU82-031 Data Report, Volume 1. Can. Data Report of Hydr. and Ocean Sciences. No. 12.

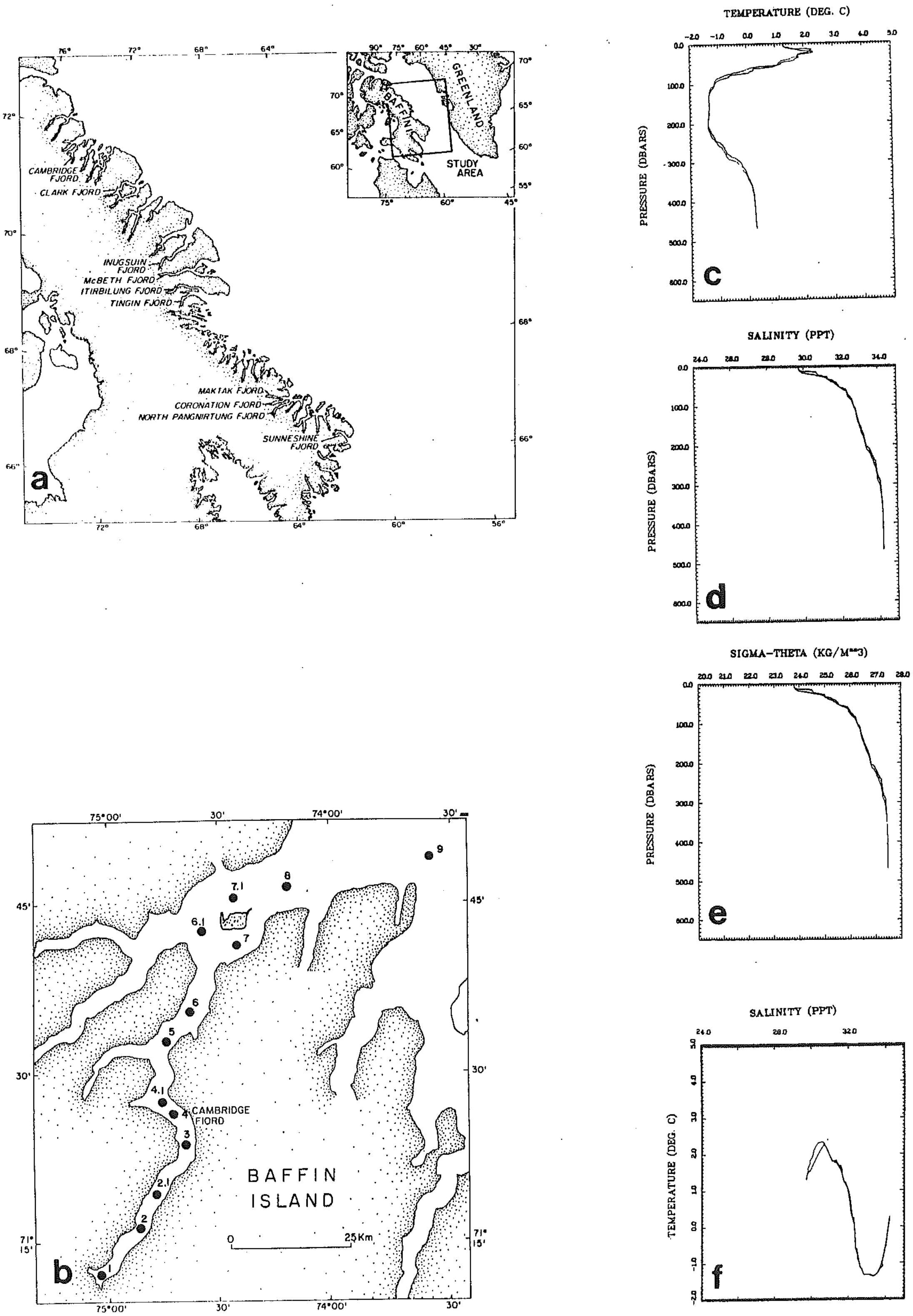


Figure 1. (a) Location of Baffin Island Fjords mentioned in text; (b) Cambridge Fjord, showing location of oceanographic stations; (c) temperature-depth profile taken at Station 5, 23 Sept, 1982; (d) salinity-depth profile at same time and place as c; (e) density-depth profile at same time and place as in c; (f) temperature-salinity diagram at same time and place as in c.

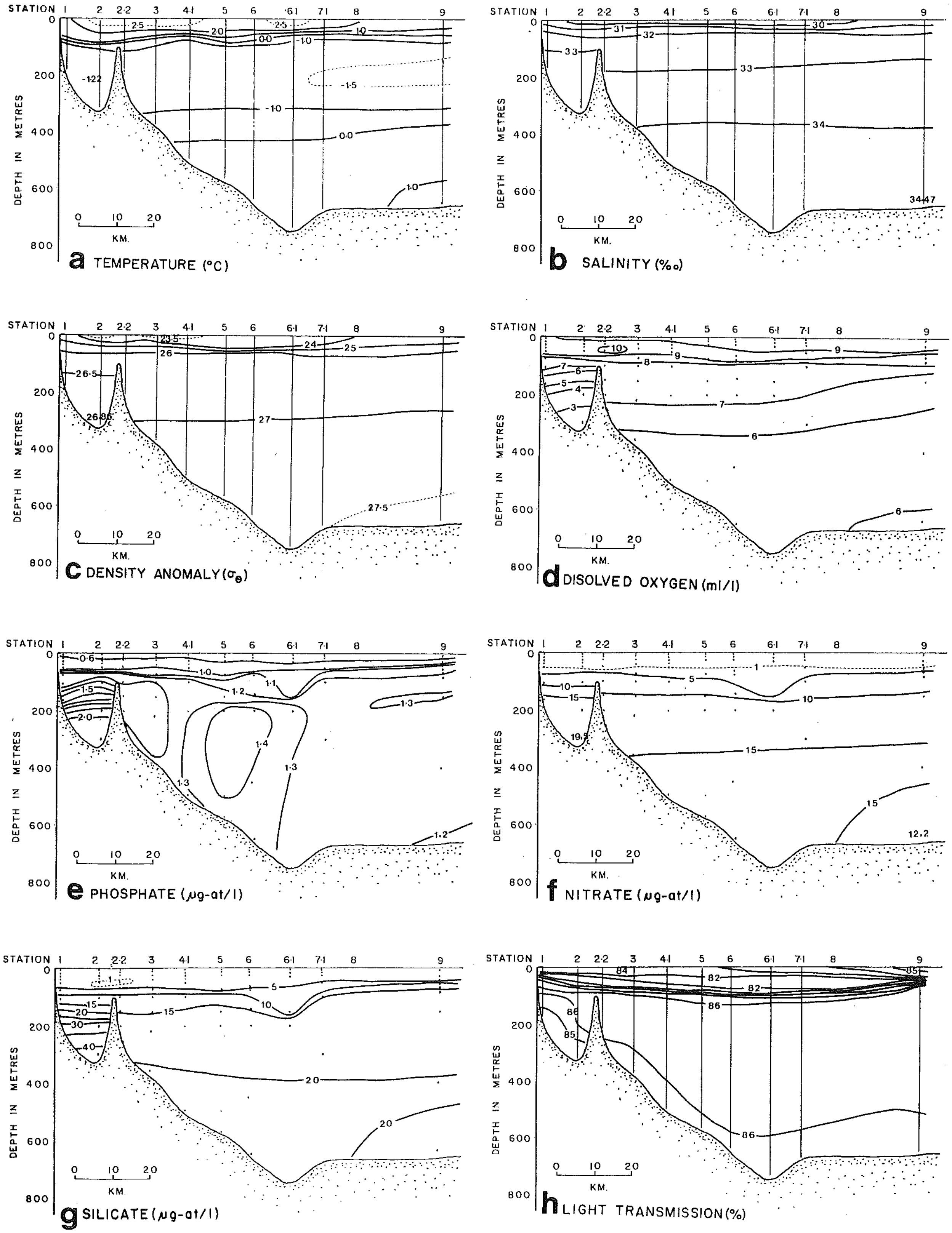


Figure 2. Vertical-longitudinal section of oceanographic properties taken in Cambridge Fjord (Fig. 1b) 20-24 Sept. 1983. (a) Temperature (°C); (b) salinity (°/oo); (c) potential density anomaly (∂_θ); (d) dissolved oxygen (ml/L); (e) phosphate (µg-at./L); (f) nitrate (µg-at./L); (g) silicate (µg-at./L), and (h) light transmission (%).

DETRITAL CARBONATE ACCUMULATION ON THE SHELF AND IN THE FIORDS, BAFIN ISLAND, EASTERN CANADIAN ARCTIC

J.T. Andrews,
INSTAAR and Department of Geological Sciences
University of Colorado, Boulder,
CO. 80309

For at least two decades workers have commented on the significance of the detrital carbonate content of sediments from the deep sea shelf and fiord sediments of western Baffin Bay. A series of ten piston cores from shelf and fiord environments have been studied for their calcite and dolomite content using gasometric analysis of the 74um fraction, and XRD of both the clay- and silt- sized fractions. In most areas we have studied carbonates represent far-travelled, exotic minerals, that have been introduced into the glacial marine/marine setting through ice-berg rafting or suspended in melt-water plumes. Resuspension can also occur through a number of different processes. Carbonate contents range between c60% and a trace. Highest values occur in cores in and around outer Frobisher Bay and peak percentages occur during deglacial events. In the fiords there is a small but significant influx of detrital carbonate into the outer fiords starting in the last 4ka which may reflect increased ice berg rafting from NW Greenland and/or increased resuspension of carbonate-rich shelf sediments. Calculations of the rate of carbonate accumulation (mg/cm2/yr) give values that range between 375 and 0.5. During the last 5000 years or so carbonate accumulation has been affected by dissolution associated, in time, with the development of the cold Canadian Current.

GEOCHEMICAL INDICATORS OF DEPOSITIONAL ENVIRONMENT IN BAFFIN ISLAND FIORDS

Buckley, D.E., and R.A. Fitzgerald, , Geological Survey of Canada, Atlantic Geoscience Centre, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2

Sediment core samples from several fiords in eastern Baffin Island have been analyzed for a number of geochemical parameters, including total metals (Si, Al, Ca, Mg, Fe, Mn, Zn, Cu, and Ni) and potentially reactive metals, as determined by selective leaching methods. These data have been compared with other indicators of sedimentary geochemical conditions, including sediment pH, redox potential, total sulphide, total carbon, organic carbon, and water content.

The geochemical characteristics of these sediments are determined predominantly by the textural properties, which reflect the ratio of layered silicates to other detrital minerals derived from nearby provenances. Within a single fiord system, several sub-basins can be geochemically identified, with most of the depositional environments being classified as geochemically immature. This is indicated by low proportions of potentially reactive transition metals and this characteristic may be related to rapid deposition and burial.

Linear regression statistical tests are applied to geochemical data in order to test models of progressive diagenesis or maturity of the sediments along transects from the head of the fiords to the seaward extremities. These tests, generally, confirm that there is little systematic alteration within each fiord.

SUBAQUEOUS SLOPE FAILURES WITHIN SEISMICALLY ACTIVE ARCTIC FJORDS

J.P.M. SYVITSKI, Geological Survey of Canada, Bedford Institute of Oceanography, Box 1006, Dartmouth, N.S., B2Y 4A2

Ten fjords along the coast of Baffin Island were surveyed from surface vessels and submersibles, in 1982, 1983 and 1985. The fjords were chosen to cross a number of environmental gradients, including seismic activity. Sunneshine Fiord (66° 30'N) fell within a low risk earthquake zone (horizontal accelerations of <0.08 g). Probability of high ground accelerations increase to the north and Tingin, Itirbilung, McBeth, Inugsuin, Clark and Cambridge (71° 30'N) fjords all fall within one of the most seismically active areas of Canada (g_h >0.3 g). Historic earthquakes greater than Richter 7.2 magnitude have been recorded in this region (Earth Physics Branch, Canada, data).

Acoustic data, from high-resolution sidescan and seismic reflection profiles, and lithologic data, from grab samples, piston and Lehigh cores, both indicate that subaqueous failures are common in all ten fjords. Areas of failure can be divided into three zones: (1) along the actively prograding fjord-head prodelta slopes, seaward of both sandurs and tidewater glaciers; (2) along the steep side-wall slopes, including off side-entry deltas, tidewater glaciers and junctions with submerged hanging valleys; and (3) on submerged sills (frontal dump moraine, kame delta, sediment mantled bedrock). Sediment some 50 to 100m beneath the seafloor may also be folded or faulted but these features mostly appear separate from the surface failure events.

The seafloor sediments have a wide range of lithologies, from massive gravelly sands to unimodal clays. Hein and Longstaffe (1985) noted that the plasticity indices varied between 2 and 41% and with the sediment type (lowest=laminated or graded; intermediate=massive; and highest= bioturbated). Like most fjords, the mineralogy is primarily hinterland glacial flour: crushed quartz, feldspar, mica, amphibole, pyroxene, garnet and ilmenite/magnetite. Water contents (wet weight %) may exceed 100% in the surface (1m) sediments and may be as low as 25% at 10m. Shear strength values range upwards to 12 KPa, with sensitivites (S_U/S_R) occassionally exceeding 10 (Hein and Longstaffe, 1982).

There are four styles of prodelta slope failure: (1) open assymetric folds on low angle slopes affecting 5 to 10 m of sediment, that may originate from sediment-loaded creep failure (*e.g.* Coronation, Maktak, Tingin and McBeth fjords); (2) seasonal or semi-continuous failure along the steep forset beds, that may be triggered by sea-ice or iceberg impacts, breaking of internal waves, and freshet &/or jokolhlaup sediment deposition (*e.g.* Maktak and Itirbilung fjords); (3) failures associated with formation of push moraines, iceberg calving and underflow discharges caused by semi-continuous tidewater glacier movement and discharges (e.g. Coronation Fiord); and (4) discontinuous and deep-seated failures postulated to be seismically triggered (*e.g.* Tingin, Itirbilung, McBeth, Inugsuin, Clark and Cambridge fjords). Some of the prodeltas show signs of more than one type of failure, and type 4 failures occur exclusively in the zone of highest ground accelerations.

Type (2) failures occur on prodelta slopes of 1.5 to 6° cut by channels (1 to 10m deep and 10 to 100m wide, values decreasing with water depth) that originate from one or more arcuate re-entrants or chutes cut into the delta lip (5 to 30° slopes). The channels may converge or even truncate one another downslope. They mostly do not have levees (these appear only when the slope falls below 2°). The channels are lined with dense well-sorted sand, occasionally in megaripples (wave lengths 12 to 30m, heights 1.8 to 2.8m). The interchannel areas consists primarily of poorly-sorted and weakly compacted v.f. sandy muds. The initial failures are thought to initiate from small retrogressive slides or local liquefaction developing into grain flows and/or turbidity currents. Slide volumes, estimated from sidescan and high resolution reflection seismic records, are found to vary between 10^3 to 10^6 m^3.

The deep-seated failures (type 4), may involve listric slide planes extending 50 or more meters in depth and involving slide volumes of 10^6 to 10^9 m^3. The slide geometry may be simple or complex, occassionally involving block translation and or remolded surficial (upper 5m) sediments. Classic slide features are invariably present--antithetic faults, compressional thrust folds and faults, caudal zone. Megachannels (5 to 30m in depth and widths of 100 to 400m) occasionally extend up to 12 km from the slide proper (Fig.1). Grain flow and turbidity current lithologies are associated with these channels. Lithologies associated with the remolded surface are mostly debris flow layers, occasionally with undisturbed blocks.

The fjord side-walls have slopes between 15° and 50° averaging ≈30°. Slopes are covered in coalescing debis flows and slumps and talus cones. Creep? folds are also common along the margins. There appear to be twice as many failures and with larger volumes along the side affected by the

Coriolis-intensified surface plume (right-hand side facing down-fjord). The slump toes may extend across the fjord basin. Failures are thought to relate more to oversteepening than to overloading but the later may play a role near the fjord-head prodelta.

Almost all sills found well within a fjord have failed many times on both the seaward and landward side of the sill. In Cambridge Fiord, between 10^8 and 10^9 m^3 of well-sorted sand, possibly from a submerged kame delta, has been traced as a non-erosive grain/debris flow deposit some 40km down-fjord into water depths greater than 800m. The deposit may reach 10m in thickness (and may represent amalgamated deposits). In McBeth fjord, a channel extends some 15 km down-fjord away from the sill. Maximum slopes occur near the sill crest ($>5^\circ$) and the area of failure, channels are confined to slopes greater than 1° and deoposits reach their maximum thickness over slopes $<1^\circ$.

Failure features identified in older and more deeply buried sequences are believed to result from three mechanisms: (1) diastrophic events as evidenced by growth faults; (2) past ice movements (i.e. glacier tongues that once overrode proximal glacio-marine sediments and including thrust blocks, overconsolidated fractured varves and push moraines); and (3) dewatering features with associated antithetic faults. In an isolated outer basin of McBeth fjord, there is good evidence that the basin collapsed through internal spontaneous liqufaction and side slope retrogressive sliding (Fig. 2). The basin deposit consisted of well-sorted silt.

REFERENCES:

Hein,F.J. & Longstaffe,F.J. 1983.Geotechnical, sedimentological and mineralogical investigations in Arctic fjords. In:Syvitski,J.P.M., Blakeney, C.P. (compilers) SAFE HU 82031 Data Report. **Can. Data Rep. Hydr. Ocean Sci. 12, Ch.11**.

________________ 1985.Sedimentologic, mineralogic, and geotechnical description of fine-grained slope and basin deposits, Baffin Island Fiords. **Geo-marine Let. 5, 6p.**

FIGURE CAPTIONS:

Figure 1. Interpreted seismostratigraphy of the prodelta environment of Tingin Fiord B.I. with an example of the DTS high resolution reflection seismic record.

Figure 2. An example of a progressive liquefaction slide in an outer basin in McBeth Fiord, B.I. based on a DTS HUNTEC seismic reflection record. Water depth ≈500 m.

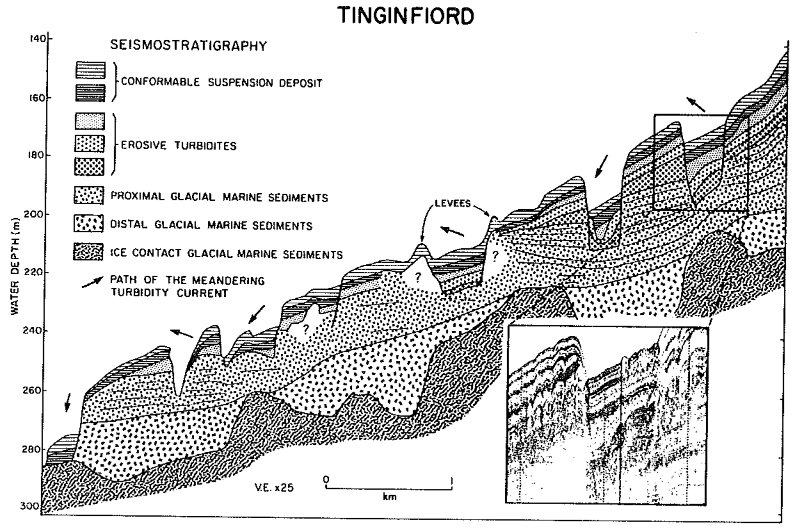

TINGINFIORD
SEISMOSTRATIGRAPHY
CONFORMABLE SUSPENSION DEPOSIT
EROSIVE TURBIDITES
PROXIMAL GLACIAL MARINE SEDIMENTS
DISTAL GLACIAL MARINE SEDIMENTS
ICE CONTACT GLACIAL MARINE SEDIMENTS
PATH OF THE MEANDERING TURBIDITY CURRENT
LEVEES
WATER DEPTH (m)
140
160
180
200
220
240
260
280
300
V.E. x25
0
1
km

FIG. 1

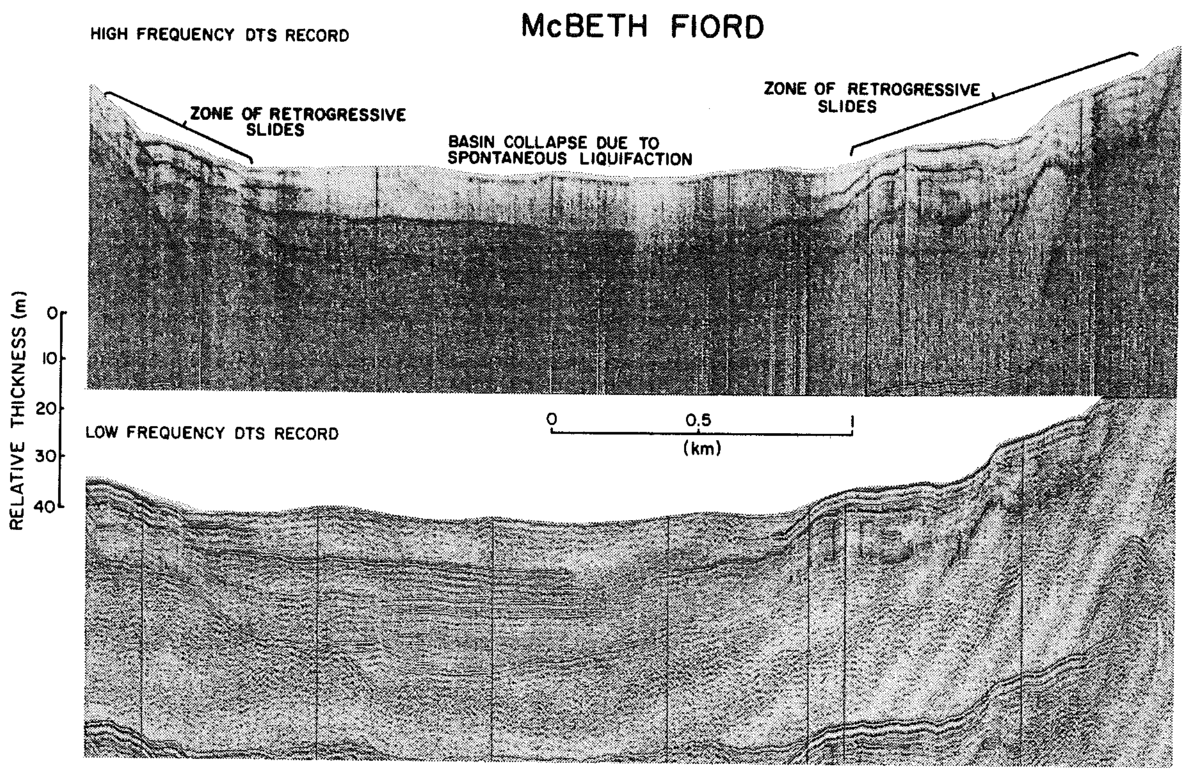

McBETH FIORD
HIGH FREQUENCY DTS RECORD
ZONE OF RETROGRESSIVE SLIDES
BASIN COLLAPSE DUE TO SPONTANEOUS LIQUIFACTION
ZONE OF RETROGRESSIVE SLIDES
RELATIVE THICKNESS (m)
0
10
20
30
40
LOW FREQUENCY DTS RECORD
0
0.5
1
(km)

FIG. 2

Contrasts in sediment mass transport and depositional processes in two British Columbia Fjords.

by

David B. Prior and Brian D. Bornhold
Coastal Studies Institute
Louisiana State University
Baton Rouge, Louisiana

Brian D. Bornhold
Geological Survey of Canada
Pacific Geoscience Centre
Sidney, British Columbia

Comparisons of sediment distributions and bottom morphology in Kitimat Arm and Bute Inlet show that sediments may reach the fjord basins by quite different mass transport processes. At Kitimat the slope instability processes involve cohesive clays and silts, whereas in Bute Inlet bottom sediment movement involves primarily sands derived from the fjord head delta.

The Kitimat debris flow (compare Bornhold and Prior, this volume) appears to have involved several interactive mechanisms, which together resulted in a large, but discrete area of deformed sediments. Only a small proportion of the total debris flow originated on the steeper delta front slopes, but accompanying deformation of the fjord bottom sediments took place over a distance of about 5 km away from the delta (Fig. 1). Interpretations of bottom morphology, acoustic signatures and cores in the debris flow are summarised in Figure 2, which combines transport processes and depositional characteristics. Shallow sliding on the upper delta front transported silts and clays (and some sand) short distances downslope. Loading, remolding and progressive shearing took place along the fjord bottom resulting in highly disturbed sediments identical in grain size to the original fjord bottom sediments. Spillover and block-gliding occurred at the distal margins of the debris flow and transported isolated blocks up to 1 km beyond the main depositional lobe.

At Bute Inlet, some large, deep-seated rotational slides have caused major, arcuate re-entrants in the delta front (Fig. 3). The slides scars lead downslope into deeply-incised branching channels (Fig. 4A) which coalesce into a single sinuous channel (Fig. 4B) which extends down-fjord a distance of approximately 25 km from the delta. The channel floor has an average gradient of about 1° and cuts through the parallel-bedded Holocene fjord bottom sediments (Fig. 5). Lobate features, comprising stacked sediment units are found covering the sea floor for a distance of 10 km beyond the downfjord terminus of the channel. The lobate depositional areas exhibit a wide range of local features including collapse depressions and abrupt-headed channels, and the deposits clearly overlie the former fjord floor stratified sediments. Coring revealed the presence of sands within the branching channels, on the floor of the sinuous channel and in the lobate areas. In the Bute Inlet area, therefore, sediment mass transport processes, including delta front sliding and channelised flows, have been capable of extremely long-distance sand transport over low angle bottom slopes.

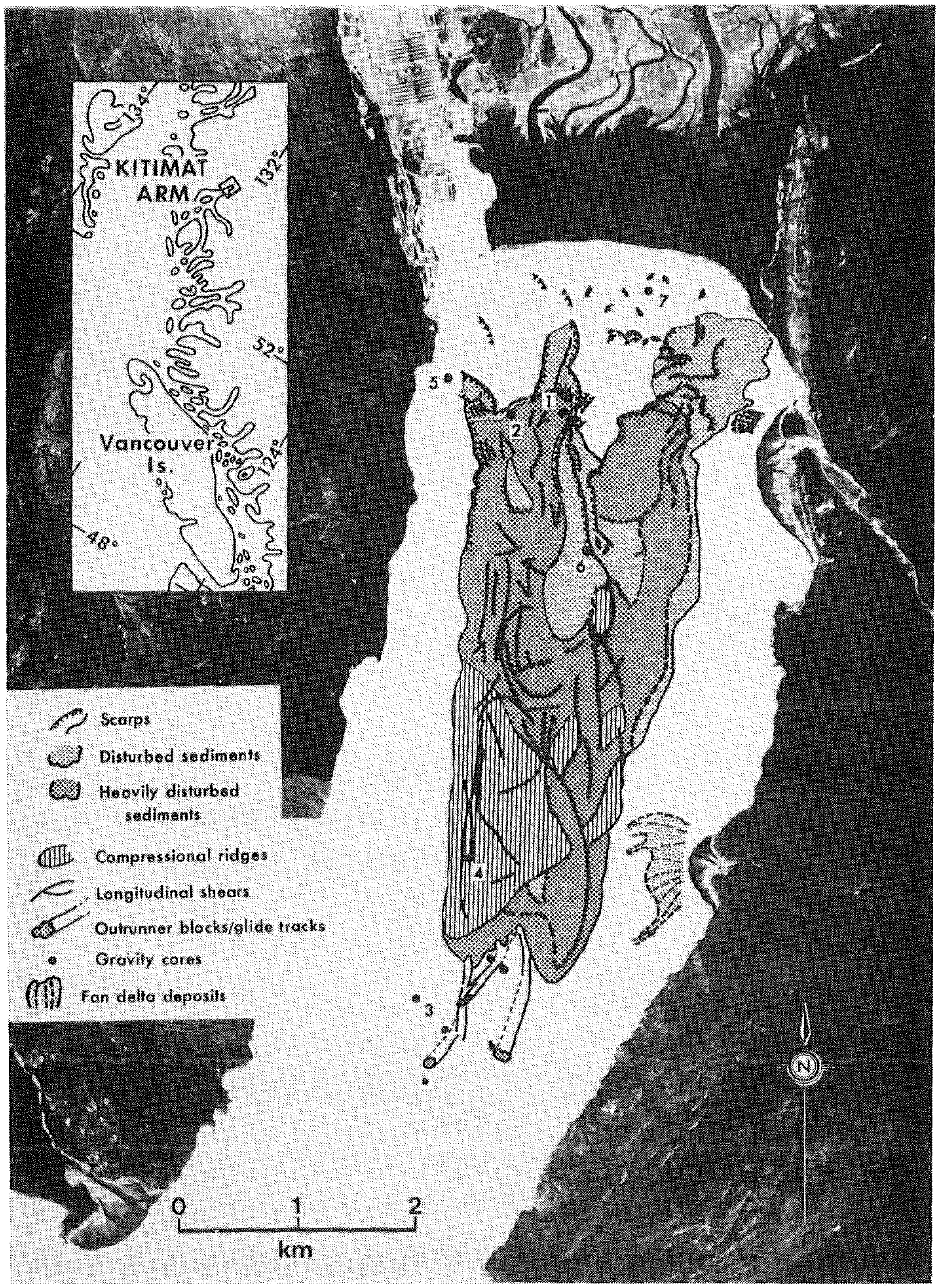


Figure 1 Location and morphology of the Kitimat debris flow.

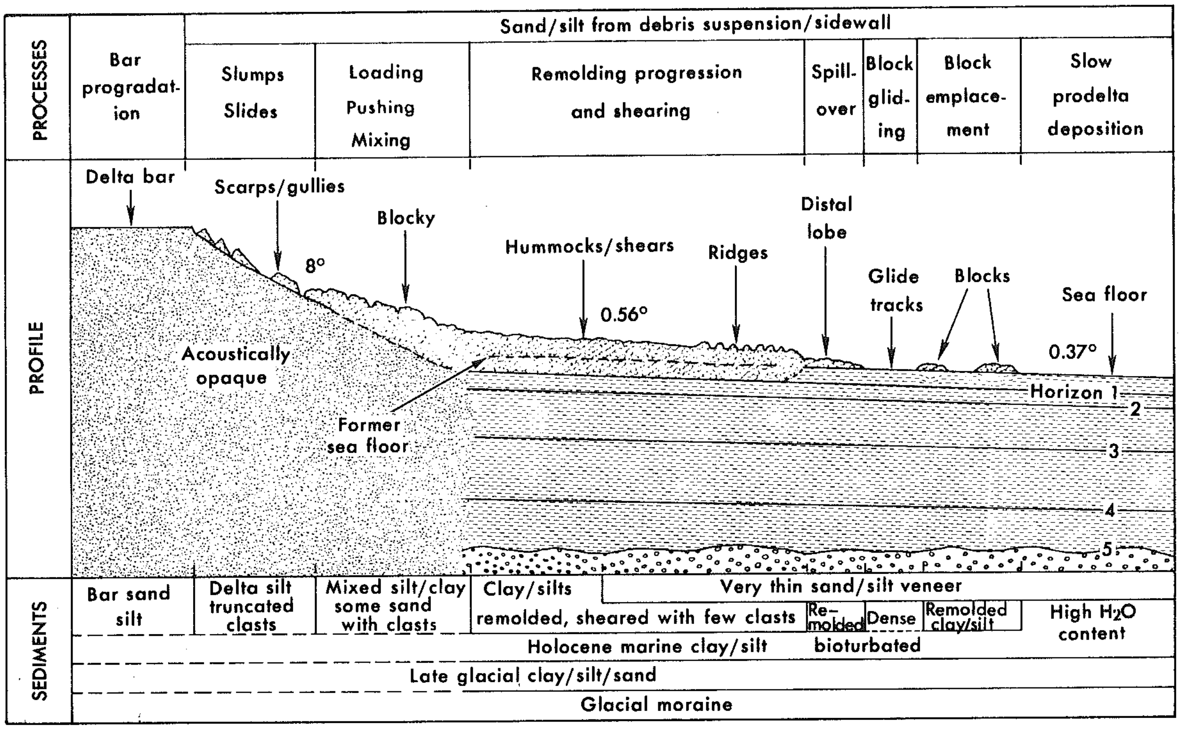


Figure 2 Summary of the characteristics of the Kitimat debris flow, relating process mechanisms and deposits to a schematic longitudinal profile from the delta to the distal margin of the flow.

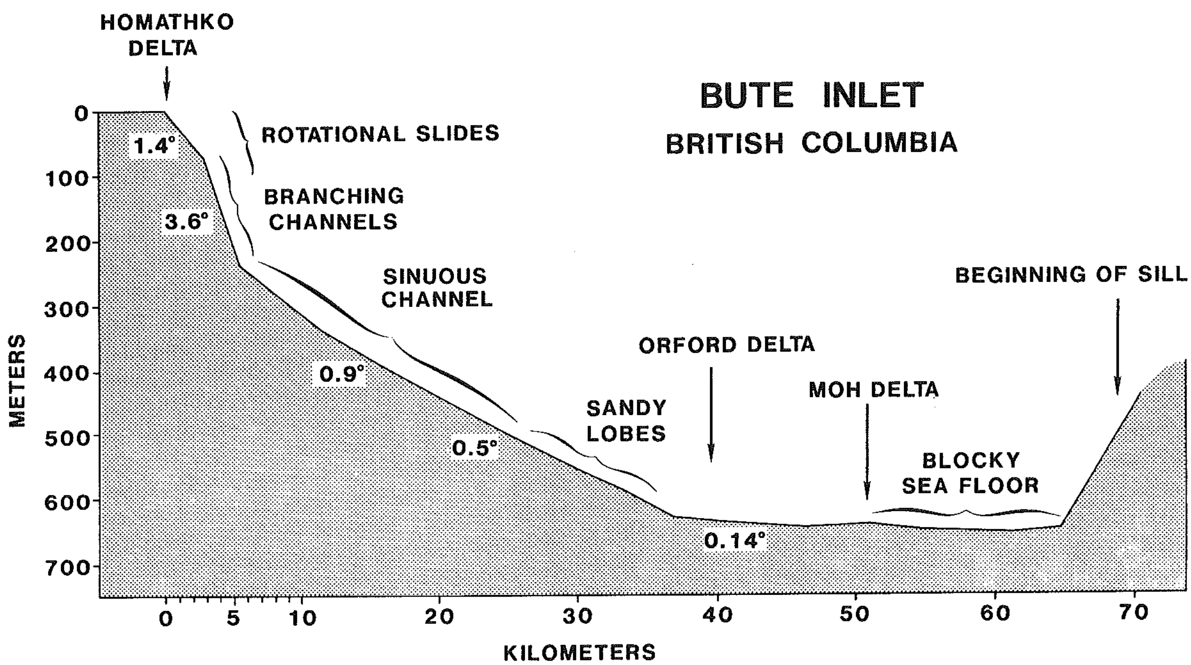


Figure 3 Longitudinal profile along Bute Inlet illustrating the locations of rotational slides, branching channels, sinuous channel and sandy lobes.

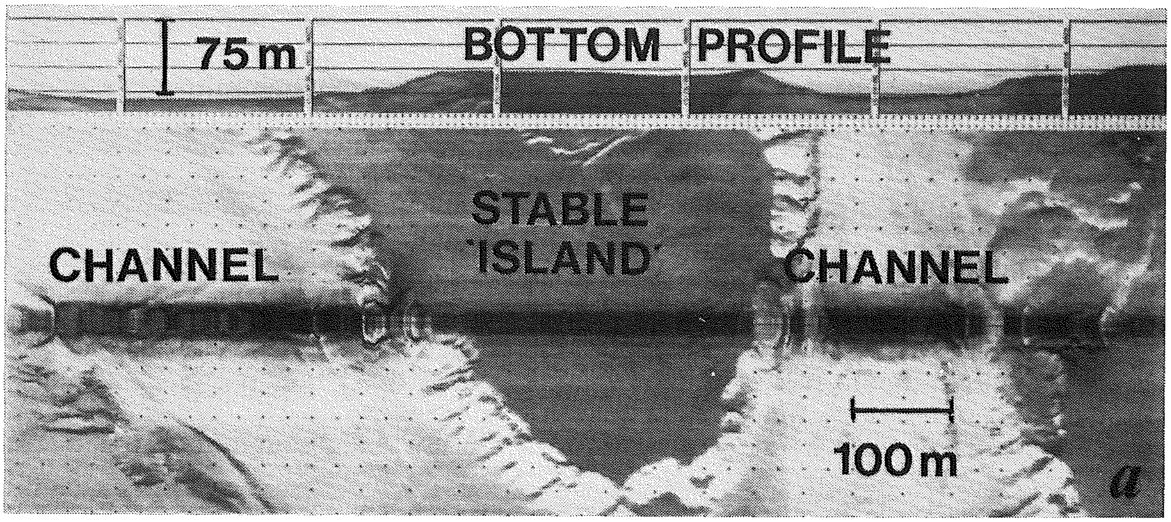


Figure 4A Side scan sonar image showing branching channels incised within undisturbed bottom sediments.

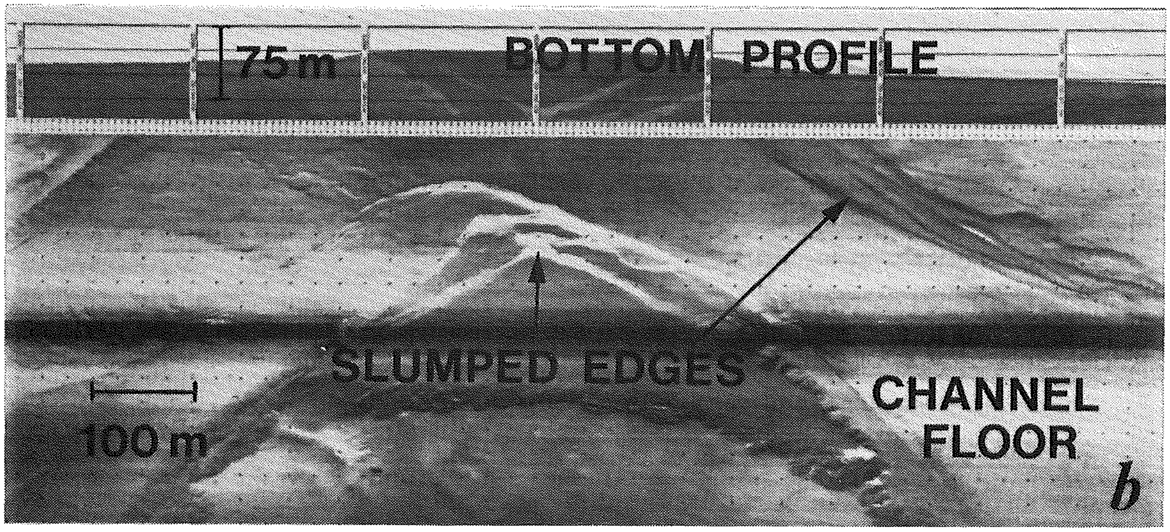


Figure 4B Side scan sonar image across a portion of the sinuous channel.

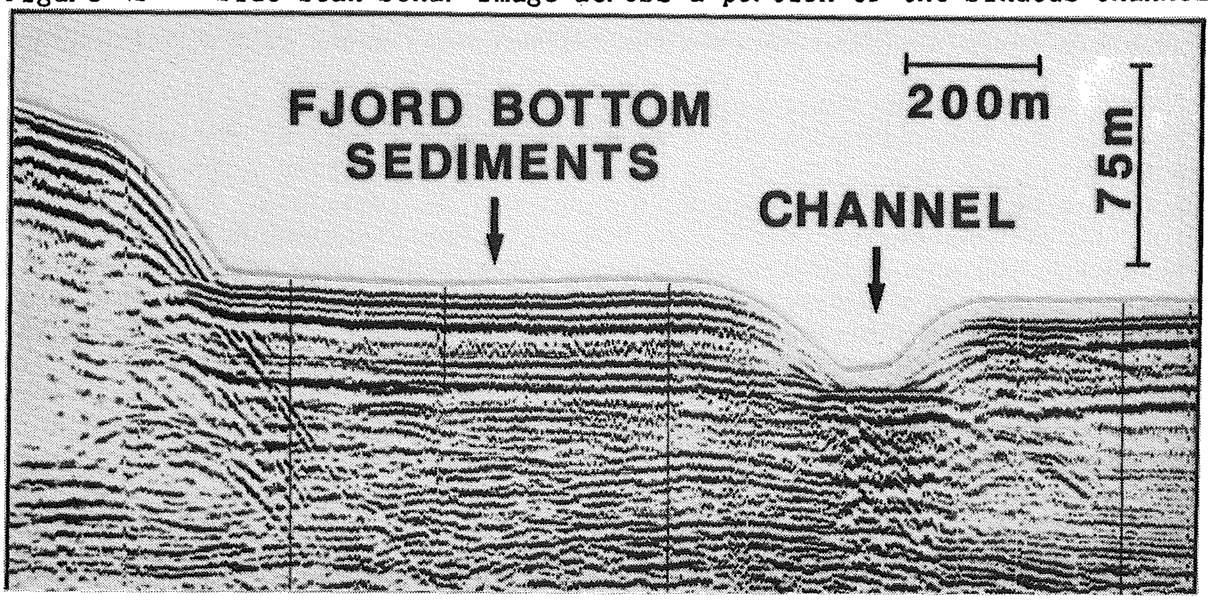


Figure 5 Air gun profile across the fjord and its stratified bottom sediments cut by the sinuous channel.

INTERTIDAL SEDIMENTATION IN HIGH ARCTIC FIORDS, EAST-CENTRAL ELLESMERE ISLAND

M.T. Krawetz and S.B. McCann, Department of Geography, McMaster University, Hamilton, Ontario.

The coast of east-central Ellesmere Island in the vicinity of latitude 79°N (Fig. 1) is characterized by long fiords, separated by bold headlands which project into Kane Basin and Smith Sound. High, steep, often vertical, glaciated, bedrock slopes are the main coastal landform, but moderately-wide, boulder-strewn tidal flats constitute the major element in the intertidal depositional environment. Since wave action is negligible, due to the very restricted fetches and short open water season, the joint effect of tidal and sea ice processes provides the main dynamic activity in the shore zone. Other key features of the area are the numerous tidewater glaciers and the variety of Quaternary deposits which occur at intervals around the coast.

The region is mesotidal with a semi-diurnal tidal oscillation and a mean range of 2.9 m expanding to 4.8 m at large tides. Sea ice conditions are severe with a restricted open water season, usually less than 6 weeks long. Thick, multi-year sea ice, with berg ice derived from further north, dominates the offshore waters, impinges on the headlands, and enters the outer part of the fiords. However, the ice cover within the fiords consists largely of first year sea ice, together with berg ice derived from actively calving fiord-head and fiord-wall glaciers. The northern margin of the North Water polynya abuts Cape Herschel in the southern part of the region.

This paper focusses on three different tidal flat settings within these ice-dominated, tidal environments. The interactions are best illustrated by considering the following factors in each setting: source of intertidal boulders, mode of transport of boulders, and arrangement of boulders.

1. Alexandra Fiord tidal flats are well-developed at the site of the former R.C.M.P. post where the intertidal zone consists of two morphologic units: an upper bedrock scarp situated between the highest high water mark and the mean water level, and a lower depositional platform situated between the mean water level and the lowest low water mark. The intertidal platform is 75 to 100 m wide and extends uninterrupted for 4 km alongshore. A general sequence of seaward coarsening sediments from silty sands to clast-supported gravels occurs across the tidal flat surface though this pattern is frequently disrupted by the micro-topography of the underlying bedrock. Superimposed on these deposits are boulders which are randomly distributed across the flats becoming more numerous, larger, and rounder seaward. The largest concentration of boulders occurs at the low water mark to form a boulder barricade. The boulders in the barricade are large, round, and of mixed lithologies, reflecting the characteristics of the Quaternary deposits in the backshore. The boulders on the flats are smaller, more angular, and of the same lithology as the local bedrock. Many of the boulders are partially or completely surrounded by moats, the result of tidal current scour. The main mode of boulder transport is rafting by first year floes.

2. Erik Harbour is a small, shallow, protected embayment on the southeast corner of Rosse Bay, adjacent to the till bluffs and moraines marking the southern margin of the large, tidewater Leffert Glacier. In contrast to

Alexandra Fiord there is an abundant supply of sediment to the shore zone, and the most distinctive sectors of the wide intertidal zone are characterized by a thick veneer of soft mud interspersed with low gravel-boulder mounds surmounted by very large boulders. No multi-year ice enters the embayment which is protected by shallow entrance shoals. Rolling and pushing are the modes of transport of the large boulders. The muds are concentrated by tidal currents.

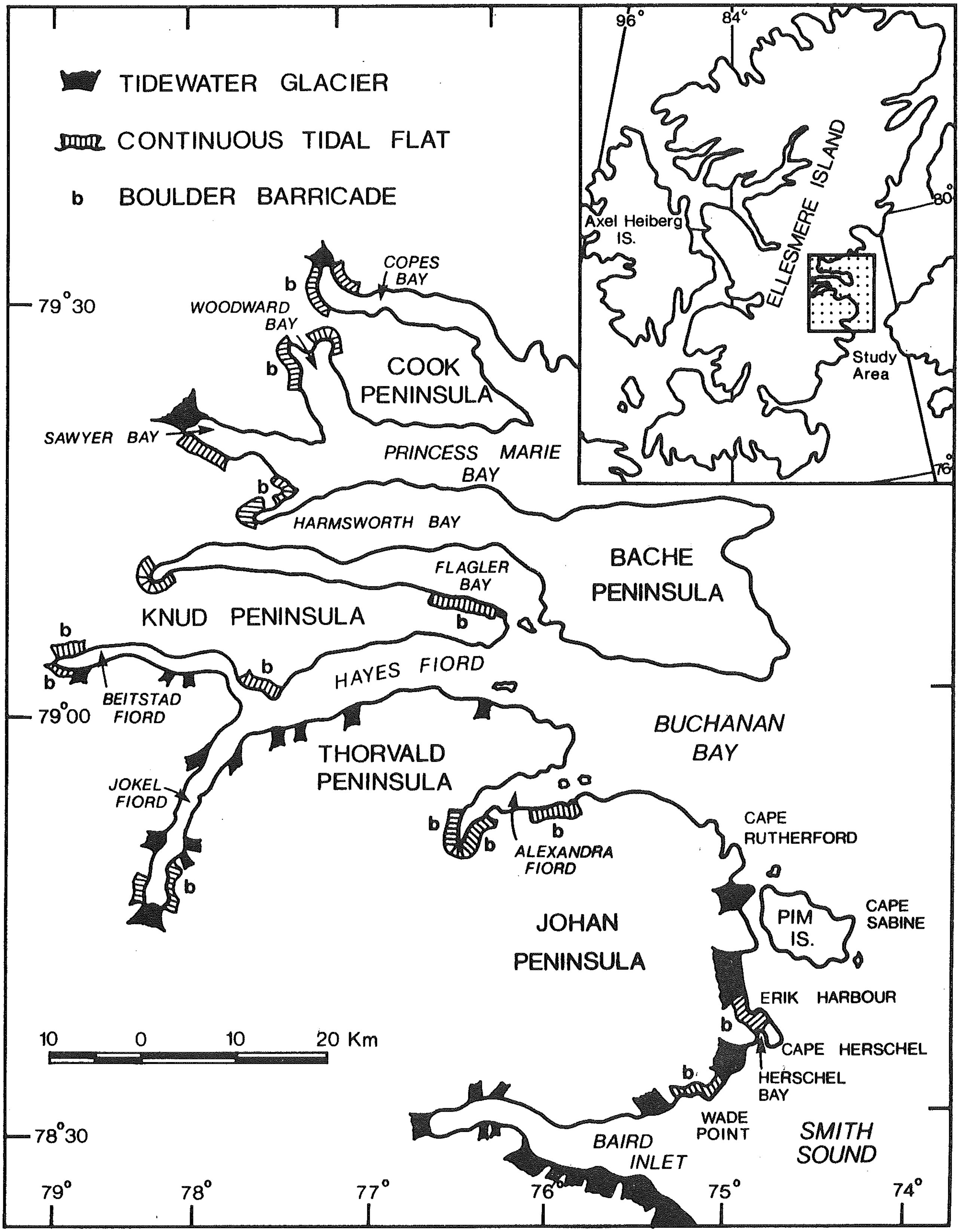
3. Herschel Bay is a deep, south-facing embayment adjacent to the North Water polynya. The head of the bay is plugged by glacial deposits, and there is an abundant source of boulders. Very thick floes (4-5 m) of multiyear ice and berg ice enter the deep bay and are driven ashore. A boulder barricade has been constructed by this ice impinging from the seaward side and gouging the bed. This is the only example seen by us of this mode of barricade formation which was originally described by Tanner (1939).

The sources of boulders, modes of boulder transport, and boulder arrangements at the three tidal flat sites are summarized in Table 1.

TABLE 1

Boulder transport processes and responses in the intertidal zone, east-central Ellesmere Island.

	BOULDER SOURCE	MODE OF TRANSPORT	BOULDER ARRANGEMENT
Alexandra Fiord	Backshore - erosion of thin drift and some erosion of bedrock	Rafting by first year ice	Scattered on flats Barricade
Erik Harbour	Alongshore and backshore - abundant supply from recent glacial deposits	Rolling and pushing by first year ice	Scattered on flats
Herschel Bay	Backshore and subtidal gouging of substrate	Gouging and pushing by large multiyear ice floes	Boulder pavements Boulder barricade



TIDEWATER GLACIER
CONTINUOUS TIDAL FLAT
b BOULDER BARRICADE
COPES BAY
WOODWARD BAY
COOK PENINSULA
SAWYER BAY
PRINCESS MARIE BAY
HARMSWORTH BAY
FLAGLER BAY
BACHE PENINSULA
KNUD PENINSULA
HAYES FIORD
BEITSTAD FIORD
BUCHANAN BAY
THORVALD PENINSULA
JOKEL FIORD
ALEXANDRA FIORD
CAPE RUTHERFORD
JOHAN PENINSULA
PIM IS.
CAPE SABINE
ERIK HARBOUR
CAPE HERSCHEL
HERSCHEL BAY
WADE POINT
BAIRD INLET
SMITH SOUND
79°30
79°00
78°30
79°
78°
77°
76°
75°
74°
10 0 10 20 Km
96°
84°
80°
76°
Axel Heiberg IS.
ELLESMERE ISLAND
Study Area

FIG. 1

Contrasts in form and sediment distribution between some some glaciomarine fjords - Spitsbergen and Baffin Island

I.J.M. VanderMeer, Iysisch Geojnafisch en Spitsteengen BodenKundig laboratorium, Amsterdam, The Netherlands

G. Boulton, School of Environmental Sciences, University of East Anglia, Norwich, U.K.

Comparisons are made between the overall form of fjords in Spitsbergen and Baffin Island. Baffin Island fjords have steeper margins and lack a large platform just above sea level compared with Spitsbergen examples.

This strongly influences the overall distribution of sedimentary facies in the fjords and the gross geometry of sediment bodies.

DISTRIBUTION AND DYNAMICS OF SUSPENDED PARTICULATE MATTER IN BAFFIN ISLAND FJORDS

WINTERS, G.V.; SYVITSKI, J.P.M. AND MAILLET, L. Geological Survey of Canada, Bedford Institute of Oceanography, Dartmouth, N.S., B2Y 4A2

In the fall of 1982, 1983 and 1985, a survey of the character of suspended particulate matter (SPM) in waters of 10 Baffin Island fjords was undertaken as part of project SAFE (Syvitski and Schafer, 1985). *In situ* properties considered included CTD, monochromatic light attenuance and 3-D macrophotography profiling. More than 1000 CTD/rosette samples were analyzed for SPM concentration, grain size distribution, mineralogy (XRD), CHN and atomic C/N ratios, and optical and SEM analysis of filtrate residue (including energy-dispersive X-ray anlysis). Samples were collected in the months of August and September. To further extend our study to other seasons, a climate-driven sediment-discharge stochastic model [SEDQ] was developed, based on reasonable estimates of drainage basin characteristics (*e.g.* river type, lake filtering, topography, glacier distribution and movement), and on source and timing of discharge events. Air photos and LANDSAT images of water turbidity aided in the calibration of the model. Detailed methods and data are provided in Asprey *et al.* (1983), Winters *et al.* (1984) and Syvitski *et al.* (1984).

Based on SEDQ predictions the fluvial-borne suspended sediment [Q_s] is released into the fjords primarily during the spring (end of June-beginning of July) freshet. Exceptions occur where rivers drain glacier-dominated hinterlands (*e.g.* Coronation and Maktak fjords). There, the release of sediment is more dependent on warm sunny days and Q_s will be further distributed over July and August. The total Q_s input into individual fjords is estimated between 10^6 to 10^8 kg a^{-1}. The Penny icecap fjords (*e.g.* Coronation, Maktak, North Pangnirtung) have between 94% and 99% of Q_s input through their fjord-head basin. Other fjords investigated had significant sediment contribution from their side-entry basins; in the case of Inugsuin Fiord, side-entry contributions may reach 97%.

Depending on the size of the river, sediment plumes may extend a few to 50 km from a river mouth, occasionally reaching the Baffin Island shelf. The plumes are strongly influenced by the Coriolis force (deflecting flow to the right), the stage of the tide, and by winds.

During the fall season, the concentration of SPM [C_s] in the fjords may reach 45 mg L^{-1} proximal to tidewater glaciers, but a more typical range elsewhere is between 0.5 and 4.0 mg L^{-1}. C_s is highest near river mouths and this may result in maxima at the fjord-head or mid-fjord depending on the location of the Q_s input discussed above. Where Q_s is primarily through the fjord-head, C_s decreases down-fjord as does the C/N ratio. C_s is high within the surface layer (which may be as thick as 50m) reaching maximum concentrations just under the halocline/thermocline. A large portion of this material is biogenic (plankton and plankton debris, fecal pellets--Fig. 1D). The mid-depths have the lowest concentrations and particles are in the form of floccules and agglomerates (Fig. 1C). Near the fjord floor (*i.e.* the bottom 150m), C_s increases. Bottom water particles are in individual or aggregate (clast) form (Fig.1F) and often occur with iron oxyhydroxide coatings. C_s is also high in waters overlying sill and outer fjord (shelf) approaches (Fig.1E).

Many of the fjords have mineralogically unique SPM that reflects hinterland geology. For instance Coronation and Maktak fjords have SPM rich in quartz and feldspar; Itirbilung and McBeth fjords are rich in micas; Inugsuin and Clark fjord waters are rich in heavy minerals. Where the mica component is high the size and abundance of inorganic floccules increases.

In 1982, Coronation Fiord had a dominance of small silt grains (Fig. 1A) proximal to its tidewater glacier. Floc size, mucoid (Fig. 1B) concentration and the biogenic component increased down-fjord. A number of the particles had metal (Mn, Fe, Cr) coatings. Individual particles dominated the surface and bottom waters and mucoids reached maxima at mid-depths.

In 1982, the inner basin waters of McBeth Fiord was dominated by radiolarian and picoplankton. The middle fjord basin was rich in floccules and fecal pellets. The outer fjord/shelf environment was dominated by mucoid stringers with attached mineral grains and concentric diatoms. Rip-up clasts near the seafloor provided evidence of bottom resuspension. Near bottom SPM maxima were present on both sides of the sill and over the outer fjord complex (islands and basins). A deep water renewal (flushing) event at the northern entrance to the fjord (MC8 and MC9, Fig. 2) was indicated by the distribution of Baffin Bay plankton that had penetrated into the fjord basin.

The concentration of individual grains and biogenic debris increases in the turbulent water environments such as the extensive Sunneshine sill suggestive of current (tidal) resuspension (Fig.1E). Many of the larger mica grains are attached to rip-up debris (Fig. 1F).

In Inugsuin Fiord, stringer organic matter (chain algae) was dominant at the fjord head, decreasing down-fjord and with depth. This distribution may relate to a large seiche event that piled the surface layer up at the fjord-head, with the relaxation of down-fjord winds. Floc size was found to increase with distance seaward and the outer fjord/shelf stations were very agglomerate rich suggesting intimate plankton-sediment interactions.

The 1983 survey of Cambridge, Itirbilung and McBeth fjords occurred during freeze-up and was three weeks later in the season than the 1982 survey. There was a five to ten fold reduction in the water column-averaged SPM concentrations in 1983. The mean grain size also decreased in 1983. With little change in seasonal runoff between the two years, we speculate that the settling velocity of SPM in Baffin Island fjords is very rapid, with the water column clearing in about thirty days (given an average fjord depth of 500m).

The mean (deflocculated) grain size, D_f, ranged from 3 to 14 µm. The floc size is much larger and ranged from 8 to 1000 µm. Most size variation occurs in the surface layer and reflects mainly local terrestrial inputs or biogenic debris. The finest grained samples, with $D_f < 5$ µm, were found in Coronation Fiord near the ice front and in an area of high SPM concentrations. In neighbouring Maktak Fiord, D_f was coarser (9 µm) at the fjord-head, but in association with lower SPM concentrations. In most fjords, D_f increases downfjord reflecting the biogenic-rich shelf water influence. The highest values of D_f in Sunneshine Fiord occur in the bottom waters and confirm the occurrence of resuspension processes in that system.

REFERENCES:

ASPREY, K.W.; BISHOP, P.;BLAKENEY,C.;LEBLANC,W. ;SYVITSKI,J.P.M. and WINTERS, G.V. 1983. SAFE 1982 SPM data. In: SYVITSKI,J.P.M AND BLAKENEY, C. (compilers) SAFE HU82031 data report, V.1. Can. Data Rep. Hydrogr. Ocean Sci. #12, 5-1 to 5-30.

SYVITSKI,J.P.M.; FARROW,G.E.; TAYLOR,R.; GILBERT, R.; EMORY-MOORE,M. 1984. SAFE 1983 Delta report. In: SYVITSKI,J.P.M (compiler) SAFE HU83028 data report,V.2. Can. Data Rep. Hydrogr. Ocean Sci. #28, 18-1 to 18-91.

SYVITSKI,J.P.M. and SCHAFER, C.T. 1985. Sedimentology of Arctic fjords Experiment (SAFE): 1. Project Introduction. ARCTIC (in press).

WINTERS,G.V.; SYVITSKI,J.P.M; KELLY,B. and CLATTENBURG,D. 1984. SAFE 1983 attenuance and SPM data. In: SYVITSKI,J.P.M (compiler) SAFE HU83028 data report,V.2. Can. Data Rep. Hydrogr. Ocean Sci. #28, 4-1 to 4-128.

FIGURE CAPTIONS:

FIGURE 1. Scanning electron micrographs of SPM particles from B.I. fjords. A)Coronation ice-proximal surface sample; B)mucoid matting with other planktonic material in 10m water, outer McBeth Fiord; C)biogenic-rich floccule at the head of McBeth Fiord--50m depth; D)plankton-rich fecal pellet mid-fjord in McBeth--30m depth; E) individual mineral grains and biogenic debris in 30m of water on Sunneshine Sill; F) resuspended mica grain with attached rip-up debris from the bottom waters (520m) of McBeth Fiord.

FIGURE 2. Axial cross-section of McBeth Fiord, B.I., with suspended particulate matter contoured in mg L^{-1} for samples collected Sept.18/19, 1982. The shadded area shows the presence of concentric diatoms, implying deep water renewal into the fjord.

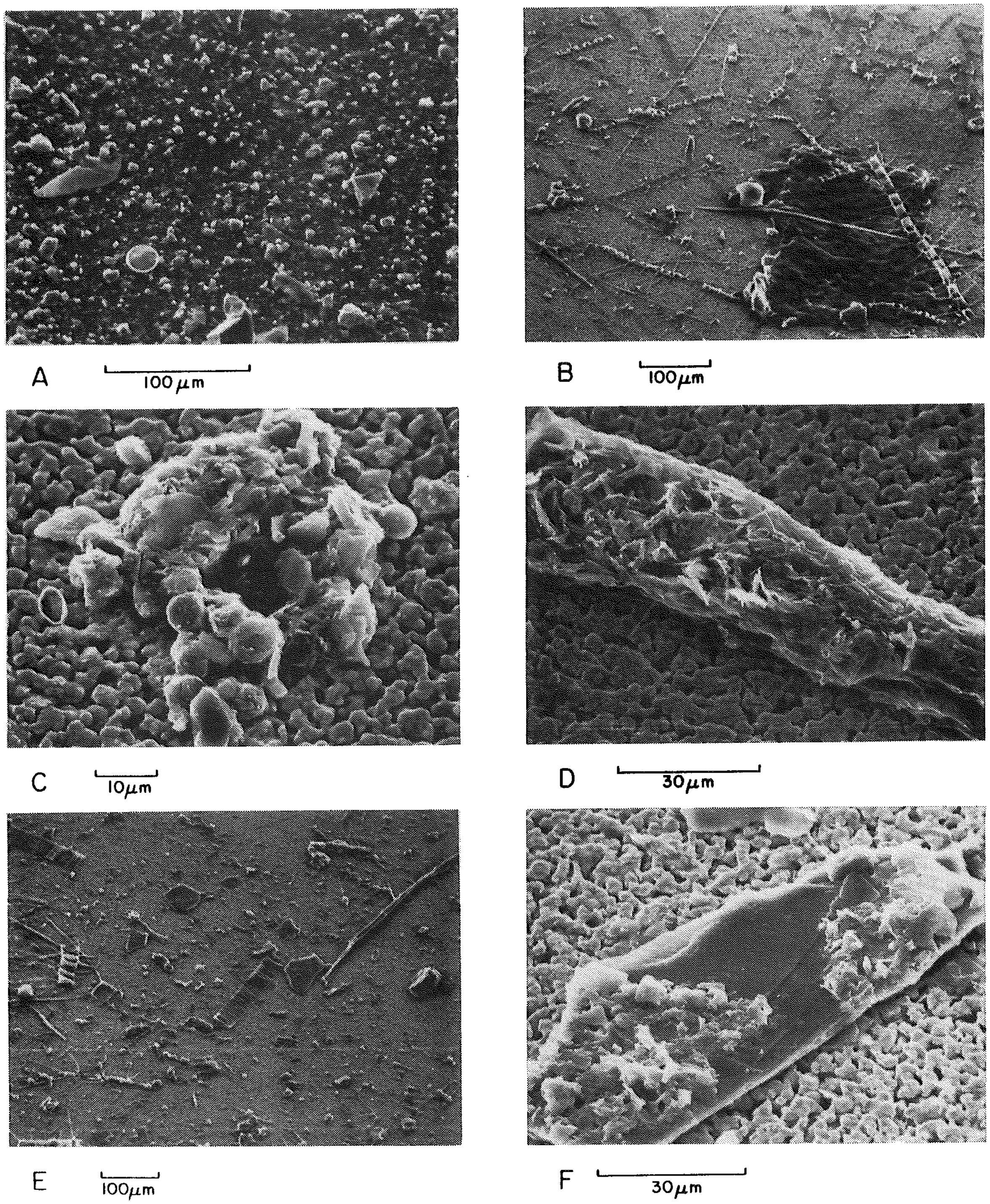


FIG. 1

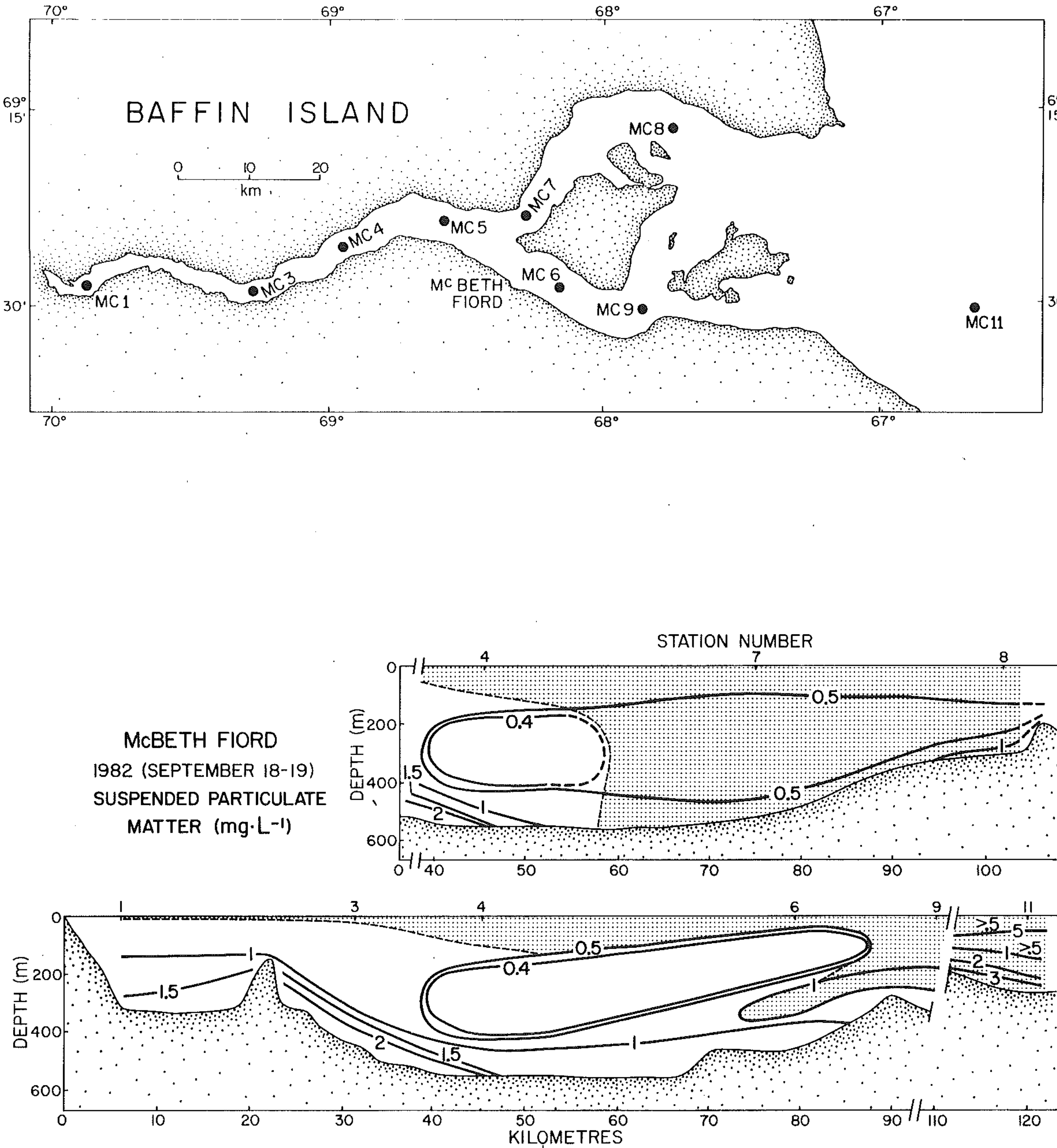

BAFFIN ISLAND
70°
69°
68°
67°
69° 15'
30'
0 10 20
km
MC1
MC3
MC4
MC5
MC6
MC7
MC8
MC9
MC11
Mc BETH FIORD
McBETH FIORD
1982 (SEPTEMBER 18-19)
SUSPENDED PARTICULATE
MATTER (mg·L⁻¹)
STATION NUMBER
DEPTH (m)
KILOMETRES
0.5
0.4
1.5
1
2
3
>5
5

FIG. 2

AEOLIAN PROCESSES, CONTROLS AND FEATURES IN THE EASTERN CANADIAN ARCTIC

Cheryl McKenna-Neuman and Robert Gilbert
Department of Geography, Queen's University, Kingston Ontario
K7L 3N6

Although idealized models of particle movement by wind are well established, the nature, magnitude and interaction of the broader environmental controls are so spatially and temporally variable that there is no universal model of aeolian transport. Two potential end points in this global variation are represented in the example of a desert and a proglacial sandur. The chief difference between these relates to the role of moisture, as water and ice, and to the action of snow as an aeolian agent. Other distinctions in the suite of environmental controls relate to the nature and role of the vegetation, surface roughness elements and large scale topographic features. Finally, the maturity of the sediments is a key factor in controlling the mode and distance of transportation.

While detailed measurements of aeolian transport rates and the controlling factors have been made in the extremely arid global deserts and even in temperate cultivated regions experiencing periodic droughts, the literature on proglacial aeolian activity is descriptive and fragmentary. However, from this literature two key facts are clear. First, aeolian activity on proglacial sandurs during the Pleistocene was of sufficient magnitude to have created significant deposits of loess and sand in North America and Europe (French, 1976). Second, this activity can occur year round, even during the winter months when sandur sediments are frozen and periodically snow covered.

Further detailed measurements from areas of the Canadian arctic currently subject to aeolian activity are needed to expand our understanding of these processes and to fit them into a global scale of aeolian environments. Such work may also serve as a useful tool in the interpretation of paleoenvironments and of non-aeolian environments, particularly in the context of marine sediments (Gilbert, 1982).

Our ongoing studies in south Pangnirtung Pass on Cumberland Peninsula, Baffin Island (66°22'N 65°33'W) are a first step in the assessment of these questions.

With a few exceptions, regional winds in the present arctic periglacial environment of Canada are not significantly stronger than in temperate regions (Figure 1). Arctic extremes in windspeed frequency bracket those based on temperate data although the greater consistency in the later may in part reflect the smaller data base used. During the summer, Pangnirtung experiences average winds with the exception of some low frequency, high windspeed events. Pangnirtung is particularly calm during the winter while the spring and fall are transition seasons during which winds are generally light but strong wind events do occur.

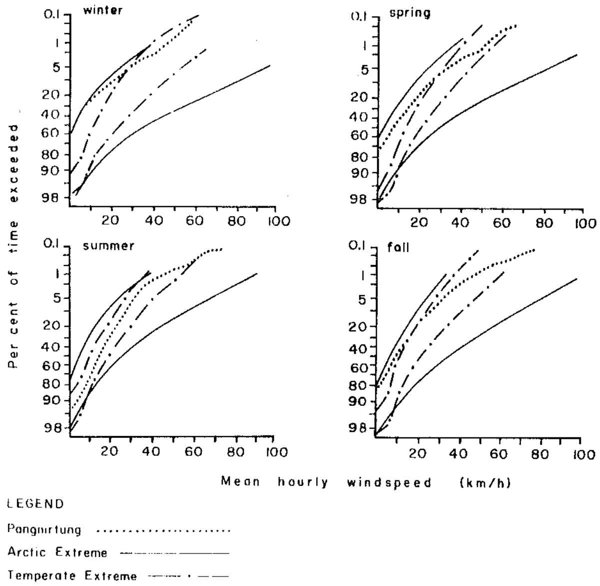


Figure 1. Windspeed frequency data summary for Pangnirtung, 18 arctic stations and 6 southern Canadian cities.

However, two other factors appear to be instrumental in the operation of aeolian processes within the Pangnirtung Pass area: topographic modification of regional winds and the nature of the land surface.

The implications of the first factor, topographic wind modifications, are as follows. As reviewed by Oke (1978), an acceleration in windspeed occurs at any point where the air flow converges, as for example on the upwind side of an obstacle such as a boulder, moraine or valley wall or through a narrowing passage such as a valley. The converse occurs for flow divergence. Therefore, even though regional wind shear velocities may be well below the threshold range of the sediment, transport is likely to occur in areas of air flow acceleration. Topographic effects of this nature are very significant in Pangnirtung Pass ranging from perturbations in flow associated with an obstacle as small as an individual rock or boulder to as large as the valley form itself.

The second factor, the nature of the land surface, incorporates three effects. Most important, this environment provides an abundant and renewable supply of immature, glacial and glaciofluvial sediments in the readily transported fine sand and silt size range. Further, this supply is accessible; that is, the sparse arctic vegetation minimizes trapping and shielding of particles. The one surface condition which distinguishes the periglacial, aeolian environment from any other is the seasonal presence of low density, easily transported snow crystals which at low temperatures can behave as agents of erosion and abrasion in the same way that windborne silt and sand particles do (Dietrich, 1977).

However, moisture in the form of either pore water or ice also retards aeolian transport through intergranular cohesion. Transitory adhesion structures associated with the presence of pore water develop during the summer on the Weasel river sandur. Many of the aeolian sand sheets and climbing dunes in the same area are stabilized through pore and segregated ice at their core. During the winter, the protection of surface sediments through pore ice becomes vulnerable to sublimation and abrasion, particularly in areas of scant snow cover. Time lapse photography at the Pangnirtung study site from September 1984 to March 1985 confirms that the snow cover is patchy to non-existent during much of this time.

On the basis of this largely descriptive review of the major controls of aeolian activity in an arctic, periglacial environment, the variety of aeolian sedimentary features identified within the Pangnirtung study area are organized into the conceptual model in Figure 2.

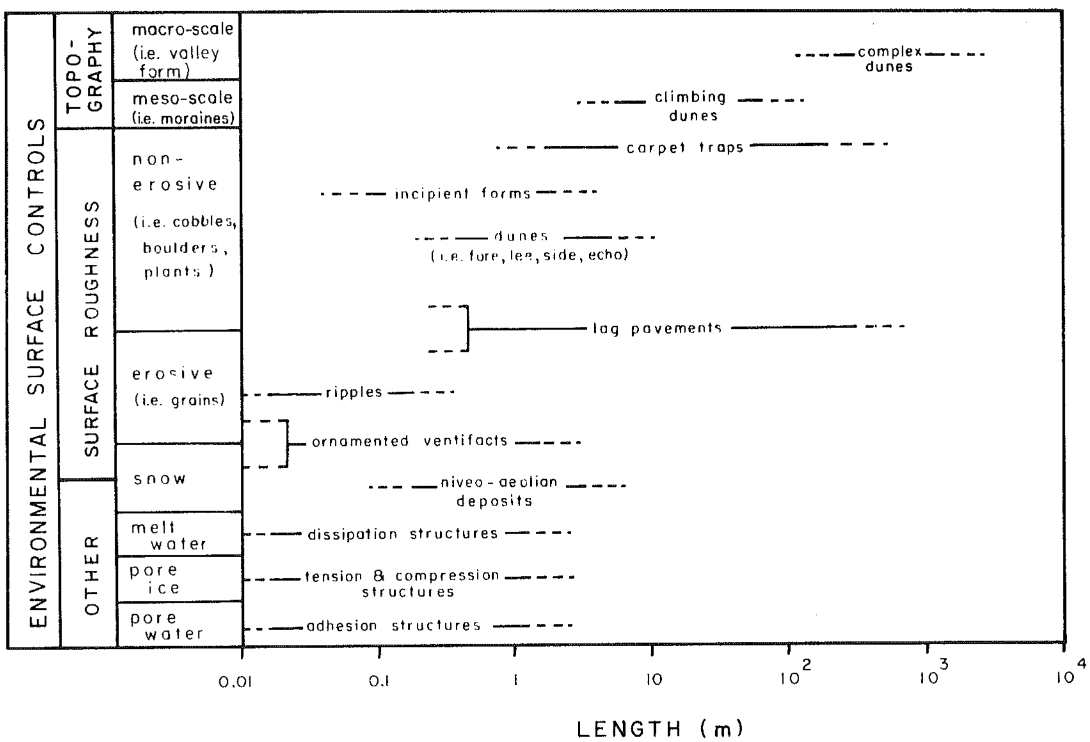


Figure 2. Aeolian sedimentary features in Pangnirtung Pass as related to environmental surface controls.

While wind shear velocity determines the potential for the transport and deposition of sediment, it is clear that the resulting features themselves are determined in large measure by other factors, some of which are indicated in Figure 2.

References

Dietrich, R.V., 1977. 'Impact abrasion of harder by softer materials', J. of Geol., 85, 242-246.

French, H.M., 1976. The Periglacial Environment. Longman, London, 309 p.

Gilbert, R., 1982. "Contemporary sedimentary environments on Baffin Island, N.W.T., Canada: Glaciomarine processes in fiords of Eastern Cumberland Penninsula', Arctic and Alpine Research, 14, No. 1, pp. 1-12.

Oke, T.R., 1948. Boundary Layer Climates, Methuen and Co. Ltd., London, 372 p.

Lake Linnevatnet, Svalbard, a possible 40.000 years continous record of lacustrine and marine sedimentation.

Jan Mangerud[a], Jon Landvik[a], Otto Salvigsen[b], and Gifford Miller[c].

[a] University of Bergen, Department of Geology, Sect.B, Allegt.41, 5000-Bergen, Norway.
[b] Norwegian Polar Research Institute, P.O.Box 158, 1330 Oslo Lufthavn, Norway.
[c] University of Colorado, INSTAAR, Campus box 450, Boulder, Colorado 80 309, USA.

Salvigsen mapped a morphologically distinct shoreline, 87 m a.s.l.(A at Fig.1) along the lake Linnevatnet, south of the mouth of Isfjorden, Spitsbergen. Paired Mya truncata from the shoreline were radiocarbon dated to c.36.000 years B.P. (T-5211), which we consider to be a minimum age. There are no signs indicating that glaciers have overrun the shoreline, so the preliminary conclusion is that the area has been ice-free for at least some 40.000 years.

Lake Linnevatnet is situated 12 m a.s.l., and is nearly 40 m deep (Bøyum and Kjensmo 1978). A six m long core from the deepest part of the lake showed three m of lacustrine sediments, overlying three m of marine sediments with a basal radiocarbon date on marine shells of 9.600 years B.P. (Bøyum and Kjensmo 1980). It seems unlikely that such a deep basin should be emptied for sediments except during glaciations. A core that could penetrate the entire sediment sequence beneath the floor of Linnevatnet, would therefore be a good test of the hypothesis that the area has remained ice-free for at least 40.000 years.

A coring program was therefore planned within the co-operative research project between Univ.of Bergen (Mangerud, Landvik, and several students) and the Norwegian Polar Research Inst.(Salvigsen). This is a project on the Quaternary geology of the Isfjorden-Van Mijenfjorden areas (e.g.Salvigsen et al.1983, Mangerud and Salvigsen 1984, Mangerud et al 1984a,b,c, Landvik and Salvigsen 1985), and if we could obtain a core with a continous record back to 40.000 years, or even longer, it would be an important standard for correlation of the many sections we are studying on land, all having obvious hiati.

At this time Miller was planning a project on Holocene glacier variations in Svalbard, and wanted lacustrine sequences to detect and date the glacier expansions. We therefore developed a common project to cover the interest of both groups.

The first step was a mapping of the lake floor with a Raytheon penetrating echosounding system (RTT-1000A) from Univ. of Colorado. The profiling was carried out the summer 1984 by Miller and Mangerud. From the profiling Arne Rasmussen, Univ. Bergen, has constructed a bathymetric map, and isopach maps for both the Holocene lacustrine unit, and the total thickness of transparent sediments. The only major reflector that could be identified in the records is the boundary between the Middle/Late Holocene lacustrine sediments, and the Early Holocene marine sediments. An acoustic basement interpreted as either bedrock or till is normally distinct. The sediment thickness is normally 10-15 m in the deeper parts of the lake, with a maximum thickness of c.20 m. A major result of the profiling was the discovery of shallow basins (9-13 m deep) in the southern part of the lake that apparently have the same sedimentary sequence as the deep (nearly 40 m) basin. From the the profiling and the constructed maps, a coring program has been designed.

At present we are planning to core one basin that has a thin Holocene sequence (point D, Fig.1) and where it is relatively easy to reach the older sediments. This basin apparently receives almost all its sediment input from a cirque with young end-moraines (B, Fig.1), and we hope the sedimentation will monitor the glacial situation in that cirque. We further plan to core a basin (C, Fig.1) outside the main river inlet, with a thick Holocene sequence, and thus high resolution. If time allows, we will also core the deepest basin.

The coring equipment has been developed at the University of Bergen, mainly by Søgnen, Landvik, and Mangerud. Basically it is a strengthening of the 11 cm diameter piston corer that we have used for lake coring in Norway. We will also bring a 6.3 cm sampler for the same equipment, and "russian peat samplers". The samplers are forced into the sediment and elevated by hand-operated winches. 15 cm diameter alumina pipes will be used as casing. The coring equipment will be shipped to Svalbard the summer 1985, and the coring carried out from winter ice during April 1986.

The plans for the scientific program are as follows:

Miller and co-workers, Univ. of Colorado, will study the Holocene lacustrine sequence for sedimentological and other signals of glacier variations and climatic changes. They also plan an extensive dating program on this part of the cores. Allan Werner, Ph.D.student supervised by Miller, in the summer of 1985, will map endmoraines in front of glaciers within the watershed, and establish at least a relative moraine chronology. He also plans to collect some 1.5 m cores from Linnevatnet, for a preliminary understanding of the impact glacier expansion had on the lake sedimentation.

Mangerud and co-workers, Univ.of Bergen, will study several problems, the program being partly dependent on the time span covered by the cores. At present we find it most probable that the cores will reach at least 40.000 years back in time, and we are mainly planning under that assumption. If it turns out that the cores only span some 12.000 years the research program on the cores will be reduced.

As mentioned above, a major interest is to date the basal part, in order to determine how long the area has been ice-free. Radiocarbon, thermoluminescense, uranium series and amino acid methods will be attempted for dating the core. As Linnevatnet is situated only 12 m a.s.l., the lake is very sensitive to sea level changes. From the earlier cores it is known that below the Holocene lacustrine beds there are marine beds, corresponding to the Late Weichselian/Early Holocene shorelines, with a maximum elevation of 55 m a.s.l. Below these beds there might be lacustrine sediments from an assumed Weichselian low relative sea level (Boulton 1979, Miller 1982), and below that, marine sediments corresponding to the 80 m (40.000 years) shore-line. The possibility of a continuous sedimentary record also for periods of low relative sea level stands is extremely important.

Along the river from Linnevatnet to the sea (E, Fig.1), Ida Lønne, research student, Bergen, is studying marine sediments below a till (Mangerud et al.

1984c) which according to preliminary amino acid analyses (Magne Bolstad, research student, Bergen) just predates the 87 m shoreline, and thus will extend the Linnevatnet record further back in time. Lønne and Tom Sandahl, another research student, Bergen, are also investigating sequences of shallow marine, littoral, and terrestial sediments around Linnevatnet that were deposited after the last glaciation of the area, and thus in time should be directly correlatable to the core-sequence (e.g. at point F, Fig.1).

Several different groups of microfossils (diatoms, forminifera, etc.) from the cores will be studied for paleoecological reconstructions; pollen also will be studied for understanding long distance transport during different climatic situations. The paleomagnetic record, to be investigated by Reidar Løvlie, Bergen, may be crucial for understanding secular variations and apparent reversals at this high lattitude (Løvlie et al., manus). The sedimentology of high arctic lakes is poorly investigated, and Michael Talbot, Bergen, will use the cores for studies of several aspects of the sediments.

References

Boulton, G. 1979: Glacial history of the Spitsbergen archipelago and the problem of a Barents Shelf ice sheet. Boreas 8, 31-57.

Bøyum, A. and Kjensmo, J. 1978: Physiography of lake Linnevatnet, Western Spitsbergen. Verh.Internat.Verein.Limnol.20, 609-614.

Bøyum, A. and Kjensmo, J. 1980: Post-glacial sediments in lake Linnevatnet, Spitsbergen. Arch.Hydrobiol.88, 232-249.

Landvik, J.Y. and Salvigsen, O. 1985: Glaciation development and interstadial sea-level on central Spitsbergen, Svalbard. Polar Res. 3 n.s.,1-10.

Løvlie,R., Markussen,B., Sejrup,H.-P. and Thiede,J. (manusript): Magnetostratigraphy in the Arctic Ocean sediment cores; arguments for geomagnetic excursions within oxygen-isotop stage 2-3. Manus submitted to Earth Plan. Sci.Lett.

Mangerud,J. and Salvigsen, O. 1984: The Kapp Ekholm section, Billefjorden, Spitsbergen: a discussion.Boreas 13, 155-158.

Mangerud, J. Elgersma,A., Helliksen,D., Landvik,J. and Salvigsen,O. 1984a: The Late Weichselian (25-10 ka B.P.) glacial maximum in Isfjorden and Van Mijenfjorden, Spitsbergen, Svalbard. Ann.Arct.Worksh. INSTAAR, Univ.Col., 67-68.

Mangerud,J., Elgersma,A., Helliksen,D., Landvik,J., and Salvigsen,O. 1984b: The Late Weichselian glaciation in Isfjorden and Van Mijenfjorden, Svalbard. Pp.16-17 inSeds.and climate in the Arctic. Report.

Mangerud,J., Lønne,I., Sandahl,T. and Salvigsen,O. 1984c: Kvartærstratigrafien i og omkring Linnevatnet, vestkysten av Svalbard. Geolognytt 20, 37.

Miller, G. 1982: Quaternary depositional episodes, Western Spitsbergen, Norway: Aminostratigraphy and glacial history. Arctic and Alp.Res. 14, 321-340.

Salvigsen,O.,Lauritzen,Ø. and Mangerud,J. 1983:Karst and karstification in gypsum beds in Mathisondalen, Central Spitsbergen, Svalbard. Polar Res. 1 n.s., 83-88.

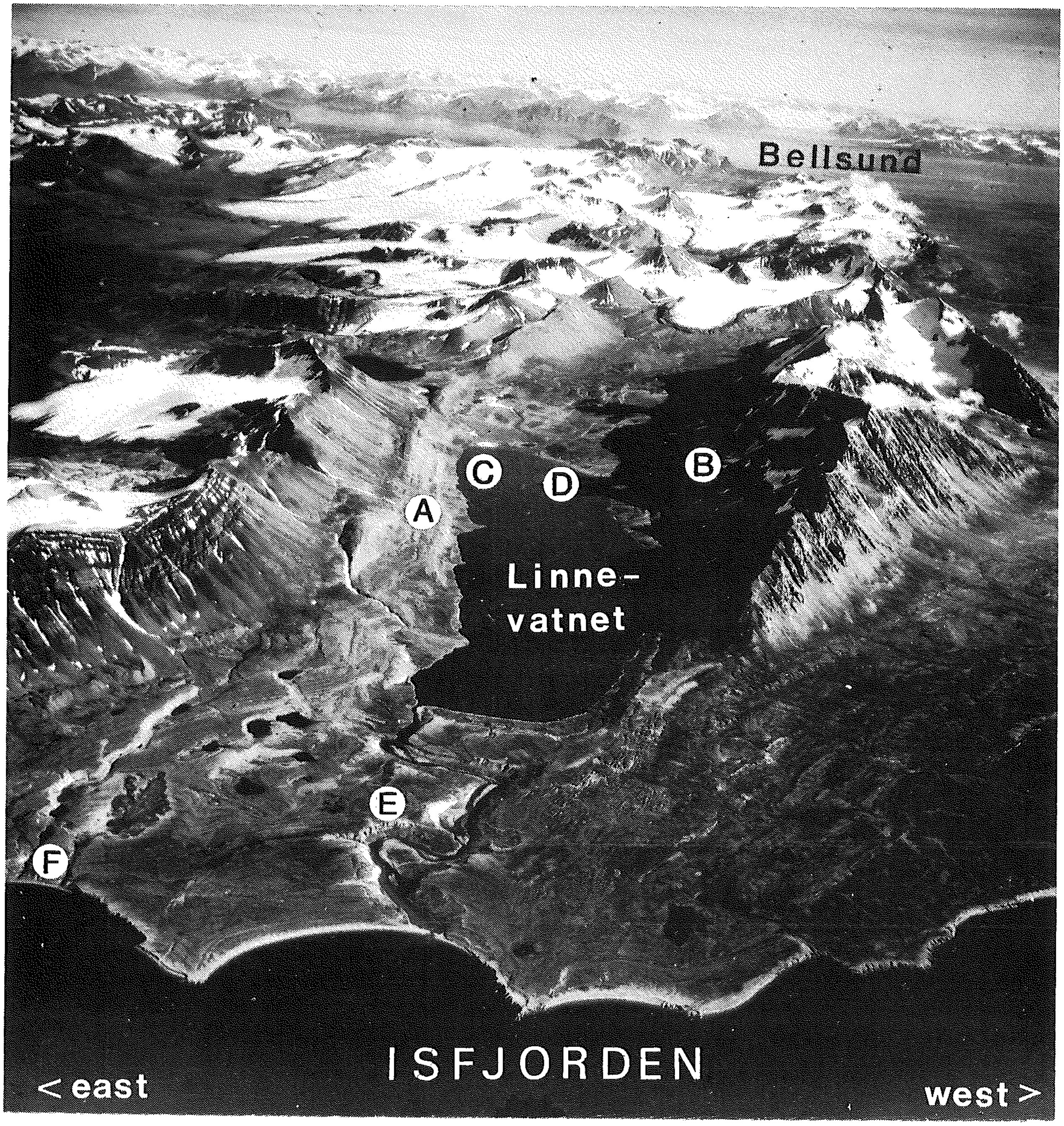


Fig. 1. Oblique airphoto (Norw. Polar. Res. Inst.) of Linnevatnet. Photo towards south. The lake Linnevatnet is 5 km long. The open ocean is just outside the right margin of the picture. A- marks the 87 m terrace. Note that the benches seen on the photo are not marine terraces, but bedrock benches. B- marks a subrecent endmoraine, from which the glacial river drained into a basin marked D. C- marks the basin with thick Holocene lacustrine sediments, transported in by the river that has its inlet in the southern end. The deep (40 m) basin covers most of the lake north of C-D, except the northern shore. E- marks some of the sections along the Linne River, and F- the sections in Solovjetskibukta that includes a buried soil.

ISOTOPIC COMPOSITION OF LACUSTRINE BRINES IN COASTAL AREAS OF THE CENTRAL CANADIAN ARCTIC

Pierre Pagé, Département des Sciences de la Terre
Université du Québec à Montréal, Montréal H3C 3P8

Two meromictic lakes in the Central Canadian Arctic Archipelago actually exist below the postglacial marine limit: Lake Garrow is on Little Cornwallis Island, and lies 12 m above sea level. Lake Sophia is located on the eastern side of Cornwallis Island, and is 7 m higher than the adjacent Wellington Channel. Apart from being stratified with respect to temperature and dissolved oxygen, these lakes contain in their deepest part a 25 m stratum of hypersaline water. The chloride concentrations are 2.6 and 1.7 times that of sea water in Lake Garrow (52 ppt) and Lake Sophia (35 ppt). The mixolimnion in both lakes is filled with a mixture of normal meteoric water and sea water (-21.9 $^0/_{00}$ to -23.5 $^0/_{00}$ in $\delta^{18}O$ with respect to V-SMOW, -170 $^0/_{00}$ to -190 $^0/_{00}$ in δ^2H), since the salinity is between 2 to 5 ppt. Salinity increases to 15.74 ppt at 9 m depth in Lake Sophia, and 36.06 ppt at 12 m depth in Lake Garrow, which corresponds to the middle of the halocline. Further down, the water has $\delta^{18}O$ and δ^2H values intermediate between sea water and precipitations (-8.9 $^0/_{00}$ to -10.4 $^0/_{00}$ in $\delta^{18}O$ and -70 $^0/_{00}$ to -90 $^0/_{00}$ in δ^2H). The deep waters fit on a regression line with a slope of 8 and a slight ^2H excess ("d" parameter).

The concentration of the sodium chloride solution, together with the depletion in heavy isotopes with respect to sea water is interpreted as an intra- or sub-permafrost freeze diagenesis in a coastal aquifer once filled with sea water, and later drained into the lacustrine basins. During the freezing of sea water, the isotope fractionation factors are greatly influenced by the activities of the water and the different solutes in the residual brine. Laboratory experiments have shown that the fractionation between ice and water, in closed-system, evolves with a ratio $\varepsilon_{^2H}/\varepsilon_{^{18}O}$ around 7. This ratio increases to 10.8, at -10°C, during intense freezing of sea water; isotope distribution then proceeds between ice and concentrated sea water, or mirabilite and water, the main hydrated salt being precipitated at around 4 times the initial salinity of the solution. At some time during a similar natural process, a very slow accretion of frozen ground would have permitted equilibrium fractionation between ice and water, following an open-system Rayleigh process, that maintained the residual brine near the global meteoric water line ($\varepsilon_{^2H}/\varepsilon_{^{18}O}$: 8), and before precipitation of hydrated salts started.

Radiocarbon activities were measured in Lake Garrow at 24 m depth (2,600 years B.P.), 27 m depth (3,800 years B.P.) and finally at the bottom (45 m: 4,100 years B.P.). In Lake Sophia, the total mineral carbon at 30 m yielded an activity of 121.4 percent modern carbon, while at the bottom an age of 1,100 years B.P. was obtained. Thus it is believed that Lake Garrow monimolimnion is isolated since postglacial emergence, while the Lake Sophia deep layer still receives through taliks modern influx of freeze concentrated sea water, like in a highly stratified estuary.

Moreover, $\delta^{13}C$ measurements with respect to PDB show that surficial water in both lakes is influenced by sea water (+1.1 $^0/_{00}$ in Lake Sophia and +0.4 $^0/_{00}$ in Lake Garrow), while organic matter contributes to the dissolved carbon of the deep strata (-12.3 $^0/_{00}$ in Lake Garrow and -2.0 $^0/_{00}$ in Lake Sophia), thus giving a minimum age to any ^{14}C measurement in Lake Garrow. Nevertheless, the oldest ^{14}C age fits well on the emergence curve of Resolute.

One may conclude that hypersaline waters are an epiphenomenon of permafrost existence, already known in surficial frozen ground and active layer, and important in sub-permafrost captive aquifers of coastal areas. The existence of such lakes should be a matter of synchronization between postglacial uplift, permafrost growth and groundwater flow; their fate should be desalination by advection or diffusion, unless they are protected by a sheltered morphometry, or a very reduced watershed.

STRATIGRAPHY AND SEDIMENTOLOGY OF HIGH ARCTIC COASTAL LAKE BASINS NORTHERN ELLESMERE ISLAND, NORTHWEST TERRITORIES

Michael J. Retelle, Department of Geology and Geography
University of Massachusetts, Amherst.

Sedimentary sequences contained in coastal lacustrine basins on northern Ellesmere Island offer a high resolution record of glacioisostatic uplift and climatic change during the Holocene.

Sediment cores were recovered from lakes at two sites on northern Ellesmere Island. At the first site, three lakes along Robeson Channel (81 55'N, 63 21'W) are referred to as the Beaufort Lakes and are entirely freshwater. The lakes contain fine- to coarse-grained glaciomarine sediments overlain by finely laminated lacustrine sediments. The glaciomarine sediments, deposited during isostatic depression of the coastal zone, are fossiliferous massive to mottled pebbly and sandy silt. The longest marine core section demonstrates distinct trends in coarse sediment influx. The base of the core secton (estimated pre-8000 B.P.) contains fine silty clay with <2% sand. Macrofossils are scarce in this section. Faunal occupation, as well as coarse sediment deposition by ice rafting and meltwater influx, was likely precluded due to the persistence of landfast sea ice or an ice shelf during this period of the glacial maximum (cf. England, 1983; England and Stewart, 1983). Upper sections of the marine record include abundant macro- and microfauna and an increase of coarse sediment (up to 26% sand), presumably due to the breakup of ice in the embayment and increased runoff during the mid-Holocene Climatic Optimum. Increases in the >62 um fraction are also prevalent at marine to lacustrine zones in the cores due to erosion of the basin threshold and reworking of glaciomarine sediments during shoaling of the basin.

Lacustrine sediments are generally well-laminated silty clay with mean grain size approximately 3 um. The nature of lamination in the lacustrine sediment is apparently a function of the sedimentation rate and presence or absence of density stratification in the individual lake basin. In the lake with the lowest sedimentation rate (est. .02 to .03 cm/yr) bedding is massive to diffuse throughout the entire lacustrine section. In the other two lakes the average sedimentation rate is significantly higher (.07 to .08 cm/yr). Lacustrine sediments in the latter lakes exhibit numerous sequences of well-defined graded and non-graded laminations of variable thickness up to 1.5 cm. Sets of well-defined laminae are commonly separated by massive and diffuse laminations up to 5.0 cm thick. Counts of lacustrine laminations in two of the lakes indicate that the lakes are probably not annually laminated. It is more likely that discernible laminations were deposited during periods of peak runoff or when sediment buildup on the prodelta slope caused basinward slumping and turbidite deposition. Thinning of laminae upsection (upcore) may indicate that a decrease in runoff from the mid-Holocene to the present is either due to climatic cooling or an increase in vegetation in the catchment area.

On northern Marvin Peninsula (83 00'N; 75 30'W) work has begun on two lakes referred to as Lakes A and B (Hattersley-Smith ét al., 1970; Jeffries et al., 1983) that contain relict sea water with salinity up to 30 0/00. Laminated lacustrine sediments up to 1 meter thick overlies coarse pebbly to cobbly glaciomarine drift in these basins. The presence of this coarse glaciomarine unit implies an open embayment for the ice-rafted coarse sediments. Hence, dating of this unit and of the isostatic emergence of the lake will provide important information on the inception and growth of the Ward Hunt Ice Shelf which presently blocks the embayment and fiords of the north coast of Ellesmere Island.

References Cited

England, J., 1983, Isostatic adjustments in a full glacial sea: Canadian Journal of Earth Science, volume 20, p. 895-917.

Hattersley-Smith, G., Keys, J.E., Serson, H., and Mielke, J.E., 1970, Density stratified lakes in northern Ellesmere Island: Nature, volume 225, p. 55-56.

Jeffries, M.O., Krouse, H.R., Shakur, M.A., and Harris, S.A., 1983, Isotope geochemistry of stratified Lake "A", Ellesmere Island, N.W.T., Canada: Canadian Journal of Earth Sciences, volume 21, p. 1008-1017.

Stewart, T.G., and England, J., 1983, Holocene sea-ice variations and paleoenvironmental change, northernmost Ellesmere Island, N.W.T., Canada: Arctic and Alpine Research, Volume 15, p. 1-17.

ICEBERG PITS: DESCRIPTION AND POSTULATED ORIGIN

J. V. Barrie, W. T. Collins
C-CORE
Memorial University of Newfoundland
St. John's, Newfoundland A1B 3X5

Circular depressions or pits up to 10 m deep are found below 80 m water depth on the Northern Grand Banks of Newfoundland. One particular pit, 100 m wide, originally discovered in October 1980, east of Hibernia was relocated in October 1984. Two submersible dives were carried out to investigate this pit. A series of two events are postulated for the formation of this feature. Morphologically, its overall 'amphitheater' shape, a steep back (south) wall and two side walls, (surrounded by a berm) and a shallow sloping north entrance suggests the formation was a result of the grounding of an iceberg. Subsequently, bearing capacity failure is hypothesized to explain the deep (10 m), oversteepened nature of the pit and the 10-15° dip of the clay beds towards the centre of the feature. The hard clays that lie directly below the thin surficial sand with pebble armour are likely of Tertiary to early Pleistocene age. The feature is partially infilled and probably was deeper originally. Two passes with the Huntec DTS system in 1980 and two passes with a 3.5 kHz system in 1984 showed a total pit depth between 5 to 7 m compared to the actual depth of 10 m. It is possible that the pits documented on the Grand Banks could be underestimated by between 30 to 50% due to limitation of profiling systems over such steep-walled features.

ICEBERG SCOURING IN HUDSON BAY

S. Whittaker[1], B Chevalier[1], Hank Geerlof[2]

Iceberg scour marks are present on four site survey locations (A-1, B-1, B-2 and C-1) conducted for Canadian Occidental Petroleum by Geomarine Associates in Hudson Bay. Water depths range from 135 to 185m. Equipment deployed during the survey produced quality sidescan sonar, echosounder, and sub-bottom profiler data. Grab samples and bottom photographs provided ground truthing of the geophysical interpretation. Surficial sediments are dominated by silty-clay with few gravel and pebble inclusions.

Two types of iceberg scour marks identified are "typical" and "corduroy".

"Typical" iceberg scour marks have smooth tracks and are linear or arcuate in shape ranging from 1m to 3km in length, 10 to 500m in width (berm crest-to-berm crest), and 1 to 8m (berm crest-to-berm trough) deep. "Typical" iceberg scour marks show a dominant NE-SW trend arcuate to the NE. These scour marks heavily scar all sites except C-1 where they are less frequent.

The "corduroy" iceberg scour marks have a ribbed appearance resulting from regularly spaced lineations normal to the track direction. These are fewer in number and shorter in length than the truncating "typical" scours. "Corduroy" drift tracks are confined to B-1 and B-2 sites. The ribbed appearance is probably caused by metastable grounded ice wobbling along its track.

The scour marks present at the sites are believed to be relict iceberg scour marks. Their size, morphology, and water depth rules in favour of scours formed by grounding icebergs. The age of these iceberg scour features is uncertain, but they are assumed to postdate the uppermost accumulation of the Recent mud which they scar. The features are not assumed to be modern iceberg scours since no icebergs have been known to exist in Hudson Bay in modern time.

[1] Geomarine Associates Ltd., Halifax, N.S.

[2] Canadian Occidential Petroleum Ltd., Calgary, Alberta.

DIGS-85: Dynamics of Iceberg Grounding and Scouring:

Observation of Iceberg Scour Marks by Manned Submersible

H.W. Josenhans[1], Barrie, J.V.[2], Woodworth-Lynas, C.M.T.[2] and Parrott, D.R.[1]

[1]Atlantic Geoscience Centre
Geological Survey of Canada
PO Box 1006
Dartmouth, N.S. B2Y 4A2

[2]Centre for Cold Ocean Resources Engineering
C-CORE
Memorial University of Newfoundland
St. John's, Newfoundland
A1B 3X5

Direct observations of fresh and relict iceberg impact and scour sites were performed using the manned submersible PISCES IV in conjunction with the DIGS-85 experiment, on Makkovik Bank, Labrador. Detailed inspections were made of several sites identified by the DIGS-85 study as iceberg grounding sites and fresh scour marks. Observation of an iceberg scour feature which had been formed just five days prior to the dive showed fragments of ice imbedded in the seafloor. Degradation of the scour feature by bottom currents and macro-benthos had already begun indicating a high rate of erosion of the scour berms on this portion of the Labrador Shelf.

A scour identified on a 1979 side scan sonar survey on Saglek Bank was re-surveyed prior to a submersible dive. The scour was readily identified on the sonar records and a relatively new scour which cross-cut the original was discovered. A previous re-survey of the site in 1982 showed no evidence of the new scour. Submersible observations on the scours showed the original scour had undergone considerable modification by currents and macrobenthos. The fresh scour cut through the original and showed fragmented boulders (volcanic) in the scour trough. It is proposed that these boulders were fragmented in place.

Inspections of both fresh and relict iceberg grounding sites were made in over-consolidated glacial tills as well as unconsolidated glaciomarine silts. The character of the sediment exerts considerable influence on both the formation of the fresh scour and the rate of degradation of the scours.

DIGS-85: Dynamics of Iceberg Grounding and Scouring: Iceberg and Seabed Mapping Observations

C.F.M. Lewis[1], D.R. Parrott[1], J.H. Lever[2], D. Diemand[2], M. Dyke[3], W.J. Carter[3], A.F. Stirbys[4]

[1]Atlantic Geoscience Centre
Geological Survey of Canada
PO Box 1006
Dartmouth, N.S. B2Y 4A2

[2]Centre for Cold Ocean Resources Engineering
C-CORE
Memorial University of Newfoundland
St. John's, Newfoundland
A1B 3X5

[3]Geonautics Limited Box 8143
St. John's, Nfld
A1B 3M9

[4]Gulf Canada Resources Inc.,
Calgary, Alberta
T2P 2H7

A major field program supported by the Canada Environmental Studies Revolving Funds, was undertaken off the coast of Labrador during the summer of 1985 to document the dynamics and processes of iceberg grounding and scouring. Data on three groundings were collected. Wind, current and tidal flucuation data were collected for calculation of the driving forces on each iceberg. Instrument packages placed on selected icebergs measured the accelerations, attitude and orientation changes through the grounding cycles. The size and shape of the monitored icebergs were determined through stereo photography of the above-water portions and by using sector scanning sonar below the water lines. These data are used to calculate forces exerted on the seabed by grounded iceberg keels. The resultant scouring of the seafloor was investigated through surveying with high resolution seismic, side scan sonar and towed camera systems. Documentation of iceberg deterioration was obtained and temperatures of freshly calved bergy bits were recorded. Observations by manned submersible of the seabed effects at one of these iceberg grounding sites and at other sites showing the effects of ice scour processes are presented in a companion paper by Josenhans et al.

The field experiment has resulted in the collection of a unique data set containing the driving forces acting on free-floating and grounded icebergs; iceberg size and shape; resultant motion of the iceberg; and observations of the seabed scours produced. Video coverage of a grounded iceberg that rolled and subsequently floated free was obtained, and it is believed that one of the grounded icebergs surveyed was in the process of forming a pit (an isolated grounding feature). In all, full documentation was obtained for 3 icebergs in contact with the seabed in water depths ranging from 107 to 170m. These were grounding and pitting events; as yet we lack information on scouring events (i.e. events that procduce long linear scour marks). Lesser information was obtained on 9 other icebergs and several more groundings were inferred. Future plans include collection of geotechnical data in the scoured areas for model studies.

Pumping Away Tide Water Glaciers and Ice Shelves

by
E.L. Lewis
Institute of Ocean Sciences
Sidney, B.C.
V8L 4B2

Many authors have concluded that bottom melting is very significant in terms of tide water glacier or ice shelf dynamics, making such melting of major importance to studies of sea level variations and climate change. An ice pump is a heat engine working between ice/water interfaces at different depths, driven by the change in freezing point with pressure, $\partial T_f/\partial p$, which has a value of about -7.5×10^{-3} °C per bar. Basal melting by the ice pump mechanism does not require any external source of sensible heat in the water but does require circulation between these interfaces. Downward moving water at surface freezing point possesses sensible heat to melt ice at depth, while water rising from that depth becomes supercooled as the pressure drops and so allows ice formation near the surface. The overall effect is to move ice from depth to the surface and make floating ice sheets tend towards uniform thickness. Such a pump operating near the surface of the pack-ice covered Arctic ocean has been described by Lewis and Perkin (1983). Evidence for the pumps' operation at the Ross Ice Shelf, Antarctica, is given in Lewis and Perkin (in press) and Figure 1, taken from this paper, shows the supercooling immediately below the sea ice in McMurdo Sound where massive underwater ice formation was taking place.

After ice forms from supercooled water the remaining fluid is more dense due to salt rejection and sinks; similarly water that has melted ice at depth attain a positive bouyancy. Thus the pump is self starting, but the pump rate may be greatly increased by externally driven water movement and the dynamics of most oceanic regimes provide such a stronger circulation. In general, pump rates depend on two factors, the ability to transfer heat from the water to the ice through a planetary boundary layer, and the rate of water movement between the sites of melting and deposit of ice. The former factor, considered alone, gives a maximum pump rate dependent upon the depth interval between the sites (i.e. freezing point change) and the fluid velocity past the ice/water interface. This analysis should be applicable to the case of sea ice where the underlying waters are usually well mixed over the depth interval. These maximum pump rates, calculated from the theory of MacPhee (1983) are shown in Figure 2 and compared to the experimental data of Bogorodsky and Sukhorukof (1983) for sea ice in the Arctic Ocean.

Large ice shelves may be very variable in thickness so that upward drainage to the sea surface would only be possible close to the ice front, crevasses excepted. Tidal movement beneath the ice shelf should allow pump action providing the ice sheet thickness varied significantly over the distance of the tidal excursion. Intermediary level pumps would then be expected, transforming deep glacial ice to sea ice deposits beneath the shelf at shallower locations. Under a large ice shelf one might expect to find domed regions where, after initial melting had taken place, the bouyancy of the melt-diluted water would not allow it to be moved from the system, so quenching the pump. Tidal action may also entrain waters from greater depths and provide a sensible heat source to augment pump action (MacAyeal (1984)).

Lewis, E.L. (continued)

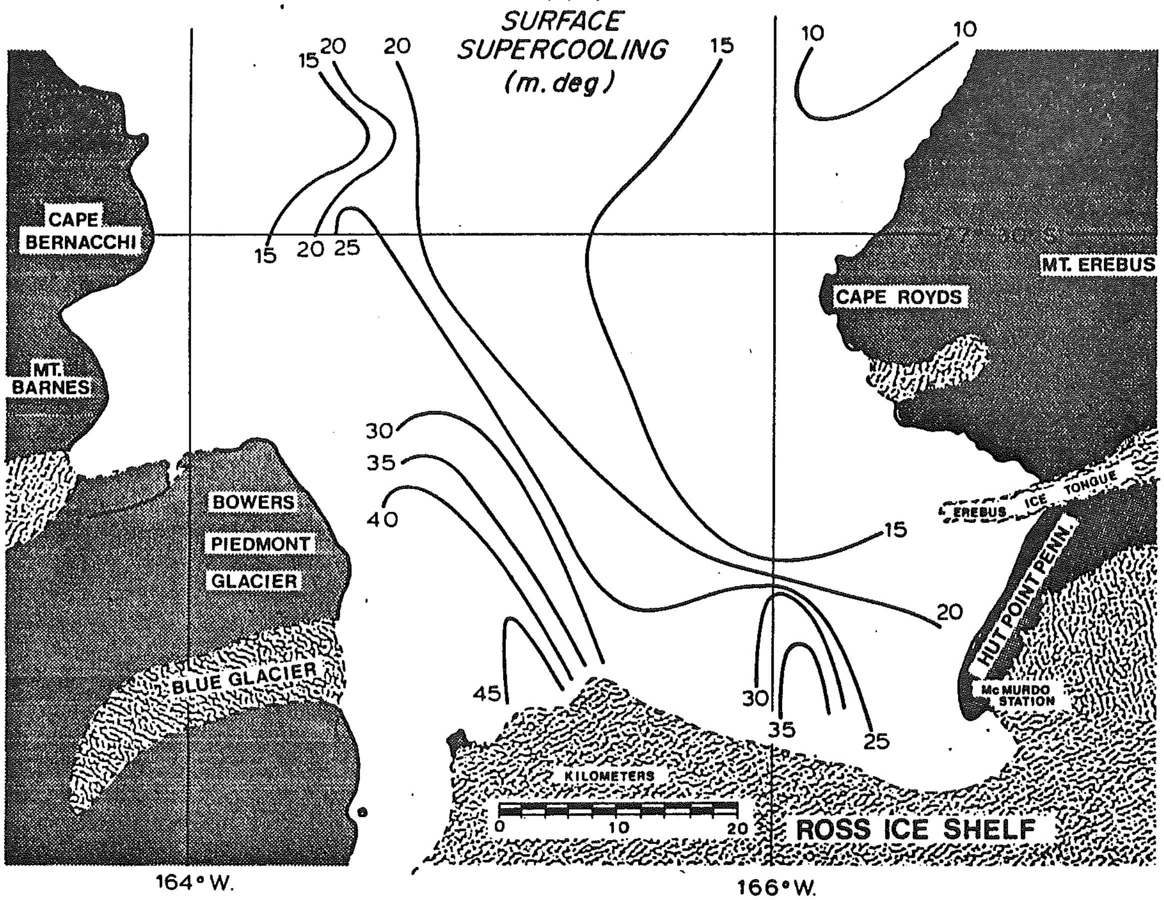


Figure 1. Contours of surface supercooling 2 m beneath the bottom of the sea ice sheet in McMurdo Sound Antarctica. Such supercooling must be produced by water coming into contact with ice at depth, then upwelling to the surface. The supercooling is relieved at the sea ice/water interface, with salt rejected into the water helping to augment the vertical circulation.

Uncertainties as to the roughness of the ice/water interface for glacial ice do not allow exact melt rates to be determined from Figure 2 but it is extremely probable that actual values will be between the "rough" and "smooth" plots on the graph. Using this figure together with oceanographic data given by Lewis and Perkin (in press) indicates that near the edge of the Ross Ice Shelf in McMurdo Sound, melt rates of up to 6 m per year could take place, assuming no restriction in water movement over the depth interval of pump operation.

It is worth noting that Figure 1 which gives our observations in October/November 1982, contrasts with the observations of Gow et al. (1982) who report a complete absence of underwater ice in McMurdo Sound in the same months of 1980. This must mean that the circulation patterns around Ross Island altered after 1980 allowing water from beneath the ice shelf to moving up to the sea surface.

Lewis, E.L. (continued)

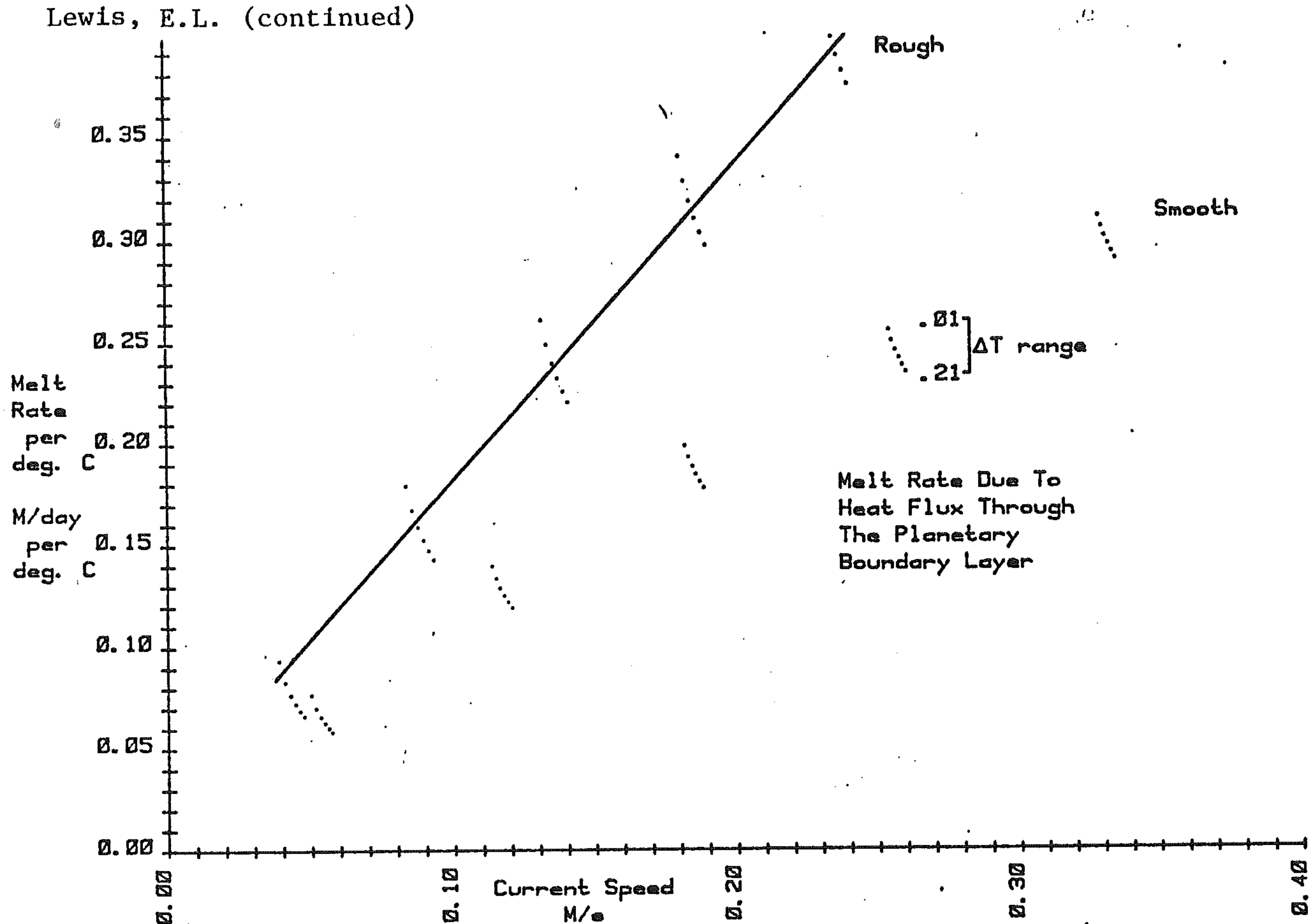


Figure 2. Melting rates per ^{o}C of ΔT, the temperature difference between the ice/water interface and the far field water, for "rough" and "smooth" ice boundaries. Surface roughness $Z_0 = 0.001$ and 0.00005 respectively. This rate is almost independent of the actual value of ΔT, the range utilised being shown. These values are calculated from McPhee (1983): the line is from the experimental results of Bogorodskiy and Sukhorukov (1983).

References

Bogorodskiy, V.V., and K.K. Sukhorukov, 1983, Physical Conditions of Bottom Melting of the Arctic Sea Ice Pack. Izvestiya, Atmospheric and Oceanic Physics, Vol. 19, No. 8, 667-669.

Gow, A.J., S.F. Ackley, W.F. Weeks, and J.W. Govoni, 1982, Physical and Structural Characteristics of Antarctic Sea Ice. Annals of Glaciology 3, International Glaciological Society, 113-117.

Lewis, E.L., and R.G. Perkin, 1983, Supercooling and Energy Exchange Near the Arctic Ocean Surface. Journal of Geophysical Research, Vol. 88, No. C12, 7681-7685.

Lewis, E.L., and R.G. Perkin, (in press), Winter Oceanography of McMurdo Sound in Oceanology of the Antarctic Continental Shelf, S. Jacobs, ed, Am. Geophy. Union.

MacAyeal, D.R., 1984, Thermohaline Circulation Below the Ross Ice Shelf: A Consequence of Tidally Induced Vertical Mixing and Basal Melting. Journal of Geophysical Research, Vol. 89, No. C1, 597-606.

McPhee, M.G., 1983, Turbulent Heat and Momentum Transfer in the Oceanic Boundary Layer Under Melting Pack Ice. Journal of Geophysical Research, Vol. 88, No. C5, 2827-2835.

Sedimentary and morphological features of a late Weichselian shallow glaciomarine sequence in the central North Sea.

A J Bent

Marine Earth Sciences Research Programme, British Geological Survey, Murchison House, West Mains Road, Edinburgh, Scotland, EH9 3LA.

Detailed seismic and sedimentological studies of data from the central North Sea (Fig. 2) have revealed a complex sequence of sedimentary facies and associated morphological features. This study concentrates primarily on sediments identified as late Weichselian and Holocene in age.

The sedimentary characteristics (Table 1) and morphological features (Figs. 3 and 4) are attributed to glacial and glacial marine processes related to a grounded tidewater glacier bordering a shallow epeiric sea.
Facies A and B represent sub-glacial and ice-front deposits, although the age and lateral relationships of parts of A are uncertain. The deformed bedding in A and winnowed nature of the sediments suggest that it was deposited as a flow till or alternatively that the unit has been subject to re-working. Both facies are associated with a hummocky depositional surface and morainal banks. A continuous, ice pushed ridge, subparallel to the ice front, marks the eastern maxima of the last ice front. Relict sand waves on the banks reflect higher energy conditions over these highs. Facies C accumulated proximal to the ice front where dropstone laminates containing layers of gravel, sand and silt were rapidly deposited by meltwater plumes and ice rafting. With increasing distance from the ice front and greater water depths the coarser input rapidly decreased producing the ice distal dropstone muds and hemipelagic muds of facies D. The ice scoured base of facies D is attributed to sea-ice scouring in water depths of between 20 and 30 m. Closer to the ice-front this surface is smoothed out, reflecting shallower water depths and the presence of groundfast sea ice.

The fossiliferous layered and lenticular bedded sequences in Facies E and F were deposited in a shallow marine intertidal environment characterised by an absence of glacial processes and in both cases they represent a return to normal marine conditions.

Facies G, although it outcrops at the seabed, is thought to be a sequence of proximal and distal dropstone muds and the upstanding ridges shown in figure 2 are morainal banks perhaps marking the eastern maxima of earlier ice sheets.

Discussion

The sedimentary and morphological features are the product of a grounded tidewater glacier and, prior to the wasting of the ice front, an extensive cover of grounded and floating sea ice. Concomitant with the breaking up of the sea ice subglacial tills and ice-proximal dropstone laminates were deposited along the western edge of the study area. As the ice front retreated and the rise in sea level overtook the effects of isostatic readjustment, a gradual transition from a distal iceberg facies to a marine facies occurred. In response to this sequence of events the sediments display a distinctive upward and eastward fining.

FACIES	CHARACTERISTICS
A	Soft to firm, slightly muddy pebbly sands: The colour varies from red to grey-brown reflecting a change in the underlying bedrock. Generally massive with striated clasts up to 8cm diameter passing down into sandier units with contorted bedding and clay laminae. Mean grain size = 2.6 to 3.1 phi, Sd = 2.1 to 2.9 phi. Seismically structureless with a hummocky depositional topography this facies is restricted to water depths less than 110m.
B	Soft, grey to grey-brown pebblly muddy sands: Massive, coarsening up units 0.5 to 2 metres thick with sharp contacts. Contains clasts up to 6cm diameter and numerous shell fragments. Mean grain size = 3.5 to 4.0 phi, Sd = 2.7 to 3.0 phi. Seismically similar similar to A forming linear moraine like features, (Fig. 2d).
C	Soft, grey-brown, layered sands and muds with dropstones: Thinly interbedded sands and muds forming sequences 0.3 to 0.5m thick, finning up into thicker units of interlaminated clays and silts. Lenticular bedding and intercalated contacts are seen in the coarser sequences whilst dropstones up to 4cm diameter occur throughout.Contains occasional shell fragment. Mean grain size = 4.5 tO 5.1 phi, Sd = 3.0 to 3.1 phi. On boomer and pinger records appears coarsely to finely layered and where present the basal reflector appears to be smooth but irregular.In small channels the reflectors appear to be ponded rather tha draped.
D	Very soft, grey-brown, silty muds: Poorly laminated with dark grey monosulphide layers 2mm to 20mm thick. Often passes up into more homogenous brown muds. Contains some shell fragments and plant material, but only rare dropstones. Mean grain size = 5.7 to 8.0 phi, Sd = 1.7 to 2.9 phi. Siesmically well layered and laterally continuous, the reflectors are disturbed only by pockmarks and occasional gas blanking. The base is marked by an irregular erosion surface (Fig. 2a), and in places a distinctive bright layer.
E & F	Soft, brown, Interbedded muds and sands: Finely bedded and lenticular bedded sequences forming units 0.5 to 3.0m thick with gradational contacts. Sand layers are massive and often graded. Whole valves preserved throughout but no dropstones. In places this facies has been reworked and contains stiff balls of dark grey sandy mud whilst the layering has been destroyed or contorted. Mean grain size = 5.9 to 6.4 phi, Sd = 2.1 to 2.3 phi. This Facies occurs at two horizions. First, E, a lower poorly defined unit characterised in places by an irregular upper surface that has been attributed to sea ice scouring. Secondly, F, an upper unit that overlies facies D and generally occurs within the seabed multiple.
G	Firm to stiff, brown mud with dropstones. Generally massive with occasional monosulphide banding. Contacts are sharp and individual units may be greater than 5m thick. Dropstone content varies from common to rare and are up to 5cm in diameter. Mean grain size = 6.2 to 6.6 phi, Sd = 2.4 to 2.8 phi. Seismically structureless or opaque, this facies forms distinctive highs and in the west the base is marked by a strong sub-horizontal reflector. Further east the sediments infill a channeled base.

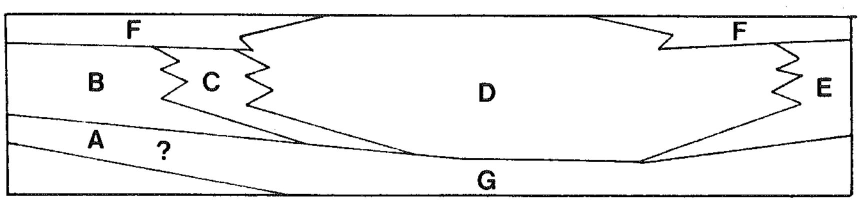


Table1. Characteristics of the seven facies types.

Fig1. Relationships between facies.

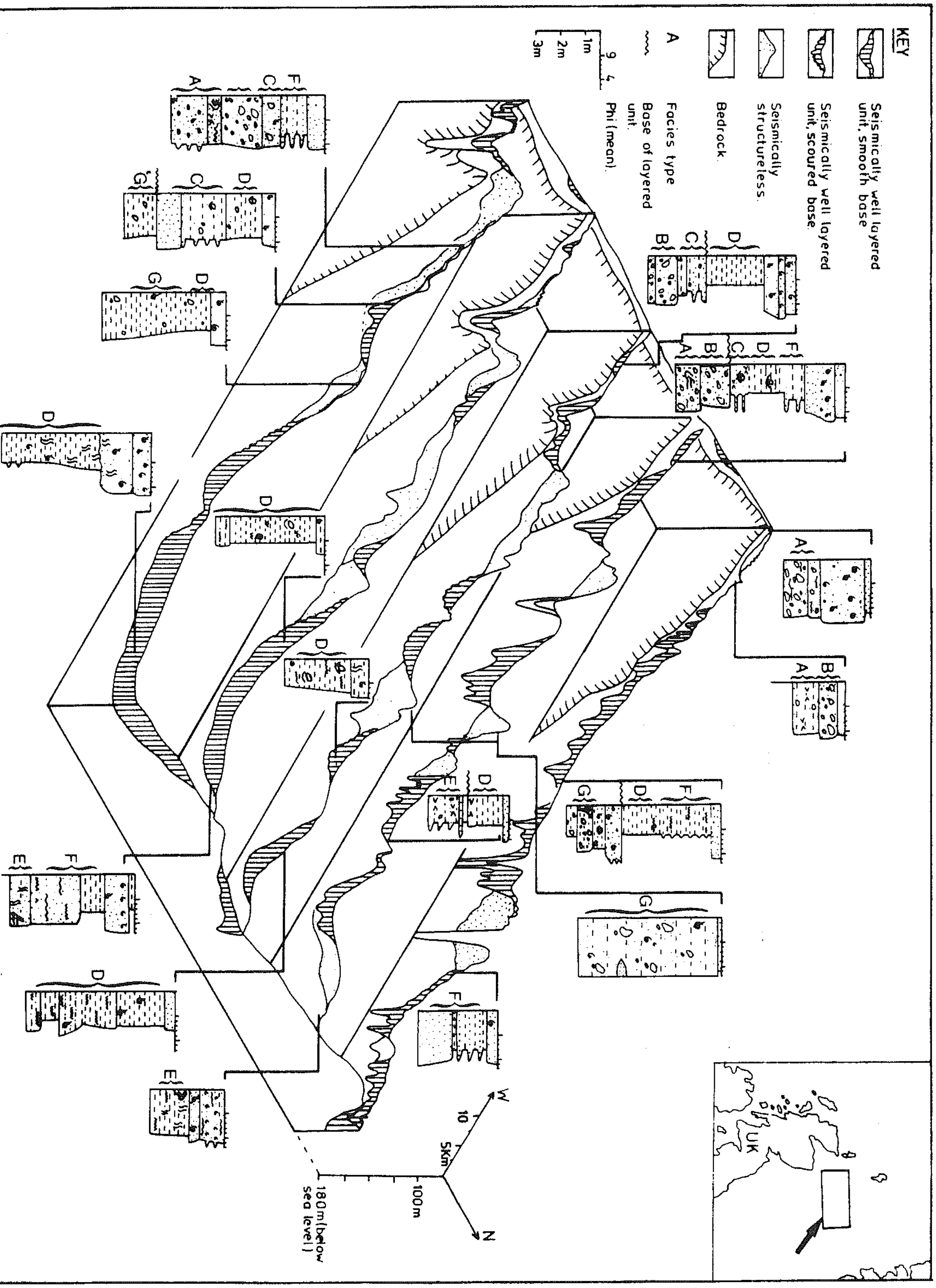


Fig. 2 Seismic features and facies distribution. Inset shows location of study area.

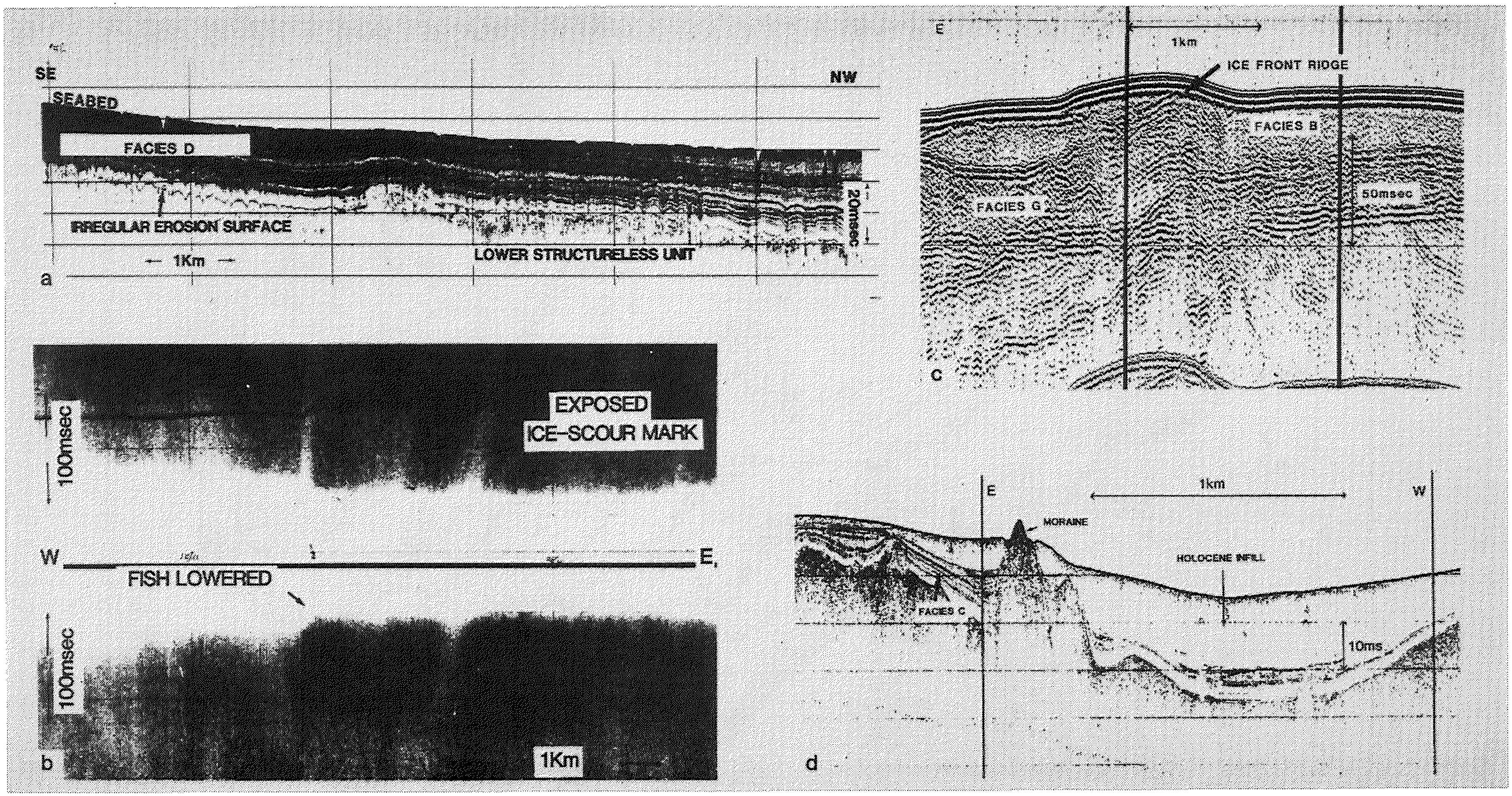


Fig.3 a:Boomer record showing Facies D and the irregular ice scoured base. b:Side Scan Sonar of ice scoured surface outcropping at seabed. c:Sparker record showing ice front ridge and possible push structures. d:Boomer record of "moraine like"feature.

ICEBERG CALVING AND ITS INFLUENCE ON ICE-PROXIMAL, SUBAQUEOUS GLACIGENIC LITHOFACIES

by

Ross D. Powell
Department of Geology
Northern Illinois University
DeKalb, Illinois 60115 USA

A glacier terminates in a lake or sea as an ice shelf (or ramp or floating glacier-tongue) or a tidewater front (or ice cliff). Iceberg calvings occur at the grounding line of a tidewater glacier and are very energetic events, whereas floating sheets detach at some distance from the grounding line in much more passive events. Because of these different modes of iceberg calving, ice-proximal lithofacies at tidewater termini may include a random or rhythmic interstratified-sediment lithofacies (laminite in sedimentary rocks) more commonly, and in more volume, than those lithofacies at an ice shelf grounding-line. The interstratified-sediment lithofacies is useful for indicating grounding-line proximity in ancient subaqueous glacigenic facies associations.

This paper presents a mathematical model which predicts that an iceberg calved above water level from the face of a tidewater front can either impact the floor or come sufficiently close, so that it or its preceding pressure wave could redistribute bottom sediment by sediment gravity-flows. The first part of the model considers the free-fall of the ice block through the air as a missile that loses most of its potential energy during impact by drag and creation of a wave as a heaved free-surface.

If the block retains momentum after impact, then its descent through the water column is modelled under simple hydrodynamic flow conditions. Results of the modelling have been tested in the field by timing the return of icebergs to the water surface and estimating fall distance, and size and shape of the blocks. The times are within ranges predicted by the mathematical model.

The model describes the case of seracs spalling from the face above water level by Reeh-type calving (Reeh, 1968) from fracture propagation (Iken, 1977); a process that occurs continually at tidewater fronts. With time, quite a large volume of ice can be lost in this manner, and enough falls occur that the number of bergs which influence bottom sediment is quite large. Large sheets can also fracture above water level and when they descend vertically could likewise influence bottom sediment. Those that topple forward and shatter on impact can only influence bottom sediments indirectly by the surface wave produced. Icebergs that calve subaqueously then float to the surface may redistribute sediment if they were in contact with the bottom. That case is probably relatively minor compared with other calving cases, because most subaqueous ice is lost from melting by sea or lake water, rather than calving.

Implications from the modelling are that iceberg calving from tidewater fronts is a very important process to consider for generating ice-proximal sand and/or silt laminae and/or beds in dropstone mud or dropstone diamicton lithofacies. To provide perspective of the importance of calving, other processes producing interstratification require discussion and evaluation.

Major sources to produce interstratificaiton by episodic depositional or erosional events are: (i) stream discharges (ii) tidal currents, (iii) wind-generated wave currents, and (iv) slumps and subaqueous sediment-gravity-flows.

Stream discharges commonly produce cyclopsams up to about 1 km from a grounding line and cyclopels beyond. Stream discharges under some glacial regimes are very important sources of interstratified ice-proximal lithofacies and criteria for their recognition is accumulating (Mackiewicz et al., 1984; Cowan et al., in press).

Tidal currents can produce strata like cyclopels or traction-sorted silt and/or sand strata. Tidal forcing by a flexible ice shelf could enhance velocities such that tidal currents transport coarser sediment or leave a coarser lag deposit. Tidal strata should be distinguishable from those originating from iceberg calving at tidewater fronts.

Wind-generated waves are obviously absent near the grounding line of an ice shelf and are only a factor at tidewater fronts when they end in water depths above fair weather wave-base. In fact, a tidewater front with its base at lake or sea level cannot have ice-proximal laminae produced by calving because bergs land on a beach face. Any interlaminated sediment offshore must have laminae produced by wave, tide and other bottom traction-currents or from sediment gravity-flows initiated in shallow water, probably by storm events. When a tidewater front ends in water depths below fair weather wave-base laminae may be most commonly produced by iceberg calving. In addition to wind-generated waves, waves from calving bergs can redistribute shallow-water sediment as sediment gravity-flows into deeper water, especially in restricted water bodies such as fjords.

Slumps and subaqueous sediment-gravity-flows may be generated by (i) biogenic gas, (ii) ice-push from summer/winter glacier front fluctuations and from "jerky motion", (iii) earthquakes, (iv) high sedimentation rates creating slope over-steepening and entrapment of pore water, or re-distribution from the mouths of subglacial streams, (v) wave-induced liquefaction, (vi) tidal forcing causing liquefaction, and (vii) iceberg calving. The first three processes occur much less frequently and less regularly than the last four which, given different sedimentation rates could result in variations in the intensity of stratification.

Under high rates of sediment accumulation one or a combination of the last four processes must be active for interlaminated sediment to be produced. Of the four, slope over-steepening, wave-induced liquefaction and iceberg calving can occur at tidewater fronts whereas only slope oversteepening and tidal forcing occur at the grounding line of an ice shelf. Although sediment gravity-flow deposits cannot be used to identify the cause of flowage, iceberg calving and slope over-steepening are probably the most common causes.

Considering all methods of genesis of interstratified sediments near a grounding line, a tidewater front provides more favorable conditions for their production than does an ice shelf. Furthermore, iceberg calving is a major factor in favor of the tidewater glacier environment.

SEA FLOOR EVIDENCE FOR GLACIER SURGES, NORDAUSTLANDET, SVALBARD.

Anders Solheim
Norwegian Polar Research Institute
P.O.Box 158, N-1330 Oslo Lufthavn
Norway

Austfonna ice cap, Nordaustlandet, Svalbard (Fig.1) has one of the longest grounded glacier fronts on the northern hemisphere. Between 1937 and 1938 Bråsvellbreen which acts as a seperate ice stream due to underlying bedrock topography, surged, and the front advanced approximately 20 km in open marine conditions. Since then, the front has retreated up to 5 km.

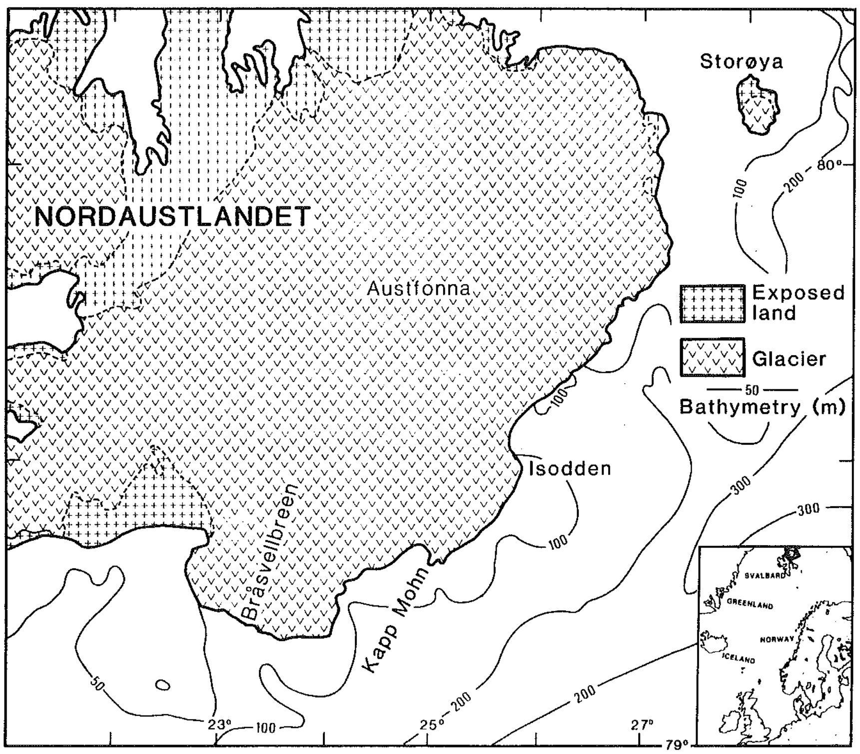


Fig.1. Austfonna ice cap and the study area.

Sediments in the area that was covered by the glacier after the surge (the surge zone), are mainly pebble-rich diamicton. The main variation is difference in degree of consolidation, from the stiff Late Weichselian (Late Wisconsin) basal till, to the loose top sediment. However, a few cores show that patches of the pre-surge, more ice-distal sediment, are preserved relatively undisturbed, only given a slight overcompaction during the relatively short time interval of glacial coverage. Microstructure of the sediment is currently being studied, but appearantly it is difficult to reveal properties that are characteristic for surge-affected sediments.

High frequency geophysical records, on the other hand, reveal a suite of morphological features that are ascribed to the surge process. These include:

- An end moraine, of which a major part was rapidly deposited from meltwater during and shortly after the surge, giving rise to a characteristic shape of the distal part of this ridge feature.
- Singular sediment mounds and straight discontinuous ridges that form a rhombohedral pattern, resulting from crevasse fill through a squeeze-up process, and is preserved through stagnation of the glacier after the surge.
- Arcuate, discontinuous, subparallel ridges along the thickest part of the glacier, resulting from annual winter advances during the latest few years.

What is most striking for the area seen as a whole, however, is the distinct change in morphology across the end moraine, from the relatively smooth, undisturbed sea floor on the outside to the sharply structured pattern in the surge zone.

The ability of this morphology for identification of surges was then tested on another ice-stream of the Austfonna ice cap. The area between Kapp Mohn and Isodden (Fig.1) most likely had a major surge around 1873. High frequency acoustical records from a few profiles outside this area gave a convincingly similar pattern to the one identified outside Bråsvellbreen. The surge extent of this ice stream can be mapped in good detail both from the end moraine, which in this case is somewhat less well expressed, and from the marked morphologic change between the surge zone and the area unaffected by the surging ice proper. The rhombohedral ridge pattern and sediment mounds are easily recognizable, but the subparallel, arcuate ridges was not detected. The latter may indicate that this part of the glacier is still stagnant, but the lines were not run as close to the present-day ice front as outside Bråsvellbreenn.

More work to fully cover this area is being carried out during September and October this year, and more results may come up before the meeting.

Sedimentary facies of an early Middle Pleistocene tidewater glacier, North Sea.

M S Stoker

Marine Earth Sciences Research Programme, British Geological Survey, Murchison House, West Mains Road, Edinburgh, Scotland, EH9 3LA.

Early Middle Pleistocene sediments in the West Central North Sea (Fig. 1) represent sub- and pro-glacial deposits of a grounded tidewater glacier. The regional distribution of these sediments indicates that this ice-sheet had a limited offshore extent, and was spatially related to the Forth Approaches area (Stoker & Bent. In press). Detailed core analysis has identified five sedimentary facies which represent a transition from subglacial through glaciomarine to more typical shelf marine (Fig. 2).

Facies 1 consists of firm, very poorly sorted, dominantly matrix-supported, gravelly sandy muds. These sediments are not present in every core and appear to form a localised, mounded unit up to 3m thick, which overlies pre-Quaternary strata with a sharp, erosional contact. Gravel forms up to 30% of the sediment but clast orientations are variable and no discernible structure is visible. This facies represents a subglacial till and may either be a remnant of a previously more extensive till cover, or the seemingly isolated tillmount may be an original feature and represent a localised ice-grounding point.

Facies 2 comprises medium to coarse, very poorly sorted, matrix-supported, gravelly muds and gravelly muddy sands. Over most of the area the base of this facies rests unconformably on pre-Quaternary strata, although locally it overlies facies 1 sediments. Laterally and vertically facies 2 sediments pass transitionally into facies 3 and/or facies 4 sediments. The geometry of this unit is sheet-like which suggests that sedimentation was not constrained in any way and was able to expand laterally. Internally, it varies from massive to crudely bedded, the latter highlighted by the variation in gravel content (Fig. 2). The coarse nature of the sediment implies deposition from powerful sediment-laden currents. Isolated blocks of facies 1-type sediment within this sequence were derived from slumping off, or melt-out from the ice-margin. Facies 2 clearly represents a proximal glaciomarine environment with meltwater streams issuing from the base of the glacier and depositing their load subaqueously into a shallow sea.

Facies 3 is an interbedded, sand/mud sequence which forms a localised transition zone between facies 2 and 4. Coarsely interlayered sand/mud bedsets comprise very fine to very coarse, poorly sorted, ripple-laminated sand alternating with structureless mud. A thicker bed of fine to coarse sand capped by a gravel layer forms a distinct upwards-coarsening unit within the sequence. Bedding surfaces, although sharp, are generally non-erosional. The presence of rippled and graded sand beds and coarse gravel layering suggest deposition in an area still subject to powerful sediment discharges; an ice-proximal environment is indicated.

Facies 4 is represented by poorly sorted, matrix-supported, slightly sandy and gravelly muds. The muds are predominantly structureless although occasional sandy lenses, sand-filled infaunal burrows and isolated gravel clasts are present. The high clay content and lack of current indicators suggest a low energy environment, but with a subsidiary input of coarser material. This facies is interpreted as distal glaciomarine with the coarse fraction representing ice-rafted detritus.

Facies 5 consists dominantly of poorly sorted, bioturbated sandy muds, which are commonly associated with complexly laminated sand and muds and normally graded sands, and moderately sorted structureless mud. These represent more typical marine shelf sediments. The contact wih facies 4 is gradational and partly subjective, taken on the presence or absence of a distinct ice-rafted, gravelly component. Although some of the sandy detritus may be ice-rafted, this is difficult to confirm as sand forms an important constituent of the shelf sequence even in the underlying non-glacial, Lower Pleistocene sediments.

Clast types throughout the glacigenic sequence are of local Scottish derivation. Although the majority of the clasts are faceted, striated pebbles are mainly restricted to facies 1. In contrast, fossil remains occur in all facies except facies 1.

Discussion

The overlapping facies relationships (Fig. 2) show an overall fining-upwards trend. This pattern reflects the decreasing proximity of the ice-margin, and an associated reduction in volume of coarse detritus transported to the area, with time. It is envisaged that facies 1 was deposited subglacially during the final stages of ice-advance while facies 2 to 5 were deposited diachronously in a proglacial environment as the glacier melted and retreated westwards. These facies associations are typical of those described by Powell (1984) for a grounded tidewater glacier regime.

References

Powell, R.D. 1984. Glacimarine processes and inductive lithofacies modelling of ice shelf and tidewater glacier sediments based on Quaternary examples. Marine Geology, 57, 1-52.

Stoker, M.S. & Bent, A. (In press). Middle Pleistocene glacial and glaciomarine sedimentation in the west central North Sea. Boreas.

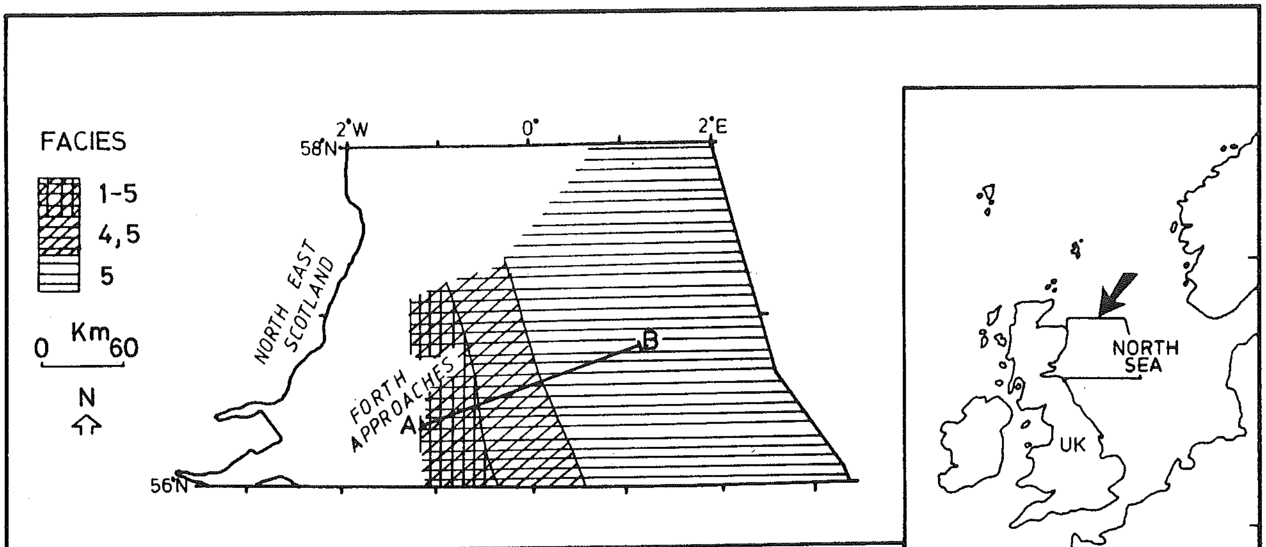


FIG.1 Location and facies distribution

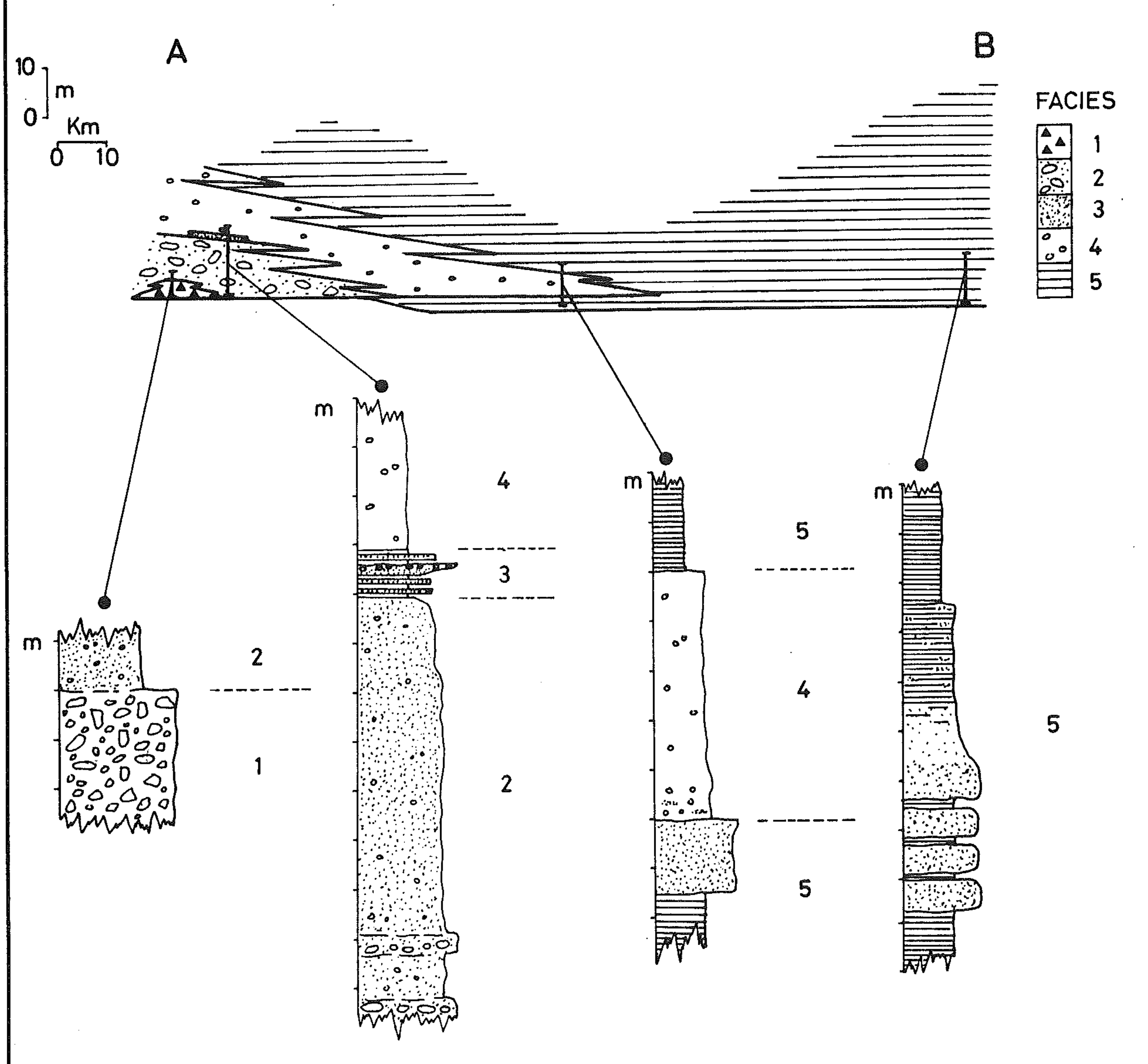


FIG.2 Facies relationships (Section A-B, Fig.1) and typical logs

ARCTIC LAND-SEA INTERACTION

Glaciomarine sedimentation on Southern Victoria Island, N.W.T.

David Sharpe, Geological Survey of Canada, 601 Booth St, Ottawa

Geological mapping of Late Quaternary sediments on Victoria Island, N.W.T. has provided data on the distribution and nature of glaciomarine sediments. Most of the sediment is proximal to source, that is, ice-marginal in nature. Very little sediment has been deposited far from the ice-contact environment unless it has been transported into deeper oceans basins beyond present uplifted land surfaces. These findings are indicated by rapid areal facies changes within outwash-glaciomarine delta systems and within subaqueous fan deposits. Many lateral moraines are predominantly composed of subaqueous deposits produced by sediment gravity flow mechanisms. These deposits show abrupt lateral facies transitions from massive diamictons to graded sand sequences over short intervals. The results of studies attempting to understand the processes of glaciomarine sedimentation at tidewater glaciers has improved the above interpretations.

The study of proximal raised Quaternary glaciomarine sediments by mapping and by facies analysis provides detailed areal control on sedimentation and facies distribution that is not possible with offshore deposits. The study of glaciomarine sediments offshore can be improved by understanding of these raised sequences that act as models for similar offshore forms such as the morainic ridges, delta or fan forms mapped on Victoria Island.

MORPHOLOGY AND PROCESSES OF THE CANADIAN BEAUFORT SEA COAST

BY

JOHN R. HARPER, ARLENE COLLINS AND P. DOUGLAS REIMER
Dobrocky Seatech Ltd.
9865 West Saanich Rd.
P.O. Box 6500
Sidney, B.C.
V8L 4M7

An analysis of the Canadian Beaufort Sea coastal zone (Alaska/Yukon Border to the Baillie Islands) was conducted to provide regional summaries of (a) coastal morphology, (b) coastal stability and (c) coastal processes. The analysis will be used in the development of resource management strategies and in the evaluation of proposed development (e.g., impact and design assessment). A total of 2,077 km of coastline was examined using aerial photographs, low-altitude oblique video imagery and information from previous field studies.

The Coastal Information System, developed by the Geological Survey of Canada, was used to systematically characterize coastal morphology and to record data in a digital data base. Six coastal types were defined from the data base and were used to characterize the coastal zone. The results indicate a predominance of erosional landforms (80% of the coastline mapped) with relatively few (<20%), widely distributed accretional landforms.

Over 1,000 comparisons of coastal stability were made using 1950's and 1970's aerial photographs. The results indicate that the Beaufort Sea coast is undergoing significant regional retreat. Most sections of the coast exhibit mean coastal retreat rates greater than 1 m/yr; however, areas of the active Mackenzie River delta are retreating almost everywhere at rates greater than 2 m/yr (Fig. 1). A maximum retreat rate of 18 m/yr was measured in the Shallow Bay portion of the delta.

The presence of significant quantities of terrestrial ice in the coastal sediments is one of the primary causes of the wide-scale retreat. It is also hypothesized, however, that the Canadian Beaufort Sea is undergoing a relative sea-level rise that is contributing to the rapid retreat. There is circumstantial evidence that supports this contention, including tide gauge records from Tuktoyaktuk and observations of drowned stream valleys along much of the coast. The tide gauge records suggest a relative sea level rise of as much as 1 mm/yr, although the record is complicated by considerable scatter. Observations of coastal rivers indicates that many of the lower-river valleys are drowned and, in fact, the active areas of the Mackenzie River delta are among the most rapidly retreating sections of the entire coast, also suggesting active submergence.

The predominance of erosional coastal landforms is a result of terrestrial ice in the coastal sediments and possibly as the result of a relative sea level rise. An important exception to this trend occurs on the western Yukon coast where long, linear barrier islands appear stable to accretionary; it is speculated that onshore movement of material due ice-push in the nearshore is the primary process responsible for supplying material to these barrier islands. As such, two conceptual models are used to describe major coastal types: one model to describe the processes contributing to erosional landform development that predominates along the coast and another model to describe the processes contributing to the relative stability of the western Yukon coastal barrier islands.

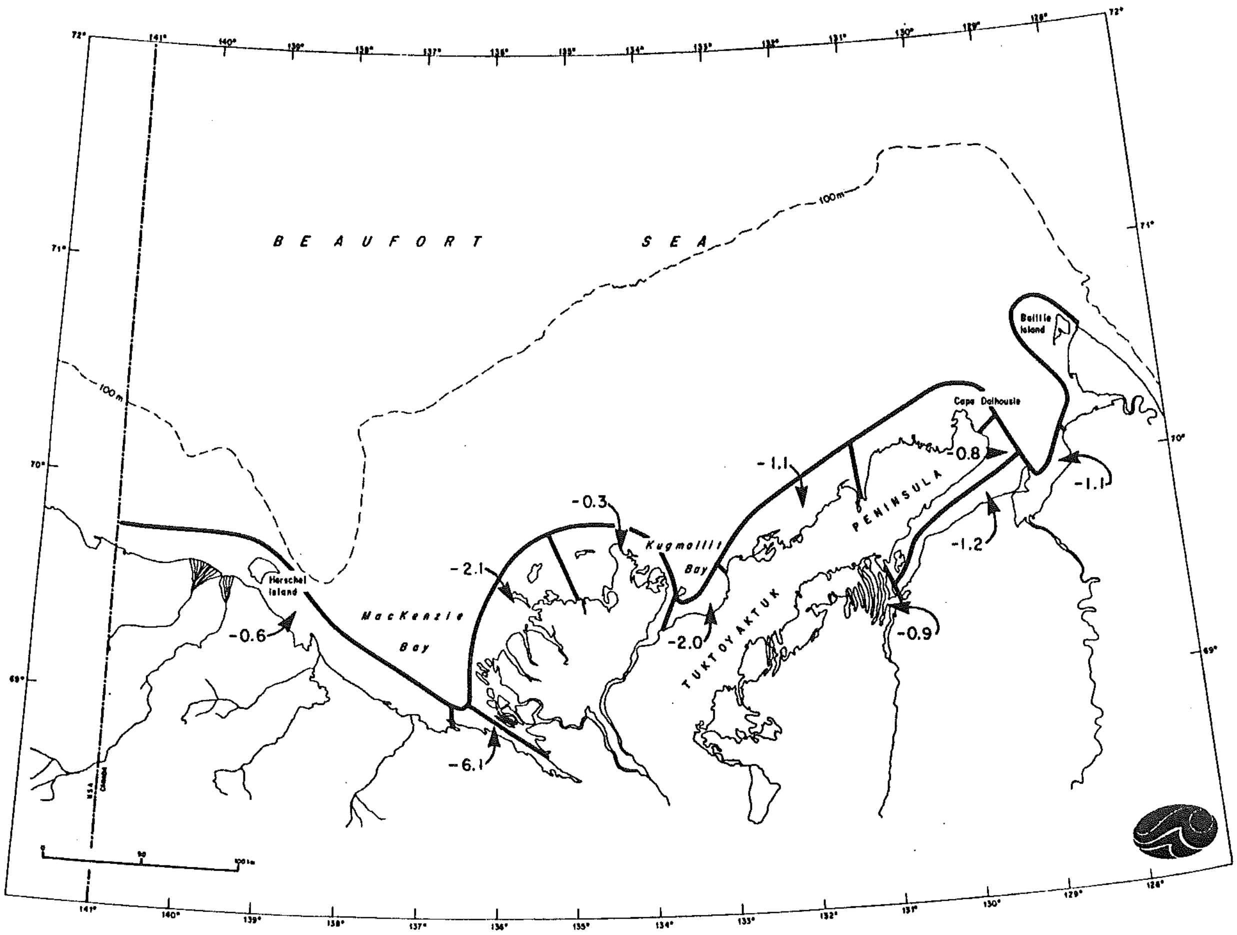


Figure 1. Mean Coastal Retreat Rate (m/yr) for segments of the Canadian Beaufort Sea Coast

ACKNOWLEDGEMENTS

This study was supported through a contract from Indian and Northern Affairs Canada, Northern Oil and Gas Action Plan (NOGAP).

An Integrated Approach to Studies of the Physical Environment of the Nearshore Arctic Coast of Alaska

Many studies of the environment of the coastal waters of arctic Alaska during the past 10 years have been associated with oil and gas leasing and exploration in the U.S. Oil and gas exploration and development more than 3 miles offshore is under the jurisdiction of the U.S. Department of the Interior, Minerals Management Service (MMS). The MMS funds and administers studies to acquire information needed for preparation of environmental impact statements, environmental assessments, and permitting. The MMS divides the Alaskan arctic coast into three lease planning areas between the Bering Strait and longitude 141° West, the Beaufort Sea, Chukchi Sea, and Hope Basin areas (Figure 1). Thus far, three lease sales have been held in the Beaufort Sea area. Section 20 of the Outer Continental Shelf Lands Act Amendments of 1978, requires that the Secretary of the Interior conduct environmental studies and monitor the human, marine, and coastal environments.

The MMS-sponsored arctic coastal studies have followed a general sequence, reflecting current knowledge and oil and gas program information needs. Early studies were baseline efforts, designed to describe aspects of the physical and biological environments. Once the basic description was obtained, ecosystem studies were initiated to better define the interrelationships of the physical and biological components of the environment. Social and economic effects of oil- and gas-related activites are also investigated as another component of the Environmental Studies Program (ESP). At the same time, predictive models were developed for application in conducting assessments. The models have evolved in response to continuing needs and some remain under development. Also, as offshore activities move toward development and production phases, more studies are oriented to monitoring potential environmental effects. This presentation focuses upon the MMS-sponsored studies of physical processes and their evolution in the preceeding context.

Major themes of many studies relate to the effects of potential oil spills on the environment (particularly on the biological resources) and potential hazards posed by the physical environment. Analyses of leasing alternatives require study of the probabilistic aspects of various consequences. In order to assess the probability of effects of oil spills on the biological resources, it is necessary to determine: (1) the probability of spills; (2) the probable transport of hypothetical spills; (3) the characteristics and behavior of spilled oil in the environment; and (4) the effects of spilled oil on the biological resources. As a prerequisite, it is necessary to understand oceanographic physical processes in offshore and coastal areas, especially to address steps (2) and (3).

Consequently, initial MMS studies of arctic physical processes, including coastal meteorology, oceanography, and sea ice, were conducted as baseline studies. Field measurements were conducted of water properties along the coast and in the coastal lagoons. At the same time, winds and atmospheric pressure were recorded to better define the winds of the coastal areas.

This effort resulted in description of a summer arctic sea breeze and of topographic steering of coastal winds. The winds and measured currents together define the surface motion of the water (and oil spills) in the absence of sea ice. Sea ice has been surveyed under the ESP using satellite remote sensing (principally LANDSAT imagery) for the past 10 years. The patterns of sea ice motion, pressure ridge formation, patterns of leads, and the probable mean and extreme seasonal ice edge patterns have been mapped.

Given baseline information, it is necessary to arrive at probabilistic behavior of oil spills in order to assess effects of proposed oil and gas activities. Consequently, the MMS has sponsored development of models which compute probable oil spill trajectories based on tides, stochastic winds and storm tracks, and sea ice cover. Probabilities of spills are combined with trajectory probabilities to define the probability of interaction of a beach or "target" with oil. Models are verified against several sets of tidal and wave data.

The nature of the spilled oil, of course, changes with exposure. Consequently, MMS-sponsored oil weathering models are used to define the amount and nature of the oil left in a hypothetical spill at a given time. The model incorporates the interaction of oil particles and sea ice during weathering. Additional work is currently examining the interaction of suspended particulate matter and oil during weathering. Other models now under development will help predict probable interaction of oil and suspended particulate matter in the nearshore coastal zone, and probable distribution of oil spills on and along beaches.

Many studies of potential hazards of the physical environment to oil and gas activities have been descriptive in nature. The investigation of the hazard to undersea pipelines which may be posed by ice-ridge gouging has received direct observations for the past several years. Study of baseline ambient air quality is proposed, although air quality has thus far not been a major issue in the areas considered. Analysis of storm surges, however, are in the modeling stage. The storm surge model is adapted to account for sea ice. In addition, because leasing is now extending into deeper waters, a multiseason oceanographic study is planned to improve knowledge of Beaufort Sea shelf circulation to the 200 meter isobath. This information will then be used to help further refine our predictive abilities. Relative to the needs of the MMS offshore oil and gas leasing program, the trend for studies of physical environment has been to increasingly focus on specific areas of probable activity and otherwise to obtain "generic" information (or models) useable in many areas and circumstances.

(Presented by William G. Benjey, United States Minerals Management Service, Alaska OCS Region, P. O. Box 101159, Anchorage, Alaska 99510)

ARCTIC REGION

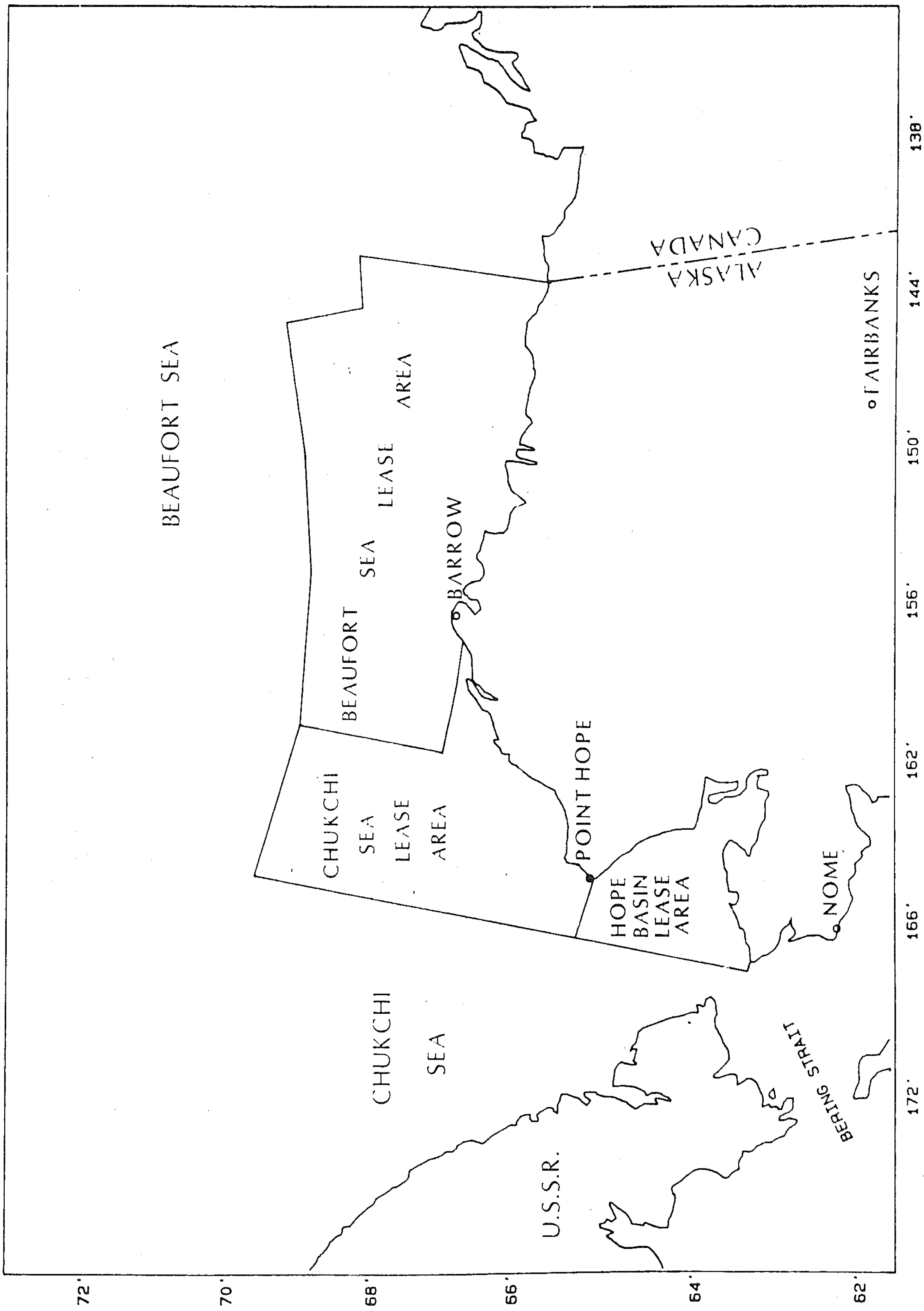


Figure 1

GROUND ICE SLUMPS, BEAUFORT SEA COAST, YUKON TERRITORY

David G. Harry

Terrain Sciences Division

Geological Survey of Canada

Ground ice slumps represent a major erosional landform, unique to permafrost environments (e.g. French, 1974; Mackay, 1966, 1971). They are widely distributed along the Beaufort Sea coastline of the Yukon Territory, where they are associated with high rates of coastal recession (e.g. Lewis and Forbes, 1974). Defined genetically as retrogressive thaw flow slides (McRoberts and Morgenstern, 1974), these thermokarst features occur where massive ice or ice-rich sediments have been exposed by mass wasting or erosion. Many slumps appear to be polycyclic, with periods of rapid development and enlargement separated by intervals of relative quiescence. The nature of the triggering mechanisms which result in slump reactivation remains poorly understood, however they may involve a combination of both thermal and mechanical energy inputs into the system. In this regard, recent proposals to construct shore-based facilities for offshore hydrocarbon exploration and production provide a strong incentive for continued study of ground ice slumps.

Between Shingle Point and Kay Point, ice-rich sediments occur in association with two main terrain types, as defined by Rampton (1982). Southeast of King Point, rolling moraine deposited during the Buckland Glaciation forms a discontinuous series of hills and ridges, which rise 10-20 m above the surrounding lacustrine plains. The ridges are underlain by ice-rich till and, in some instances, lenses and layers of massive segregated ice. To the northwest of King Point, a glacier ice-pushed ridge extends parallel to the coastline as far as Kay Point at elevations of 60-70 m a.s.l. This is constructed from ice-rich and glacially deformed silts, sands and gravels. In both areas, ground ice slumps form a common coastal landform. They frequently possess a cirque-like morphology, with a steep (35-35°) actively eroding headwall forming an arc surrounding a gently sloping (5-10°) basin characterized primarily by debris transport and deposition. In some cases, basin coalescence leads to the formation of a linear slump, in which the scarp face extends parallel to the coastline.

A variety of processes are involved in ground ice slump evolutin, as the term "thaw flow slide" suggests. As the exposed ice-rich face thaws, sediment is released and flows across the face in a slurry either as sheetwash or, more commonly, within channels controlled by irregularities within the permafrost. The saturated debris accumulates at the scarp foot, often forming a series of arcuate ridges ponding water and debris against the scarp. Only rarely is the scarp itself subject to direct wave attack. More frequently, wave erosion removes redeposited debris from the basin thus exposing permafrost at lower levels within the scarp. In many instances, the ice-rich sediments are overlain by a variable thickness of organic material and ice-poor diamicton, marking previous thaw and mudflow events. As the underlying thaw face retreats, this surficial layer becomes progressively undercut and is liable to fail catastrophically by block collapse. The rate at which each of these processes operates is highly variable, both in time and space. For example, the rate of thaw is controlled to a great extent by the pattern of incoming solar radiation; this is influenced by many variables including slope aspect and cloud cover. Similarly, a late-lying snowbank, or a major debris fall, can cover and insulate segments of the exposed face, substantially retarding its rate of thaw.

Ground ice slumps represent a dynamic coastal landform in permafrost regions and yet, because of their irregular cycle of development, it is not easy to quantify their contribution to coastal change. For example, between 1954 and 1985, some slump headwalls on the Yukon coast have retreated by as much as 60 m. However, since good-quality air photo coverage dates only from the 1950's, it is difficult to determine the frequency and magnitude with which ground ice slumps are initiated, grow, decay and are reactivated. Certainly, both the geomorphic and stratigraphic evidence suggest that they have formed a major element of landscape evolution in this region throughout Holocene times. Further studies of the energy and sediment balance, together with a better understanding of the control exerted by cryostratigraphy, will be necessary in order to predict the occurrence and evolution of ground ice slumps in areas of potential Beaufort Sea shorezone development.

REFERENCES

French, H.M.
1974: Active thermokarst processes, eastern Banks Island, Western Canadian Arctic; Canadian Journal of Earth Sciences, v. 11, p. 785-794.

Lewis, C.P. and Forbes, D.L.
1974: Sediments and sedimentary processes, Yukon Beaufort Sea coast; Environmental-Social Program, Northern Pipelines, Task Force on Northern Oil Development, Report 74-29.

Mackay, J.R.
1966: Segregated epigenetic ice and slumps in permafrost, Mackenzie Delta area, N.W.T.; Geographical Bulletin, v. 8, p. 59-80.

1971: The origin of massive icy beds in permafrost, western Arctic coast, Canada; Canadian Journal of Earth Sciences, v. 8, p. 397-422.

McRoberts, E.C. and Morgenstern, N.R.
1974: The stability of thawing slopes; Canadian Geotechnical Journal, v. 11, p. 447-469.

Rampton, V.N.
1982: Quaternary geology of the Yukon coastal plain, Canada; Geological Survey of Candaa, Bulletin 317, 49 p.

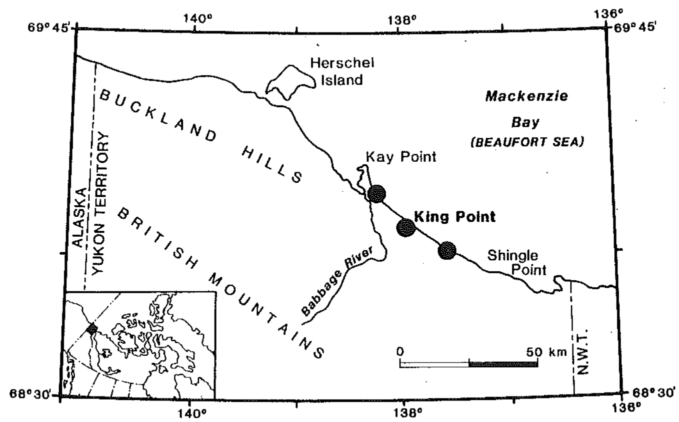


Figure 1: Location map of ground ice slump sections examined in 1984/85.

The Eroding Coast of the Alaskan Beaufort Sea, its Sediment Supply and Sinks

by

E. Reimnitz, S.M. Graves, and P.W. Barnes

U.S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA, 94025

Using two 1:50,000-scale NOS charts, from surveys spaced 30 years apart, this study delineates patterns in coastline changes and sediment yields from erosion for 344 kms of Alaska's Beaufort Sea coast. Excluding the large Colville Delta, which advances at an average rate of 0.4 m/yr, the overall coastline is eroding at a rate of 2.5 m/yr. In places the local long-term erosion rates are as high as 18 m/yr, while accretion rates near the active mouths of the Colville River are as high as 20 m/yr. The coastal plain deposits in the western third of the study area are fine-grained mud; here average erosion rates are highest (5.4 m/yr). The rest of the study area is composed of sandy to gravelly deposits, which erode at 1.4 m/yr. This difference suggests that the grain size of bluff material exerts the dominant control on coastal retreat rates. Other important factors include bluff height, ice content and thaw settling, bluff orientation, and degree of exposure to the marine environment. Vertical crustal motion has not played an important role during Holocene time, as evidenced by the constant elevation of 120,000 yr old shoreline deposits traceable for 200 km from Barrow to the Colville River (Hopkins and Carter, 1980), and by 30 yr observations on tidal benchmarks along the Beaufort Sea coast.

In calculating sediment yield we consider not only the materials in coastal bluffs above sea level, but the submerged profile to 2m depths. Assuming this profile to be in dynamic equilibrium, we account for material eroded to a depth of 2m below msl as the profile migrates landward. The upper part of this roughly 5 m thick eroded section contains up to 75% ice, and the sediment yield is reduced accordingly in our calculations. The annual yield from coastal retreat thus calculated is 2.5 x $10^6 m^3$, with the offshore contribution slightly higher than the onshore contribution. Based on our evaluation of sparse data on sediment carried by Arctic streams, we estimate the annual sediment yield from the adjacent drainage areas is 2 x $10^6 m^3$, a rate that is slightly less than that from coastal erosion.

Knowledge of recent patterns in coastal retreat, coupled with knowledge of factors controlling this retreat, allows us to estimate the configuration and location of past and future coastlines (Figure 1). We find no support for the theory of Wiseman, et al. (1973), that the evolution of coastal embayments and lagoons begins with the breaching and coalescing of large lakes, followed by thaw settlement. Rather, the existence of older, coarse-grained, and erosion-resistant barrier-island and beach deposits excerts a strong influence on the locus and shape of some of the newly forming embayments. Others, however, remain unexplained.

If the present coastal-retreat rates have been sustained since sea level approached its present position about 5,000 yr BP, then the corresponding ancient shoreline could have ranged from 7 to 27 km seaward of the present one, in accordance mainly with grain-size variations in coastal bluffs. Furthermore, if erosion occurred only to 2-m water depths, as assumed in our sediment yield calculations, 10-20 km wide and 2m deep platforms should be widespread around the Arctic Ocean. Since such wide platforms do not exist, and since we can show that thaw settling contributes much less to the shape of the marine profile in the Arctic than previously proposed (Klyuyev, 1965; Tomirdiaro, 1975) coastal retreat must be associated with erosion reaching to depths much greater than 2 m. The sediment yield therefore could be manyfold larger than we calculated. A growing body of evidence from interpretations of boreholes, seismic reflection data, Foraminifera, and soil engineering properties of surficial sediments shows that the seafloor of the inner shelf seaward to at least 20-m depth is indeed an erosional surface truncating older strata. Considering the rapid, and deep-reaching erosion, shallow bays, lagoons, and barrier islands do not provide adequate long-term sediment sinks accomodating materials introduced at the present high rates. Modern deposits found in some of these features may be held there for some time, but are soon re-introduced to the sea as the shelf profile moves through the locality (Figure 1). We therefore conclude that the sediment yield from coastal retreat and rivers largely by-passes the shelf. Part of this sediment flux is seen in form of a 2-3 m thick, transient "roto-till" layer draped over large regions of the open shelf, a result of ice-keels plowing up underlying strata and mixing these sediments with modern materials and fauna.

Within the conterminous United States, the Gulf of Mexico coast has the highest erosion rates. The Texas coast, fringed by a low coastal plain of unconsolidated sediments, marked by vertical crustal stability, and therefore in some respects similar to that of the Beaufort Sea, retreats about 1.2 m/yr (May, et al., 1983), or about half the Beaufort Sea average. Since coastal erosion in Arctic regions is restricted to three summer months when waves and coastal currents are active, erosion rates there must be multiplied by a factor of four for a meaningful comparison with the rates of ice-free low-latitude coasts, which experience waves and currents year round. Accordingly, Arctic erosion rates are 8 times higher than Texas rates. Additionally, Arctic fetches are severely restricted during the navigation season by the ever present polar pack, unlike the long and constant Texas fetch which allows generation of larger and more pervasive waves. Lastly, most of the damage to low latitude coastlines is done by winter storms, when the Arctic coastline is well protected by ice. Classic wave theory therefore can not account for the sediment dynamics of the Arctic coastal zone.

Considering the rapid shoreline development by petroleum industry, our poor understanding of Arctic coastal processes begs for accelerated research in this region.

REFERENCES

Hopkins, D.M. and Carter, L.D., 1980, Discrepancy in correlation of transgressive marine deposits of Alaska and the eastern arctic, in Proceedings of the 9th Annual Arctic Workshop, INSTAAR, University of Colorado, Boulder, Colorado, p. 12-13.

Klyuyev, Ye. V., 1965, The role of permafrost factors in the dynamics of bottom topography in polar seas, Oceanology of the Academy of Sciences of the U.S.S.R., v. 5, no. 1, p. 78-83.

May, S. Kimball, Dolan, Robert, and Hayden, Bruce P., 1983, Erosion of U.S. shorelines, EOS, Transactions, American Geophysical Union, p. 521-522.

Naidu, A. S., Mowatt, T. C., Rawlinson, Stuart E., and Weiss, Herbert V., 1984, Sediment characteristics of the lagoons of the Alaskan Beaufort Sea coast and evolution of Simpson Lagoon, in The Alaskan Beaufort Sea: Ecosystems and Environments, Barnes, P. W., Schell, D., and Reimnitz, Erk (eds.), Academic Press Inc., Orlando, Florida, p. 275.

Tomirdiaro, S.V., 1975, DOKLADY, Earth Science Sections, Thermoabrasion-induced shelf formation in the eastern arctic seas of the USSR during the Holocene, v. 219, no. 1-6, 23-26.

Wiseman, W.J., Coleman, J.M., Gregory, A., Hsu, S.A., Short, A.D., Suhayda, J.N., Walters, C.D., and Wright, L.D., 1973, Alaskan arctic coastal processes and morphology, Tech. Rept. 149, Louisiana State University, Baton Rouge, LA., p. 171.

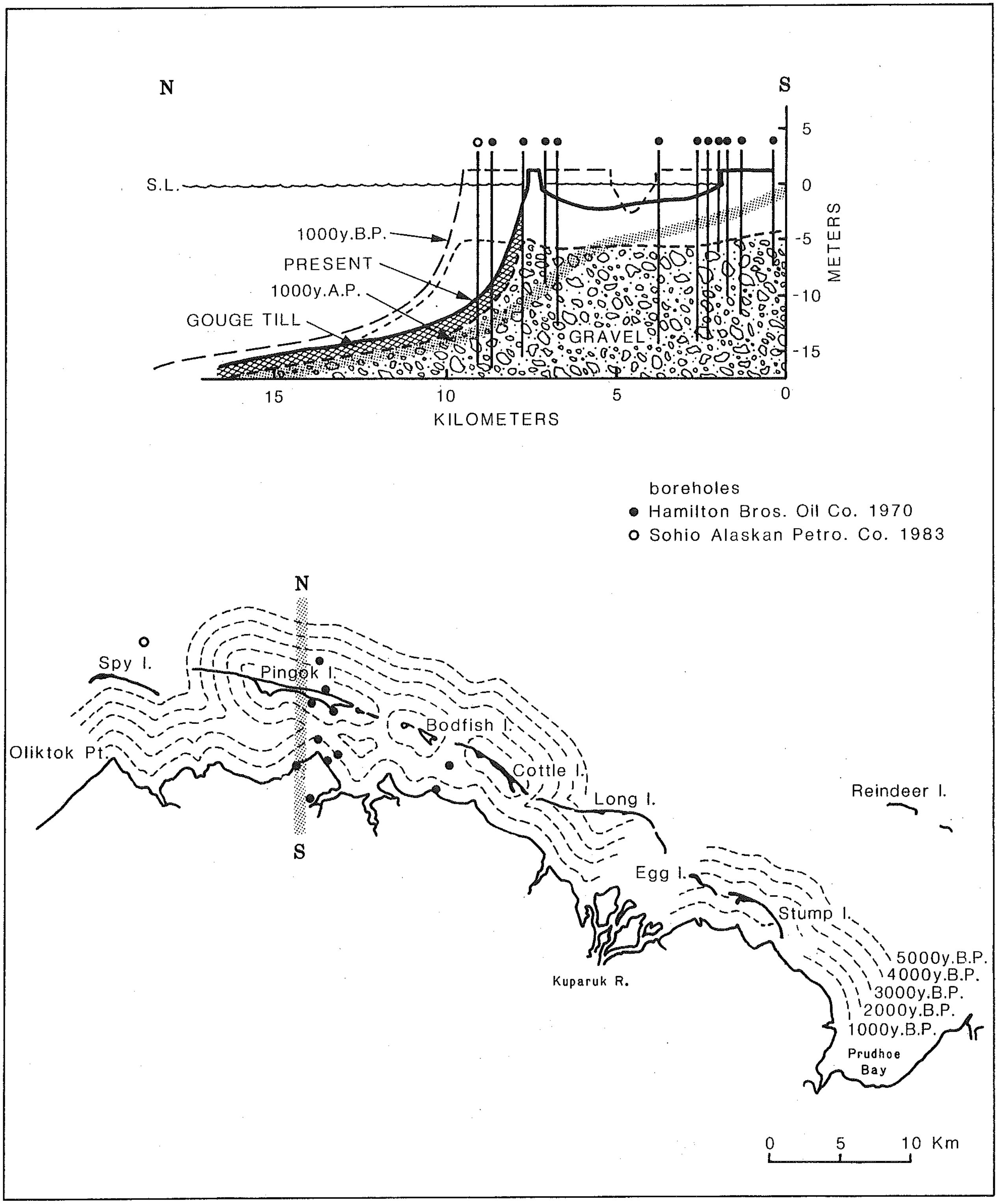


Figure 1. Simpson Lagoon paleoshorelines (after Naidu et al. 1984) and our interpretation of lagoon profile evolution taken along shaded line N-S. Depths to massive fluvial gravel generalized from soil borings.

ARCTIC AIR QUALITY STUDY IN THE BEAUFORT REGION

by

F. Fanaki, B. Martin and J. Markes

Atmospheric Environment Service
Downsview, Ontario, Canada

1. INTRODUCTION

1.1 The overall main objective of the Air Quality Project is to assess the environmental impact of air pollutant emissions associated with hydrocarbon development in the Beaufort Region. This objective will be met by the following sub-objectives:

1. development of a data base of atmospheric parameters related to air quality,
2. conducting a series of short duration field studies during which intensive measurements of the air quality of the area are made,
3. development and evaluation of air quality models for air quality assessment with specific application to the hydrocarbon development.

1.2 During the year 1984-85 Air Quality Branch's efforts were concentrated on objectives 1 and 2. A tall meteorological tower (100 m) as well as a 10 m tower were instrumented and a winter field study was carried out.

The study was successful in providing meteorological data and identifying unique Arctic features during the winter. This paper describes briefly the field measurement, the method adopted in conducting the study and illustrates the observations obtained.

2. METEOROLOGICAL TOWER AND WINTER FIELD STUDY

2.1 During the early stages of the program, it became apparent that problems could be encountered in the construction of a tall tower in the study area (lack of funds and time). To bypass these problems, a survey was made of existing towers in the Mackenzie Delta and Beaufort coastal areas. Four towers were discovered, one operated by the Canadian Broadcasting Corporation (CBC) - Northern Services in Inuvik, and three by Dome Petroleum in their Beaufort Sea operation.

The Inuvik CBC tower proved most suitable. Also, Inuvik has a high frequency of periods of light winds and stable conditions which are critical from a pollutant dispersion point of view. The tower was instrumented at five levels with the lowest level at 20 m and the highest at 91 m. This instrumentation provides a continuous record of wind speed, wind direction, temperature and humidity. Recording equipment was installed in the CBC transmitter building at the base of the tower. Due to the interference of this building to the flow at low level, it was decided that a second shorter tower was needed to measure meteorological parameters at the 10 m level. A 10 m tower was erected upwind (prevailing wind) from the 100 m tower and was instrumented to measure windspeed, wind direction and temperature. Solar radiation sensors, designed to measure the incoming and reflected solar energy, were installed at the 2 m level (above ground) on this smaller tower.

The data from both towers are recorded continuously and are averaged every 10 min. A sample of the tower output data is shown in Figure (1). The table displays the meteorological parameters as well as the standard deviations of wind and temperature.

2.2 The second phase of the project consisted of a winter field study with the following objectives:

1. to augment and to verify data obtained from the two towers,
2. to examine the structure of the atmospheric boundary at that location,
3. to determine the dispersion characteristics of pollutants under arctic winter conditions.

The field study was carried out during the month of February (1985). This month was chosen because winter conditions typical of that area would prevail during this time frame (-50°C). The month also has longer days (8 hrs of daylight) that allowed for more operational hours.

The field study consisted of several coordinated sets of measurements taken over a two week period. These include: minisonde flights at two locations, acoustic sounder measurements, bivane measurements, plume rise photography and measurements of concentration and size distribution of particulates common to the study area.

Temperature and wind profiles from the two manned minisonde stations near and down range from the tower verified data being received from the tower instruments. They also provided information on the fine structure of the atmospheric boundary layer. Another integral part of the study was to examine the characteristics and rise of industrial plumes under Arctic conditions. The plume from the power house in Inuvik was chosen for this study. The plume was photographed every 15 seconds over a period of 10 minutes. The rise of the plume was determined and compared to existing models. The application of the acoustic sounder at that location seems obvious, particularly for determining the mixing height. This type of information is important for the region because the stability can be strong and, the potential for multiple layering is significant. Figure (2) is a sample of the acoustic sounder trace showing the occurrence of multi-layer inversions.

About 20% of the 1440 meteorological observations described calm atmospheric conditions (wind speed ranged from 0-1 m/s). A strong wind condition (9-10 m/s) occurred 2% of the time. For the remainder of the time the average wind speed ranged from 4 to 6 m/s. Air temperature varied from -30 to -50°C during the observation period. Most of the time the atmosphere is stable. During stable conditions the roughness height and the drag coefficient were less than those occurred during unstable conditions.

Strategically placed sensors provided background information on the quality of the air in the hydrocarbon development area. Table (I) shows the type, size and concentration of the particulate that were observed in the study area.

TABLE I: Particulate type and concentration ($\mu g/m^3$)

Particulate Size (μm)	Cl	NO_3	SO_4	Na	NH_4	K
5.8 - 9.0	.151	.014	.059	.040	.047	-
4.7 - 5.8	.142	.012	.058	.035	.049	-
3.3 - 4.7	.166	.013	.068	.043	.047	.005
2.1 - 3.3	.258	.017	.096	.130	.039	-
1.1 - 2.1	.280	.029	.077	.087	.052	.010
0.7 - 1.1	.316	.061	.206	.180	.057	.009
0.4 - 0.7	.186	.034	.280	.059	.073	-
0 - 0.4	.156	.022	.229	.045	.076	-

ACKNOWLEDGEMENTS

The authors would like to express their thanks to the Department of Indian and Northern Affairs for funding this project. They gratefully acknowledged the interest in an support of this work by the AES Western and Northern Region staff, in particular Mr. W.D. Brakel and Mr. N. Parker. Thanks are also due to the CBC Technical staff, in particular Mr. P. Russell.

TABLE I
INUVIK METEOROLOGICAL TOWER DATA
-1985-

-------------------- JDAY=51 TIME=1700 ----------------------------

LEVEL	U	D	V	VD	T	RH	SU	SD	SV	ST
1	3.1	312.1	3.0	48.5	-35.7	M	1.0	13.4	12.8	0.1
2	5.1	318.7	5.1	41.6	-35.6	M	0.9	6.3	6.4	0.1
3	5.8	307.4	5.8	52.4	-35.8	M	0.8	5.3	5.3	0.1
4	6.3	300.7	6.3	59.2	-35.8	M	0.7	4.1	4.1	0.1
5	6.7	317.6	6.7	42.4	-36.0	M	0.6	3.7	3.7	0.1
6	7.3	311.8	7.2	48.1	-36.1	M	0.7	4.5	4.5	0.1

Figure 1: 10 min. averaged windspeed (U), wind direction (D) vector windspeed (V), vector wind direction (VD), temperture (T) and their standard deviations. M. means missing data.

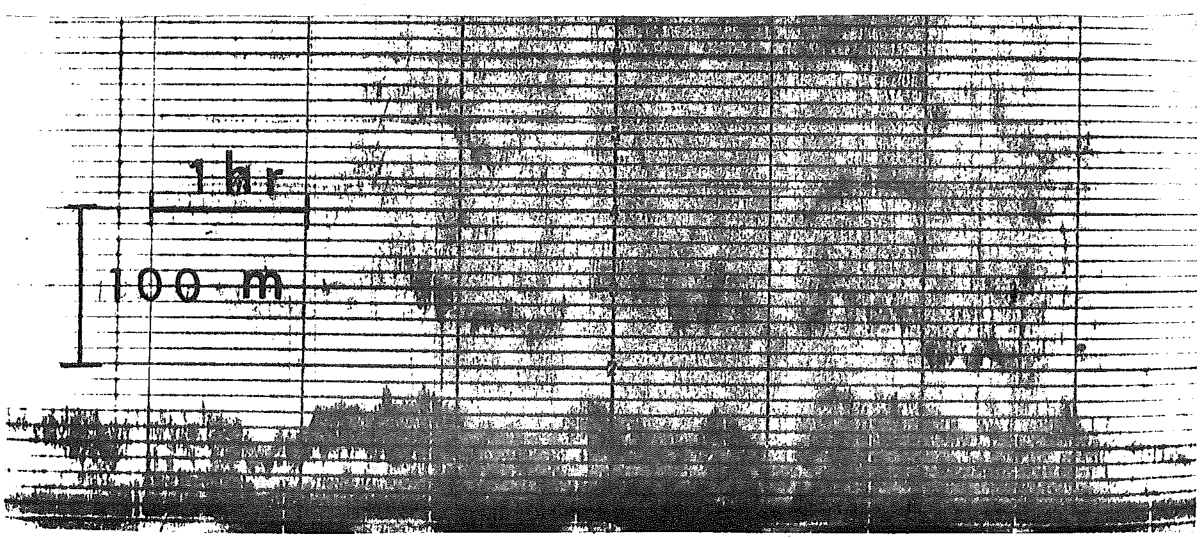


Figure 2: Variation of height of elevated inversion layers at Inuvik, Feb. 17, 1985.

Coastal dune formation an effect of the land-sea interaction under the new glacial arctic climate

Wang, Ying and Zhu, Da-Kuei
Marine Geomorphology and Sedimentology Laboratory Nanjing University, Nanjing, China.

A sand dune coast is distributed 45km along the northern part of Luanhe River delta plain (39°25'-39°47'N). It is a 1 to 4km wide belt and the wider part is in the south near the Luanhe River. The average height of the sand dunes is about 25m, and the highest peak is 42m located near Qilihai lagoon in the middle section.

The Dunes consist of well sorted medium-fine sand with high roundness values, and the heavy mineral assemblage is similar to the Luanhe River sediments V marks, small pocks and attached diatom, on the surface of quartz sands indicate that the sands have passed through the processes of a coastal beach. Transverse dune ridges parallel the seashore in the trend of NE 20°-30°. The inner dunes are chains of barkhans and gradually decrease their height landward. The gentle wind slope of dunes face NE and ENE dominant winds, and the steep slip faces to leeward of southwest. The coastal dunes are very close to the modern seashore, with a beach zone less than 100 metres wide, and are presently being undermined by wave attack. Sand dunes do not appear in the southern part of Luanhe River delta, even though the modern fluvial sediment supply is mainly to the south.

The annual sediment discharge of the modern Luanhe River is 24.08×10^6 tonnes and consists of fine sand and silt. The sediment entering the sea is mainly toward the southeast. Fine sand is deposited between the river mouth to a water depth of 5.5 m; coarse silt is distributed to 9.7m water depth; silt and clay to 13m, and poorly sorted clay sand is deposited beyond. The long shore drift is from Luanhe River southwestward towards Hulinko, 30km from the river mouth. The present gradient of submarine coastal slope in the south is 1:400, and 1:500 to 10m contour. Thus, there have been sediment supply to the south, but because of the fine sediment and the steeper slope, there is still no sand dune development. These sediments have been periodically removed by south-easterly wave; transverse to the coast forming a sand barrier and lagoonal system. There is also small long shore drift up to the north, but only 4.8km from the river mouth.

The late Quaternary River bed sediments formed the base of the delta, overlain with interbedding of fluvial and marine deposits. There have been four delta lobes formed since the Holocene, and the sand dunes belong to lobe I of early Holocene age. All of the delta lobes are protruding seaward with sand barriers surrounding them. The coast dynamics are different on both sides of the Luanhe River delta. The NE and ENE winds prevail with strong winds in the north; the outer depth boundary of wave action is 4 to 5.5m; semidiurnal tide currents, flow northeastward on flood and southwestward on ebb. The situation in the south is contrary, and the outer depth boundary of modern wave action is only 4m. It seems that modern dynamics and fluvial sediment supply do not coincide with the sand dune development. Dune development is not formed under todays conditions. The sand forming the dunes was derived from offshore, when exposed to wind at low tide during early Holocene low sea level stand. There is a large area of medium and fine sand deposited in the near shore and to a water depth of 13m offshore along the sand dune coast. The grain size and mineral components of the sand indicate that these sands are the source for the dunes. The offshore gradient is 1:280 to -5m of modern coastal slope, but 1:1000 to -10 metres.

Even with today's average tidal range of 1.5m, the slope of ten meters is wide enough for wind blowing sand to roll to shore during low tide. According to C^{14} dating, the delta lobe I which is the base of sand dune coast, was formed during 8025 $\pm$ 105 Y.B.P. The sea level during that time was located 13m of present. It is the first cold phase of Holocene according to climate and eustatic changes studies by Yang and Xie (1984): New Glacial I during 8200 to 7000 Y.B.C. (Denton and Karlen, 1973). During this cold period, the air temperatures were 5° to 6°C lower than modern times, the frigid zone moved 5 to 7° latitude down to the south. River sediment discharge was also high and with coarser debris, as the frost weathering processes were strong during the New Glacial. In addition, cyclonic storms came from the north more frequently, under strong gale and violent storms. Sands on the wide, gentle sloped coastal zone were moved to form the larger scale coastal dunes. It might be said that the sand dune coast in the northern Luanhe River delta was formed during the Holocene lower sea level under Arctic climate influence i.e. sand dune coast was an effect of land-sea interaction during first cold phase of Holocene.

A sand dune coast extends 315km along Muritania Atlantic Ocean (19°-16°) with the trend parallel to the coastline from north to south. It consists mainly of medium sands, as seen on sea bottom deposit, but is coarser than the desert sands of the Sahara. Several sand dune trend northeasterly to southwesterly from the desert to the coast, but the dune ridges are with hard cover of calcium on the crest. Also, there is a marine terrace, 3 to 4m above sea level 0.5 to 80km in width, to separate the coast dune belt from the inland desert one. C^{14} dates show the terrace was formed 5755 $\pm$ 120 years B.P., and the lagoon depressions, located between the marine terrace and coastal dunes, were contemporaneously formed between 5745 $\pm$ 100 years B.P. (Trimirst lagoon in the north) and 5910 $\pm$ 115 years B.P. (middle lagoon). Lagoon deposition consists of sandy clay and gypsum. The heights of the coast dunes are 10 to 30m, and the gentle slope faces northwesterly sea wind, which also differs from the desert sand dune series. A C^{14} date shows that Muritania coastal dunes formed during 5270 $\pm$ 170 years B.P. It was exactly correlated with the time of second phases of New Glacial, i.e. 5300 years B.P. in the northern hemisphere. We do not have more evidence to discuss the paleoclimate theme.

Coastal zone is a special area with the meteorologic and hydrologic factors which differ from both terrestrial and oceanic settings. It is also the area with strong interaction between land and sea, and the sand dune coast might be an effective example showing the interaction. As sand dune coast develops when strong prevailing onland winds blow large amount of sand up from the sea shore; medium tidal range and gentle coastal slope are also the basic factors to improve the developing of sand dunes. However, during cold phases of Holocene under the Arctic climate influence, it offers a better environment to satisfy all the factors for sand dune development.

Archaeological Implications of Isostatic Adjustment in Northern Labrador

by

J. Peter Johnson, Jr., Geography Department, Carleton University

An analysis of the location, elevation and age of archaeological sites in conjunction with physical evidence of isostatic adjustment in the same locales generally supports the hypothesis that older sites in northern Labrador occur at higher elevations than more recent ones. However, as one proceeds northward, overlap of sites of different ages is possible along some coastal areas owing to smaller amounts and slower rates of uplift since occupation began. This is particularly apparent where the geomorphology offers few places suited for occupancy along the shores. In areas of low relief, it is possible to find sites which were formerly beside the sea, but now are up to several kilometers from it. Thus, it is possible that in some areas distance from the modern shore becomes as, if not more, important than elevation above sealevel in the distribution of sites of different ages. This is especially so where differential uplift occurs normal to the trend of the coast. The traditional reconnaissance methods used to locate sites along the outer coast are not suited to finding such "interior" ones. Evidence in the form of erosion of some archaeological sites and coastal features in the northernmost areas suggests that submergence may also be a complicating factor. Maps and diagrams are presented to illustrate these problems.

CLIMATIC CONDITIONS IN SOUTHEASTERN LABRADOR-UNGAVA DURING THE EARLY HOLOCENE

George A. King
Limnological Research Center and
Department of Ecology and Behavioral Biology
220 Pillsbury Hall
University of Minnesota
Minneapolis, MN 55455

The main aspects of the regional vegetation history of the southeastern section of the Labrador-Ungava peninsula is known from pollen data collected from over twenty sites in the region. From the regional pattern of vegetation change the general climatic history of the region can be qualitatively reconstructed. Particular attention will be drawn to changes in regional temperature gradients through the early Holocene and the possible effect of the wasting ice sheet on the regional climate between 8.0K and 6.0K.

Isopoll and isochrone maps of selected pollen taxa illustrate the movement of vegetation zones through the region following deglaciation. Although the general pattern of vegetation change is a time-transgressive change from tundra to closed spruce forest, different areas show major variations in this general sequence. Specifically, in southeastern Labrador, which was deglaciated earlier than any part of the study area, herb tundra succeeded to a shrub tundra, which later was colonized by white spruce at 8.0K and balsam fir at 7.5K. These two trees formed a forest more productive and probably more floristically diverse than that in the area today, persisting from 7.5K to 6.5K. Later populations of these trees decreased and black spruce became the dominant tree by 6.0K.

Farther west in the Sept-Iles area, deglaciation was later than in the southeast, and the initial vegetation was forest tundra instead of herb tundra, succeeded by a rich white spruce-birch-fire forest at 7.5K. Fir populations fell at 6.4K and black spruce then became the dominant tree.

Toward the interior of the peninsula the pattern of vegetation change is simpler; an initial shrub tundra was replaced by spruce forest as late as 5.2K south of Schefferville. Fir populations were never significant north of 52° 30'N.

Thus from 8.0K to 6.0K, three different vegetation zones occuppied the region that today is covered only by closed spruce forest. Shrub tundra bordered the retreating ice sheet, closed fir forest occupied a strip of land about 160 km wide along the coast, and a transitional forest tundra zone occurred between these two vegetation types.

From the regional pattern of vegetation change three inferences can be made concerning the climatic history of the region. First, the climate gradually warmed between the time of deglaciation, when the climate was cold enough to support only tundra vegetation, and 6.5K in the south, when fir populations reached their maximum level. Maximum warmth was not reached until 5.2K in the north near Schefferville, when the forest canopy closed. Thus southeastern Labrador-Ungava was still relatively cool when much of central and northeastern United States was warmest.

Second, three vegetation zones were compressed in this region during the early Holocene relative to their breadth today, suggesting that the regional temperature gradient between 8.0K and 6.0K was steeper than it is today.

Third, the period between 7.5 and 6.0K, when fir populations were much higher than today, suggests that the region must have had a more maritime climate then. Fir today has its maximum abundance in the maritime regions of Canada and thus more frequent summer precipitation or lower evapotranspiration than today were probably the critical climatic variables enabling fir to become abundant.

A possible climatic mechanism for increased moisture availability is the steeper temperature gradient, causing more storms to track through the region than today (Macpherson 1981). The climate became more continental after 6.5K, as evinced by the decline in fir populations.

A landscape feature possibly controlling these climatic variables and the atmospheric circulation in the region during the early Holocene is the remnant Laurentide Ice Sheet. Although deglaciation began by 12.0K in the southeastern section of the peninsula, a significant area was still covered by ice at 7.0K. The ice apparently caused a steepening of the temperature gradient in the region, but it may have had several other effects as well. Cloud cover or fog frequency may have increased southeast of the ice simply because of cooling of warm air masses advected into the region when they reached the relatively cold ice sheet. This would have decreased the early summer evapotranspiration and favored fir trees after the climate had warmed sufficiently. The ice may have also prevented strong zonal flow from taking place during the summer until perhaps 7.0K, preventing dry Pacific air from entering the region (Macpherson 1981).

Reference

Macpherson, J.B., 1981. The development of the vegetation of Newfoundland and climatic change during the Holocene. In Macpherson, A.G. and Macpherson, J.B., editors, The Natural Evironment of Newfoundland, Past and Present, Dept. of Geog. Memorial Univ. of Newfoundland, pp. 189-217.

CORRELATION OF LATE QUATERNARY EVENTS: TORNGAT MOUNTAINS AND LABRADOR SHELF

Peter Clark Department of Geological Sciences, University of Illinois, Chicago, IL 60680

Heinar Josenhans Atlantic Geoscience Centre, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2

W.D. McCoy Department of Geology and Geography, University of Massachusetts, Amherst, MA 01003

Based on radiocarbon dates, amino acid analyses, and pebble lithologies, we have attempted to correlate late Quaternary glacial and postglacial units in the Torngat Mountains, northern Labrador, with units mapped on the adjacent continental shelf.

The late Wisconsinan Laurentide Ice Sheet drained through major valleys of the Torngat Mountains as outlet glaciers, depositing a regional system of lateral and terminal moraines. This moraine system, which has been mapped from Saglek Fiord north to Noodleook Fiord, includes the Saglek Moraines described by Ives (1976) in the Nakvak Brook watershed. A radiocarbon date of 18,210 $\pm$ 1900 BP on total organic matter (TOM) from lake sediment dammed by a segment of the moraine system in Nakvak Brook valley (cf. Short, 1981) is interpreted as a maximum date for deposition of the moraine system because of possible contamination by old carbon. A radiocarbon date of 8700 $\pm$ 470 BP from outer Kangalaksiorvik Fiord provides a minimum date for deglaciation of the Labrador coast.

Glacial sediments comprising the late Wisconsinan moraine system in the Torngat Mountains are locally derived of underlying bedrock. These sediments are correlated with upper till (unit 3B) mapped in troughs and saddles on the continental shelf. This unit is normally consolidated, locally derived of underlying crystalline or Tertiary bedrock, and pinches out in water depths less than 160 m. TOM radiocarbon dates range up to 25,000 BP for this unit, but these are also interpreted as possibly contaminated by old carbon and thus too old.

A glaciomarine unit conformably overlies (drapes) late Wisconsinan till on the shelf and on the land. This unit is a gravelly, clayey silt, contains abundant foraminifera, and has up to 60% limestone in the pebble fraction. Radiocarbon dates suggest deposition of this unit began ca. 10,000 BP on the shelf and 8700 BP on the (submerged) land, and ended by 8000 BP. Limestone pebbles in this unit suggest a source from sediment-laden icebergs and pack-ice from the north, probably Hudson Strait.

Amino acid analyses of mollusc shells and foraminifera tests from grab samples and piston cores taken from the shelf are inconclusive. Two samples of *Macoma* (?) shell fragments from a grab sample of the glaciomarine sediments yielded very different alloisoleucine-isoleucine (aIle-Ile) ratios in the free fraction. One had no detectable free alloisoleucine, suggesting a late Wisconsinan or early Holocene age, and the other had an aIle-Ile ratio of 0.29, suggesting a pre-Wisconsinan age. The latter sample has likely been reworked from an older deposit. The former sample may be in place or may have been mixed with the glaciomarine unit during sampling or by iceberg grounding.

Hiatella arctica (?) shell fragments from grab samples of the till yield aIle-Ile ratios of 0.15 $\pm$ 0.02 in the free fraction, suggesting a middle or late Wisconsinan age. These ratios provide only a maximum age for the till.

AIle-Ile ratios from the total hydrolysates of *Elphidium* tests taken from piston core (HU83-030-36) samples of the glaciomarine unit and the upper part of the till (3B) may be interpreted as indicating a late Wisconsinan age if the effective temperature for the tests has been about 6 oC, or 2.5 oC warmer than the temperature measured at the sediment-water interface (420 m depth) at the station in October, 1983.

References

Ives, J.D., 1976, The Saglek Moraines of northern Labrador: A commentary: Arctic and Alpine Research, v. 8, p. 403-408.

Short, S.K., 1981, Radiocarbon date list I: Labrador and northern Quebec, Canada: Institute of Arctic and Alpine Research Occasional Paper No. 36, 33 p.

Late Quaternary Onshore/Offshore Stratigraphic Correlation and Glacial Reconstruction, Southern Baffin Island, Arctic Canada.

Jay A. Stravers; Institute of Arctic and Alpine Research, Campus Box 450, University of Colorado, Boulder, Colorado 80309

Regional reconstructions based on ice flow indicators and till provenance studies (Figure 1) indicate that three ice masses influenced the Foxe/Wisconsin glaciation of southern Baffin Island and the adjacent continental shelf. They include: 1)a local ice cap (LI of Figure 2) over the Meta Incognita Peninsula, 2)a major ice tongue originating from the Foxe Basin Dome to the northwest and flowing southeastward down Frobisher Bay (FB of Figure 2), and 3)glacial ice probably originating to the south from Labrador/-Ungava, flowing in Hudson Strait and northeastward across the tip of the Meta Incognita Péninsula (FI of Figure 2).

Late and Mid Foxe/Wisconsin glacial phases are recognized based on relative weathering data, amino acid analysis, and radiocarbon dates. The Late Foxe reconstruction (Figure 2) shows extensive ice cover over the Meta Incognita Peninsula with local outflow merging with ice in both Frobisher Bay and Hudson Strait. An important feature of this reconstruction is that Frobisher Bay ice (the Hall Advance or FB of Figure 2) terminated with in outer Frobisher Bay. A radiocarbon date of 41,900 from Loks Land (Figure 2) comes from marine deposits that were not overridden by Late Foxe ice. The Hudson Strait ice stream did however support extensive ice flow onto the continental shelf as well as flow across the tip of the Meta Incognita Peninsula (Figure 2). The prevalent northeastward flow direction associated with this ice (Figure 1) probably indicates a deflection of the ice stream by grounded ice extending onto the continental shelf from outer Hudson Strait.

The Mid Foxe/Wisconsin glacial reconstruction is similar to the late glacial in terms of origins and major flow directions of the three ice masses however much more extensive ice is indicated. Ice flow indicators and till provenance data (Figure 1) from the Buerger Point area (see Figure 2 for location) indicate extensive flow down Frobisher Bay covering 500m summits. Furthermore, Hudson Strait ice also deposited abundant foreign erratics to similar elvations in Jackman Sound.

The onshore glacial drift of Southern Baffin Island correlates to the Baffin Shelf Drift offshore (Praeg et al. in press). The Baffin Shelf Drift consists of multiple till sequences in Hudson Strait and to the east of Resolution Island. However, only double or single till sequences are found along outer Frobisher Bay and further north on the continental shelf. The onshore data suggest that much of this drift was deposited during the Mid Foxe/Wisconsin stade when both Frobisher Bay and Hudson Strait ice advanced to the shelf edge.

The Late Foxe/Wisconsin onshore data show no contribution of grounded ice from Frobisher Bay while Hudson Strait ice was advancing to the shelf edge. The multiple till sequences offshore in outer Hudson Strait indicate that this glacial style was important during atleast the last glaciation and possibly earlier.

Praeg, D.B., MacLean, B., Hardy, I.A., and Mudie, P.J., in press; Quaternary Geology of the Southeast Baffin Island Continental Shelf, N.W.T. G.S.C. Paper 85-14, in press.

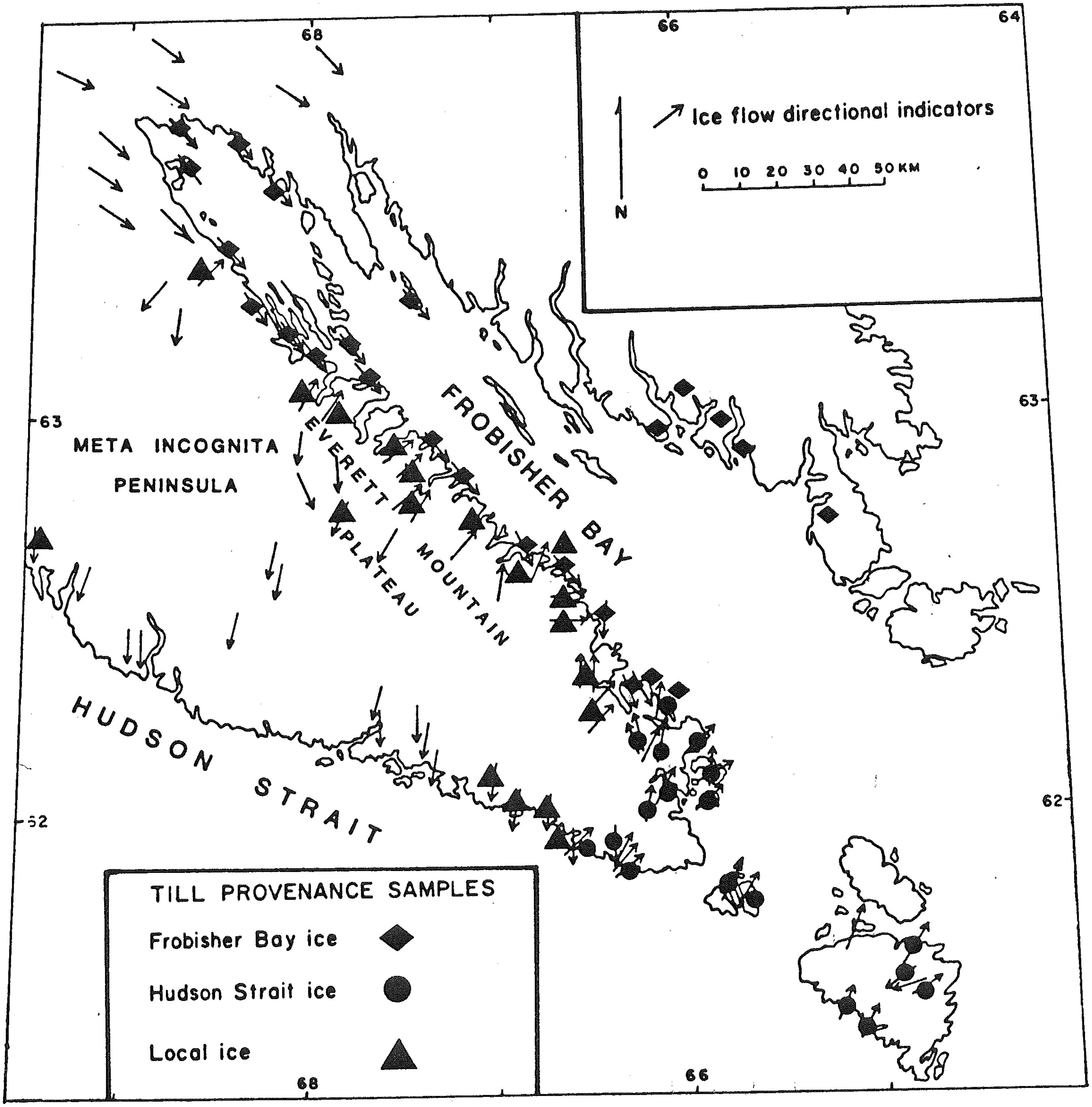


FIGURE 1 Ice Flow Indicators and Till Provenance Sample Sites From Southern Baffin Island.

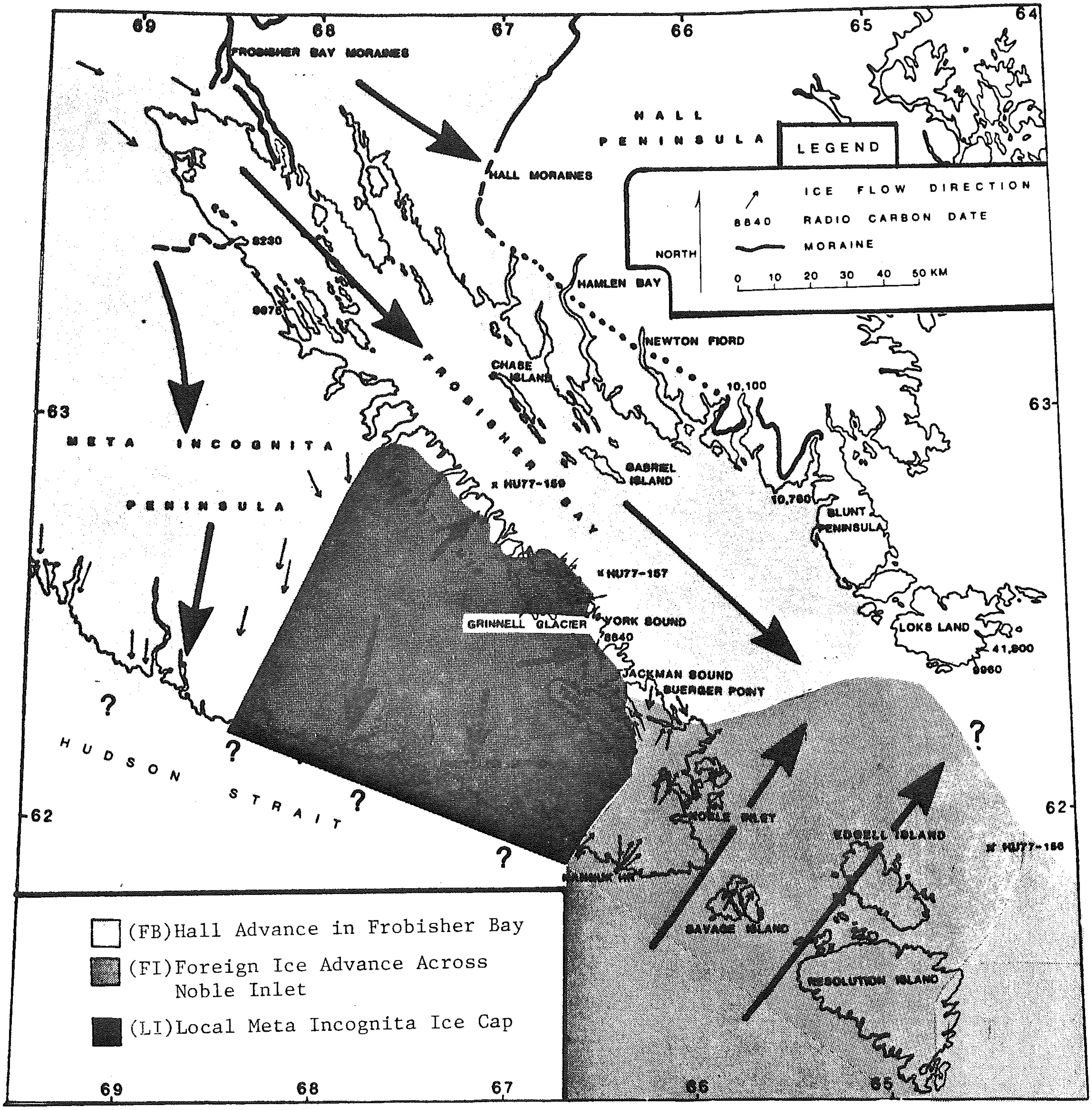


FIGURE 2 RECONSTRUCTED DISTRIBUTION OF LATE FOXE/WISCONSIN GLACIAL ICE MASSES OF THE META INCOGNITA PENINSULA, SOUTHERN BAFFIN ISLAND.

Onshore - Offshore Correlation - Northern Labrador

H.W. Josenhans, A. Jennings, P. Clark,
T. Bell and R. Rodgerson

3.5 Khz subbottom seismic surveys of Nachvak fiord and Saglek fiord have recently been completed and show a succession of glacial and post glacial sediments. The acoustic stratigraphic sequences within the fiords can be correlated with seismic units mapped further seaward on the Labrador shelf. Analysis of 10 piston cores taken from the various acoustic stratigraphic units recognized in the fiords will be presented. Extensive ground truth is availbale for the outer Labrador shelf stratigraphic sequence and is based on X-ray analysis, lithological analysis, texture, sedimentary structures, geotechnical properties and C^{14} ages. A comparison of outer shelf and fiord sediment lithology and stratigraphy will be discussed.

EVIDENCE FOR A LATE WISCONSINAN LOW SEA LEVEL STAND OF 100-120m FROM THE SCOTIAN SHELF TO THE GRAND BANKS OF NEWFOUNDLAND

Gordon B.J. Fader
Atlantic Geoscience Centre
Bedford Institute of Oceanography
P.O. Box 1006, Dartmouth, N.S. B2Y 4A2

A widespread, submarine, low sea level stand is interpreted to occur on the continental shelf off south eastern Canada from Georges Bank to the Grand Banks of Newfoundland. The low sea level stand is recorded at depths between 110-120m lower than present on the Scotian Shelf, and slightly less between 100-110m on the Grand Banks of Newfoundland. Radiocarbon dating of glacial sediments eroded by a subsequent transgression and overlying post-glacial sediments, indicate an age of 15,000 years for the time of the low sea level stand.

Additional evidence for the low sea level stand includes (1) textural characteristics of seabed sediments above and below the low sea level stand, (2) the occurrence of a widespread terrace at the low sea level position, (3) the distribution of glacial till below and its absence above the low sea level stand, (4) the distribution of unconformities across glaciomarine sediments above the low sea level position, (5) the distribution of relict vs modern iceberg furrows at the seabed associated with the terrace, (6) the occurrence of subaerially leached hardpan on the bank areas of the shelf, and (7) the regional distribution of surficial formations controlled or associated with the low sea level position and subsequent transgression.

The submarine terrace which was formed during the low sea level stand is largely unwarped and occurs at approximately the same depth across the entire shelf. However, near the approaches to the Bay of Fundy, the terrace occurs in progressively shallower depths to the north, interpreted as resulting from late glacial rebound of the Fundy region due to the presence of late glacial ice on land. A shallower occurrence for the low sea level position occurs in Chedabucto Bay and is attributed to erosional protection of glacial sediments by extensive late Wisconsinan ice centered on Cape Breton Island.

Across the Grand Banks of Newfoundland, geological evidence suggests a small amount of warping of the low sea level stand of approximately 20m, from the northern Hibernia area of Grand Bank, to the southern Tail of the Bank area. This may have resulted from a delay in isostatic rebound of the southern Grand Banks by the presence of a shelf centered ice dome.

The consistent depth of occurrence of the low sea level position across the shelf and its lateral continuity indicate that: (1) isostatic rebound was more or less complete before sea level began to rise, which is in agreement with regional models on the timing and extent of Wisconsinan ice in eastern Canada (2) little differential rebound has occurred since its formation, (3) the ice sheet had largely retreated from the shelf area by the time of maximum sea level lowering or else the terrace would be discontinuous and (4) the age of the terrace is probably the same across the shelf.

During the subsequent Late-Wisconsinan-Holocene transgression, beginning at 15000 YBP, the sediments and bedrock surface between the low sea level position and the present shoreline were modified in a high energy beach environment. Large areas of well sorted sands and gravel (including boulders) were developed across the banks and inner shelf, the residual products of eroded glacial till and glacio-marine sediments.

Late Weichselian and Holocene Relative Sea Level History of Brøggerhalvøya, Spitsbergen.

Steven L. Forman, Daniel H. Mann* and Gifford H. Miller

INSTAAR and Department of Geological Sciences, University of Colorado, Boulder

*Quaternary Research Center, AK-60, University of Washington, Seattle

Abstract

Radiocarbon dating of whale bones on raised beaches record a relative sea level history for Brøggerhalvøya in the Kongsfjorden area of Spitsbergen that indicates a two-step deglaciation on Svalbard at the end of Late Weichselian glaciation. The Late Weichselian marine limit was reached before 13,000 yr BP and was followed by relatively slow emergence to about 11,000 yr BP probably in response to ice-unloading in eastern Svalbard and the adjacent Barents Sea. The rare occurrence of whale skeletons dating to about 13,000 and 12,000 yr B.P. indicates that the west coast of Spitsbergen had at least seasonally ice-free waters at those times. Final deglaciation of Spitsbergen itself is recorded by the rapid emergence of Brøggerhalvøya after 10,000 yr B.P. This was followed by a possible transgression during the mid-Holocene and another in modern times. Raised beach morphologies suggest striking differences in nearshore depositional processes before and after 10,000 yr B.P. that are probably related to changes in the rate of uplift and in sea ice conditions.

SEA LEVEL CHANGE, AND THE LATE WISCONSINAN GREENLAND ICE SHEET

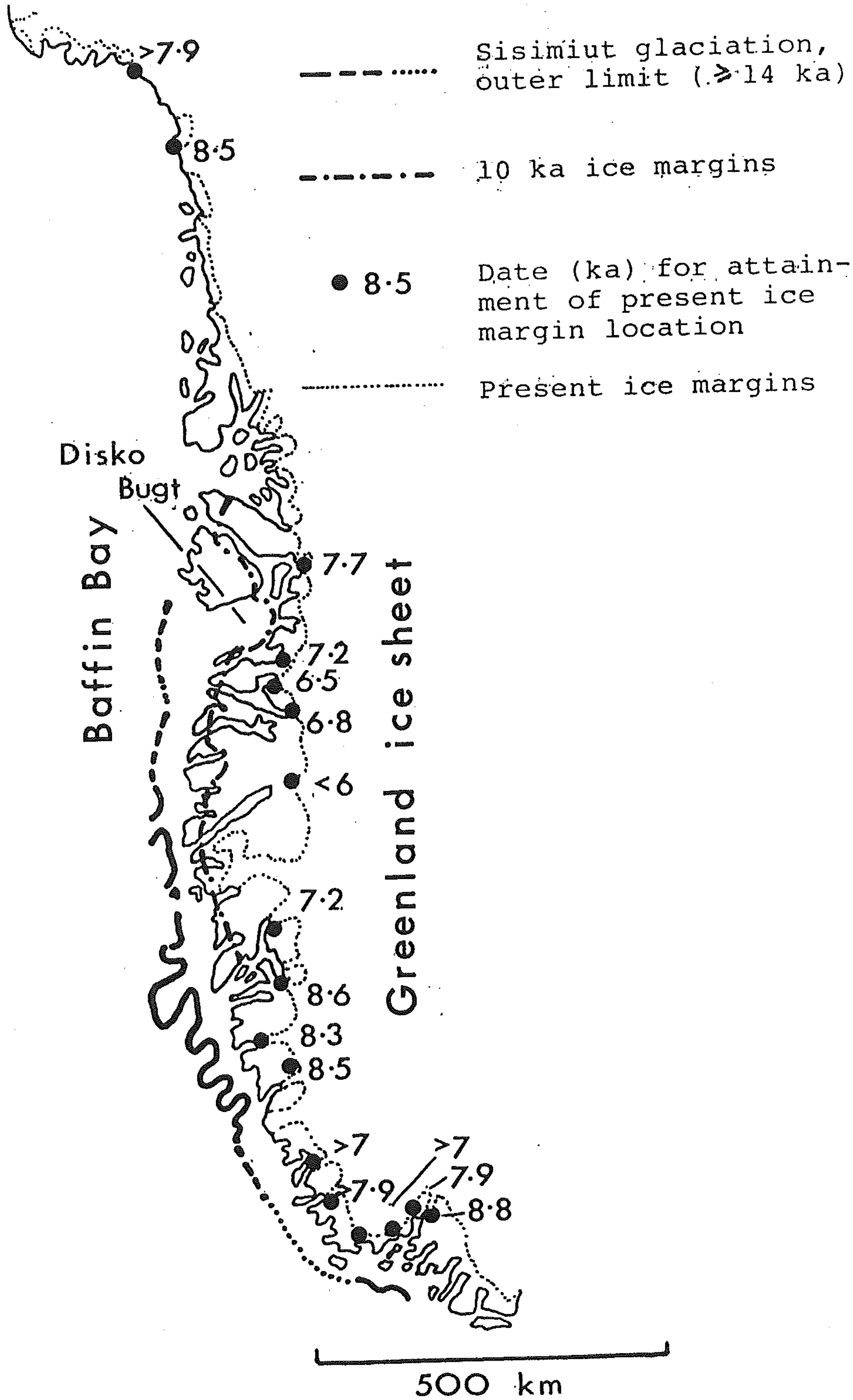
By Svend Funder

Geologisk Museum, Østervoldgade 5-7
DK-1350 Copenhagen K, Denmark

During the Sisimiut glaciation (Late Wisconsinan) the Greenland ice sheet covered all, or nearly all of West Greenland and extended up to 50 km beyond the present coast[1]. Break up of the ice margins began at or before 14 ka[1], and after some millenia of recession the present situation was attained at 6-9 ka (ref.1 and accompanying map).

While the later part of the deglaciation process is known in some detail then the early part - taking place over areas which are now sea - is poorly known, and has received slight attention. This paper reviews the evidence for this early deglaciation-phase, which - scant as it is - may imply that sea level rather than climatic change was the driving force, and that the sea/land transition formed a major glacio-dynamic obstacle in the deglaciation process.

Bathymetrical surveys on the shelf off central and southern West Greenland have revealed the presence of several moraine systems running along the coast[3,4,5]. Likely candidates for the Sisimiut glaciation maximum are moraines on the inner shelf[1], which reflect a highly lobate ice margin where land-based sectors, 30-90 m below present sea level, were interrupted by outlet glaciers that extended to the outer shelf margin through deep troughs (see map).



Past and present ice sheet margins in West Greenland.
Source of data: refs 1,2,3,4,5,7.

The mainly land-based nature of the ice margin is implied also by observations of features indicative of later marine transgression over some of the moraines[3,4], and it may be speculated that initial break up was afforded by sea level rise lifting the ice margin off the ground.

Marine control in this early deglaciation-phase is further implied by the ^{14}C-dated deglacial and isostatic records on land[1,2,6,7], which have shown that by 9-10 ka the entire ice margin, spanning more than 20 degress of latitude, was located close to the sea/land transition near the present coastline. The map figure shows part of this ice margin (from refs 2,7), and it appears that not only the shelf but also major inlets and fjord-systems had been cleared of glacier ice.

The relation of the ice margin to the sea/land transition, and the synchronism of this event throughout the region support the conclusion that the early deglaciation-phase, ending at c. 10 ka, was essentially a response to rising sea level which rendered the shelf-bound portions of the ice sheet unstable, causing retreat until the ice margin was once more land-based at the new sea/land transition, near the present coast.

The subsequent delaciation-phase involved retreat of a mainly land-based ice margin. This process is known from dating of marine sediments and moraines[1,6,7], and, as seen from the map, both the amount of retreat and its duration varied between areas - apparently as a result of local climatic variations. In the cool and moist climate in the north hardly any retreat occurred, and the ice margin has remained firmly planted on the sea/land transition throughout the Holocene. In the humid climate of Disko Bugt and the fjords of South Greenland the Holocene retreat amounted to some tens of kilometres, while only the warm dry areas of central West Greenland saw large scale melting which in 4-5 millenia exposed a 200 km wide rim of land.

The available data therefore may interpreted to show that deglaciation in West Greenland fell in two distinct phases characterised by different glacial regimes, and possibly controlled by different factors.

REFERENCES

1. Kelly, M. 1985. A review of the Quaternary geology of western Greenland. In Andrews, J.T. (ed.): Quaternary environments, eastern Canadian Arctic, Baffin Bay and western Greenland. George Allen and Unwin, London. 461-502.

2. Weidick, A. 1984. Studies of glacier behaviour and glacier mass balance in Greenland - a review. Geogr. Annlr A66, 183-195.

3. Sommerhoff, G. 1975. Glaziale Gestaltung und marine Überformung der Schelfbänke vor SW Grönland. Polarforschung 45, 22-32.

4. - - - 1981. Geomorphologische Prozesse in der Labrador- und Irmingersee. Ein Beitrag zur submarinen Geomorphologie einer subpolaren Meeresregion. Polarforschung 51, 175-191.

5. Brett, C.P. and Zarudzki, E.F.K. 1979. Project Westmar, a shallow marine geophysical survey on the West Greenland shelf. Rapp. Grønlands geol. Unders. 87, 27 pp.

6. Weidick, A. 1976. Glaciation and the Quaternary of Greenland. In Escher, A. and Watt, W.S. (eds): Geology of Greenland. Geol. Surv. Greenland, Copenhagen. 430-458.

7. Unpublished field observations by the author in the Disko Bugt area.

LAND-SEA INTERACTIONS IN AN ARCTIC MARINE LOW ENERGY ENVIRONMENT, NORTHERN ELLESMERE ISLAND, N.W.T., CANADA

(Halifax, 6.-8. 11. 1985) by Lorenz King, D-6300 Giessen FRG

In many areas of the Canadian Arctic sequences of many prominant raised beaches are well known from aerial photographs or maps in scientific papers. These proofs of isostatic rebound are missing in many tributary fiords of Greely Fiord, northern Ellesmere Island. Borup, Hare and Otto Fiord have been investigated by means of aerial photographs and partly by own field studies: Many raised deltas can be found here and glaciers are pushing up moraines near sea-shore or even in the fiords in a marine environment.

LANDSAT imagery (up to 81°N) helps to portray the development of sea ice in areas that usually are not covered by the regular Canadian reconnaissance flights. The duration of the ice free period is very different from year to year and from area to area. Radiocarbon datings and comparisons to the results in the surrounding areas give indications to the amount and time of the isostatic rebound. Field measurements give indications of the amount of material that is transported into the fiords by rivers and glaciers. These large amounts are a necessary condition for the delta formation. Photogrammetric evaluations proove that moraines in the marine environment experience very little erosion after their formation.

The comparatively large amounts of materials transported and deposited into the fiords are due to the following facts:

- Alpine relief is surrounding the fiords.
- Mainly marine deposits are reworked by glaciers.
- Isostatic rebound and thus creation of potential energy close to the shore-lines favours also reworking of materials.
- Thermokarst processes along the rivers favour fluvial erosion.

In contrast to the terrestrial geomorphological processes, marine processes happen in a low energy environment and thus imply a good conservation of the morphology created by land-sea interactions. It is necessary to consider much more the great importance of the marine component for the interpretation of terrestrial landforms.

THE INFLUENCE OF SEA-LEVEL FLUCTUATONS, DISCHARGE VARIATIONS AND SEA CONDITIONS ON ARCTIC DELTA FORMATION: EXAMPLES FROM BAFFIN ISLAND

J. P. M. SYVITSKI, Geological Survey of Canada, Bedford Institute of Oceanography, Dartmouth, N.S., CANADA

Deltaic sediment deposits along the coast of Baffin Island are mostly Quaternary in age. They to lie unconformably over a Proterozoic basement. However, in the Salmon River delta (N.E. Baffin Island), the Quaternary sediments lie disconformably over well-sorted and mostly unlithified Tertiary deltaic sediments. Such a relationship may also exist for other foreland deltas (such as the Cape Aston delta).

The initial architecture of the Quaternary deltas is controlled by the nature of glacial erosion (or lack of it) of the basement rocks; most of the deltas are located in present or paleo-glacier valleys. These ice-flow valleys suffered at least one major phase of erosion; the last phase possibly occurred during the Early Foxe. Deltas at the heads of the fjords contain exposed sediments laid down since the Late Foxe glacial retreat. Along the forelands of the fjord coast, delataic sequences are progradational and contain sediments deposited since Early Foxe time. In both cases, the deltas contain raised terraces of varied origin. The terraces reflect hiatus periods of marine erosion (i.e. barrier or beach ridge development related to an intense storm event) or non-deposition (i.e. a marked discharge transition, loss of ice cap drainage from hinterland, shifting of depositional lobe) in a fluctuating sea-level situation. The principal objective of this study was to determine whether the deltaic terraces common to these deltas are related to minor fluctuations in sea-level or represents variations in discharge or sea state conditions.

The stratigraphy of these Quaternary deltas is grossly similar: basement bedrock is sporadically overlain by variable amounts of basal or stagnation till deposits, which as in turn overlain by proglacial lacustrine or lagoonal or marine deposits, capped by sandur/deltaic deposits. The following (after Syvitski et al., 1986) is one of many possible scenarios of the interaction of sea level and fjord-valley sedimentation.

As the ice caps form, geodetic sea level falls because of eustatic processes. However, relative sea level rises as the land is depressed to an even further extent under the newly formed ice load (sea level will also be influenced by the gravitational attraction between ice and sea). The result is a marine transgression along the fjord coast. With the river valley occupied by a valley glacier, sea level may adjust its position against the tidewater glacier (Fig. 1). Glacier movement would then determine the land-sea boundary as it is the most dynamic force operating during that time. Since glacier retreat can be rapid (10-100's m a^{-1}) and because crustal response to glacier retreat is slow (0.1 m a^{-1}), the sea transgresses up the fjord valley as ice retreats. Crustal response, initially greater than eustatic-related sea level rise (0.01 m a^{-1}), undergoes deceleration and proglacial sediment is rapidly deposited (0.3 - 1 m a^{-1}). Thus the marine transgression will slow, then halt. At the maximum (marine limit), sediment is deposited either conformably or disconformably on the glacial/proglacial sediments as shallow-water marine deposits. (Depressions behind bedrock or moraine sills may be initially infilled with fluviolacustrine or lagoonal sediments). As uplift continues, fluvial cannibalism increases. The lower units become incised, leaving terraces plastered along the valley walls. In areas of shoreline tilt, river gradients can be increased further and such fluvial rejuvenation brings increased denudation, delta building and basin filling.

We have yet to ascertain whether tidal conditions have changed over the last 10,000 years along the Baffin Shelf. Data on raised intertidal areas is sparse but suggests comparable tides over the past 6,000 years. Today the fiords endure annual wind events that are much in excess of what is needed to produce maximum wave heights for a given fetch. Thus, the absence of storm ridges have been used to ascertain periods of prolonged annual ice cover. In Cambridge Fiord (Fig.2), interpreted raised sequences suggest a seasonally ice free period during the last 1700 years, a permanent ice covered period between 1700 and 3000 years B.P., and a more open water period before 3000 years B.P. Two terraces on the nearby Keel River delta bracket the period covering the perennial ice cover--- paleohydraulic data suggests that this period was characterized by lower discharge conditions (colder summers, development of snowfields).

Five older raised terraces on the Cambridge delta were formed over a 1250 year period during an interval of delta progradation between 6000 y B.P. and 4750 y B.P. The time between the formation of these terraces (and thus peak periods of erosion) ranged from 100 to 500 years. As the rate of emergence has decreased (exponentially), the annual rate of erosion has also decreased exponentially (for details see Syvitski et. al., 1984). The terraces appear to reflect periods of discharge maxima in an otherwise falling discharge scenario. Since the delta was in ice-contact and the present drainage basin condition has not been able to structurally modify the delta, the discharge maxima may relate to periods of maximum ice melt during the summer, possibly including jokulhlaup events.

The Keel River delta includes four terraces constructed over the last 4750 years. Interpolated uplift curves suggest that they were formed at 1000 to 1500 year spacings during the neoglacial period. The paleo-Keel River was highly meandering with preserved oxbow lakes. The modern Keel River occupies the Coriolis side of the valley and is more anastomosing (a function of coarser sediment input from side-entry fans developed during the Little Ice Age). The Keel is not considered an ice-contact delta and its terraces appear to have formed during more gradual climatic/discharge shifts during an otherwise unidirectional lowering of sea level. More detailed data are needed (changes in the rate of delta progradation will produce a psuedo sealevel shift as observed in the sediment record).

This project, involving many scientists including Jay Stravers (INSTAAR), is also testing the hypothesis that terrace formation may relate to intervals of intense paleoseismicity. We know that large failures on the paleo-Keel delta forset beds have occured. Recent studies of the USGS from on the Knik delta, Alaska, have suggested that terrace formation may relate to liquefaction of parts of the delta surface: the return interval on these earthquake events is about 500 to 700 years (Bartsch-Winkler and Schmoll, 1984).

REFERENCES:

Syvitski, J.P.M., Farrow, G.E., Taylor, R., Gilbert, R. and Emory-Moore, M., 1984. SAFE: 1983 Delta Survey Report. In SYVITSKI, J.P.M. (compiler), *Sedimentology of Arctic Fjords Experiment:HU 83-028 data report, Volume 2*. Can. Data Rep. Hydrogr. Ocean Sci. 28, 18-1 to 18-91.

Syvitski, J.P.M., Burrell, D.C., and Skei, J.M. 1986. Fjords: Processes and Products. Springer-Verlag, N.Y. 700p.

Bartsch-Winkler, S. and Schmoll, H.R. 1984. Bedding types in Holocene tidal channel sequences, Knik Arm, upper Cook Inlet, Alaska. J. Sed. Pet. 54, 1239-1250.

FIGURE CAPTIONS:

Fig. 1. One of the many possible scenarios indicative of the interaction os sea level fluctuations and fjord-valley sedimentation (timing of events are arbitrary).

Fig. 2. Holocene raised terraces on the Cambridge and Keel River deltas, Baffin Island.

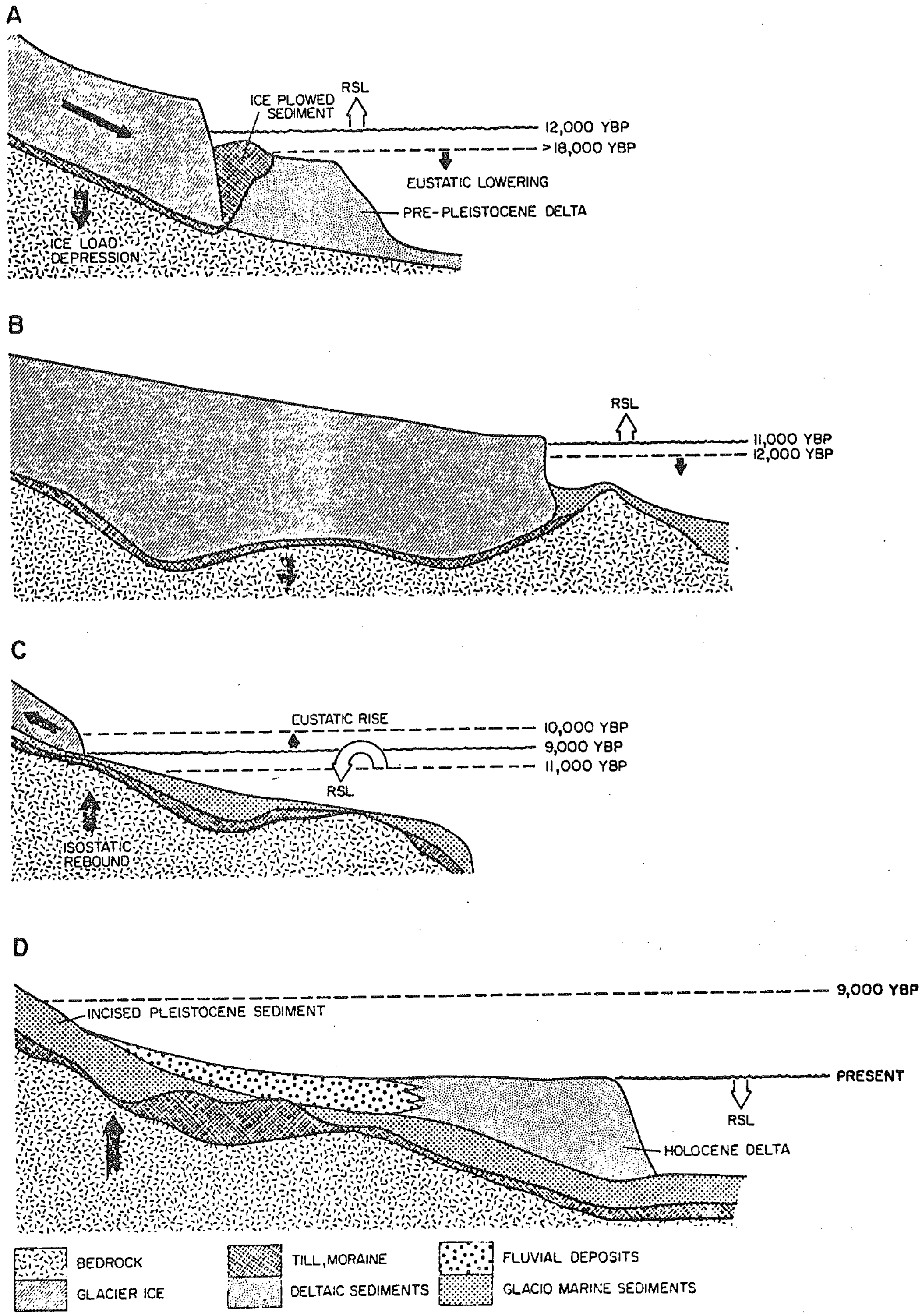

A
ICE PLOWED SEDIMENT
RSL
12,000 YBP
>18,000 YBP
EUSTATIC LOWERING
PRE-PLEISTOCENE DELTA
ICE LOAD DEPRESSION
B
RSL
11,000 YBP
12,000 YBP
C
EUSTATIC RISE
10,000 YBP
9,000 YBP
11,000 YBP
RSL
ISOSTATIC REBOUND
D
9,000 YBP
INCISED PLEISTOCENE SEDIMENT
PRESENT
RSL
HOLOCENE DELTA
BEDROCK
GLACIER ICE
TILL, MORAINE
DELTAIC SEDIMENTS
FLUVIAL DEPOSITS
GLACIO MARINE SEDIMENTS

Figure 1

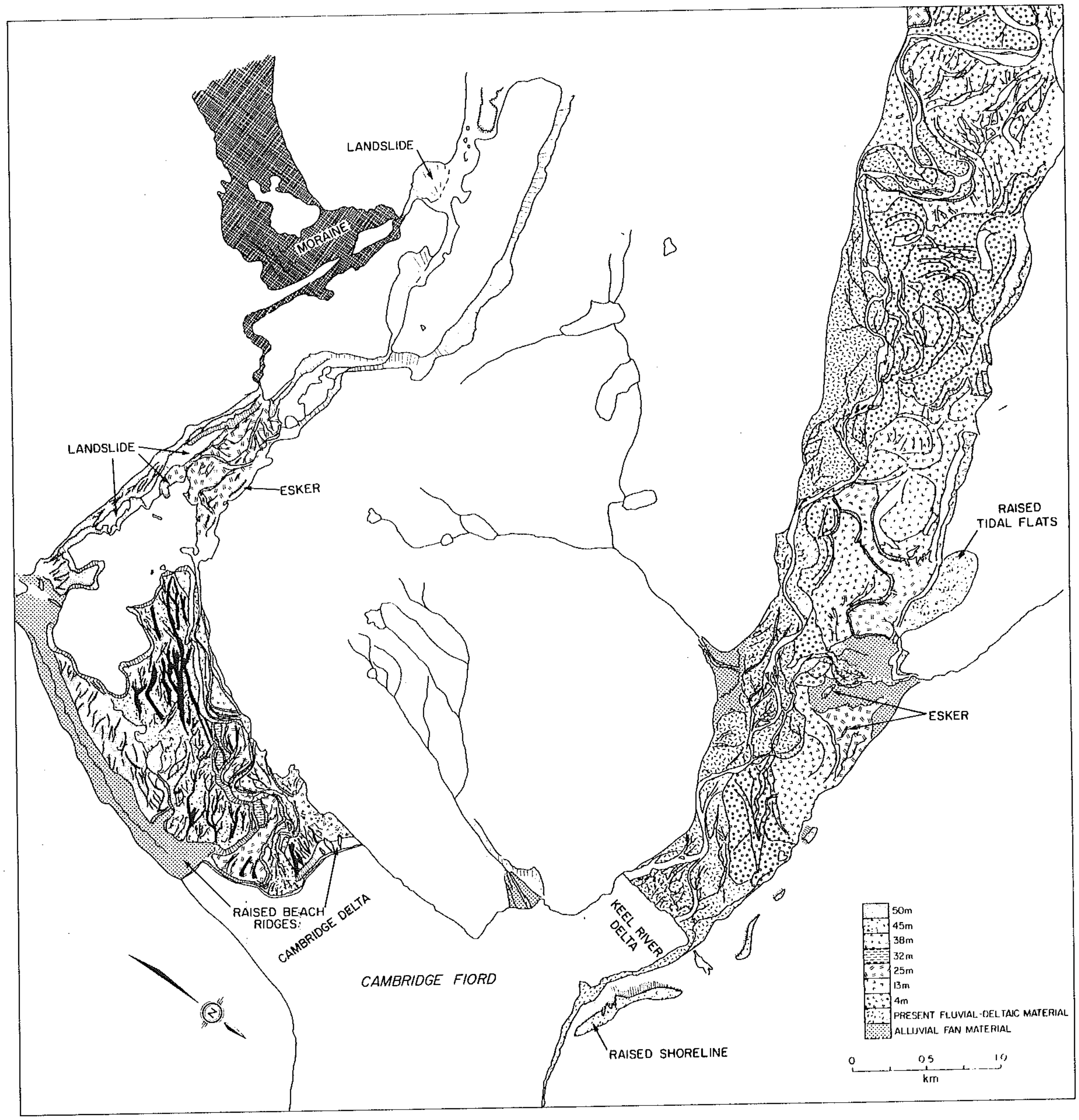

LANDSLIDE
MORAINE
LANDSLIDE
ESKER
RAISED
TIDAL FLATS
ESKER
RAISED BEACH
RIDGES
CAMBRIDGE DELTA
KEEL RIVER
DELTA
CAMBRIDGE FIORD
RAISED SHORELINE
50m
45m
38m
32m
25m
13m
4m
PRESENT FLUVIAL-DELTAIC MATERIAL
ALLUVIAL FAN MATERIAL
0
0.5
1.0
km

Figure 2

GLACIO-MARINE OUTWASH DELTAS, EARLY ICE RETREAT AND STABLE ICE FRONTS IN THE NORTH EASTERN COASTAL REGION OF UNGAVA

James Gray[1], Bernard Lauriol[2] and Jean Ricard[1].

Evidence from marine limits, moraine and glacial outwash belts, and particularly from radio-carbon dated shell layers at several levels in a large glacio-marine delta complex, sheds new light on withdrawal of the late Wisconsin ice sheet from the northeastern tip of the Ungava Peninsula. This ice withdrawal was accompanied by a marine transgression into the

lower Deception River Valley, and by subsequent coastal emergence. Figure 1 is a preliminary small scale map showing marine limit elevations and a number of ice front features.

A sharp decrease in marine limit elevations is apparent as one progresses from the outer coast and offshore islands (such as Charles Island and Maiden Island) to the heads of fjords, such as Deception Bay and Douglas Harbour (the latter not shown on figure 1). This is exactly the reverse of what would be expected if the high marine limits were related to ice loading. Such high limits along the coast may be attributable to early deglaciation of the outer coast in the Cap-de-la-Nouvelle-France region, with much later withdrawal of ice from the heads of the fjords onto the interior plateau. Moraine belts and sequences of very extensive and very thick glaciofluvial deposits, mainly ice frost marine deltas, trending parallel to the coast in the Cap-de-la-Nouvelle-France region, lend support to this interpretation. During the summer of 1984 and 1985 we have been able to study the stratigraphy of one of these ice front marine deltas in detail. Some chronological data is also available through radio-carbon dating of marine shells and wood contained in the delta sequence.

This delta is located in the Deception River Valley (figure 1). Although somewhat eroded by the Deception River and its tributaries, the delta complex originally covered an area of 5km x 2 km. It is 60m thick from bedrock to its top surface which is situated close to the local marine limit at approximately 120m. a.s.l. Figure 2 shows the stratigraphy exposed in 2 sections incised by the Deception River down to bedrock.

At the base of the section RD 3-1, glacially scoured bedrock bearing evidence of northward flowing ice was noted. It is overlain successively by 5m of till, 7m of marine silts and clays, and about 50m of marine sands with occasional gravel layers. *Portlandia arctica* shells indicative of a very cold glacial environment, found at the base of the marine silts and clays have been dated by the particle accelerator method at 9,800 ± 200 BP (Beta Analytic Inc). Further samples from shell beds at 13m and 56m above the base have been recently submitted for dating. The *Hiatella artica* shells,

1 Department de Geographie Université de Montréal
2 Department of Geography, University of Ottawa

found in situ near the top surface, at a regional attitude of ~ 110m, will give a date for, 1) the completion of the delta building sequence of events and concomitant retreat of the Ungava ice sheet from the vicinity and, 2) the beginning of accelerated postglacial emergence at the site.

In this regard, it is useful to consider evidence from a shell date of 6740±150 BP in a truncated marine sequence in the adjoining exposure RD3-2 and from a wood date of 4620±110 BP at the base of a terrestrial sequence in the same exposure. Delta building probably continued until shortly after 6740 BP, and was followed in the following 2000 yr. interval by at least 40m of sea level regression with accompanying incision of the delta by the Deception River.

From the persistent orientation towards the NW of the delta strata, it appears that ice sheet drainage had to be persistently into Hudson Strait by way of a narrow fjord, drainage to the west probably remaining blocked by large distributary ice lobes from the plateau ice cap. These ice lobes have, over many glaciations, been responsible for the deeply dissected valleys presently occupied by Lac Duquette and Lac Francois - Malherbe. At circa 6,000 BP, ice withdrawal from these valleys led to re-establishment of the drainage in a westerly direction, as indicated by terrace patterns during the phase of rapid emergence and delta incision. The very thick (6m thick) interbedded peats and aeolian layers at the top surface of the delta present an interesting problem, however. If they were developed in a situation of impeded drainage, they may represent a hiatus between the end of the delta building phase and the beginning of erosional dissection of the delta.

Although much work remains to be done, linking morphological features to stratigraphy and 14C dates in the vicinity of this delta complex, the results obtained so far, when linked with the evidence shown on figure 1,

suggests the following conclusions:-

1. There is firm evidence for deglaciation and a marine transgression in the Cap-de-la-Nouvelle-France region prior to 10,000 BP.

2. This implies relatively early ice retreat on the southern side of Hudson Strait, probably by both Ungava and Hudson Strait ice.

3. A discarded date obtained by Matthews in 1967, of 10,450 BP from shells in the Deception Bay area may in fact prove to be valid.

4. The northern front of the Ungava ice remained relatively stationary in the vicinity of the Deception River valley for a long interval after 10,000 BP, perhaps till as late as 6000 BP, prior to subsequent retreat and disappearance.

5. Postglacial emergence was delayed until ~ 6000 BP, and then occurred rapidly, being accompanied by deep incision of delta sediments by the Deception River and its tributary gullies.

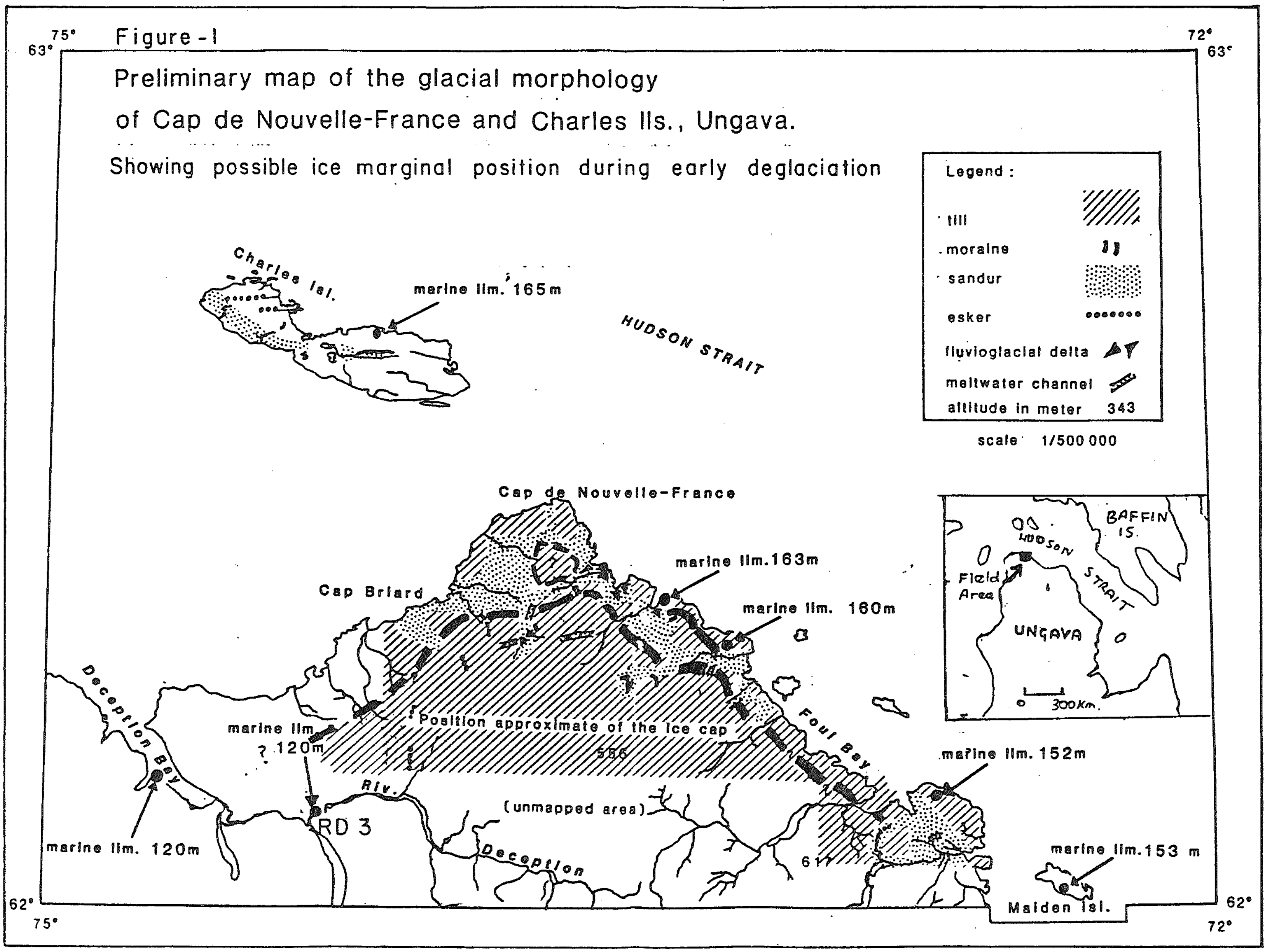


Figure - I
Preliminary map of the glacial morphology of Cap de Nouvelle-France and Charles Ils., Ungava.
Showing possible ice marginal position during early deglaciation

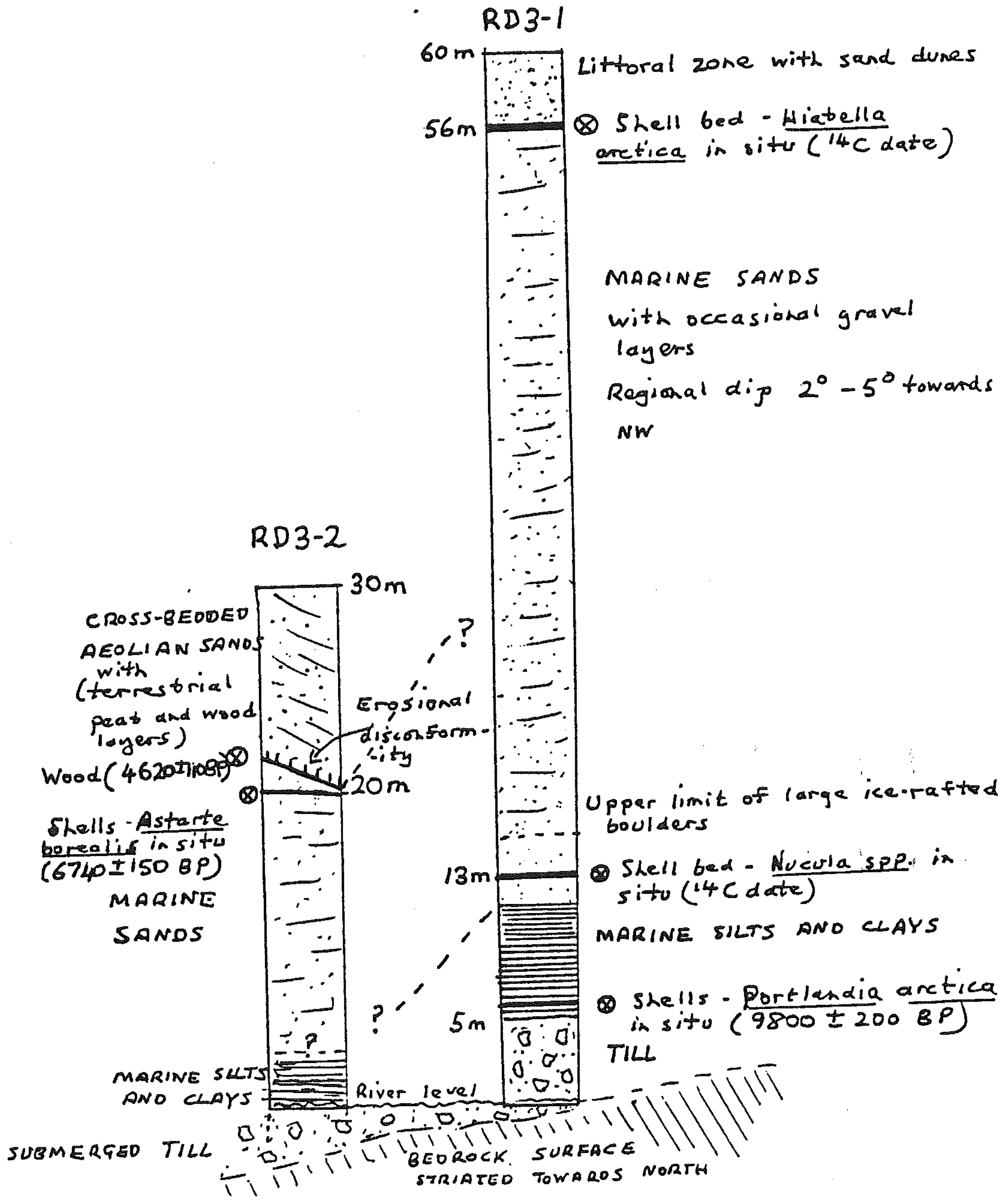


FIGURE 2 STRATIGRAPHY AND ^{14}C CHRONOLOGY FOR 2 EXPOSURES IN A GLACIO-MARINE DELTA IN THE DECEPTION RIVER VALLEY, UNGAVA

PAST, PRESENT, AND FUTURE RELATIVE SEA LEVEL CHANGE IN HUDSON BAY

HARVEY THORLEIFSON

Institute of Arctic and Alpine Research and Department of Geological Sciences, University of Colorado, Boulder CO 80309 USA.

The splitting of the Laurentide ice sheet roughly 8000 C14 years ago, presumably by calving through Hudson Strait and into glacial Lakes Agassiz and Ojibway, resulted in the drainage of a huge volume of freshwater from the latter lakes and the establishment of Hudson Bay. Rapid retreat of sea level in the region resulted from isostatic rebound produced by release of the weight of the ice sheet. Subsequent uplift also responded to the diminishing volume of water in Hudson Bay; the same volume change made a slight contribution to the early Holocene rise in global sea level. An integrated model for the history, the present trend, and the probable future trend of relative sea level in the region has been assembled from radiocarbon dated former sea levels, tide gauge trends, and gravity anomalies.

An account of the Holocene history of sea level in Hudson Bay is a required input for geophysical modelling and for paleogeographic reconstruction of the region. The dynamics of the late stages of the Laurentide ice sheet were influenced by Hudson Bay paleobathymetry, as was the environment of the area throughout the Holocene. As sea level retreated, rivers extended their courses and formerly submerged surfaces were made available for colonization. Climate was influenced by changes in the extent and configuration of land and sea.

Assessment of the present rate of vertical crustal movement may be made by inferring a rate from radiocarbon dated emergence curves or through statistical analysis of the trends of tide gauge data. The present rate of sea level change includes two components, isostatic crustal uplift and global eustatic sea level change. Comparison of present-day regression rate inferred from uplift curves with the trend of tide gauge data could in theory be used to obtain the present rate of global sea level change but in practice a value for the latter variable has been obtained elsewhere and has been used to derive uplift rate from tide gauge trends. Two tide gauges are available in Hudson Bay. The Churchill gauge has yielded uplift values of about 0.5 m/century. Previously published values of over 2 m/century for the short-lived station located at Inoucdjouac, Quebec are considered to be in error;a rather uncertain value closer to 1.5 m/century has been obtained. Assessment of present vertical movements are neededfor consideration of geodetic levelling networks and for engineering design.

Present uplift rates and extrapolation of uplift curves into the future indicate that a substantial amount of uplift remains to be completed. Furthermore, existing negative gravity anomalies have been used to infer sufficient remaining uplift to nearly eliminate the bay. A reconstruction of the likely product of this remaining uplift is useful in the consideration of the paleogeography of the region during interglacial and preglacial time. The extent or possible absence of the bay is an important variable in speculations on the nature of glacial inception. If it can be assumed that the predicted post-rebound geography can be corrected for long-term tectonism and denudation, the model can be used in the consideration of preglacial drainage networks as well as in the tracing of seaways established during times of high global sea level. With reference to the latter, faunal affinities of Upper Cretaceous rocks imply the former existence of a seaway extending across Hudson Bay at that time. A reconstructed preglacial topography combined with a model of Upper Cretaceous eustatic sea level can be used to assess the paleobathymetry of such a seaway.

The Formation of Arctic Ocean Halocline Properties by Continental Shelf Processes

E.P. Jones
Bedford Institute of Oceanography,
Dartmouth, Nova Scotia, Canada
and
L.G. Anderson
University of Göteborg
Göteborg, Sweden

A distinctive feature of the central Arctic Ocean is a pronounced halocline between depths of about 100 m and 200 m that separates the cold, relatively fresher Arctic Ocean surface layer from the warmer, more saline Atlantic layer. Associated with this halocline is a prominent nutrient maximum, observed first in the Canada Basin as early as 1948 from the Russian NP-2 Ice Station (Nikiforev et al., 1966) with subsequent and more complete data being obtained particularly from the T3 Ice Island (Kinney et al., 1970). The same features but with the nutrient maximum more sharply defined were observed in water column profiles obtained near the North Pole during the LOREX expedition (Moore, et al., 1983). We found very similar features to those near the North Pole over the Alpha Ridge during the CESAR expedition, and, with the measurement of additional chemical constituents, have been able to suggest a more definitive picture of the halocline water of the Arctic Ocean.

A model proposed for the maintenance of the halocline (Aagaard et al., 1981; Melling and Lewis, 1982) forms the basis for a description of the distribution of the chemical constituents throughout the halocline. According to this model, the halocline is maintained by cold, saline water formed along the vast continental shelves of the Arctic Ocean during the production of sea ice. This water subsequently advects into the central regions of the Arctic Ocean. The temperature-salinity relationships suggest the halocline is comprised of two types of water, both formed as described above with the shallower region containing the nutrient maximum. We postulate that this maximum is formed as a result of nutrients having either been regenerated on the shelves as a result of the decay of biogenic matter or having reached the shelves by some direct process such as river input or transport from the Bering Sea, then being carried by the cold, saline shelf water to the halocline. Longer residence times on the continental shelves for water forming the upper part of the halocline would allow time for the uptake of nutrients. Different sources of water as well as shorter residence times on the shelves may distinguish the lower halocline water from the upper halocline water. The possibility of different regions being involved in the formation of the halocline will also be discussed.

References

Aagaard, K., L.K. Coachman and E.C. Carmack, On the halocline of the Arctic Ocean, Deep Sea Res., 28, 529-545, 1981.

Kinney, P., M.E. Arhelger and D.C. Burell, Chemical characteristics of water masses in the Amerasian Basin of the Arctic Ocean, J. Geophys. Res., 75, 4097-4104, 1970.

Melling, H., and E.L. Lewis, Shelf drainage flows in the Beaufort Sea and their effect on the Arctic Ocean pycnocline, Deep-Sea Res., 29, 967-986, 1982.

Moore, R.M., M.G. Lowings and F.C. Tan, Geochemical profiles in the Central Arctic Ocean: Their relation to freezing and shallow circulation, J. Geophys. Res., 88, 2667-2674, 1983.

Nikiforev, Ye. G., Ye. V. Belysheva and N.I. Blinov, The structure of water masses in the eastern part of the Arctic Basin, Oceanology, 6, 59-64, 1966.

FACTORS AFFECTING THE EXTENT OF THE FAST ICE COVER IN SOUTH-EASTERN HUDSON BAY.

P. Larouche and P. Galbraith

Champlain Centre for Marine
Science and Surveys
P.O. Box 15500
901, Cap Diamant
Quebec (Que.)
G1K 7Y7

Since 1982, at the Champlain Center for Marine Sciences and Surveys, scientists are doing winter research in physical and biological oceanography in southeastern Hudson Bay. This work is done, for the major part, from a camp established on the landfast ice close to shore. However, it appears that the area covered by the landfast ice could change drastically from year to year. While in most years about half the region is covered from the Belcher Islands to the Quebec coast line, some years see the cover extend throughout the region while in still other years the cover suffers very early breakup. This variability in the ice cover constitutes a major problem to our winter surveys. So, we decided to try to establish the sources of that variability and see if we could predict the ice cover some time in advance of our surveys. To do that, we used Lansat pictures of the area since 1972 to see the interannual changes of the ice cover together with the usual weather observation collected in Great Whale. The working area (fig. 1) is delimited to the east by the Quebec shoreline, to the west by the Belcher Islands and to the north by a series of small islands and shoals. It is these physical attributes which are most surely the reason why pack ice tends to consolidate there into fast ice. It is the extent of the fast ice cover to the west which changes from year to year, and that we are trying to predict.

The first factor we looked for was the winter intensity expressed by the number of degree-days. The results seems to indicate that there is no relation between this factor and the ice extent. Next, a quick look at the momentum balance equation shows the wind stress as the dominant factor followed by the water stress, or the internal stress depending upon the free drift state. In conjunction with Nimbus 6 and 9 satellite photographs showing the breakoff of two giant floes (approximately 10 Km in diameter) from the fast ice cover, the study of the equation gives a close approximation of the actual drift when adding a 10 cm/s current parallel to the coast toward the south-west.

Ten cm per sec. might seem to be a strong value, but current meter moorings removed from the region a few weeks before that show 5 cm per sec. currents possible. A 10 cm per sec. current during three days is then not too far off, considering usual difficulties in linking theory with what actually happens.

For the drift calculations, we used a C_w/C_{10} ratio of two, given by McPhee [1980] along with a surface wind coefficient (C_{10}) of 1.5, a value often seen associated with smooth floes. Given that the rather high current velocity of 10 cm per sec. contributes about as much as the 3.9 metres per sec. mean wind speed over the three day period, we can assume that the water stress on the fast ice cover is below the breakup threshold limit because we don't normally see the whole cover breakup with 4 m/s winds. This means that the wind stress on the sea ice probably is responsible for the formation and/or breakup of the fast ice cover. Next step was to look at the records of wind in Great Whale and try to correlate them with the extent of the fast ice cover. So it might be possible to predict the extent of the cover a couple months before the beginning of our surveys.

McPhee, M.G. 1980. An analysis of pack ice drift in summer. Sea Ice Processes and Models. Ed. by R.S. Pritchard, University of Washington Press, Seattle.

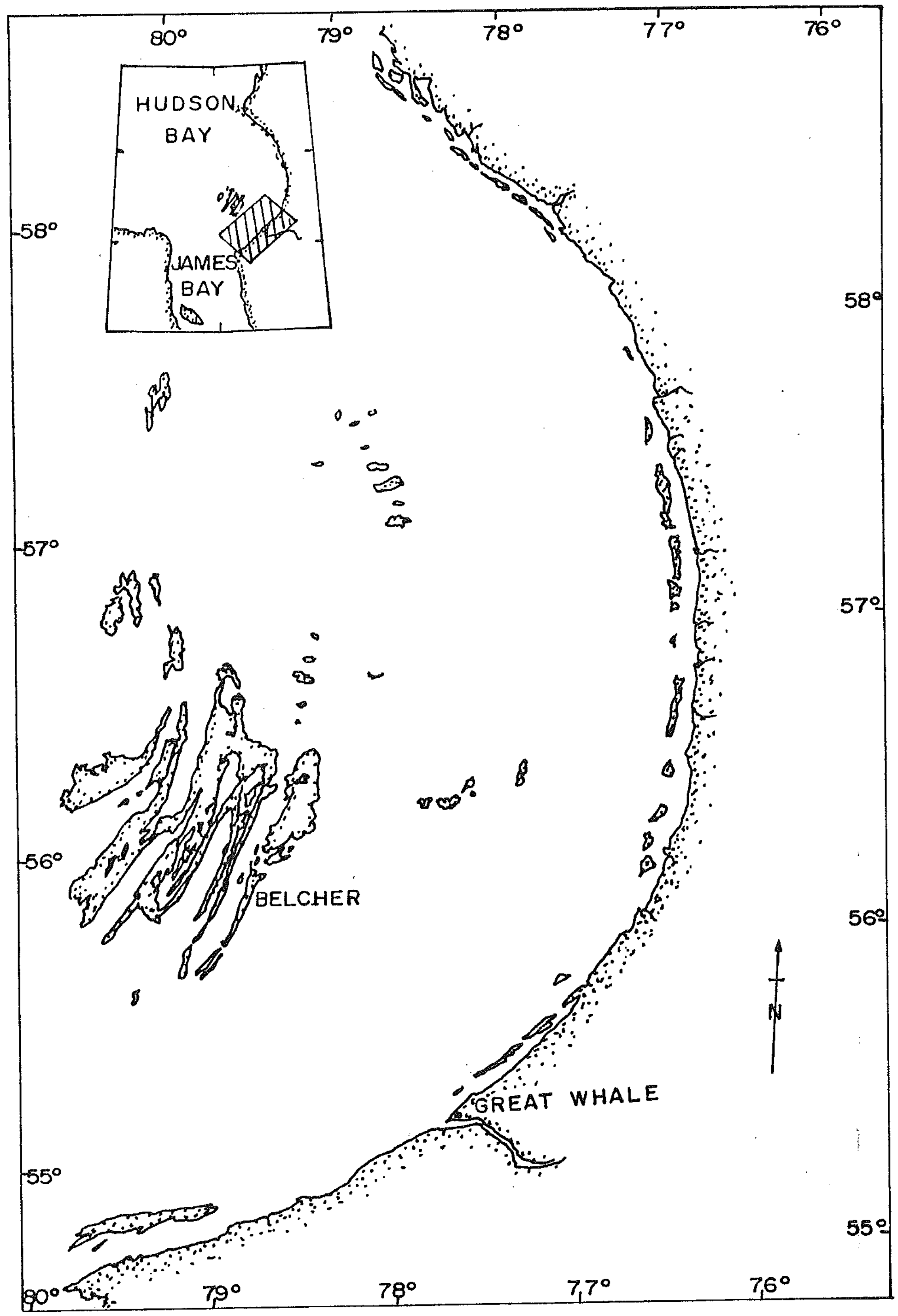


Fig. 1 Study Area

DIATOMS AS SEA-ICE INDICATORS?

by

Kerstin M. Williams

INSTAAR, University of Colorado, Boulder.

Four marine cores from fjord and shelf areas of eastern Baffin Island were examined for down-core variations in diatom content. The cores were (1) HU76-26 from the outer part of Scott Trough, (2) HU78-24 from the inner part of the same area, (3) HU82-Su 5 from the outer parts of Sunneshine fjord and (4) HU77-156 from the area around Resolution Island. All four cores have two common features: a diatom-barren zone from early to mid Holocene, and a diatom period from around 6,000 to 5,000 and continuing to the present. There could be three conceivable reasons accounting for the barren zone. (1) Dissolution of biogenic silica, (2) winnowing of diatoms and (3) permanent sea-ice cover over the core sites during the time span in question. Regarding the first of these hypotheses, careful examination of the biogenic silica available in the samples revealed no evidence of corrosion; well-preserved benthic or freshwater diatoms were found, although very rare, as were sponge spicules. Therefore, it is unlikely that dissolution is responsible for the absence of diatoms. The barren core-samples contain particle sizes of the same range as, and smaller than, diatoms. Thus it seems unlikely that winnowing (hypotesis no. 2) can be the cause of the absence of diatoms. The third possibility - permanent ice cover - has arguments both for and against its validity. Arguments in favor of this are that marine diatoms need light and some open water for blooming. This would fit the available down-core record. Arguments against are the occurrence of "warm" foraminifera and mollusc faunas during the early- to mid Holocene in these areas. These features do not contradict ice cover, however, since it is possible to have an abrupt warming of the water from the relatively fresh layer immediately underneath the sea-ice to the saline water lower down. Thus, based on evidence presently available, the hypothesis of permanent sea-ice cover over the core sites seems the most tenable of the hypotheses considered.

GLACIAL-INTERGLACIAL CHANGES IN GLOBAL DEEP-WATER CHARACTERISTICS

Thomas B. Kellogg

Institute for Quaternay Studies and
Department of Geological Sciences
University of Maine at Orono
Orono, ME 04469

Variations in the areal extent of the cryosphere appear to exert an important control over glacial/interglacial changes in the mode and location of formation of high-latitude source deep and bottom water masses. During interglacials, when ice extents are minimal, these bottom water masses form by the mechanisms which are well documented. Climatically related advances and retreats of oceanic sea ice in the northern hemisphere result in shifting loci of formation of NADW. Glacial advances of grounded ice sheets to the continental shelf margins in Antarctica preclude formation of AABW on antarctic continental shelves. These shifts in source areas for AABW and NADW involve source waters with slightly different characteristics of salinity, temperature, oxygen content, and nutrient levels. Deep and bottom waters should, therefore, have different characteristics in glacials than they do during interglacials.

LATE QUATERNARY PALEOCEANOGRAPHY OF THE BAFFIN ISLAND CONTINENTAL SHELF: BENTHIC FORAMINIFERAL EVIDENCE.

Lisa E. Osterman, Smithsonian Institution, Department of paleobiology, NHB E-207, Washington D.C., 20560, and Alan R. Nelson, U.S. Bureau of Reclamation, D-1632 Engineering and Research Center, P.O. Box 25007, Denver, CO, 80225

Foraminiferal analysis of ten piston cores collected by the C.S.S. HUDSON from the continental shelf of Baffin Island, N.W.T., Canada indicate major ocean current fluctuations during the Late Quaternary. The upper section of all cores contain post glacial deposits and a microfauna consisting of arenaceous foraminifers and Cibicides lobatulus in the youngest-most sediments, preceeded by a Nonion labradoricum/Melonis zaandamae zone, and an Immigration zone only in the southern cores. The lower section of all the Baffin Island shelf cores consist of a Cassidulina reniforme zone, except in the southern cores where there are older foraminiferal zones.

The Holocene climatic optimum is believed to be represented by the high foraminiferal abundance and diversity of the Immigration Zone and the Nonion/Melonis zone. Melonis zaandamae is a subarctic species and is found only in the northern shelf cores from approximately 8,000 to 12,000 BP, occurring earlier and for a shorter time span in shallower water. Transects of the foraminiferal zonation along the shelf show that to the south M. zaandamae is replaced by N. labradoricum, indicating cooler water. The presence of Melonis in the northern shelf cores suggests that relatively warmer subarctic water was more important in the northern Baffin Bay gyre, during late deglaciation, and became diluted with cooler coastal water as the warm current traveled south along the Baffin Island continental shelf.

The arenaceous zone of the northern and middle continental shelf represents the Holocene dissolution of calcareous foraminifers. This dissolution is probably related to the re-establishment of the cold nearshore arctic water which affected the deeper and more northerly cores before the shallower and southern cores.

One of the best reasons for studying nearshore cores is the close relationship between the land and marine records. This reasoning rings most true in this study of nearshore cores because the cores from different areas of the continental shelf provide insights into the local glacial chronology of the area. The foraminiferal record of the northern shelf seems to indicate a glacial advance between 12,000 and 16,000 BP. This advance corresponds to low numbers of foraminifers, increases in carbonate, and changes in the sediment size (decreased grain size in deep water and increased grain size in shallow water). In the mid-shelf area there does not appear to be any evidence of glaciation in the cores since 16,000 BP. The southern cores contain the longest record of foraminiferal fluctuations. These cores indicate at least two periods of glaciation, one from 8,000 to 12,000 BP and an earlier glaciation at 18,000 BP.

The Late Quaternary History of a Fiord/Shelf Transect, Northeastern Baffin Island

Anne E. Jennings, INSTAAR, and Dept. of Geological Sciences, Univ. of Colorado, Boulder, CO, 80309

The fiords and cross-shelf troughs along the eastern coast of Baffin Island are depositional basins located adjacent to the former northeastern margin of the Laurentide Ice Sheet.The sediments in these basins are key resources for understanding glacial/ocean interactions on late Quaternary time scales. Three piston cores, collected along a transect from the outer part of Clark Fiord to the outer part of Scott Trough (Fig. 1) were studied with two main objectives: 1. To determine the sedimentary processes and responses associated with the last glacial/present interglacial transition and neoglaciation and 2. To determine what information on the terrestrial glacial record can be gained from the study of continuous sediment records from sites close to the former ice margin. Several methods, including radiocarbon dating, rock- and paleomagnetism, textural and mineralogical composition and foraminiferal analysis, were employed to provide an "absolute" chronology for each core and to delineate sedimentologic and oceanographic changes along the transect.

On the basis of "corrected" radiocarbon dates, the sediment record in the three cores spans the latest Pleistocene through the Holocene. During this time period, on Baffin Island, the maximum recorded extent of the late Foxe Glaciation occurred, followed by deglaciation and the expansion of local glaciers during neoglaciation.

Three sediment units were delineated in the three cores. These are interpreted to record "glacial", "deglacial" and "post-glacial" or "interglacial" conditions on Baffin Island, as well as changing oceanographic conditions in Baffin Bay. No apparent sedimentary response to neoglacial conditions was recognized in the sediments of the fiord/shelf transect.

Glacial Unit: 12,400 BP to 8,400 BP. This unit is characterized by average sedimentation rates of 36 cm/1000 yrs. Foraminiferal assemblages are dominated by *Cassidulina reniforme*. Ice rafting, from sources to the north of the study area was far more extensive in Baffin Bay and along the outer shelf than on the inner shelf. Icebergs may have been impeded from tracking along the inner shelf during late glacial time by more extensive, permanent or semi permanent coastal fast ice than occurs today.

Deglacial Unit: 8,400 BP to 7,000 BP on the shelf and to 6,100 BP in the fiord. In the two shelf cores, the onset of deglaciation is marked by the dilution of ice-rafted minerals by the increased sediment input from deglaciation of Baffin Island, a foraminiferal assemblage containing abundant *Melonis zaandami*, and an increased average sedimentation rate (160 cm/1000 yrs. on the inner shelf). Deposition of ice-rafted material continued to be less extensive on the inner shelf than on the outer shelf and in Baffin Bay, indicating that icebergs continued to be concentrated farther offshore during deglaciation.

In Clark Fiord, deglacial sedimentation is documented by a rapid average sedimentation rate (520 cm/1000 yrs) and deposition of massive and very faintly laminated silty clay from meltwater overflows. During deglaciation, icebergs did not enter Clark Fiord from the shelf or from the heads of Gibbs or Clark fiords. This is concluded from the absence of all ice-rafting indicators (sand, detrital carbonate, expandable-lattice clays) from the base of the core (7,400 BP) until 6,100 BP.

Post Glacial or Interglacial Unit: 7,000 BP and 6,100 BP to the present on the shelf and in Clark Fiord, respectively. Average sedimentation rates decrease in all cores, although the timing of the decreased rate on the shelf precedes that in Clark Fiord by 800 years. Interglacial conditions on the shelf and in Clark Fiord are represented by increased ice rafting and extensive dissolution of biogenic and detrital carbonate. The very sudden increase in ice-rafting indicators at 6,100 BP in Clark Fiord may indicate the return to the present-day pattern of sea-ice break up in the fiord and along the outer coast, allowing icebergs to enter the fiord.

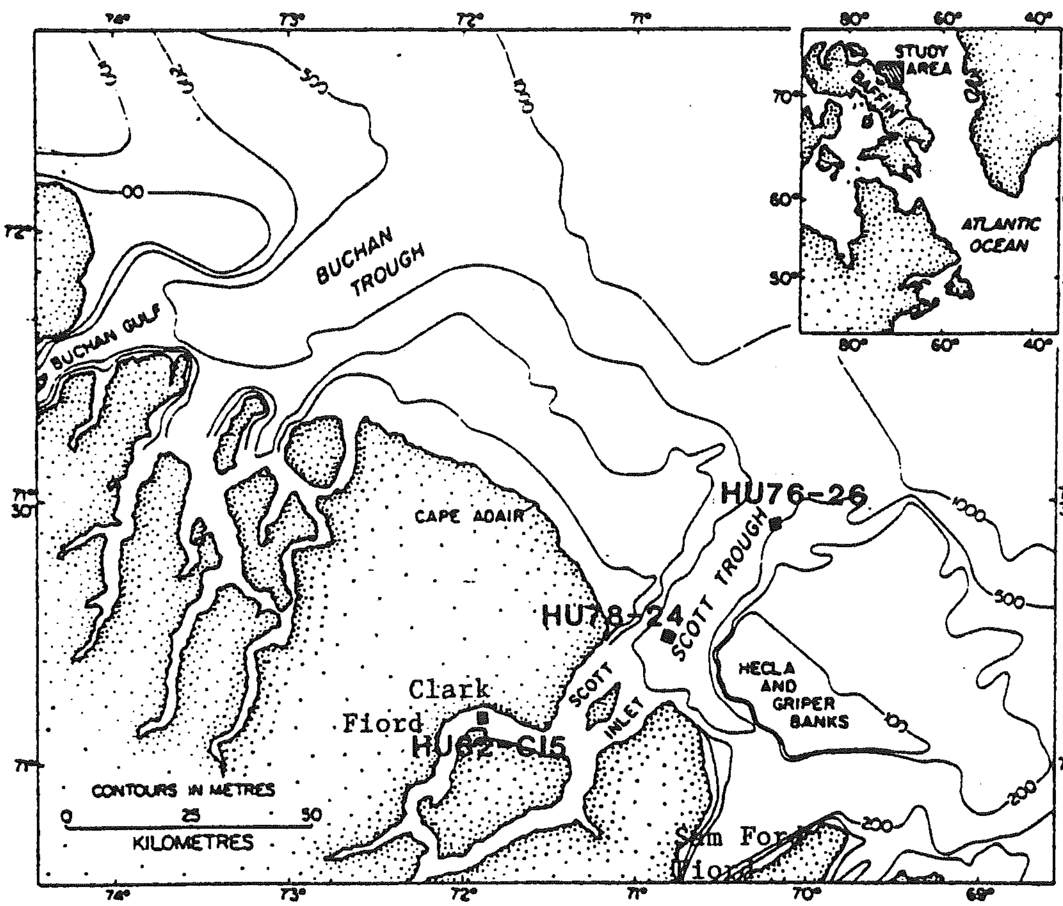


Figure 1. Index map showing location of HU82-C15, HU78-24 and HU76-26 and bathymetry of the continental shelf in the Scott Inlet-Buchan Gulf area (Modified from MacLean et al, 1981).

GLACIAL STYLE AND OCEANIC CONTROLS ON GLACIATION OF WESTERN SPITSBERGEN, SVALBARD ARCHIPELAGO

Gifford H. Miller[1], Hans Petter Sejrup[2], Scott Lehman[1] and Steven Forman[1]

[1]INSTAAR University of Colorado Boulder, CO, 80309, USA
[2]Geological Institute, Div. B, University of Bergen, 5000 Bergen, Norway

Glacial style

The glacial history of western Spitsbergen is characterized by repeated ice advances of generally limited dimensions derived primarily from local ice caps centered over mountainous regions along the west coast. Ice-free refugia existed across large stretches of the western and northern coasts during at least the last two glacial cycles, and little evidence has been reported to suggest that the coastal summits of the northwestern portion of the archipelago were inundated by actively eroding glacial ice. In contrast, the eastern, and especially southeastern portion of the archipelago has been extensively glaciated by marine-based ice sheets centered over the shallow banks of the northwestern Barents Sea. The existence of a Barents Sea Ice Sheet extending from Fennoscandia to Svalbard in Late Weichselian time remains controversial. If such an ice sheet existed, its northwestern margin did not overwhelm the Svalbard archipelago as has been previously suggested.

Glacial History

Glacial and marine deposits along the eastern coast of Spitsbergen and the adjacent eastern islands record only a deglacial sequence initiated ca 10 ka ago, whereas glacial deposits of late Weichselian age along the western and northern coasts are for the most part restricted to isolated occurrences within a few km of extant outlet glaciers. Undisturbed raised marine deposits formed prior to 40 ka ago mantle most of the coastal lowlands in the same region. Glacial unloading occurred prior to 12 ka ago, by which time isostatic recovery had already exceeded the eustatic sea-level rise. The occurrence of occasional whalebone in the oldest of these deposits indicates that the Norwegian Sea was already seasonally ice free by that time, but the geomorphic characteristics of the beach deposits suggest more extensive sea ice than in modern times characterized the summer seasons. More abundant whalebone and a dramatic increase in the diversity of the molluscan fauna in deposits dated <10 ka BP indicates the establishment of essentially a modern oceanographic circulation regime by that time.

The pre-Late Weichselian glacial history has been deciphered from the extensive exposures of interbedded till, glacial-marine and marine sediments preserved along the north and west coasts of the archipelago. Correlation and absolute age control have been derived from amino acid ratios in molluscan fossils and pedologic data with U-series and C^{14} calibration at the younger end of the scale. The amino-acid data have been used to differentiate the last four glacial advances (episode A, the Late Weichselian, and the older episodes B, C and D).

Episode B sediment includes a till documenting local glaciation without a major regional ice advance. Whalebone from a nearly complete skeleton imbedded in permafrost in episode B sublittoral sand has yielded a C^{14} age >62.5 ka BP and two U-series dates of 62 ± 15 ka BP and 63 ± 1 ka BP. U-series shell dates (37 ± 3 ka BP) are clearly too young. Because of the relatively warm micro and macro fauna and light oxygen isotope ratios in episode B foraminifera, out tentative best estimate for the age of the event is late isotope stage 5 (70 to 90 ka BP).

Episode C includes the last regional glaciation of northwestern Spitsbergen. The sedimentary sequence includes an initial local advance followed by a regional ice advance that flowed around the higher coastal regions. The clearly interglacial nature of the microfauna suggests that this event occurred early during isotope stage 5 or late stage 6.

Episode D deposits are less abundant and have not been firmly tied to a specific glacial advance, but their elevation above sea level implies that they are associated with isostatic unloading associated with deglaciation.

Older glacial and marine deposits have been identified that are characterized by their amino acid ratios in associated molluscs, but their absolute age is difficult to ascertain. The oldest deposits yet sampled may be late Pliocene.

Oceanic control of glacial style

The late Weichselian glaciation of Svalbard suggests extensive marine-based ice-sheet glaciation dominated south-eastern Svalbard whereas the north-western portion of the archipelago was influenced by limited local glacier advances. This contrast in glacial style suggests a basic glaciological assymetry influenced the archipelago during he Late Weichselian glaciation. The assymetry has remained in effect through the Holocene. The best example of such assymetry and a useful analogue for Late Weichselian conditions are the Nordaustland ice sheets. The entire southeastern sector (ca 150 km) of Austfonna, largest of the Svalbard ice bodies, is marine-based, terminating in the sea. In marked contrast, the northwestern sector of the ice sheet (ca 180 km) is land-based with only a few outlet glaciers reaching the sea. The distance between the two sectors is only 70 km, yet a sufficient climatic gradient exists across this stretch to produce a marked glaciological assymetry. The Edgeøya icecaps display a similar assymetry.

We argue that the modern glaciological assymetry is similar to that implied by the field evidence for the Late Weichselian glaciation and that this glacial style may have characterized Svalbard throughout the Quaternary. Furthermore, we suggest that the controls on the assymetry are the same for modern and Pleistocene ice sheets, and are related to the availability of moisture and the ablation-reducing capacity of the adjacent oceans.

ISOTOPIC EVIDENCE REGARDING THE NATURE OF THE LAST THREE DEGLACIAL HEMI-CYCLES ON WEST SPITSBERGEN, SVALBARD

Lehman S.J, Sejrup H-P* and G.H. Miller

Institute of Arctic and Alpine Research, University of Colorado *Geology Institute, Sec. B, University of Bergen, Norway

We offer the preliminary results of two pilot studies aimed at testing the chronologic and paleo-environment determining capabilities of isotopic studies in shallow-water glacial-marine environments for both forminifera and mollusca on West Spitsbergen. The studies result from NSF supported collaborative efforts between INSTAAR and the University of Bergen (foraminifera, H-P. Sejrup) and with Brown University (molluscs, R.K. Matthews).

Along the west coast of West Spitsbergen, at Brøggerhalvøya, geographically continuous stratigraphic exposures reveal a long and often detailed record of Quaternary glacial and marine events in the area (Troitsky et al, 1979; Miller, 1982). Sejrup et al. (this vol.), Miller (1982), and Miller and Forman (1984) have identified a detailed litho-, amino-, and biostratigraphy for Site 15 on Brøggerhalvøya. At the site, two upward-coarsening sequences of marine sediment ("Aminozones B", younger,and "C", older, of Miller, 1982), each underlain by till, are interpreted to record progressive glacio-isostatic recovery during deglaciation. In both sediment sequences the foraminiferal abundance and diversity exceed values cited for modern fjord environments on Spitsbergen (eg. Nagy, 1967; Elverhoi et al. 1980). Radiometric dates (Miller; unpub. data) refer Aminozone B to late marine isotope stage 5.

Oxygen and carbon isotopic values were determined for the benthic foraminifera *Elphidium excavatum* and *Cassidulina reniforme* at Site 15 (Figure 1). As a check on the reliability of the isotopic results, samples from several key levels were run in duplicate or triplicate for each taxon. In the worst case samples of *E. excavatum* were out by 0.4 permil del-018 (greatly exceeding the analytical precision of the instrument). Furthermore, the species dependent isotopic offset between the two taxa showed changes in both magnitude and sign through the record. These observations combine to suggest that our record is affected to some extent by reworking. Despite this, a record of isotopic variation can be discerned.

Within the Aminozone B deglacial sequence the oxygen isotope values display a marked shift from light values just above the Aminozone B till to heavier values up-section, reflecting the diminishing contribution of post-glacial meltwater with time. Higher in the section the oxygen isotope values lighten progressively in accordance with shallowing implied by both bio- and lithostratigraphic data. This lightening probably records a local salinity effect. Parallel analyses of carbon isotopic values reveal a marked transition from light to heavy values just above the Aminozone B till. This is thought to record a shift from a stratified watermass related to a meltwater or sea-ice lid, to conditions associated with renewed vertical circulation, enhanced ventilation and increased productivity in the adjacent surface waters. The amplitude of the light excursions above the Anminozone B till in the oxygen isotopes indicate only limited meltwater input; both the carbon isotopes and the restricted nature of the fauna at this level (>80% E. excavatum f. clavata) suggest hydrographic stress in the form of watermass stratification (relative anoxia) but not a priori freshwater swamping.

Isotopic variation within the Aminozone C faunae shows a smaller amplitude than noted in the overlying sequence and indicates no obvious meltwater of sea-level related variations. This observation is consistent with the regularity and ameliorated aspect of the faunae throughout Aminozone C sedimentation and may suggest that part of the sediment record immediately following glacial occupancy has been lost. The average oxygen-isotopic values within Aminozone C were ca. .2 per mil PDB heavier than those determined for Aminozone B in E. excavatum, and roughly equivalent in C. reniforme, despite the fact that the Aminozone C faunal assemblage displayed greater diversity and abundance.

The del-O18 (PDB) value for inorganic calcite precipitation in modern waters adjacent to the site was calculated from available hydrologic data (Normann and Pettersen, 1984). The resultant value of 3.55 per mil PDB should reflect the present (interglacial) globally integrated isotopic value as it is moderated by present salinity and temperature conditions at the site. The calculated value is similar to the fossil values for both Aminozone B and C deglacial sequences when the unquantified vital effect in both taxa is not taken into account. The heaviest (least likely to have been diluted) fossil values are .20 to .40 per mil PDB heavier than the calculated "interglacial value". This offset can only be explained by an ice-volume effect, as both vital effects and fresh-water dilution will tend to broaden the fossil isotopic departure from the interglacial value . Altering the salinity and temperature values used to calculate the modern del-O18 value within the tolerances of the associated fauna does not significantly reduce or broaden the offset.

"Warm" faunae providing heavier-than-interglacial isotopic values may suggest the presence of "warm" surface waters penetrating to the latitude of Spitsbergen at a time when global ice-volume exceeded the interglacial quantity. This may extend the observation of a Sea Surface Temperature

- isotope (ice volume) phase lag documented in the North Atlantic (eg. Ruddiman and McIntyre, 1981) to 80° N. In the tangible terms employed by Andrews (1982) the isotopic offset may record 3-8 Greenland Ice Sheet units in excess of present global ice volume (employing reasonable del-O18 of ice estimates, eg. Mix and Ruddiman, 1983) during either of the two Spitsbergen deglacial cycles. The uncertainty in the ice-volume estimate arrises from being unable to quantify the magnitude of the vital effect or the extent of dilution.

In a related study, oxygen and carbon isotope values were determined for a series of radiocarbon dated molluscs collected from post-glacial (Aminozone A) deposits on West Spitsbergen. The results presented here are restricted to those on individual valves of the ubiquitous arctic pelecypods Mya truncata and Hiatella arctica (Figure 2). We can demonstrate that isotopic variation related to the seasonality of shell carbonate deposition is not a prominent feature in our data set for the following reasons: 1) the almost constant isotopic offset between M. truncata and H. arctica for all dated collections where both occur, and 2) that different intra-shell sampling programs provide statistically similar isotopic values within a single taxon. We suggest that both M. trunacata and H. arctica interupted shell deposition during the colder winter season, thus our record reflects primarily summer hydrographic conditions.

The oxygen isotope record suggests relatively static hydrographic conditions persisting between 12.6 and 9.6 ka BP. At 9.6 ka BP a marked watermass transition (isotopic lightening) is noted that may herald the "turn on" of a North Atlantic Drift-like current in the area. This corresponds directly with the first known incursion of Mytilus edulis and other thermophilous mollusc taxa to Spitsbergen around 9.6 ka BP (Feyling-Hanssen, 1955). The north and west coasts of Spitsbergen were not influenced by meltwater generated by the breakup of western Barents Shelf ice-domes between 13 and 12 ka BP (Forman et al., this volume), indicating a surface circulation pattern that restricted its dispersion to the east and south.

REFERENCES:

Andrews, J.T. 1982: On the reconstruciton of Pleistocene ice sheets: A review. Quaternary Sci. Rev. 1: 1-30.

Feyling-Hanssen, R. 1955: Stratigraphy of the marine late Pleistocene of Billefjorden, Vestspitsbergen. Norsk Polar. Skrifter nr. 107: 187 pp.

Forman, S.L., Mann, D. and G.H. Miller, this vol: Post-glacial relative sea-level history of Broggerhalvoya, Spitsbergen, Svalbard Archipelago.

Miller, G.H. 1982: Quaternary depositional episodes, Western Spitsbergen: aminostratigraphy and glacial history. Arctic and Alpine Res. 14: 321-340.

Mix, A. and Ruddiman, W.F. 1984: Oxygen isotope anlyses and

Pleistocene ice volumes. Quat. Res. 21: 1-20.
Nagy, J. 1965: Foraminifera in some bottom samples from shallow waters in Vestspitsbergen. Norsk Polar. Arbok 1963: 109-125.
Normann, U. and F. Pettersen 1984: Hydrografiske observasjoner (havmiljodata) fra Svalbard 1979-1983. Naturvitenskap n. 40, Univertsity of Tromso.
Ruddiman, W.F and A. McIntyre 1981: The mode and mechanism of the last deglaciation: oceanic evidence. Quat Res. 16: 125-134.

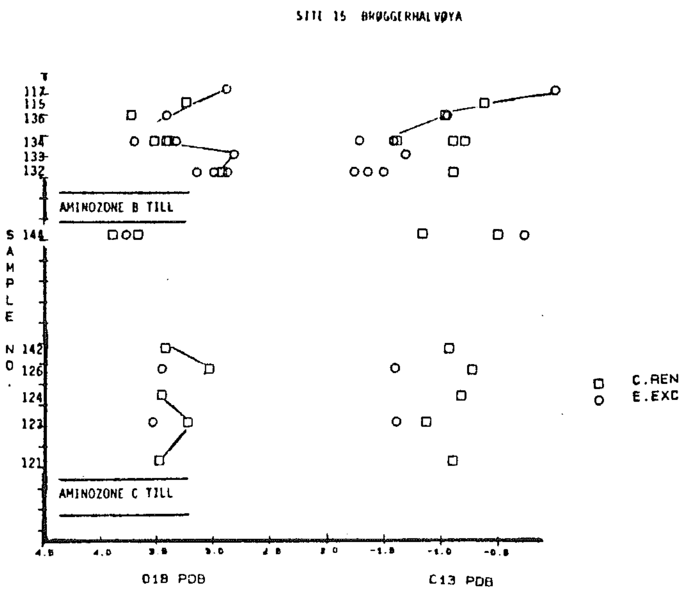


Figure 1

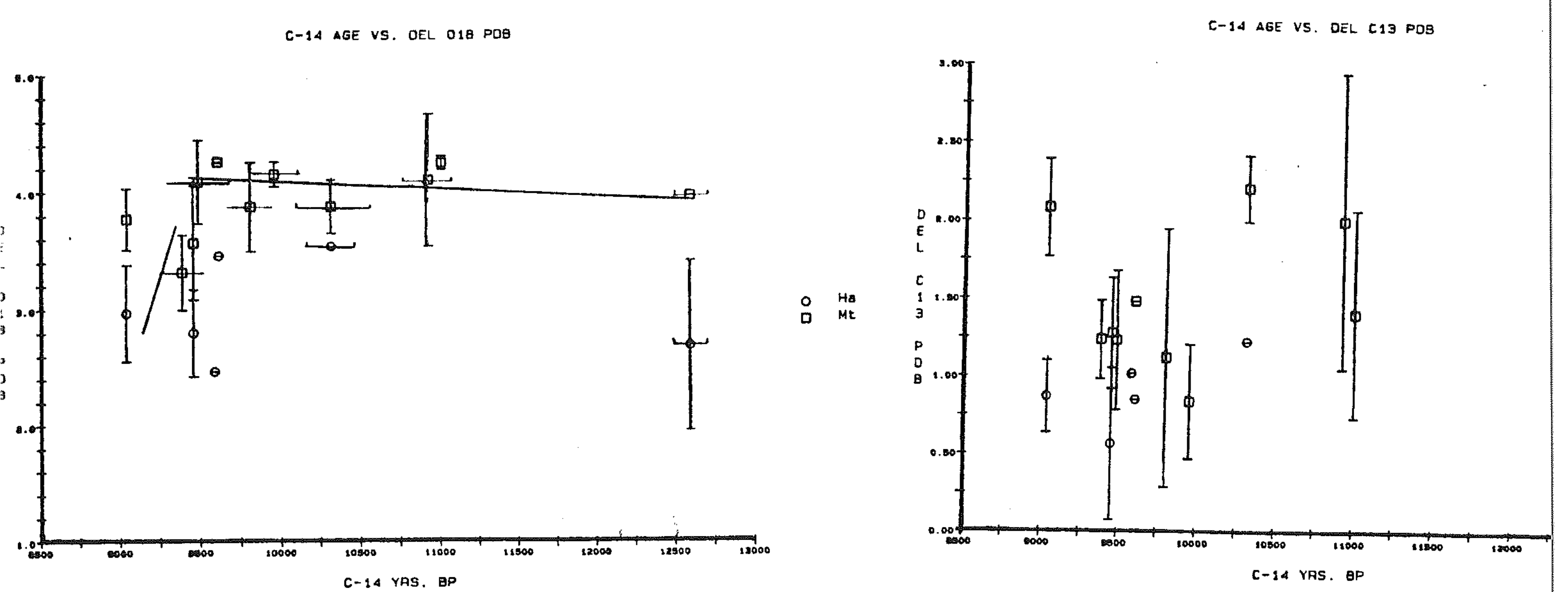


Figure 2

DINOFLAGELLATE AND POLLEN STRATIGRAPHY IN EASTERN CANADA WITH SPECIAL EMPHASIS ON THE MIDDLE WISCONSINAN EPISODE

A. de Vernal and C. Hillaire-Marcel
GEOTOP, département des Sciences de la Terre, Université du Québec à Montréal, C.P. 8888, Montréal, Québec, H3C3P8

The Middle Wisconsinan episode is characterized in Eastern Canada by interstadial conditions and a reduced ice volume. In Atlantic Canada the palynology of several deposits (fig. 1: 1) has revealed alternating boreal forest and tundra forest vegetation in a hemiarctic type environment. On the other hand, high relative sea- levels are inferred from diatom and dinocyst assemblages in some of these continental interstadial deposits. These high relative sea-levels are attributed to geoidal adjustments of glacio-isostatic origin, related to the glaciation of neighboring regions.

The existence of cool conditions at the margin of glaciated areas is probably linked to the ocean circulation patterns present at that time. The persistence of the temperate North Atlantic drift is suggested by the dominance of *Impagidinium* species in deep sea sediments from the Southern edge of the Labrador Sea (fig. 1: 2; fig. 2).

Near the Southern Greenland margin (fig. 1: 3; fig. 3) a few temperate dinoflagellate species (*Impagidinium* spp., *Nematoshaeropsis labyrinthea*) indicate a slight contribution of the North Atlantic drift to the West Greenland current. However, low salinity and low temperature species (*Brigantedinium simplex*, *Multispinula minuta*) dominate largely the dinocyst assemblages, thus indicating abundant meltwater inputs. The erratic character of dinocyst curves suggest unstable surface-water conditions and probable discontinuities in the meltwater discharge. A relatively high pollen content dominated by herbaceous taxa indicates the presence of interstadial conditions and the extension of a tundra type vegetation in the source area, which is probably the Southern Labrador coast (the source is inferred from the Holocene palynostratigraphy).

No major indicators of subarctic water inputs have been observed from the dinoflagellate records of Baffin Bay deposits (fig. 1: 4,5; fig. 4). Only a few pics of the arctic species *Multispinula minuta* with some *Brigantedinium simplex* are present in the dinocyst records. Dinocyst concentrations are very discontinuous. Their productivity and deposition may be linked to variations in the sedimentation rate, changes in the sea ice cover or the influence of meltwater inputs . The grain-size distribution as well as the $^{18}O/^{16}O$ ratios in foraminiferas (*cf.* Aksu, 1980) also respond to the strongly changing paleoenvironmental conditions. Furthermore, the abundance of reworked prequaternary palynomorphs in the sediments indicates high erosion rates.

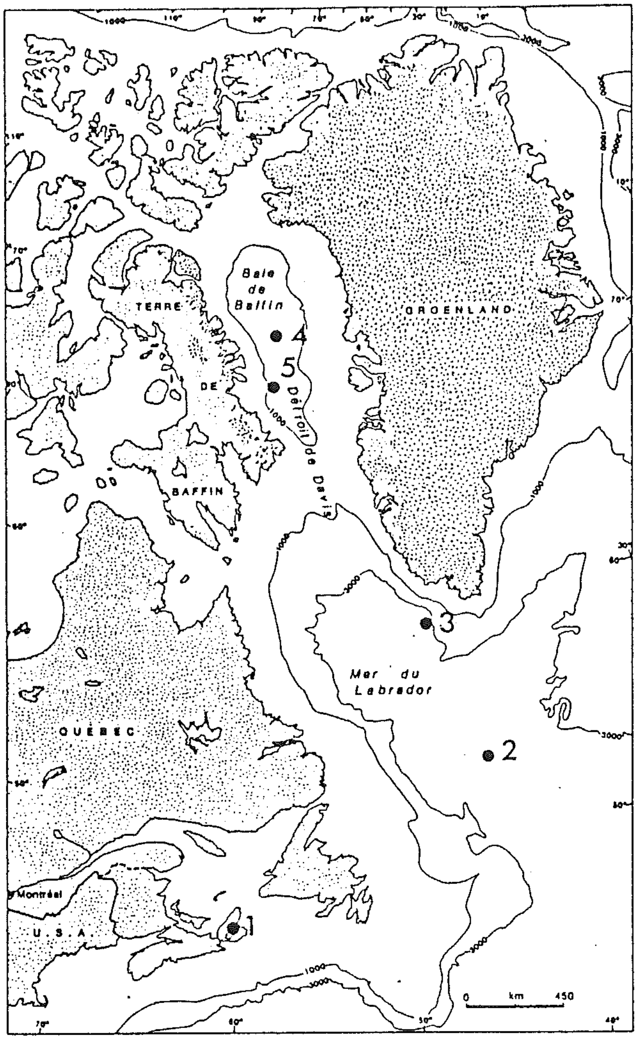


Figure 1.

1. Castle Bay and East Bay sections.
2. 84-030-003
3. HU-75-37
4. 76-029-033
5. 77-027-013

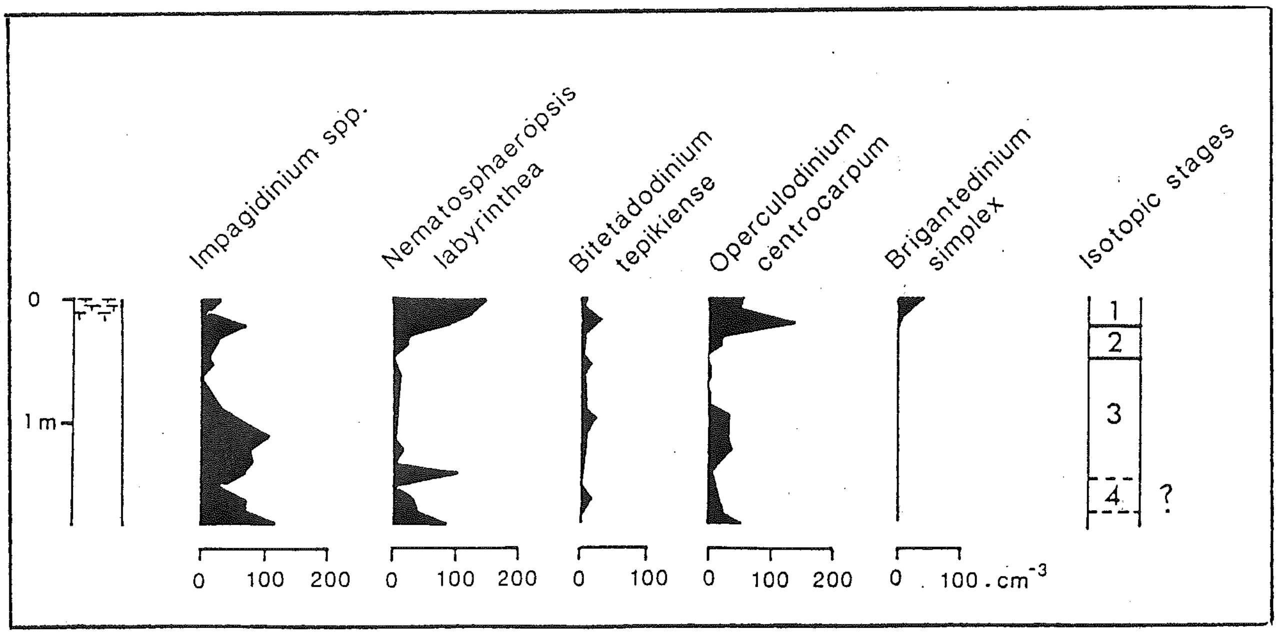


Figure 2. 84-030-003 TWC: Dinocyst concentrations

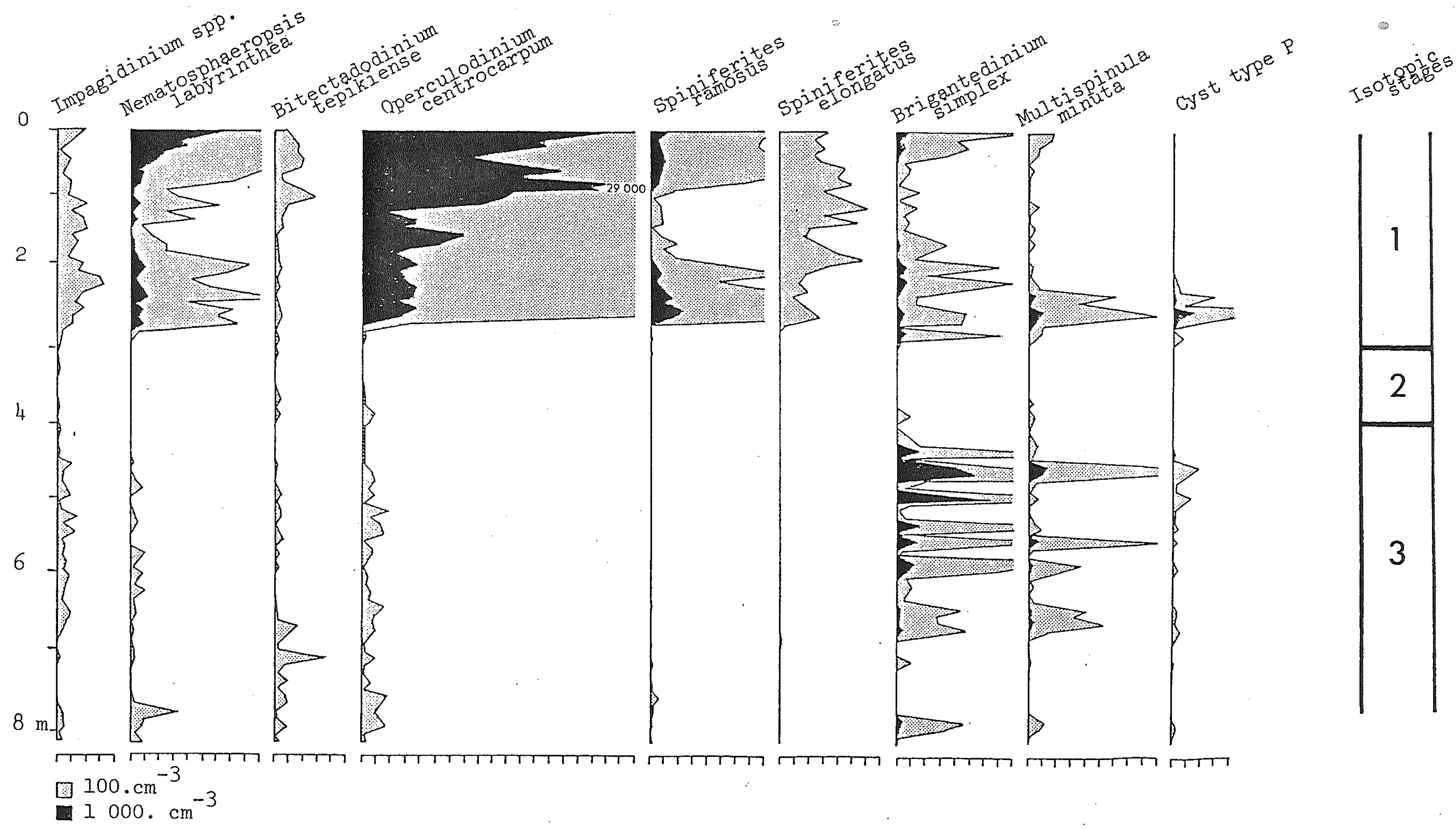
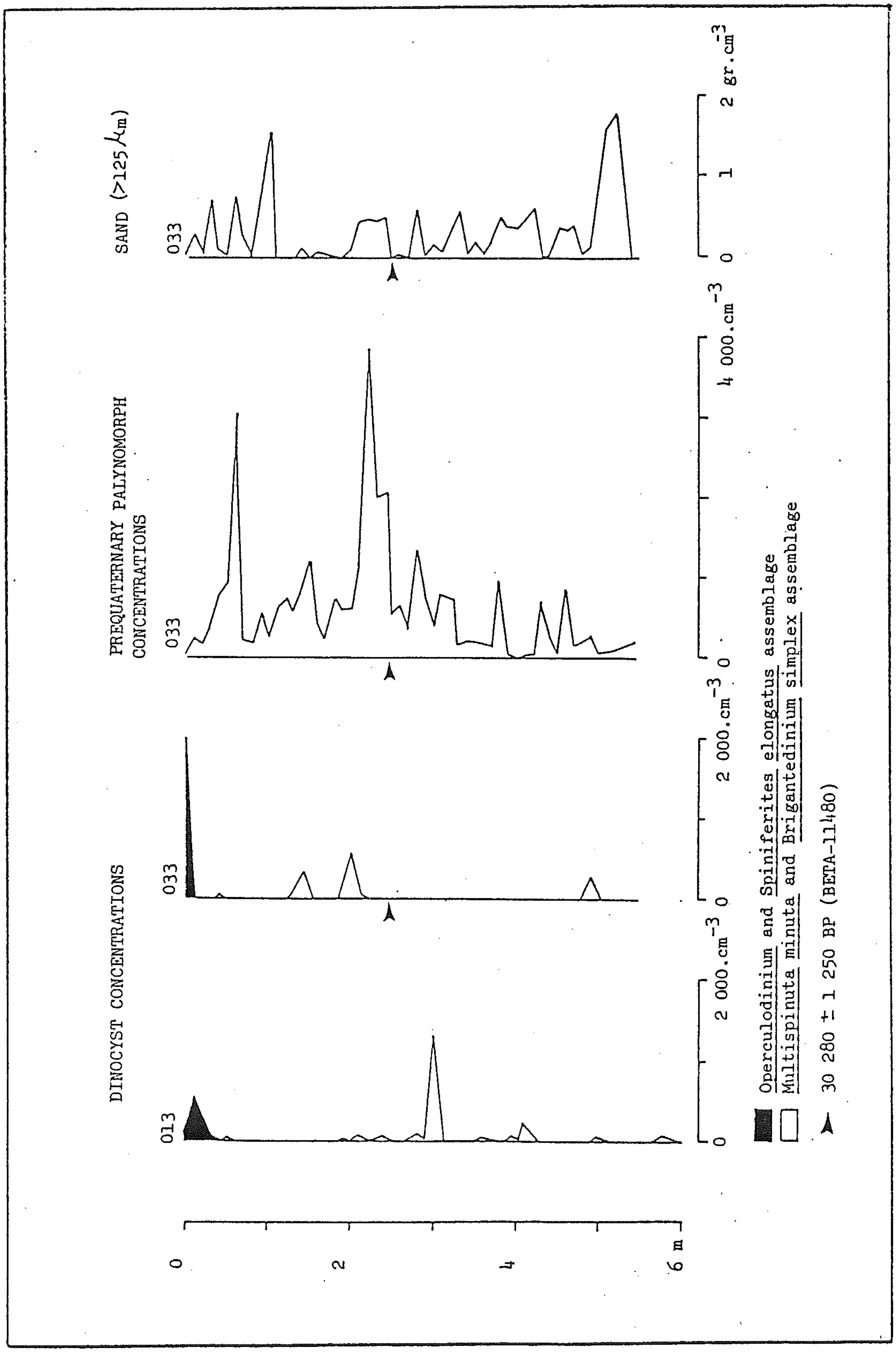


Figure 3. HU-75-37: Dinocyst concentrations



DINOCYST CONCENTRATIONS
PREQUATERNARY PALYNOMORPH CONCENTRATIONS
SAND (>125 μm)
013
033
033
033
0
2
4
6 m
0
2 000.cm-3
0
2 000.cm-3
0
4 000.cm-3
0
1
2 gr.cm-3
Operculodinium and Spiniferites elongatus assemblage
Multispinuta minuta and Brigantedinium simplex assemblage
30 280 ± 1 250 BP (BETA-11480)

Figure 4.

Animal-Sediment Relationships on an Arctic Tidal Flat: Pangnirtung, Baffin Island, NWT.

Aitken, Alec E.,[1] M. J. Risk[1] and J. D. Howard[2]
[1]Department of Geology, McMaster University, Hamilton, Ontario, L8S 4M1
[2]Skidaway Institute of Oceanography, Post Office Box 13687 Savannah, Georgia, USA 31406

The intertidal flats at Pangnirtung are among the best-developed such flats in the Arctic. An inner gravel and boulder beach grades out into sand flats, then muddy sands and sandy muds, then finally an outer boulder barricade. Benthic organisms are abundant throughout the flats. The inner, sandy areas are dominated by the large infaunal lugworm, *Arenicola*, and the muddier areas by the bivalve *Macoma balthica* (which may reach population densities of several thousand $\cdot$ m^{-1}). Another bivalve, *Hiatella arctica*, is abundant in the outer, rocky areas, and the softshell clam (*Mya truncata*) may be found, although densities are very low due to human consumption. Benthic polychaetes are common to abundant. The major species are abundant throughout the temperate and boreal waters of the northern hemisphere.

Several of the benthic organisms, especially *Arenicola*, *Mya*, and *Macoma*, make characteristic traces in the sediment. A Pleistocene outcrop of sandy sediments contained enough characteristic traces to allow us to determine that the sediments had been laid down in an intertidal environment.

Experiments on the modern flat using tracers layers and box cores showed that, in summer, the biogenic rate of sediment overturning was very high, faster than some temperature areas.

Such Arctic sediments, in outcrop, may differ only subtly from their equivalents in other latitudes. We suggest that these sediments, relative to temperate tidal flat sediments, exhibit more evidence of ice effects and fewer channels. Biologically, *Macoma* crawling traces are much more common, and evidence of predation less pronounced.

Comparison of Modern and Subfossil *Mya Truncata* from Pangnirtung, N.W.T.

Aitken, A.E. and M.J. Risk, Department of Geology
McMaster University, Hamilton, Ontario
L8S 4M1

Abstract

A preliminary investigation of modern and subfossil *Mya truncata* L. from Pangnirtung Fiord, Baffin Island, N.W.T. indicates that the longevity of this species may exceed 20 years. Age estimates are based on growth increment counts made from thin sections. Annual growth increments in *Mya truncata* are defined by alternating opaque and translucent bands within the chondrophore of the shell. Counts made in the umbonal region of the inner shell layer and beside the ligament pit of the chondrophore are more reliable than counts based on external growth ridges. This situation is particularly true in subfossil specimens due to the loss of the periostracum and subsequent corrosion of the valves.

Subfossil specimens grow more slowly than modern specimens. Subfossil specimens with shell heights of 20-30 mm are 18-20 years old. Modern specimens with shell heights of 20-30 mm are 13-15 years old. Subfossil and modern specimens also exhibit morphological differences. Modern specimens are more elongated, less inflated, and have deeper pallial sinuses and thinner shells than subfossil specimens. Differences in growth and morphology between modern and subfossil specimens may be related to the substrate in which the bivalves live; *Mya* grow faster and have thinner shells in sandy substrates than in muddy substrates.

Use of Stable Isotopes of Carbon and Nitrogen to Assess Importance of Terrestrial Detritus to a Marine Food Web: Intertidal Flats at Pangnirtung, Baffin Island, NWT.

Magwood, James P., M. J. Risk and H. P. Schwarcz
Department of Geology, McMaster University
Hamilton, Ontario, L8S 4M1

Assessing the importance of various food sources to marine ecosystems is very difficult, usually employing approximate methodology within a vague theoretical framework, and hampered by the episodic nature of most field work (especially that in the Arctic). Recently, there has been an upsurge in the use of stable isotopes as natural tracers than allow discrimination between terrestrial and marine sources. This paper is abstracted from a larger body of research involving food chains in Arctic, temperate and tropical estuaries, in which multi-isotope tracing methods are being used to determine the relative importance of terrestrial organic detritus. The focus is on bivalves, because of their ubiquity and general importance. We have analyzed the flesh, and also devised a method of extracting the organic matrix from the shell. The advantages of analyzing the organic matrix are: 1) variances are generally lower than for flesh analyses; 2) matrix values give long term estimates of dietary preference; and 3) it is possible to reconstruct fossil food chains.

Samples of the bivalves Macoma balthica and Hiatella arctica, ambient sediment, SPM, benthic algae and nearby plants were collected in July from intertidal flats at Pangnirtung, NWT. The clam flesh, shell matrix (EDTA insoluble fraction) and other samples were analyzed for isotopes of C and N. The results show that terrestrial organic matter is an important component of the nutrition of this marine ecosystem -- in fact, terrestrial carbon is more important to this Arctic tidal flat than it is to a similar tidal flat in Nova Scotia (Le Blanc & Risk, 1985). Shell matrix analyses consistently differ from flesh analyses, indicating either isotopic fractionation or a late-summer shift to seaweed detritus as a food source.

From the point of view of food-chain dynamics, it seems that Arctic development projects should consider the nearshore marine ecosystem to be linked to the land.

PHYSICAL AND BIOLOGICAL ZONATION OF INTERTIDAL FLATS AT FROBISHER BAY, N.W.T.

Janis E. Dale
Department of Geography, Queen's University
Kingston, Ontario, K7L 3N6

The interaction of biological and physical processes has produced distinct morphological and biological zonation across the intertidal flats at Frobisher Bay, N.W.T. Tidal, ice and wave action appear to be the three dominant processes acting upon the intertidal flats. Tides are semi-diurnal with a mean tidal height of 7.8 m ALLT (above lowest, low tide) and large tides up to 11.6 m ALLT. Exposure indices generated from tidal data reveal two critical heights at 5 and 7.5 m ALLT where the frequency and duration of exposure varies abruptly. Both ebb and flood dominant bedforms are evident. Ebb conditions generate the highest instantaneous velocities over the tidal flats, but average flood tide velocities are higher. Ice action during freezeup and breakup removes and transports sediment, boulders and fauna across the flats, thereby disrupting tidal and wave generated zonation.

Sedimentological and morphological characteristics found along transects across the tidal flats from high to low tide levels indicate a six-fold zonation based on sediment and boulder distribution, bedforms, drainage patterns and tidal height (Fig. 1). The six zones include the upper flat located above 5 m ALLT which is subdivided into beach and finer flat zones. The middle flats area includes three zones: the bouldery flat, very bouldery flat, and boulder ridges, while the lower flat is one unit of graded flat. Evidence from maps and air photographs suggests this classification also applies to other arctic areas having intertidal flats.

Floral and faunal communities correspond to the critical tidal heights noted above, so that three biological communities are recognised. The upper flat lies between 5.2 and 8.5 m ALLT and is subject to greater than 70% exposure when ice free. Two macroalgae, <u>Fucus evanescens</u> and <u>F. vesiculosus</u>, and two fauna, <u>Littorina saxatilis</u> and <u>Scolelepis</u> sp., inhabit this zone. Both the algae and <u>Littorina</u> appear to be ice and freshwater tolerant. <u>Scolelepis</u> is an annual species which recolonizes the upper flats each year after the ice has melted where it reaches densities of 727 animals per 100 square centimetres.

The middle flats can be subdivided into two sections based on faunal motility. The upper section extends from 4.5 to 5.2 m ALLT and has 40 to 70% exposure. Four additional species appear in this zone. <u>Etone flava</u> and <u>E. longa</u> are relatively motile. <u>Balanus balanoides</u> is tolerant of freshwater influxes, the presence of ice and high exposure. From 2.5 m to 4.5 m ALLT more perennial sedentary infauna appear such as

Tealia sp. Spionids recolonize this area each year, whereas Phyllodoce sp. is as motile as the Etone. This zone contains the most shoreward occurrence of the infaunal bivalve, Mya truncata, which inhabits burrows up to 26 cm in depth where it descends to escape unfavourable surface conditions.

The greatest diversity of flora and fauna occurs below 2.2 m ALLT where the exposure rating is below 10%. Many of the species are perennial, intolerant of freezing temperatures and low salinity. Ten faunal species reach densities of 2.75 animals per square metre in the lowest intertidal zone. Numerous species of macroalgae, tubiculous polychaetes and molluscs were found to inhabit this lower zone exclusively.

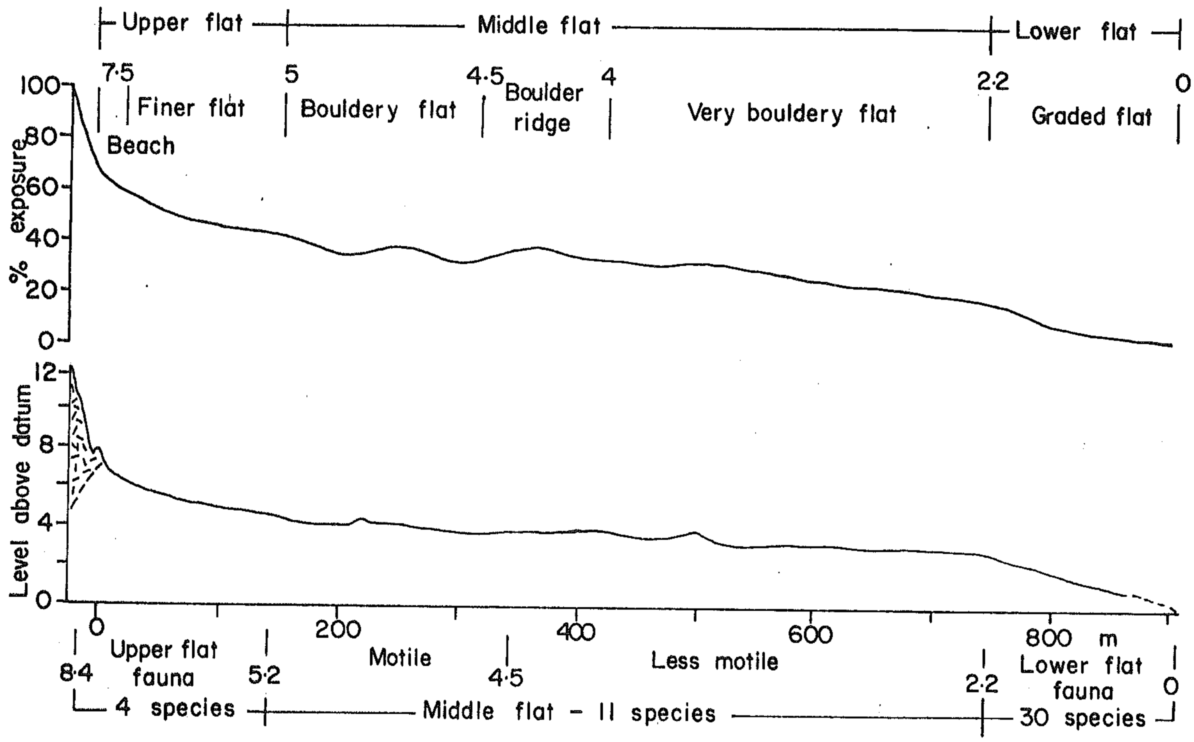


Fig. 1. Morphological and biological zonation of intertidal flats at Frobisher Bay.

POSTER ABSTRACTS

MAGNETIC SUSCEPTIBILITY, BAFFIN ISLAND FIORD CORES

J.T. Andrews
INSTARR and Department of Geologival Sciences,
University of Colorado, Boulder, CO 80309

Volume magnetic susceptibility is a rapid and non-destructive method of logging downcore variations in grain-size and mineralogy. As parat of the S.A.F.E. project we have measured this parameter on 18 Lehigh cores (1.5-3.0m in length) and 16 piston cores (2.5 to 11.0m) at intervals between 2 and 40 cm. Most information is gained from close sampling (2cm), an analysis of the resultant distance-series, and a comparison of the log with x-radiography. Variations in downcore volume susceptibility reflect: 1) changes in dry volume density; 2) changes in grain size; 3) changes in the concentration of minerals such as magnetite; and 4) changes in the sediment source (this latter is associated with changes in either #3 or #2 above). Of these causes, #1 can be partly eliminated by detrending the series or by applying a correction factor based on our analysis of downcore variations in dry volume density. Volume and specific susceptibility vary drastically between the northern fiords (Cambridge,Clarke) and those entering Home Bay with values typically 40 and 5x10-8 SI units respectively. Coefficients of variability, a measure of sample to sample variations, range between 20 and 99% in piston cores and reflect differences in the style and sedimentation.

DISTRIBUTION OF OSTRACODES IN CHESTERFIELD INLET, NORTHWESTERN HUDSON BAY, CANADA

William M. Briggs, Jr., Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado, 80309, U. S. A.

The modern ostracodes of Chesterfield Inlet, an arctic estuary have been investigated. Except for the unidentified ostracode taxa reported in station lists from Hudson Bay (Leslie, 1963, 1965), this study represents the first detailed analysis of ostracodes from the Hudson Bay area.

Chesterfield Inlet is a 200 km-long estuary, from its mouth on the northwestern coast of Hudson Bay, near the village of Chesterfield Inlet, to Chesterfield Narrows, its western terminus east of Baker Lake. Depths range from 110 m at its mouth to 6 m at Chesterfield Narrows. Bottom temperatures and salinities range from ~2 degrees C and ~32 ppt salinity at the entrance to Hudson Bay, to 6 degrees C and 2-3 ppt salinity near the mouth of the Quoich River, some 160 km distant.

The marine and brackishwater ostracodes of Chesterfield Inlet comprise fourty-nine podocopids (29 genera), two myodocopids and one cladocopid. The ostracode fauna is of the frigid climate type (Arctic Biogeographic Province) and is most similar to the ostracode fauna of Novaya Zemlya, with 80% of the species common to both areas.

Salinity is the most common factor affecting the distribution of ostracodes in the inlet. The greatest numbers of species and specimens occur near the mouth of the inlet; these fall off rapidly with decreasing values of salinity in the lower reaches of the inlet. *Baffinicythere howei* Hazel, *Normanicythere leioderma* (Norman), *Elofsonella concinna* (Jones), *E. neoconcinna* Bassiouni, *Sarsicytheridea bradii* (Norman) and *Sarsicytheridea punctillata* (Brady) dominate the faunas in the deeper parts of the lower reaches of the inlet, whereas at depths of <10 m, *Cythere lutea* O. F. Mueller, *Hemicythere borealis* (Sars) and, to a lesser degreee, *Baffinicythere emarginata* (Sars), dominate. This suggests that depth may play a role in influencing the distribution of some species. There is a dramatic decrease in species and numbers of ostracodes below salinity values of ~27-28 ppt, corresponding approximately to the juncture between lower and middle reaches of the inlet.

In the middle reaches of the inlet, where salinities vary between 27-13 ppt, ostracodes are infrequent or absent at sampled sites, with marine forms rare, limited mainly to euryhaline small numbers of *Sarsicytheridea bradii*, *S. punctillata*, very rare *Paracyprideis fennica* (Hirschmann) and the appearance in the upper middle reaches of the brackishwater *Cytheromorpha macchesneyi* (Brady and Crosskey). The latter species is usually associated with the foraminifer *Trochaminna rotaliformis* Wright.

In the upper reaches of the inlet bottom salinities vary between 12-0.37 ppt. Ostracodes are infrequent in this region of the inlet, usually limited to monotypic populations of Cytheromorpha macchesneyi and Trochaminna rotaliformis. A living association of freshwater Candona sp. and Cytheromorpha macchesneyi occurs at several sites in which salinity values are ~2-3 ppt. For example, these taxa were found together in 14 m of water, with bottom temperature and salinity values of 5.73 degrees C and 1.98 ppt, respectively.

The association of Candona and Cytheromorpha macchesneyi in waters with salinity values of between 2-3 ppt has important implications in paleoenvironmental interpretations, based on ostracodes, during the Quaternary. Cronin (1977) suggested a similar association of Cytheromorpha macchesneyi and freshwater species, based on a study of the ostracodes from Quaternary Champlain Sea deposits.

I thank W. P. Budgell, N. Freeman, N. Watson and D. J. Brooks, Ocean and Aquatic Sciences, Department of Fisheries and Oceans, Central Region, Burlington, Ontario, the officers, crew and scientific support personnel of M/V PETREL V. for their cooperation in the project. My participation in the 1978 Chesterfield Inlet Oceanographic Survey was made possible through a grant by the Department of Fisheries and Oceans to Professor J. C. Ritchie, Life Sciences, Scarborough College, University of Toronto, West Hill, Ontario.

References Cited

Cronin, T. M., 1974, Late-Wisconsin marine environments of the Champlain Valley (New York, Quebec). Quaternary Research 7, 238-253.

Leslie, R. J., 1963, Foraminiferal study of a cross-section of Hudson Bay, Canada. Geological Survey of Canada Paper 63-16, 28 pp.

Leslie, R. J., 1965, Ecology and paleoecology of Hudson Bay foraminifera. Bedford Institute of Oceanography Report 65-6, 192 pp.

Geomorphology of slope instability features, Kitimat Arm, Squamish Harbour and Britiannia Beach, British Columbia

by

Brian D. Bornhold
Geological Survey of Canada
Pacific Geoscience Centre
Sidney, British Columbia

and

David B. Prior
Coastal Studies Institute
Louisiana State University
Baton Rouge, Louisiana

The results of high resolution side scan sonar, 3.5 kHz subbottom profiles, coring and submersible observations are presented for three locations in British Columbia fjords where subaqueous slope instability processes have been recognised.

At the head of Kitimat Arm a major slope failure took place in 1975 involving a debris flow of cohesive muds, covering an area of the sea floor of 6.8 km^2, with a total volume of disturbed sediment of 55,000,000 m^3 (Prior et al., 1982a, b, 1984). Maps, block diagrams (Fig. 1) and examples of data are used to show the principal morphological elements of the debris flow. These include scarps 10-15 m in height near the head of the debris flow; compressional ridges and longitudinal shear patterns in the main body of the flow; well-developed depositional lobes with rugged surface relief; and outrunner blocks which are deposited beyond the toe of the flow by block gliding.

At Squamish Harbour (head of Howe Sound) the sand and silt-rich sediments comprising the Squamish delta front show evidence of several different modes of slope failure and sediment movement (Fig. 2). There are deeply-incised channels on the upper delta-front slopes which are shear-bounded and contain irregularly-shaped displaced blocks. The uppermost channel margins display extensive dendritic erosional gullying. The middle and lower delta front is heavily disturbed by shallow succesive rotational sliding which results in widespread scarp and block patterns. In the fjord floor beyond the delta the bottom morphology is broadly undulating with low relief hummocks and shallow, shear-bounded channels associated with acoustically opaque or poorly-stratified sediments.

Fjord-side fan deltas, such as Britannia Beach (Fig. 3) and Woodfibre (Fig. 2) show somewhat different bottom features also believed to be due to mass-movement processes (Prior and Bornhold - in press). Delta front chutes occur in the steep underwater fan slopes, partially filled with radiating splays of coarse-grained sediments apparently transported downslope across the fan by coarse-grained debris flows. Arcuate scarp patterns on the lower flanks of the fan delta cone at Britannia Beach represent shallow successive rotational slides, with numerous local displacements of individual blocks and slabs of sediment. Blocky, ridged depositional areas occur near the base of the fan-deltas, with little evidence of associated long-distance mass movement further down-fjord.

The poster display summarises the results of detailed large-scale mapping presented in various Geological Survey of Canada Open File Reports (Prior et al., 1983; Prior and Bornhold, 1984a,b).

References

Prior, D. B., Bornhold, B. D., and Coleman, J. M. and Bryant, W. R. (1982a). Morphology of a submarine slide, Kitimat Arm British Columbia: Geology vol. 10, p. 588-592

Prior, D. B., Coleman, J. M. and Bornhold, B. D. (1982b). Results of a known sea floor instability event: GeoMarine Letters, vol. 2, p. 117-122.

Prior, D. B., Bornhold, B. D. and Coleman, J. M. (1983) Geomorphology of a submarine landslide, Kitimat Arm, British Columbia: Geological Survey of Canada, Open File Report 5.

Prior, D. B., Bornhold, B. D. and Johns, M. W. (1984). Depositional characteristics of a submarine debris flow: Journal of Geology, vol. 92, p. 707-727.

Prior, D. B. and Bornhold, B. D. (in press). Sediment transport on subaqueous fan delta slopes, Britannia Beach, British Columbia: GeoMarine Letters.

Prior, D. B. and Bornhold (1984). Geomorphology of slope instability features, Squamish Harbour, Howe Sound, British Columbia: Geological Survey of Canada, Open File Report 1095.

Prior, D. B. and Bornhold, B. D. (1984). Subaqueous delta morphology, Britannia Beach, Howe Sound: Geological Survey of Canada, Open File Report 1096.

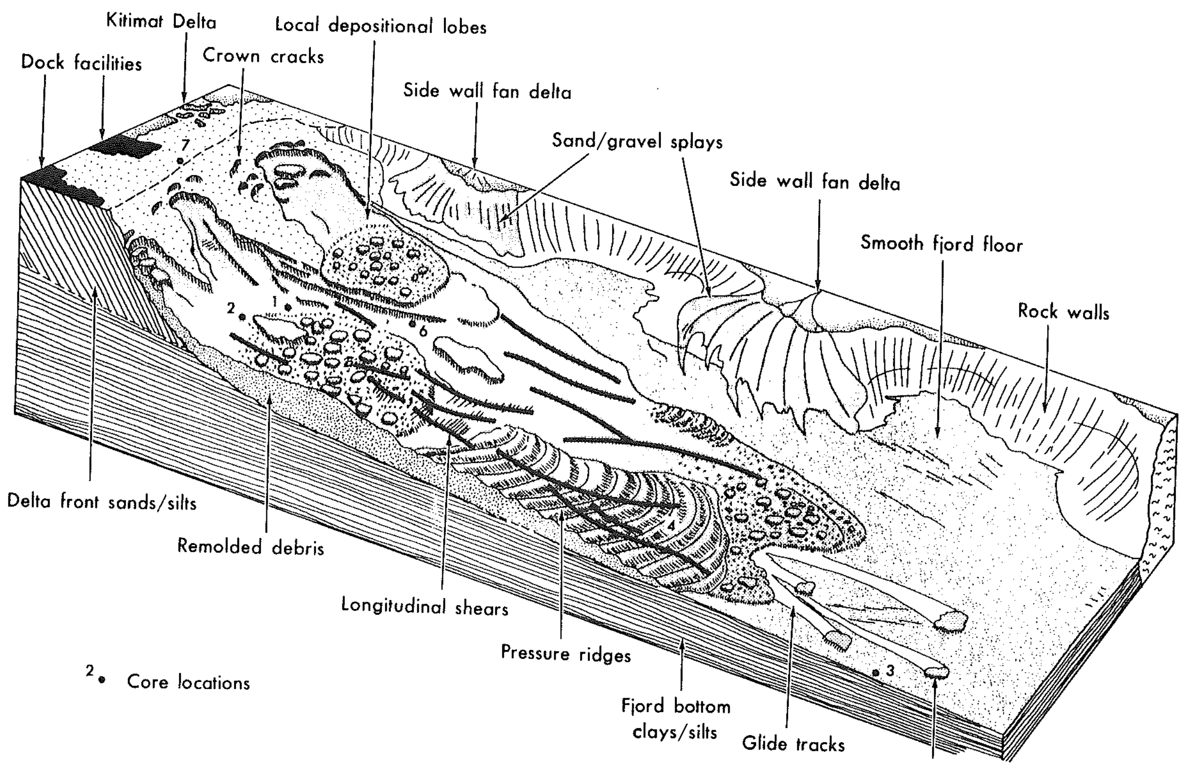


Figure 1. Schematic illustration of the morphology of the sea floor near the Kitimat Delta.

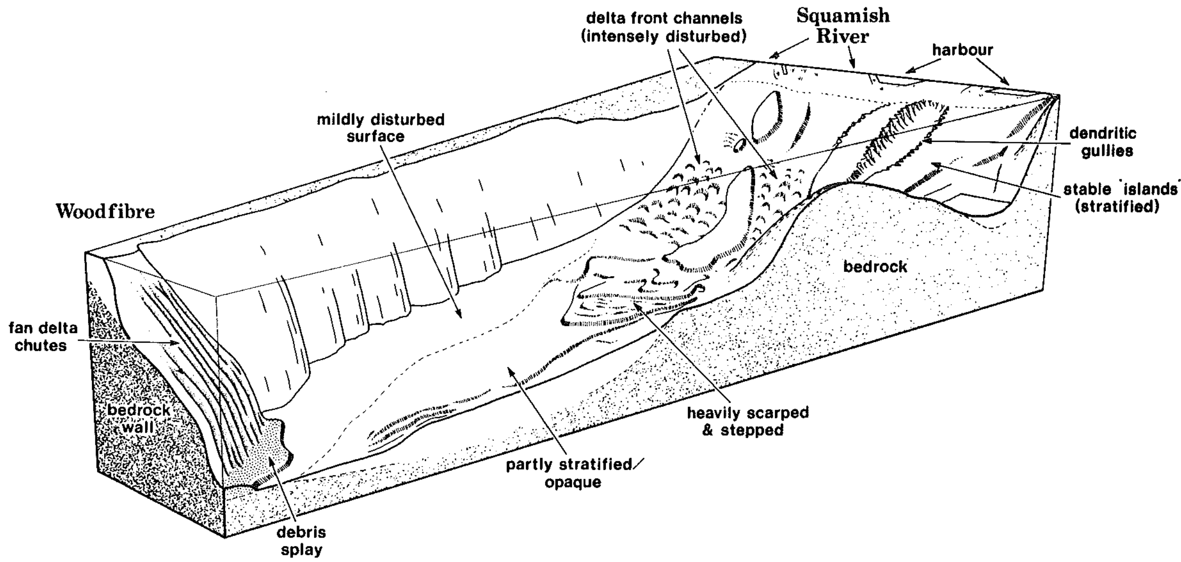


Figure 2. Schematic illustration of the morphology of the sea floor near the Squamish delta.

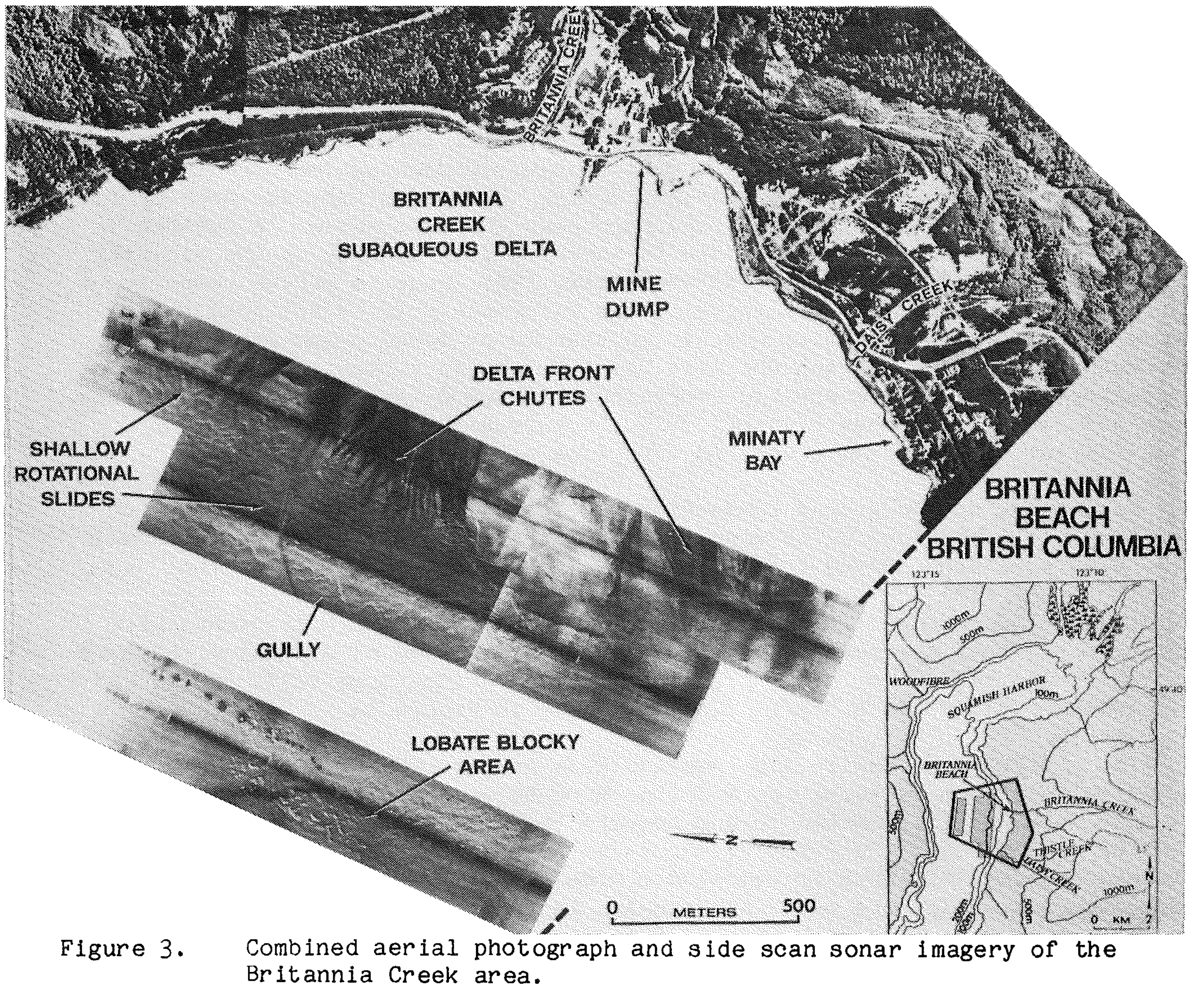


Figure 3. Combined aerial photograph and side scan sonar imagery of the Britannia Creek area.

Thermal Observations of Permafrost Growth at the Illisarvik Drained Lake Site, Richards Island, Mackenzie Delta, N.W.T.

M.M. Burgess, A.S. Judge, A.E. Taylor and V.S. Allen
Earth Physics Branch, Energy, Mines & Resources
1 Observatory Crescent, Ottawa, Canada

In August 1978, "Illisarvik Lake", located on a peninsula of northern Richards Island in the Mackenzie Delta, N.W.T. (Figure 1) and on the verge of self-drainage by natural shoreline erosion, was artificially drained. The Illisarvik experiment, proposed by Dr. J.R. Mackay, is a unique long term investigation of permafrost growth under full scale natural conditions. The predrainage lake measured some 300 x 600 m, was 45 m from the sea coast at its closest point, with a mean lake surface 7 m above sea level and maximum water depths of 4.5 m. The freezeback of the thaw-bulb (talik) beneath the lake bed and associated permafrost processes (redistribution of moisture, ice segregation and frost heave, active layer growth, ice-wedge cracking) have been the subject of ongoing multidisciplinary research, undertaken in large part by Dr. Mackay. The Earth Physics Branch (EPB) of Energy, Mines and Resources has been a principal participant through its investigations of the ground thermal regime.

Geothermal investigations focus on the monitoring of ground temperature cables, installed in hydraulically drilled boreholes in the lake bottom and surrounding shore, to delineate predrainage and postdrainage thermal conditions. Ten (10) cables were installed in April 1978 and 4 cables in August 1978, prior to drainage. In summer 1979, 10 more cables were installed to replace those which had been damaged during the predrainage ice-breakup in spring 1978, and to increase data coverage near the lake shore. A further 9 cables were installed in summer 1981 to increase data density in the vicinity of the warmest and deepest part of the talik. The location of the temperature cables is shown in Figure 2 along with the reference grid established for the study. On average the cables contain 10 thermistor sensors and extend to depths of 20 to 30 m beneath the lake bed. Of the 33 cables installed by EPB, approximately half are currently operational. Ground temperature measurements have been acquired whenever practicable, in general 3-4 times a year, and compiled into a continually updated data file.

Monitoring of the ground temperature cables prior to drainage delineated a bow-shaped talik extending to some 32 m beneath the lake bottom. Mean annual ground temperatures ranged from +3°C in the lake centre, to -3°C at the lakeshore and -7°C 250 m inland. In the deeper central part of the lake temperatures were negative beneath the talik, and temperature gradients were negative (down to the maximum depth of measurement of 90 m) averaging -50 mK/m within the permafrost section. The shape of the predrainage talik and ground temperatures along the N-S grid line are shown in Figure 3a.

The postdrainage monitoring revealed that by September 1984, 6 years after drainage, all sensors along the N-S line were below 0°C (Figure 3b) and hence permafrost by definition had formed beneath the lake bed. However there remains a large zone where temperatures are between -0.5°C and 0°C, e.g. on the N-S section this area is over 100 m wide and 15-20 m in depth, and ground temperature profiles are near isothermal. In this zone pore waters are likely in the liquid state due to a gradual freezing point depression resulting from the increasing pressure generated by the freezeback of the talik. There is thus a core zone where latent heat of freezing remains to be liberated and permafrost processes are very dynamic.

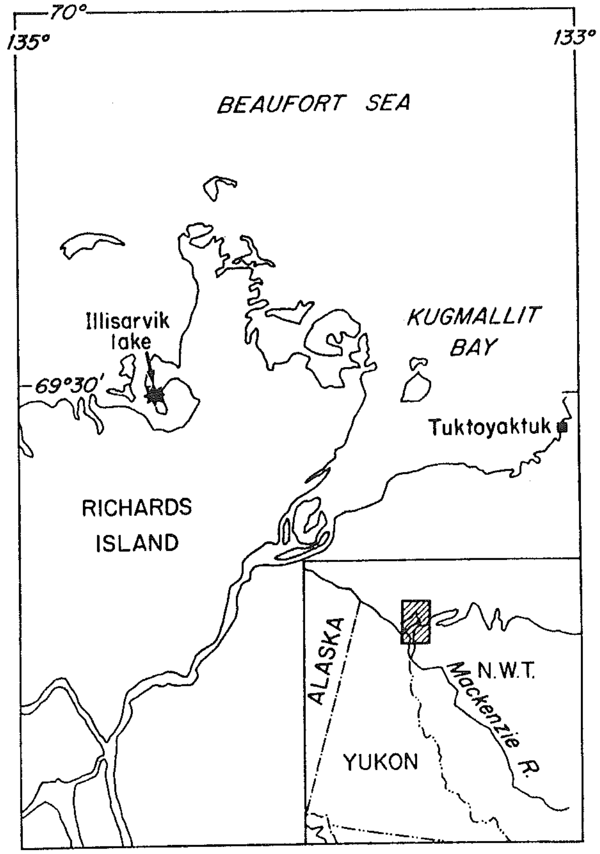


Figure 1. Location map

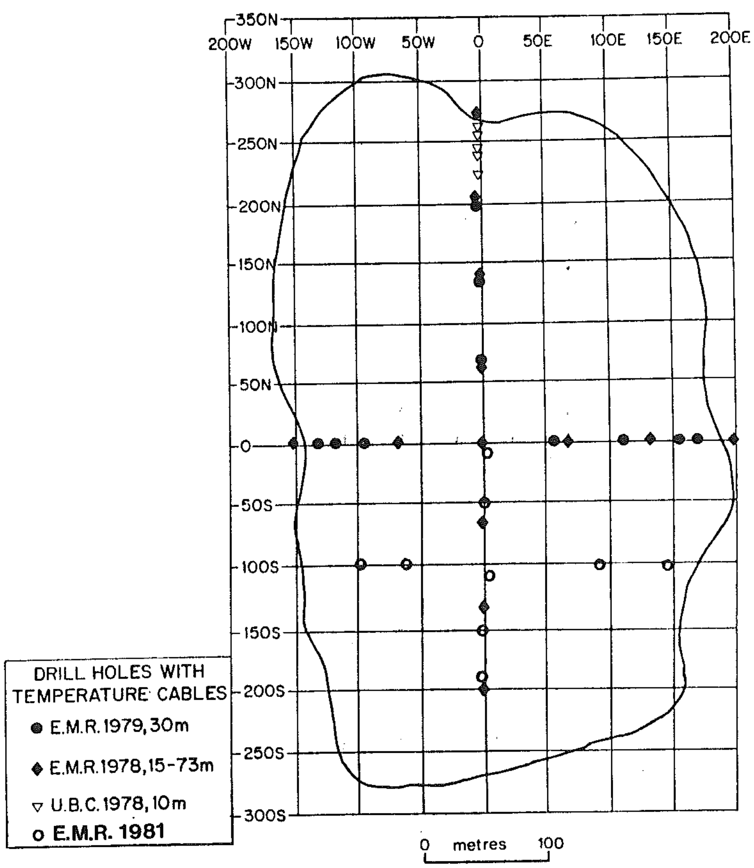


Figure 2. Temperature cable locations

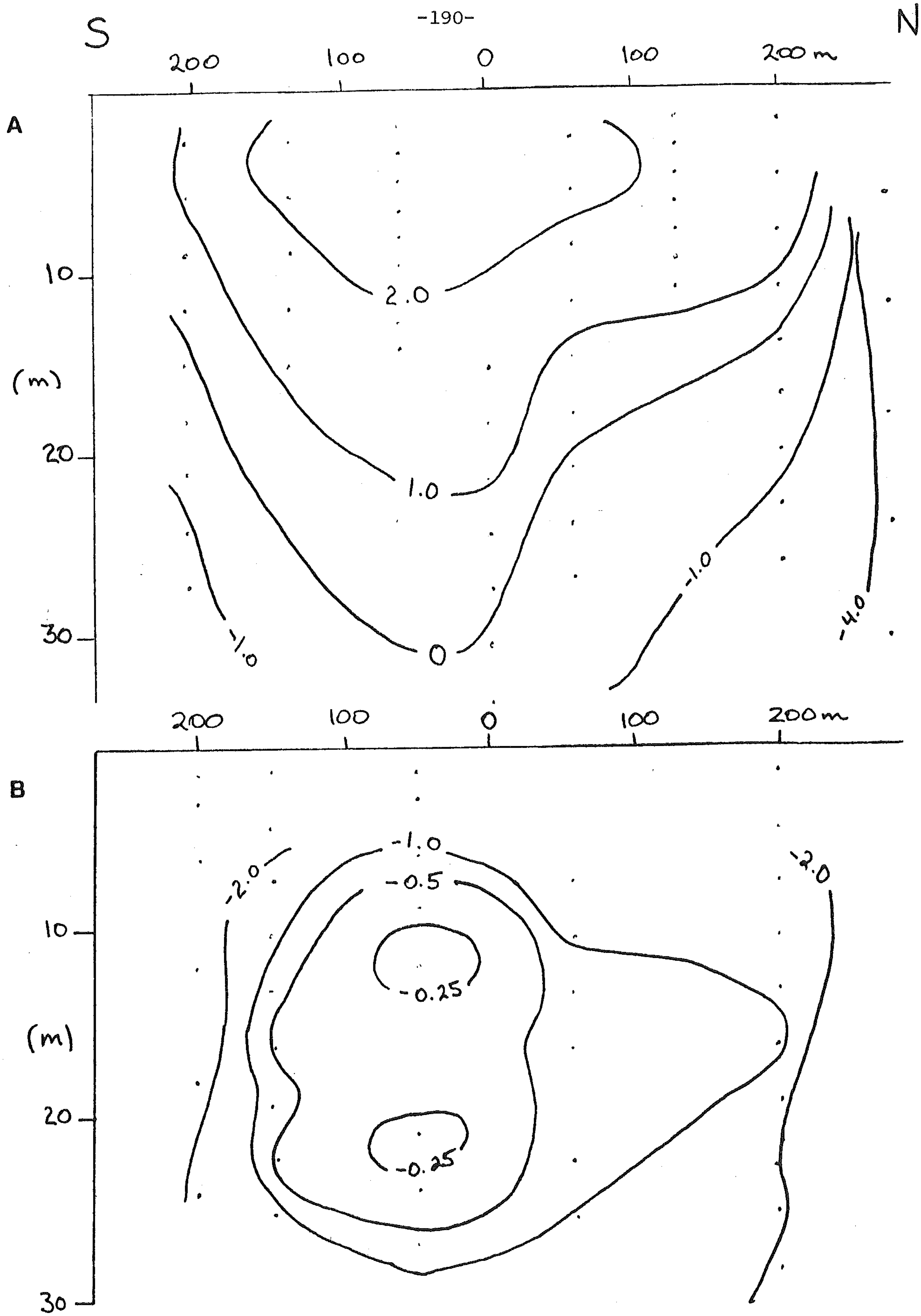


Figure 3. North-South isothermal cross section
a) 1978, predrainage b) 1984, 6 years postdrainage

Permafrost Aggradation in the Tidal Zone, Churchill, Manitoba

Larry Dyke
Department of Geological Sciences
Queen's University
Kingston, Ontario K7L 3N6

Permafrost along shorelines is characteristicly at a temperature not far below freezing. In this condition ice-bonded material is sensitive to surface disturbance and may not provide the firm foundation properties associated with colder permafrost. Emergence of permafrost-free sea or river bottom may favour relatively wide zones of warm permafrost. The temperature in this zone would depend on an interplay between the rate of emergence, the topographic profile of the coast, and the climate. Rapid emergence and a shallowly sloping coast would favour the widest zone of permafrost not yet at thermal equilibrium with the prevailing climate. A relatively warm climate (as associated with the discontinuous permafrost zone) would contribute to the extensiveness of warm permafrost on the coast.

The Arctic coast of Canada shows great variation in all of the factors considered important in determining the distribution and properties of coastal permafrost. The subsea sediments adjacent to inactive parts of the Mackenzie Delta are thought to be frozen as a result of submergence of permafrost formed during late Wisconsin time. Some off this offshore permafrost is probably being maintained by continued sub-freezing temperatures on the sea bottom. Elsewhere along the Delta thaw has taken place under the influence of Mackenzie River water. Boreholes across the coast of the Tuktoyaktuk Peninsula show permafrost to exist only onshore or where sea ice touches bottom. Further offshore, permafrost is again encountered, suggesting that warming in near-shore shallows has also been sufficient to thaw the submerged permafrost.

The extensive offshore permafrost adjacent to the Mackenzie Delta is probably not typical of arctic coastal conditions. Offshore permafrost does exist elsewhere but has likely aggraded laterally in conjuction with onshore permafrost growth. This lateral aggradation would be most extensive where onshore permafrost is thickest. In a high arctic climate a steep coast would produce the most lateral aggradation because long-emergent land would be located close to the coast, positioning a large thickness of permafrost adjacent to unfrozen sea bottom. Pronounced changes in the nature of permafrost across the tidal zone would only exist for shallowly sloping coasts and large tidal ranges. In a mild permaforst climate most or all of the aggradation would be taking place in the tidal zone. Variations in the present emergence rates would probably not have a significant influence on the nature of tidal zone permafrost because present emergence rates are slow compared with initial rates of downward permafrost growth, even in mild climates.

An attempt to understand the distribution and temperature of permafrost in the tidal zone has been made in the estuary of the Churchill River, Manitoba. It is suspected that permafrost does not exist beneath Hudson Bay but that permafrost begins to form as soon as any point emerges into subaerial conditions capable of producing permafrost. As emergence continues permafrost deepens and a wedge developes that finally equilibrates with the geothermal heat flux. Determining the position and thermal qualities of this wedge is the objective of this study.

Temperature measurements have been taken in boreholes located along a line extending from a set of raised beaches approximately 5 m above extreme high tide to a point in the tidal zone approximately 2m below extreme high tide. The tidal range is 5 m. Temperature measurements over the first year show permafrost to exist in the tidal zone but the measurements were not deep enough nor seaward enough to define the permafrost wedge. The readings do show a zone where permafrost is absent just inland of extreme high tide. This zone coincides with a band of willows parallel to the high tide line. It is possible that snow trapped in this dense foliage presents enough insulation to prevent permafrost development.

To extend this information an electrical conductivity study was made using a Geonics EM 31 electromagnetic conductivity meter. This suvey showed a high conductivity band coincident with the willows and the temperature measurements show no permafrost in this zone. Proceding into the tidal zone, conductivity decreases then increases to reach a constant value about 2 m below extreme high tide. If the conductivity is a function of the thickness of permafrost, then the attainment of a constant conductivity with distance into the estuary may represent the edge of the permafrost wedge. One dimensional heat flow theory was also used to predict the location of the permafrost wedge. The shallowest temperature reading were used to estimate the temperature changes at the ground surface that would be produced by the climate of Churchill at the high tide line. Water temperatures from other arctic rivers were used to estimate temperatures for the low tide line. Intermediate values were interpolated. Using a rate of emergence of 1 m/100 yr, a permafrost wedge 10 m thick at the high tide line and extending out to about 2m below high tide was predicted. The location of this theoretical wedge agrees well with where the conductivity survey would suggest the wedge to be..Temperature measurements were not extensive enough to verify these results but deeper measurements during 1985 may confirm the location of the wedge. An understanding of the nature of coastal permafrost at Churchill may enable its occurrence at other arctic coastal locations to be predicted given the climate, topography, and thermal properties of the coastal materials.

NOVEMBER 6 - 8, 1985

MARINE SAMPLES: DATA BASE MANAGEMENT AND SUPPORTIVE GRAPHICS AT THE ATLANTIC GEOSCIENCE CENTRE

I.A. HARDY and L.E. FISHER*

The Atlantic Geoscience Centre (AGC) a division of the Geological Survey of Canada, through its Program Support Subdivision at the Bedford Institute of Oceanography (BIO), curates, catalogues and publishes indexes of marine geological samples. They are collected by in-house scientists, other laboratories at BIO, Atlantic province universities, consulting and exploration companies. These holdings are available to individuals outside the Institute as well as to AGC staff, through AGC Data Section. This Section is responsible for ensuring that the technical samples and data at AGC are properly curated and for providing usable and effective catalogues and indices to all collected data. Soft sediment marine samples collected on Canadian Oceanographic research vessels from the seabed of the Eastern Canadian offshore, High Arctic and ocean basins are maintained within of a core storage facility with both modern ambient and cold storage warehousing. In this manner all AGC holdings are maintained for future geoscientific study. Plots in several different projections are available in 8 1/2 x 11" format or as large-scale flat bed plotter output on paper or mylar in several colours. Scales, rotations and pole projections can be adjusted to user specifications. Coded symbols can depict sample device type, cruise, station number etc., according to user needs. All incoming field sample data is now routinely listed with the National Geophysical Data Centre in their Marine Core Curators Data Base (in Boulder, Colorado) in exchange for AGC receiving listings on a worldwide basis.

* Fisher Information Systems.

Dispersal Patterns of Specific Heavy Mineral Species and Granule Compositions in Hudson Bay Bottom Sediments

Penny J. Henderson

Geology Department, University of Ottawa,
Ottawa, Ontario K1N 6N5

Terrain Science Division, Geological Survey of Canada,
601 Booth Street, Ottawa, Ontario K1A 0E8

The heavy mineral assemblage and granule (2-6 mm) composition of over 400 archival bottom sediment samples from Hudson Bay, consisting primarily of grab samples and short cores from oceanographic surveys conducted in 1961 (Pelletier and Leslie), 1965 (Pelletier), and 1971 (Sanford and Lewis), has been determined in order to establish provenance of the material. Certain heavy minerals and identifiable rock types within the granule fraction can be related to known outcrops adjacent to and under the bay. Therefore, the dispersal patterns of these specific mineral and pebble types within the bottom sediment have implications for the mode of deposition and the relative sediment contributions from continental glaciation, sea ice rafting, and fluvial sedimentation.

Preliminary studies on the granule (Shilts, 1982) and heavy mineral (Henderson, 1983) fraction from 40 sites sampled by Sanford and Lewis show that some types of pebbles and minerals are most abundant in specific areas of the bay. The distribution pattern is not random and results, most likely, from a combination of different processes. There is a strong suggestion, however, that the overriding influence on sedimentation is Quaternary ice flow. The implication that a large proportion of the samples used in the study are till or sediments derived from till is strengthened by onshore observations of surficial deposits adjacent to the bay deposited below the post-glacial marine limit (Shilts, 1973; Ridler and Shilts, 1974; Vincent, 1977; Skinner, 1973). Since this terrain represents the emerged floor of the bay, it provides insights into the probable nature of the present seafloor.

With additional bottom sediment samples, the dispersal trends are more clearly established and, consequently, the effects of the various sedimentary processes, whether fluvial, marine or glacial, may be assessed. Sediments of glacigenic origin are of particular interest since Hudson Bay is located close to the area of Wisconsin glacial inception. At present controversy exists over the configuration of the Laurentide ice sheet and the existence of an ice dome over Hudson Bay. Dispersal patterns of glacially transported sediments, therefore, may provide evidence of Late Wisconsin ice movements which will put constraints on the interpretation of the glacial history of the area.

References

Henderson, P.J.
1983: A study of the heavy mineral distribution in the bottom sediments of Hudson Bay; in Current Research, Part A, Geological Survey of Canada, Paper 83-1A, p. 347-351.

Ridler, R.H. and Shilts, W.W.
1974: Exploration for Archean polymetallic sulphide deposits in permafrost terrains: an integrated geological/geochemical technique, Kaminak Lake Area, District of Keewatin; Geological Survey of Canada, Paper 73-34.

Shilts, W.W.
1973: Drift prospecting, geochemistry of eskers and till in permanently frozen terrain: District of Keewatin, Northwest Territories; Geological Survey of Canada, Paper 72-45, 34p.

1982: Quaternary evolution of the Hudson/James Bay region; Le naturaliste canadien, v. 109, p. 309-332.

Skinner, R.G.
1973: Quaternary stratigraphy of the Moose River basin, Ontario; Geological Survey of Canada, Bulletin 225, p. 38.

Vincent, J.
1977: Le Quaternaire recent de la région du cours inferieur de La Grande Rivière, Quebec; Commission géologique du Canada, Étude 76-19.

SEDIMENTATION IN CAMBRIDGE FIORD BAFFIN ISLAND, N.W.T., CANADA

Valeria Horvath and Robert Gilbert
Department of Geography
Queen's University, Kingston, Ontario K7L 3N6

Analysis of the physical sedimentology and paleomagnetic stratigraphy of a series of six piston cores recovered during SAFE 1982 and 1983 provides information on the sedimentary environments of Cambridge fiord. The fiord is located on the northeastern coast of Baffin Island. It is 60.8 km long with surface area of 219 km^2 and a maximum depth of 708 m. The basin is subdivided by three sills at depths of 106 m, 230 m and 330 m (Fig. 1). The fiord receives inflow from a comparatively large, 1992 km^2, drainage basin of which 240 km^2 (12.1%) is ice covered.

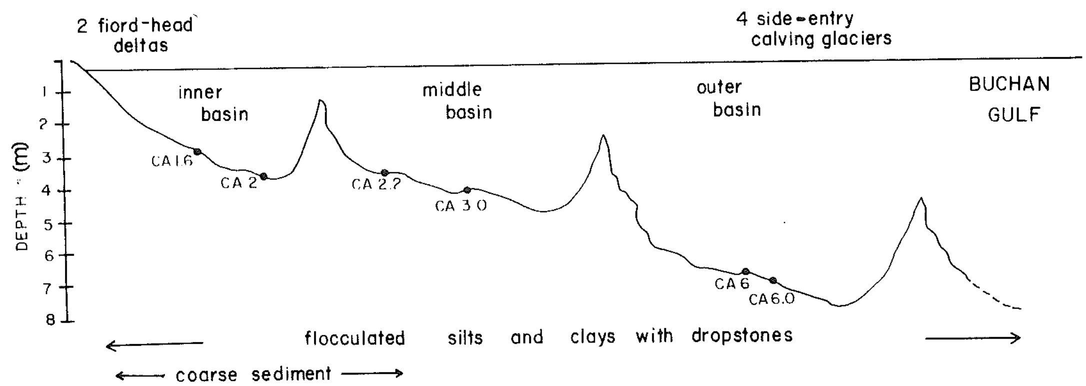


Figure 1. Schematic profile of Cambridge fiord.

Three distinct sedimentary processes can be recognized from the core materials: 1) deposition of fine-grained flocculated sediment out of suspension, 2) gravitational mass flow deposits comprised of sand layers of varying thicknesses and 3) ice rafted and dropped sediments.

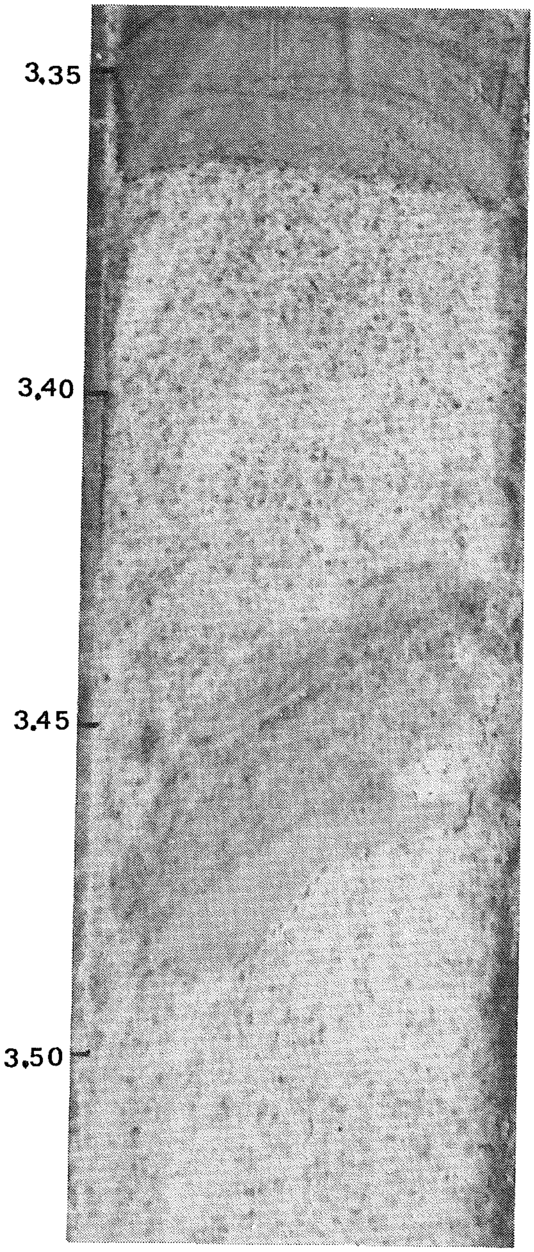


Figure 2. Core 2.2 from 3.35 m to 3.52 m showing coarse sediments containing a rip-up clast.

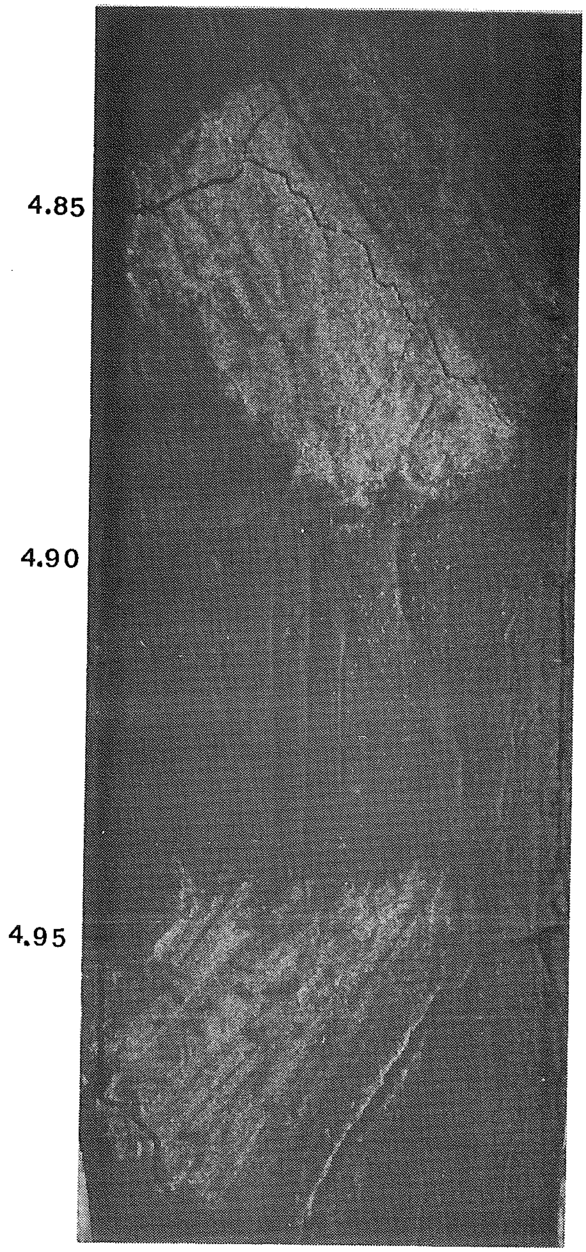


Figure 3. Core 3.0 from 4.83 m to 4.99 m showing blocks of dropped sand.

The majority of sedimentation results from the settling of particles out of suspension. The bottom deposits throughout the entire fiord basin are composed of poorly sorted, fine-skewed, leptokurtic silts and clays. These sediments appear structureless on visual examination, although x-radiographs indicate that there is some degree of internal variation. The upper portions of CA 1.6 and CA 2.2 exhibit regular banding, but the remainder of the core sediments are fine-grained and massive. Cores CA 3.0, CA 6 and CA 6.0 are entirely composed of massive fine-grained sediments. Delicate laminations appear throughout the x-radiographs of CA 3.0 indicating an apparent lack of bioturbation. Flocculation effectively increases the settling rate of the sediments in a similar manner to that described for Coronation, Maktak and North Pangnirtung fiords (Gilbert, 1982). The absence of strong bottom currents is indicated by a progressive down-fiord decrease in the mean diameter of the bottom sediments.

Within the inner basin and on the slopes of the inner sill (cores CA 1.6, CA 2 and CA 2.2) are layers of varying thicknesses of clean, moderately sorted sands, primarily in the basal portions of the cores. The layers range from a few grain diameters to more than a metre in thickness. The upper and lower contacts are sharp with no evidence of erosion. In two cores, CA 2 and CA 2.2, the coarse sediments occur as 0.5 to 1.0 cm thick, uniformly spaced bands which alternate with the fines. These deposits are considerably coarser (grain size data in Gilbert and Horvath, 1984) than any of the other sediments found within the fiord basin.

The massive layers of fine sand in CA 1.6 are attributed to grain flow processes (Middleton and Hampton, 1976). These flows originate from the surrounding deltas, fans, fiord walls and near shore areas. The sand layers of CA 2.2 are somewhat coarser than those found in CA 1.6 and they contain numerous rip up clasts of fine sediment (Fig. 2). In both cases the individual grains are sub-angular and lacking in any indication of long distance transport.

The breakup and over turning of debris laiden sea ice and icebergs are responsible for the infrequent addition of poorly sorted sediment and clasts to the entire fiord basin. Four side entry glaciers calve into the fiord near the mouth and are one source for the dropstones found in cores CA 6 and CA 6.0. Particles coarser than 2 mm are abundant in all of the Cambridge cores, especially in CA 3.0 (Gilbert, 1984). Since the majority of these coarser sediments occur in the silty deposits rather than in the sand layers, they have been attributed to drops rather than to transport in gravitational flows.

As well as individual drop stones, dumps of several particles occur, and at 4.9 m depth in CA 3.0 two inclusions of sand are found in the silts and clays (Fig. 3). They contain fine laminations of heavy minerals. Both are apparently from the same block of sand and appear to have been placed with little disturbance. We interpret these as drops from sea ice of frozen beach sand.

Since the sediment record has been neither biologically altered nor extensively deformed it can be used, with some confidence, for paleomagnetic correlations. The logs provide nearly continuous curves which coincide with the curves obtained for other Canadian arctic fiords by Andrews and Mothersill,(in press). The paleoinclination logs also visually correlate to polarity time scales and master curves developed for North America. A sediment accumulation rate of approximately 1.3 mm/a or 7.6 a/cm is inferred from the paleomagnetic records. This rate is slightly higher than those inferred for the other fiords (Andrews et al., 1984).

REFERENCES

Andrews, J.T. and Mothersill, J.S., in press. Late Quaternary paleomagnetic records from fiord sediments, Baffin Island, N.W.T.: Initial evaluation. Arctic and Alpine Research.

Andrews, J.T., Osterman, L.E. and Kravitz, J., 1984. Quaternary studies on Baffin Island cores. in Syvitski, J.P.M. (compiler) Can. Data Rep. Hydrogr. Ocean Sci. No. 28.

Gilbert, R., 1982. Contemporary sedimentary environments on Baffin Island, N.W.T., Canada : Glaciomarine processes in fiords of eastern Cumberland peninsula. Arctic and Alpine Research, vol. 14, p. 1-12.

Gilbert, R., 1984. Coarse particles in the sediments of Cambridge, McBeth and Itirbilung fiords. in Syvitski, J.P.M. (compiler) Can. Data Rep. Hydrogr. Ocean Sci. No. 28.

Gilbert, R. and Horvath, V., 1984. Preliminary observations on cores from Cambridge and Itirbilung fiords. in Syvitski, J.P.M. (compiler) Can. Data Rep. Hydrogr. Ocean Sci., No. 28.

Middleton, G.V. and Hampton, M.A., 1976. Subaqueous sediment transport and deposition by sediment gravity flows : in Stanley, D.J. and Swift, D.J.P. (eds) Marine Sediment Transport & Environmental Management, New York. John Wiley and Sons Inc. p. 197-218.

Utility of Thematic Mapper Thermal Data for Discriminating Boreal Forest Communities

Leslie A. Morrissey
Technicolor Government Services, Inc.
Moffett Field, California

Don H. Card
National Aeronautics and Space Administration
Moffett Field, California

ABSTRACT

An evaluation of Thematic Mapper (TM) thermal data for the discrimination of boreal forest types is addressed in this research. The thermal band (10.4 to 12.6 um) of the Thematic Mapper Multispectral Scanner aboard the Landsat 5 satellite provides information which is not correlated with the other six visible and infrared bands. The relative merit of thermal data from three TM scenes, representing two phenological states and one diurnal cycle, for separating vegetation cover classes is examined. The thermal bands were ranked according to their ability to differentiate all vegetation and individual vegetation types using three techniques: one-way analysis of variance (ANOVA), Monte Carlo estimation of classification accuracy, and discriminant analysis with estimation of training set accuracy. Additionally, radiant temperatures were calculated from the thermal digital data numbers (DN) to study diurnal and seasonal changes in temperature throughout the test site. This research is part of a larger effort to develop a predictive permafrost model using remotely sensed and ancillary data for the Caribou-Poker Creeks Experimental Watershed, located northeast of Fairbanks, Alaska.

Thermal infrared systems are passive and are dependent on emitted radiation rather than reflected energy from incoming solar radiation. In daytime imagery, topography is typically a dominant factor because of the thermal effects of differential solar heating and shadowing. On nighttime imagery, however, these differential solar effects are greatly reduced. Because there is no significant incoming radiation at infrared wavelengths after sunset, re-radiation of energy from surface materials is responsible for the temperatures on nighttime imagery. Seasonal changes arise from differences in the solar zenith angle, which cause differential heating in different areas, and from phenological changes in the vegetation. To assess these seasonal and diurnal differences in response, thermal bands from three TM scenes acquired August 12, September 22, and

September 23 (nighttime) of 1984 were utilized in the analysis. Lush deciduous forests characterized the August scene; by September the same vegetation had senesced, with partial leaf drop exposing the underlying soils to incoming solar radiation. For the two September scenes, daytime and nighttime thermal data were acquired within one diurnal cycle.

Analysis of variance (ANOVA) was performed to ordinate each of the thermal bands according to its ability to differentiate simultaneously all vegetation types. Individual thermal bands were ranked according to the magnitude of the F-ratio from the ANOVA, as an approximate measure of overall ability to discriminate vegetation. On a per channel basis, the September daytime band, with an F-ratio of 13.99, best differentiated vegetation, followed by the nighttime thermal band (F-ratio of 3.74); the August daytime band was least able (F-ratio of 2.58) to separate vegetation types. This ranking applies to all vegetation classes. A significant F-ratio in the ANOVA indicates at least one significant pairwise mean difference, but does not indicate which specific pair or pairs differ. Therefore, following the ANOVA, discriminant analysis was performed using two methods (Monte Carlo optimal band selection procedure and re-classification of the training data) on 843 randomly-distributed sites to identify the best thermal band for discriminating individual vegetation types. The thermal band ranking based on these two classification techniques for all vegetation was consistent with the ANOVA results.

Based on the Monte Carlo simulation, the probability of correct classification (PCC) for each vegetation type was computed for each thermal band. The best thermal band and PCC for each vegetation type was found to be as follows:

Vegetation Type	Thermal Band	PCC
Closed coniferous forest	September nighttime	79%
Open coniferous forest	August daytime	62
Conifer woodland	September daytime	67
Closed deciduous forest	September daytime	42
Mixed conifer/decid. forest	September nighttime	61
Tall and low shrub	September daytime	29

The results of the classification of training data were consistent with the Monte Carlo simulation results (above).

To assess seasonal and diurnal variations in temperature, radiant temperatures were calculated from the DN values for the September scene only; calibration factors for the August scene (ordered through the Canada Centre for Remote Sensing) were unavailable. The temperature range for the September daytime scene was from 45 to 58 degrees F, with warm south-facing slopes, cool north-facing slopes, and intermediate temperatures along the drainages. Similar patterns were also apparent in the August daytime scene. However, in contrast to the September daytime scene, south-facing slopes of the August scene had intermediate temperatures with the warmest temperatures near the drainages. As expected, the September nighttime thermal band exhibited a lower temperature range (39-40 degrees F) than the daytime scene. Based on the nighttime band, radiant temperatures were coldest near the drainages, warmest on the south-facing slopes, and intermediate temperatures wer found on the north-facing slopes.

A difference image, calculated by subtracting September nighttime from daytime temperature values, provided insight into the diurnal variations associated with vegetation classes. The greatest variations (10 degree F) were apparent in the open conifer drainages and portions of the shrub covered south-facing slopes. North-facing slopes covered with open coniferous forests showed little to no change in temperature during the daily cycle, while south-facing deciduous slopes showed an approximate 6 degree F change.

Thermal emittance for data collected during the day reflects to a large degree, the warming of slopes by the sun. To test this, the thermal digital values for all three scenes were correlated with equivalent latitude (measure of potential insolation). The September daytime scene showed a high negative correlation (-.83) with equivalent latitude indicating a significant topographic effect. In contrast, correlation for the August daytime scene and the September nighttime scene was negligible.

	August daytime	September daytime	September nighttime	Equiv. lat.
August daytime	1.000			
September daytime	.474	1.000		
September nighttime	-.302	.237	1.000	
Equivalent latitude	-.311	-.825	-.188	1.000

It is apparent, therefore, that the combination of a lower solar zenith angle and senescent vegetation enhanced the topographically-induced differences in radiant temperatures apparent on the September daytime scene. In contrast to the September scene, in August the thermal radiation was absorbed (re-emitting less energy) by the full leaf canopy of the deciduous forests, thereby reducing the effects of topography on the south-facing slopes. In addition, thermal data for all three scenes were not significantly correlated.

The authors would like to acknowledge the contribution of Laurence Strong in the preparation of the random sample data set.

HOLOCENE POLLEN INFLUX TO A SMALL LAKE IN THE FROBISHER BAY AREA, BAFFIN ISLAND

William N. Mode
Department of Geology
University of Wisconsin
Oshkosh, Wisconsin 54901

and

John D. Jacobs
Department of Geography
University of Windsor
Windsor, Ontario N9B 3P4

Hikwa Lake (unofficial name) is a small, elliptical (425m x 150m) lake in the low arctic tundra vegetation zone of southern Baffin Island. Replicate lake sediment cores were collected, and pollen analysis has been carried out in an attempt to establish the vegetational history. The percentage pollen diagram (Figure 1) suggests that low arctic tundra, as represented by shrub *Betula* (birch) percentages, was most extensive 5000-2500 years BP.

Total pollen influx to Hikwa Lake has varied by more than an order of magnitude during the past 8000 years, with the maximum (200 grains cm^{-2} yr^{-1}) occurring around 2800 years BP. and the minimum (20 grains cm^{-2} yr^{-1}) during the past 1000 years. Influx calculations are based on sedimentation rates established by three radiocarbon dates on the algal gyttja in the upper 37.5 cm of the core. Underlying the 37.5 cm of olive gray, algal gyttja is muddy sand 8.5 cm thick. The contact between the two sediments represents postglacial isostatic emergence of the lake above sea level at about 7000 years BP. The approximate age of the base of the core (ca. 8000 years BP.) is derived from an extrapolation of the sedimentation rate. Because Hikwa Lake lies outside of the Frobisher Bay Moraine, it was deglaciated ca. 9000 years BP.

Comparison of influx curves for individual taxa shows that all taxa reached maxima 3000-2500 years BP. However, for sedge and other tundra herbs, relatively high influx was sustained between ca. 6500-2000 years BP., while shrub birch and exotic *Alnus* (alder) were low until about 5000 years BP., when they began to increase. Hence, shrub birch may have been present as early as 7000 or 8000 years BP., but probably occurred only as stands and isolated individuals restricted to low elevations (comparable to its present distribution) within a dominantly herbaceous tundra until about 5000 years BP., when the population increased and spread to higher elevations. This trend reached its climax around 3000 years BP., and subsequently the shrub birch population has become more restricted in range and numbers. Exotic *Picea* (spruce) and *Pinus* (pine) influx rose somewhat later, ca. 3000 years BP. and declined by 2000 years BP.

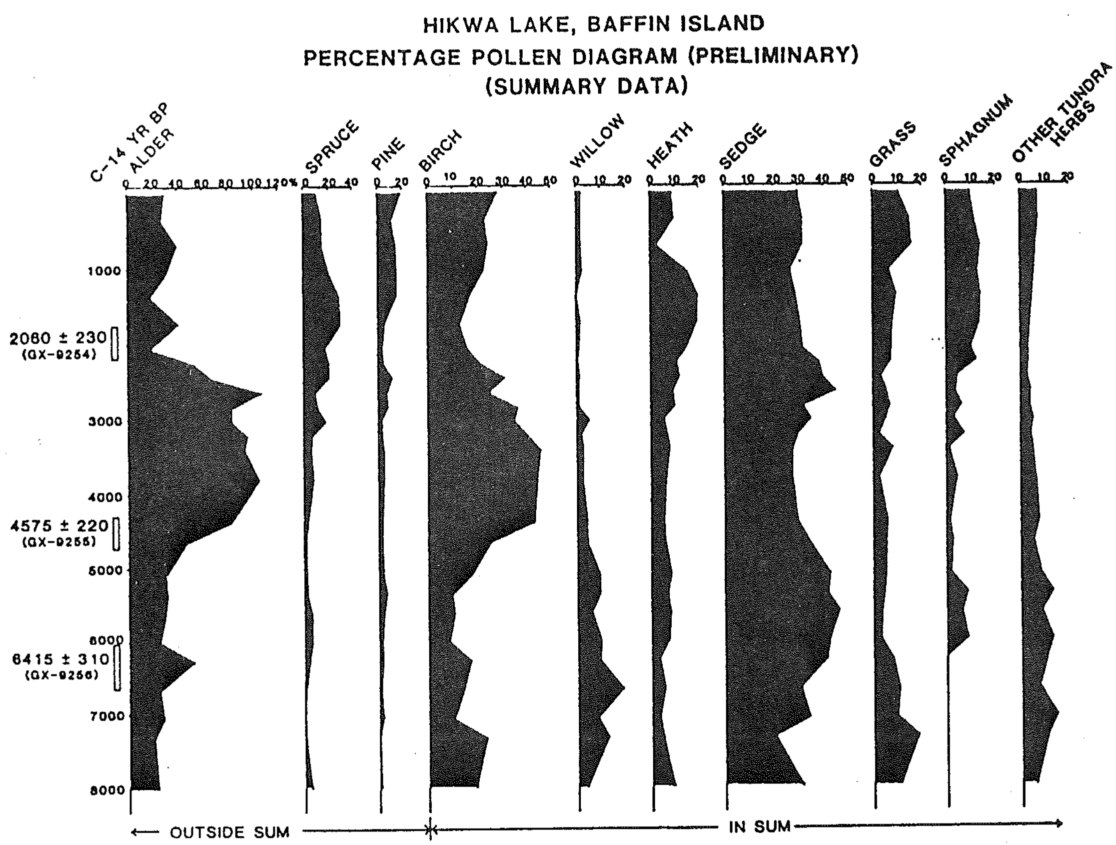

HIKWA LAKE, BAFFIN ISLAND
PERCENTAGE POLLEN DIAGRAM (PRELIMINARY)
(SUMMARY DATA)
C-14 YR BP
ALDER
SPRUCE
PINE
BIRCH
WILLOW
HEATH
SEDGE
GRASS
SPHAGNUM
OTHER TUNDRA HERBS
1000
2060 ± 230
(GX-9254)
3000
4000
4575 ± 220
(GX-9255)
5000
6000
6415 ± 310
(GX-9256)
7000
8000
OUTSIDE SUM
IN SUM

FIGURE 1.

PALYNOLOGY OF NEARSHORE MARINE AND TERRESTRIAL SEDIMENTS, EAST COAST, BAFFIN ISLAND

Susan K. SHORT, INSTAAR, University of Colorado, Boulder, CO, 80309, U.S.A., William N. MODE, Department of Geology, University of Wisconsin at Oshkosh, Oshkosh, WI, 54901, U.S.A., and John T. ANDREWS, INSTAAR and Department of Geological Sciences, University of Colorado, Boulder, CO, 80309, U.S.A.

The link between the deep-sea and terrestrial records is still not well known although significant advances have been made in the last decade. We believe that the intermediate marine environment, the Continental Shelf and deeper nearshore waters, appears to offer a promise of better linking these two environments. This poster reports on the results of pollen analyses of samples from six fiord cores and a short terrestrial peat record collected during the 1982 cruise of the C.S.S. Hudson. Our goal is the environmental reconstruction of fiord environments over the period of the last 10,000 years.

Mudie has demonstrated that the surface samples of marine sediments in the eastern Canadian Arctic contain significant amounts of pollen and that this modern assemblage can be explained in terms of present-day patterns of vegetation, climate, and oceanography. This major study of offshore modern pollen has been complemented by studies of the palynology of late Quaternary sediment cores from Baffin Bay and by studies of the terrestrial pollen rain from Baffin Island and Labrador.

Surface samples from Itirbilung, McBeth, and Cambridge Fiords were analyzed for pollen and spores; analyses of the dinoflagellate cysts contained in these samples are in progress. The pollen and spores are of terrestrial origin and thus provide a link between the terrestrial and marine environments. Mudie has demonstrated the use of dinoflagellates as proxy-indicators of paleoeanographic conditions at the sea surface.

The modern pollen spectra of the two central coast fiords, Itirbilung and McBeth, are dominated by Betula (birch) (up to 40%), Gramineae (grass family), Cyperaceae (sedge family), and Filicales (ferns), although both are located ca. 300 km northwest of the northern limit of shrub birch on the eastern coast of Baffin Island. Betula percentages are highest in the inner fiord samples but decrease in the outer fiord samples; this is correlated with an increase in the percentages of local pollen types. Filicales percentages dominate the pollen spectra in the modern samples from Cambridge Fiord, 320 km north of Itirbilung Fiord. Betula percentages are the smallest recorded in this study, but Alnus (alder) and Picea (spruce) are consistently represented in small percentages.

The McBeth Fiord region is also represented by a terrestrial record (two moss polsters and a short Late Holocene peat sections). The contrast between the modern pollen records from the terrestrial and marine environments is striking. As noted above, the exotic Betula is important in the marine samples while the terrestrial samples are dominated by Salix (willow), Gramineae, and other local pollen types.

The fossil pollen record is presented for five fiord cores. These are Sunneshine 5, southeastern Baffin Island (11,000 yr record), Itirbilung 3.1 (9500 yr record) and McBeth 4.1 (11,500 yr record), central Baffin Island, and Clark 5 (7300 yr record) and Cambridge 4.1 (2900 yr record), northern Baffin Island. Betula is an important component of the four southern cores, but Picea and other exotic pollen types are only important in the most southern fiord, Sunneshine. Betula percentages (45-60+%) dominate the entire period of record in Itirbilung 3.1. Maximum percentages are also recorded at the base of Clark 5 (ca. 6000 yr BP) and from 11,500-7400 yr BP in McBeth 4.1. In the terrestrial pollen record from northern Baffin Island, Mode recognized a Betula zone dating from 6800=5700 yr BP in Patricia Bay Lake, Clyde Forelands.

He inferred that shrub birch was growing at or quite near the Clyde area, 500 km north of its present northern limit, during that period which represented the Holocene climatic optimum. Betula is also important in several other terrestrial pollen records from the early Holocene from Clyde, Qivitu, and the Cumberland Peninsula.

McBeth 4.1 and Clark 5 register increased percentages of pre-Quaternary pollen and dinoflagellates in the mid-Holocene. This spectrum occurs significantly earlier in Sunneshine 5, however, and also in the published record from Frobisher Bay.

The record in the three northernmost cores after 6-7000 yr BP is dominated by local pollen types - Gramineae, Cyperaceae, and Filicales. In McBeth 4.1, the longest and most completely analyzed core, Gramineae pollen percentages increase after ca. 3000 yr BP. This corresponds with the published terrestrial pollen record which registers a trend from a more diverse, commonly shrub-dominated assemblage to a more impoverished, graminoid spectrum sometime between 5000 and 2500 yr BP. The short peat section from McBeth Fiord, dating after 1230 yr BP, is also dominated by Gramineae.

SHALLOW SEDIMENT TEMPERATURES AND THERMAL PROPERTIES

CANADIAN BEAUFORT CONTINENTAL SHELF

Alan Taylor and Vic Allen
Earth Physics Branch
Energy, Mines and Resources Canada
1 Observatory Cresent
Ottawa, Canada K1A OY3

Geothermal research in the deep oceans involves the measurement of temperature gradients in the upper several metres of sediment and the determination of thermal conductivity values over the same interval. The product of these two parameters is the measured terrestrial heat flux. Transient effects such as rapid sedimentation or erosion, or variation in bottom water temperatures are recognized in the raw data and corrections may usually be made, yielding a heat flux typical of the geologic environment.

Such deep ocean techniques are less often applied to continental shelf areas, where some transient disturbances may be so great that these corrections cannot be made unless some independent information is available on the nature of the disturbances. Rarely have these deep ocean techniques been applied to a continental shelf underlain by permafrost. Over three seasons, we have occupied more than 30 stations across the Canadian Beaufort Shelf, taking sediment temperature profiles to 3m at each and measuring the thermal conductivity on retrieved core. The objectives differ from the deep ocean, as one considers that the terrestrial heat flux is consumed at the base of the thick degradational permafrost and that the short sediment temperature profiles reflect this non-equilibrium situation.

The temperature profiles measured on the 1982 cruise are shown in the figure. All stations were in water depths of 30m or more and well beyond the visible Mackenzie River plume. Profiles show a considerable disturbance, some with a very high negative temperature gradient. Station 23, located on the slope in 125m of water, has a positive gradient that may be a reflection of the geothermal gradient in this non-permafrost area. Other profiles in the upper part of the figure are from the Kringalik Plateau and Ikit Trough, areas underlain by variable thicknesses of degrading permafrost. Slightly higher, and considerably more disturbed temperatures were measured in the Mackenzie Trough (lower figure), a region not underlain by thick ice-bonded sediments.

In this paper, we show that the dominant character of the profiles may be attributed to seasonal variations in bottom water temperatures that occur beyond the visible Mackenzie plume out to the shelf edge and slope. Modelling at some of the stations shows that the disturbed profiles are consistent with an annual increase in bottom water temperatures for several weeks late in the season, at or just prior to the date of measurement. Such warming may be associated with bottom current variation on the outer shelf as measured by other researchers or as suggested by bottom erosion and suspended sediment meaasurements.

The data set for the three years shows that sediment temperatures tend to be slightly lower on the plains than in the channels; and highest in the Mackenzie Trough, which is not underlain by ice-bonded permafrost. Sediment thermal conductivity values average 1.3 W/mK, considerably higher than observed in the deep oceans but correlating well with sediment lithology and the lower water contents observed.

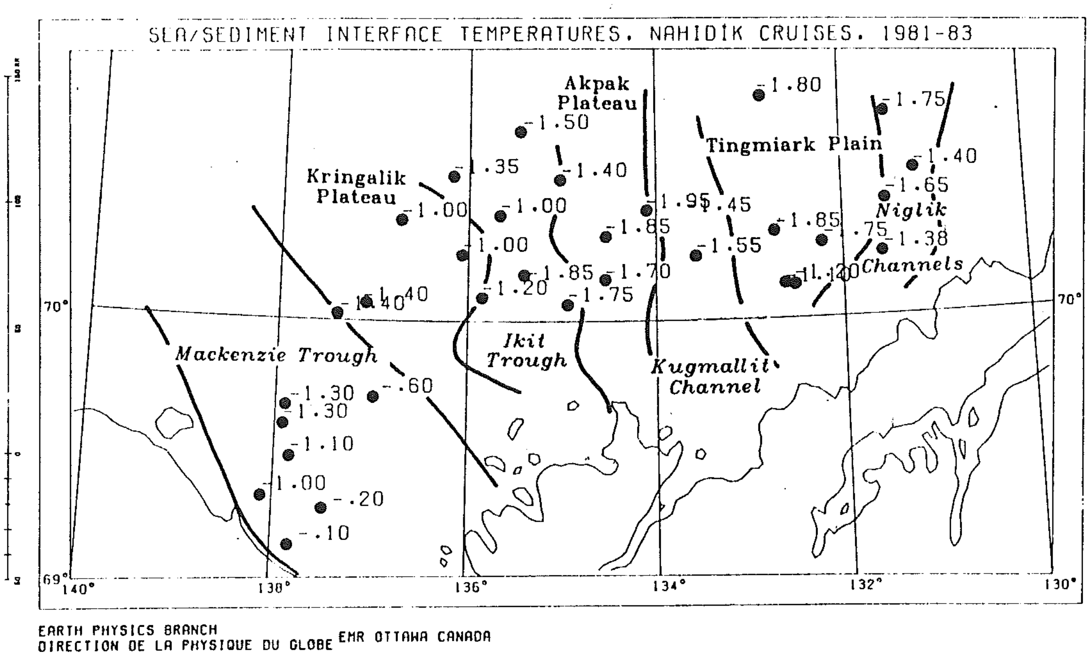


Figure 1. Sediment interface temperatures at over 30 stations during the 1981-83 cruises of the Canadian Coast Guard ship 'Nahidik'. 1981 stations are generally in the eastern regions, 1982 in the central and Mackenzie Trough regions, and 1983 along the Kringalik/Trough boundary, outer shelf and slope. Temperatures, in ^{o}C, show the slight trend to lower values on the plateau areas.

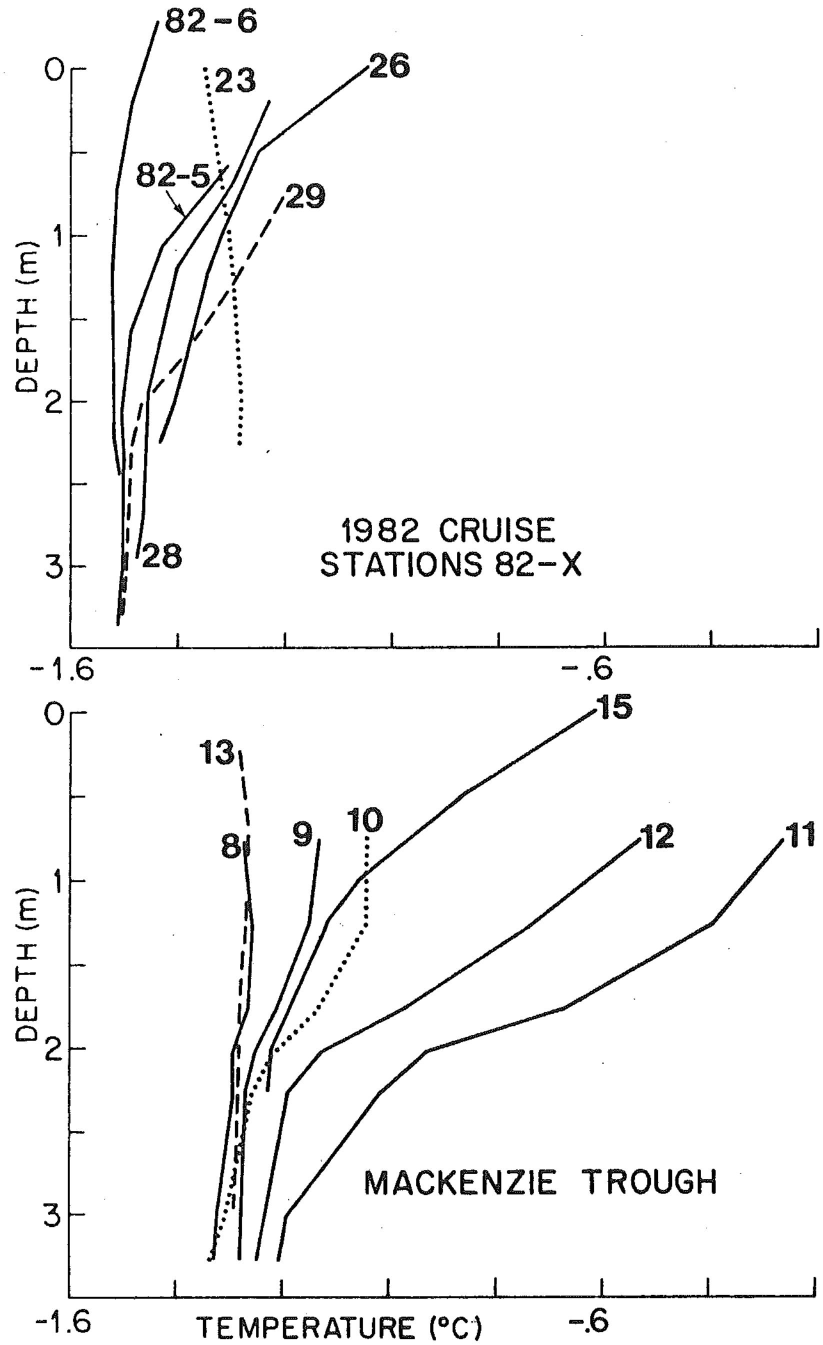


Figure 1. Sediment temperature profiles measured on the Beaufort Shelf during the September, 1982 cruise. The profiles in the upper diagram are from the outer shelf in the Kringalik Plateau and the Ikit Trough. Station 23 is on the slope. In the Mackenzie Trough, stations 8 and 13 are in 80m of water, while stations 11 and 12 are closer inshore in 30-35m but outside the visible Mackenzie plume. Mathematical modelling of the profile at station 15 suggests the highly negative gradient is a reflection of an annual warming trend by almost a degree in the bottom water.

Eiliv Larsen, Geological Survey of Norway, P.O. Box 3006,
N-7001 Trondheim, Norway.

A Middle Weichselian arctic vertebra fauna from western Norway: Climatic inferences.

A sediment sequence within a marine-cut cave with marine abrasional features well above the Late Weichselian marine limit has been studied. Seismic investigations and coring reveal a c. 15-20 m thickness of sediments above bedrock. The entire sequence consists of extremely fine-grained laminated sediments alternating with diamictic sediments. At the base, a blocky bed is thought to have originated either from marine abrasion or from blocks falling from the roof of the cave due to intense frost-shattering during an interstadial. Above this bed, a sequence of three laminated beds separated and also capped by diamictic sediments is found. The laminated beds are interpreted as having been deposited subglacially in a totally water-filled cave at times when ice-sheets covered the area. The diamictic sediments are thought to have originated from blocks falling from the roof of the cave due to frost-shattering and from slow mass-movements during ice-free periods. In the interstadial bed between the two uppermost laminated beds, almost 7000 bone and teeth fragments of birds, fish and mammals have been found. Radiocarbon dates on bones and U-series dates on speleothems from this bed cluster around 30.000 yrs. B.P.

More than twenty different species belonging to this interstadial are identified. Birds dominate, with Plautus alle and Uria lomvia as the most common species. Alopex lagopus is the dominant mammal. The great accumulation of bones in the sediment is not understood in detail. However, the findings of fish-bones in non-marine sediments clearly shows that at least some bones were brought into the cave either by man or by other amimals. Alopex lagopus might be responsible for most of the accumulation.

Most of the identified birds nest in rookerys, and it is therefore likely that the fauna is mainly a summer fauna. The presence of Alopex lagopus, Lemmus lemmus and Lagopus mutus, however, proves that food resources were also present during the winter. Pollachius virens and Brosme brosme are common today along the Norwegian coasts, but are normally not found east of north-eastern Norway. They spawn in waters with temperatures between 6 and 9^{o}C, and avoid waters colder than 4-5^{o}C. Both these species, the other fish species identified and most of the birds, show that there must have been open water, at least during the summers. The presence of Lutra lutra, indicates that open water existed in or close to the area also during the winters. It is therefore possible that the winter sea-ice limit was located close to the area, and that the ice withdrew far to the north during the summers. A further conclusion that can be drawn, is that Atlantic water entered the Norwegian Sea and influenced the fauna on the Norwegian coast during this interstadial.

MARGINAL MARINE FORAMINIFERA ASSEMBLAGES IN THREE EAST COAST BAFFIN ISLAND FIORDS

Charles T. Schafer and FIona E. Cole
Atlantic Geoscience Centre, Geological Survey of Canada
Bedford Institute of Oceanography
P.O. Box 1006, Dartmouth, Nova Scotia, B2Y 4A2

A fall of 1983 survey in Cambridge, Itirbilung and McBeth fiords provided a suite of shallow water surficial sediment samples (launch samples (100m deep) and comparable material from deep, central basins (HUDSON samples) 100m deep) that have been analyzed for thecamoebians and benthonic foraminifera.

Cambridge Fiord, the most northerly system investigated, supports the most abundant and most diverse living arenaceous population. Maximum living arenaceous species diversity per station, the average number of living arenaceous specimens per cc of wet sediment (NL/CC), and the maximum NL/CC are highest in this system. The distribution of individual living species with respect to water depth, and to proximity to the head of fiord, is not consistent from ome system to another.

The average total number of arenaceous specimens per cc of wet sediment (TN/CC) of Cambridge launch samples is four times larger than observed in McBeth and 10 times larger than noted for Itirbilung. In contrast, samples collected in southeast Baffin Bay (Hume, 1972), and which include both arenaceous and calcareous foraminifera, have an average TN/CC of only 15 compared to a grand average of 114 (standard deviation=85) for the total arenaceous population observed the three fiords investigated in this study. The larger fiord arenaceous TN/CC's are presumably a reflection of the higher species production levels that occur in these environments.

Average living calcareous species diversity per station in Cambridge Fiord is 20% higher for the deeper HUDSON samples compared to the launch suite; this relationship is evidenced to an even greater degree in McBeth Fiord and is suggestive of passive transport of living individuals. The inverse relationship between total living species number and average living species diversity per HUDSON station for the Cambridge Fiord living calcareous population is opposite to that observed in the launch samples. This inverse relationship can be attributed provisionally to the heterogeneous character of the nearshore zone in Cambridge. This zone supports a high toal number of species that apparently have relatively restricted

distributions which may be influenced by passive transport processes operating over smaller areas compared to those modulating the spatial distribution of offshore basin species (e.g., Haynesina germanica). Unlike McBeth and Itirbilung fiords, the average calcareous LN/CC is about 27% higher for the Cambridge launch samples compared to the HUDSON set. This higher shallow water average population density should be associated with a comparatively high per station diversity (launch samples) unless the microhabitats of some living species are restricted to certain local areas of the nearshore zone.

The total number of calcareous species is invariably higher than the living species number in all three fiords suggesting that the living assemblages collected during the fall season are not entirely representative of the range of environmental conditions favourable for reproduction of some species. The possiblity that reproduction times in arctic fiords are perhaps as variable as those postulated for some nearshore temperate marine settings (e.g., Buzas, 1965) must be tested in future surveys.

In Cambridge Fiord, the shift to relatively low living and non living calcareous species test percentages compared to the total (i.e., calcareous plus arenaceous) population in the offshore basin environments reflects both the disproportionate increase in arenaceous test concentration with depth and the probable restriction of well represented calcareous species to local shallow water niches.

References Cited

Buzas, M.A., 1965. The Distribution and Abundance of Foraminifera in Long Island Sound. Smithsonian Miscellaneous Collections, v.149, 88p.

Hume, H.R., 1972. The Distribution of Recent Foraminifera in Southeast Baffin Bay. M.Sc. Thesis, Dept. of Geology, Dalhousie University, Halifax, Nova Scotia

TRANSFER OF MAGNETITE FROM LAND TO SEE IN BAFFIN ISLAND FJORDS

K.W. Asprey and J.P.M. Syvitski
Geological Survey of Canada, Bedford Institute of Oceanography,
P.O. Box 10061, Dartmouth, N.S., B2Y 4A2.

Determination of the distribution of a single mineral can be a powerful technique to discern sediment sources and transport pathways in closed depositional systems. In 1983, samples were collected from fluvial-deltaic, beach and fjord (water column, prodelta and basin) invironments. Details on methodology and primary data are given in Asprey (1984). Magnetite was chosen as a tracer/ indicator mineral because it is ubiquitous to the glacially eroded sediments of Baffin Island and is easily separated from mixtures of other primary minerals. Magnetite is also a heavy mineral (density of 5.18 g cm^{-3}) and is useful in discerning the placer potential of a particular depositional environment. The magnetic properties of sediment in arctic cores have been determined to provide a temporal component to modern sediment heavy mineral distributions.

Magnetic sediment traps were installed at depths of 15 and 35m in Cambridge and Itirbilung fjords close to the fjord-head in about 50m of water. In both cases the flux of magnetite was greatest at depth (1.1 to 2.3 x 10^{-3} g day $^{-1}$ for the deeper traps compared to 6.7 to 9.2 x 10^{-4} g day $^{-1}$ for the 15m traps). The flux values are for fall season conditions in 1983 and are expected to be much higher during the spring freshet period. An earlier 1985 field season installation will confirm this hypothesis.

Magnetite concentrations [C_m] in the Keel River delta surficial sediments, Cambridge Fiord, B.I., ranged from 0 to 12.5% (mean of 3.7%) by weight. The highest values of C_m were associated with river levee deposits and environments near the delta lip. The magnetite grains are $\approx$ 0.6∅ finer than the non-magnetic fraction and nearly hydraulically equivalent. The Keel River prodelta has a lower concentration and a more uniform distribution of magnetite with a C_m range of 0.3 to 1.4% (mean of 0.8%). C_m increased with the distance from the river mouth and with decreasing grain size. A presently inactive and isostatically-raised delta at the head of Cambridge Fiord has C_m prodelta values that range from 0.8 to 1.5% (mean of 1.0%). In the adjacent marine environment, C_m increased seaward and was inversely related to grain size. C_m in the fjord basins ranged from 0.3 to 1.3% (mean of 1.1%). The grain size range of highest C_m was 32 to 125 u.m. For grains 16 um in diameter (60) the magnetite concentration abrubtly decreased (Fig. 1a). The above two observations suggest that the placer potential through the recycling and concentration of heavies from raised marine sequences is dependent on the lithology of the sediments undergoing erosion.

Lower C_m values in McBeth Fiord reflect magnetite-poor and mica-rich metasediments in the hinterland. A small side-entry delta in the middle of McBeth is an exception. Second order recycling of sediments through wave reworking resulted in C_m values as high 100% in 1 to 5 thick heavy mineral beach laminae at this locality (Fig. 2a).

The size frequency distribution (sfd) of the magnetite grains is hydraulically very similar to the sfd of the non magnetic fraction (Fig. 1b). As the grain size fines into the mud fraction, the magnetite sfd becomes better sorted. In turbidity current laminae, the magnetite grains may form pure concentrations, and be much finer grained than the surrounding non-magnetite mineral grains. Such concentrations may relate to current winnowing at the head of the turbidity current as it impacts on previously deposited sandy material (Fig.2b).

REFERENCE:

Asprey, K.W. 1984. Safe 1983 heavy mineral distributions. In. Syvitski, J.P.M. (compiler) Sedimentology of Arctic Fjords Experiment HU83028 data report, V.2. Can. Data Rep. Hydrogr. Ocean Sci. #28, 19-1 to 19-36.

FIGURE CAPTIONS:

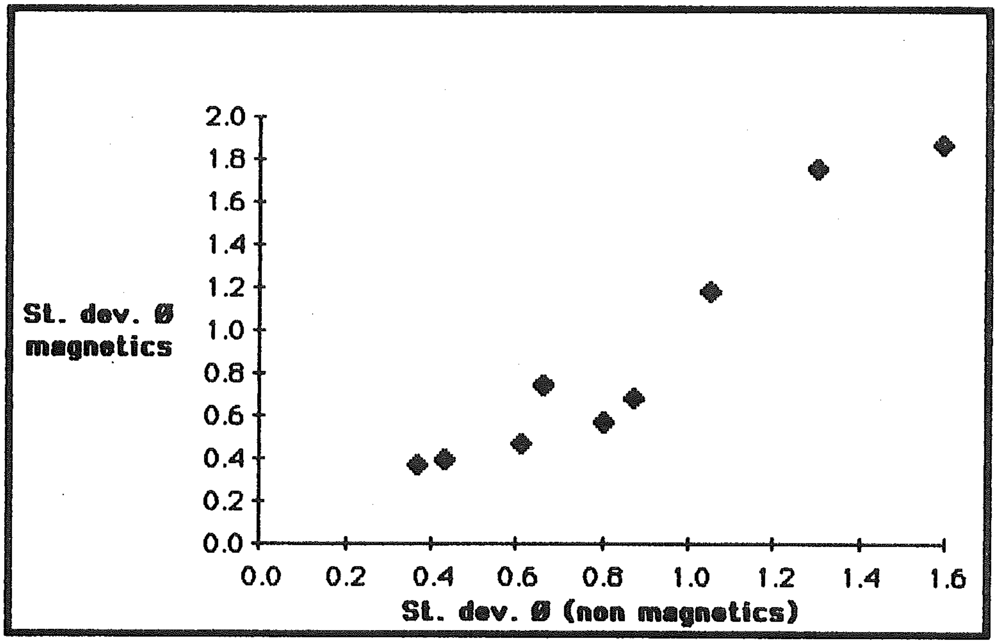
Figure 1a. The distribution of percent magnetite as a function of grain size for samples collected in Cambridge Fiord, Baffin Island.

Figure b. A comparison of the standard deviation from grain size frequency distributions of magnetic versus non-magnetic fractions of selected samples from Baffin Island fjords.

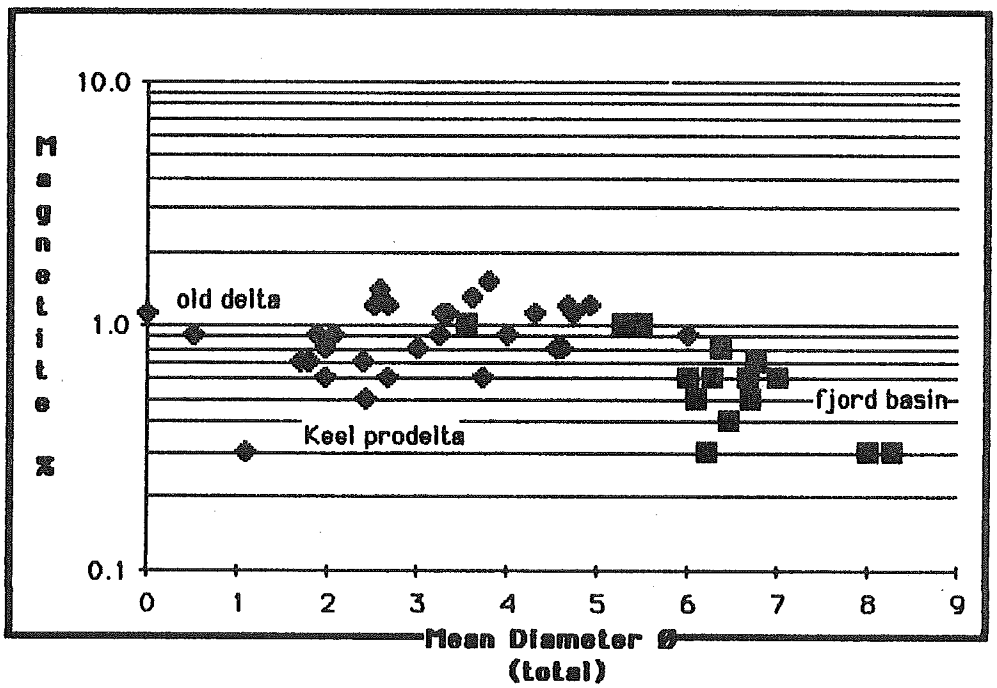
Figure 2a. A photograph of the beach foreshore in a side-entry delta in McBeth Fiord with a pit showing the concentration of magnetite and other heavy minerals in layers 1-5cm thick.

Figure b. A photograph of a 1.5 cm x 1.5 cm section of a peel from a turbidite-rich core in Cambridge Fiord (CA. 1.2:290cm interval) collected in 200m of water 2.5km from the Keel River delta. Shown are biotite rich laminae in the upper portion of the photo overlying a quartz and feldspar rich mineral layer containing a laminae of pure magnetite.

CAMBRIDGE SAMPLES

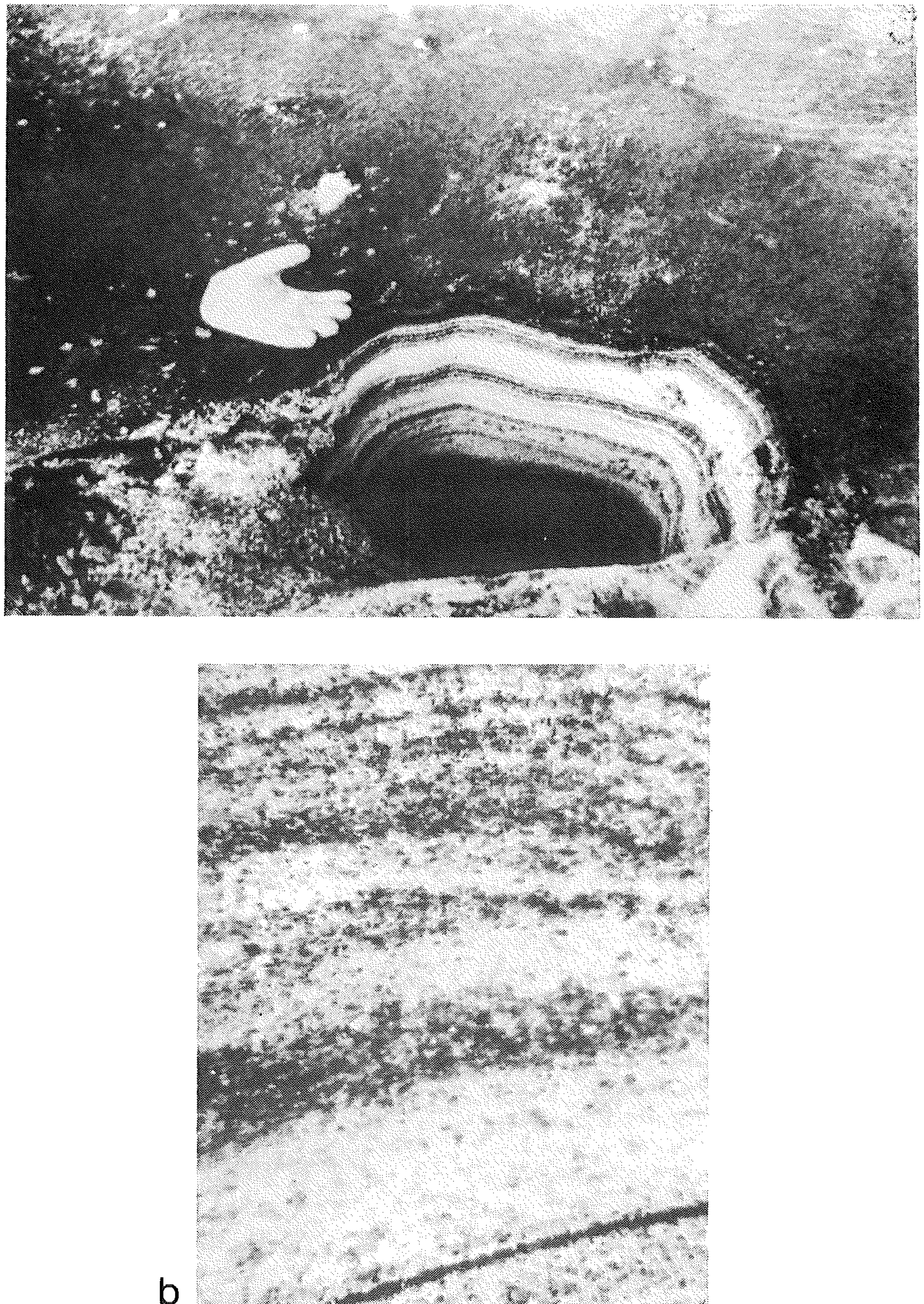


A



B

FIGURE 1



a

b

Figure 2

QUATERNARY GEOLOGY OF THE SOUTHEAST BAFFIN ISLAND CONTINENTAL SHELF, N.W.T.

D.B. Praeg, B. MacLean, I.A. Hardy and P.J. Mudie
Atlantic Geoscience Centre, Geological Survey of Canada
Bedford Institute of Oceanography
P.O. Box 1006, Dartmouth, Nova Scotia, B2Y 4A2

The Quaternary sediments of the southeast Baffin Island continental shelf have been investigated using acoustic data (Huntec DTS and 655cm^3 air gun seismic profiles, sidescan sonograms, echograms) supplemented by sample control (grabs and cores). Four acoustic units have been defined and informally named: map-unit 1: Baffin Shelf Drift - unstratified diamictons generally 100m thick but up to 300m off Hudson Strait, which were deposited from grounded glacial ice, and which reach to the shelf edge in some areas; these sediments record repeated advances of glacial ice, of varied extent, of early late Foxe and older age; map-unit 2: Davis Strait Silt - sediments generally 10m but up to a 70m thick, which are stratified where unscoured by grounding icebergs (Subunit A) and acoustically unstratified where scoured by grounding icebergs (Subunit B); these sediments record deposition from mid Foxe to Holocene time and contain microfossil evidence of ice-proximal to ice-distal glacial marine environments; map-unit 3: Tiniktartuq Silt and Clay - stratified basin-fill sediments up to 10m thick which directly overlie the stratified sediments of Davis Strait Silt Subunit A; these sediments indicate a change in depositional style in the late Foxe to Holocene; map-unit 4: Resolution Island Lag - subangular gravels and sands which occur in areas that appear largely devoid of cover to the limit of acoustic resolution (30-50cm), and which may include areas of exposed bedrock; these sediments record current winnowing of areas of thin to discontinuous Baffin Shelf Drift or Davis Strait Silt. There is no evidence for a transgressive zone marking a relative sea level lowstand in the depths represented by the date (mainly 150m). The immediate seabed of the southeast Baffin Shelf has been subjected to modification by currents in the Holocene, resulting in the formation of an extensive surface veneer which overlies the sediments of the acoustic units in thicknesses 30-50cm.

ILLUSTRATIONS OF INDICATOR SPECIES FOR SOME OSTRACOD ASSEMBLAGES FROM MARINE AND BRACKISH WATERS OF THE NORTH AND EAST COASTS OF CANADA

The marine ostracods found around the north and east coasts of Canada can be divided into several assemblages according to their tolerances for different salinities and depths. Certain Plio-Pleistocene genera and species characteristic of these assemblages are common enough to be used as indicators of the conditions under which they lived. Illustrations of these ostracods are presented in a poster display.

Q. A. Siddiqui
Dept. of Geology
St. Mary's University
Halifax, N.S.
B3H 3C3

and U. M. Grigg
Scotia Biological
Services Ltd.
P.O. Box 765
Armdale, N.S.
B3L 4K5

AMINO ACID RATIOS: NOT ONLY TIME AND TEMPERATURE.

Hans Petter Sejrup, Department of Geology, Sec. B, Univ. of Bergen, Allégt. 41, 5000 Bergen.

Well preserved interglacial marine sediments have recently been described from two sites in western Norway. Both the Fjøsanger section (Mangerud et al. 1981) and the Bø section (Andersen et al. 1983) were first interpreted to represent the last interglacial, the Eemian. This conclusion was based on pollen stratigraphy, on the paleoenvironmental implications of the marine fossils, on an index fossil and TL-dates. Data on the extent of isoleucine epimerization in molluscs and foraminifera from these sites were published by Miller et al. (1983). All the amino acid results from foraminifera suggested a close correlation of the sites, but among the molluscs analysed some species yielded much higher ratios in the Fjøsanger samples than in the samples from Bø. Lately more analysis have been performed on material from the two sites and it is mentioned by Miller & Mangerud (in prep.) that the Fjøsanger possibly represent an older interglacial than the Bø section.

Partly due to these confllicting results, one molllusc species (*Arctica islandica*) that gave different ratios at Fjøsanger and Bø was choosen for more detailed investigations. Samples from several cross sections of the valves were analysed, both from Fjøsanger and from Bø on Karmøy. In addition a recent sample from Rogne, western Norway, was sampled in the same manner. Some of the results of these analyses are shown in figs. 1-3.

As seen from fig. 1, all the fossil samples show an increase in the total amount of amino acids from the outer part of the shell towards the inner. The "zero sample" from Rogne shows a relatively uniform distribution of amino acids through the shellstructure. The alle/Ile-ratios (D/L) in both the free and the total fraction (Fig. 2 and 3), also shows a gradient with the highest ratios in the outer part of the shells. In both the free and total fraction the ratios from Fjøsanger were generally higher than those from Karmøy. For the Rogne sample ratios close to 0,015 were obtained from all over the shell in the total fraction (laboratory induced epimerization) and in the free fraction no aIle was detected.

These data strongly suggest that other factors than time and temperature affect the alle/Ile-ratios in Arctica islandica. As it usually is assumed in geochronological studies applying the isoleucine epimerization reaction, that time and temperature are the most important factors, it is proposed to be careful in the interpretation of such data until an explanation of the observed gradients are found. It is the authors opinion that such prosesses possibly also affect the protein diagenesis in other species, but due to sampling procedures and that most species are to thin for cross section sampling, the gradients have not been observed earlier.

Presently it is difficult to point at any single explanation of the observed features, possibly they are a combination of different factors, catalytic effects, radioracemization, leaching etc.

The Bergen Amino acid laboratory will continue to do detailed work on fossil material and also laboratory experiments will be performed in the effort to resolve this problem.

As a result of this problem it is proposed that the correlation with the Eemian of the interglacial beds at both Karmøy and Fjøsanger is retained.

REFERENCES.

Andersen, B.G., Sejrup, H.P. & Kirkhus, Ø., 1983: Eeamian and Weichselian Depositss at Bø on Karmøy, SW Norway: A Preliminary Report. Norges geo. Undes. 380, 189-201.

Mangerud, J., Sønstegaard, E., Sejrup, H.P. & Haldorsen, S. 1981: A continuious Eemian-Early Weichselian sequence containing pollen and marine fossils at Fjøsanger, western Norway. Boreas 10, 137-208.

Miller, G. H., Sejrup, H.P., Mangerud, J. & Andersen, B.G. 1983: Amino acid ratios in Quaternary molluscs and foraminifea from western Norway: correlation, geochronology and paleotemperature estimates. Boreas 12, 107-124.

Miller, G. H. & Mangerud, J. with contributions from: K.S. Petersen, H.P. Sejrup, W. Zagwijn, B. Menke, V. Gudina, V. Evzerov, J.-M. Punning and R. Paepe (in prep.) Aminostratigraphy of European Marine Interglacial Deposits. Manuscript.

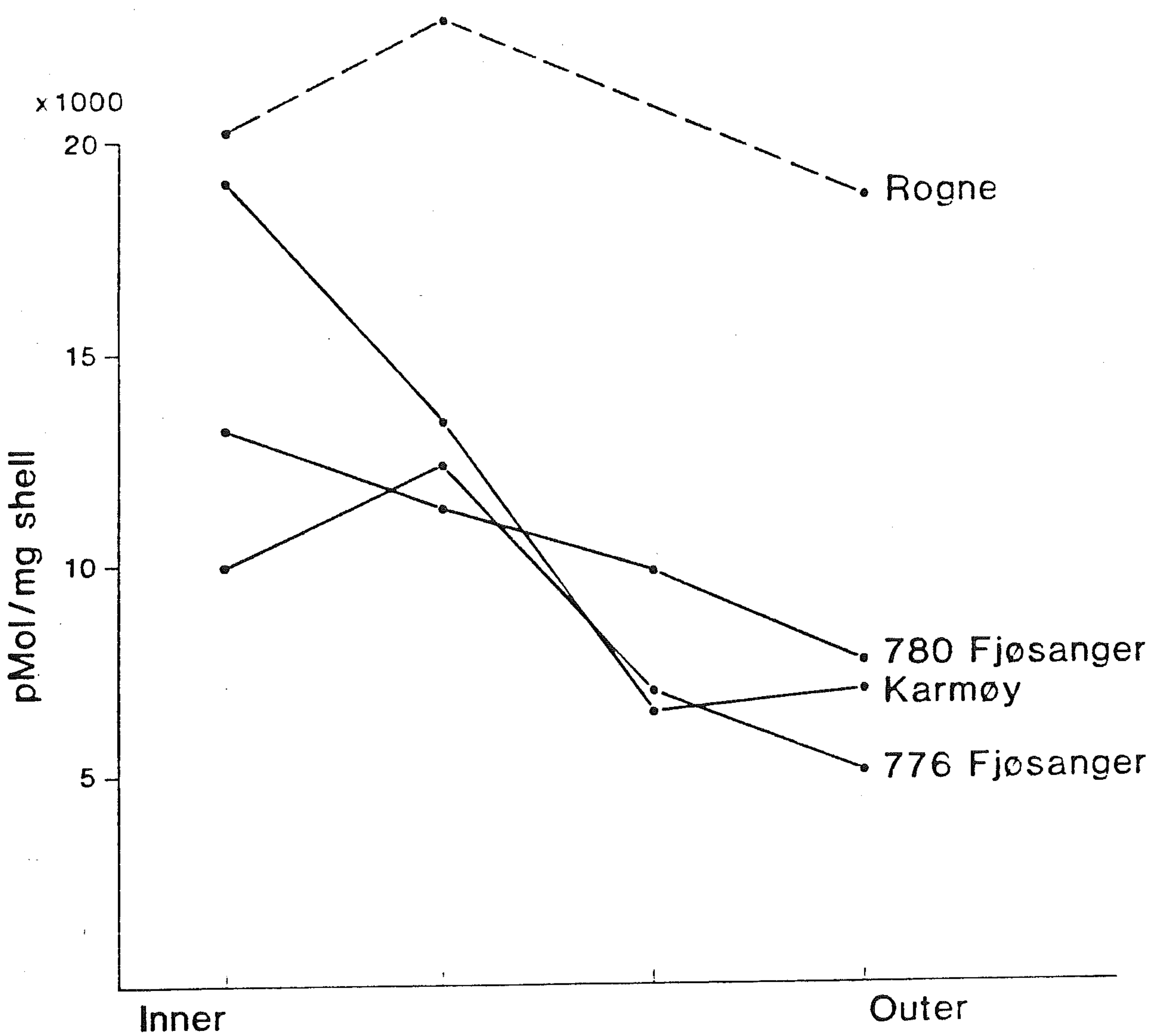


Fig. 1

Absolute content of fifteen amino acid in the total fraction (free plus bound) in samples taken in profile through valves of Arctica islandica from the two interglacial sites Karmøy and Fjøsanger, and a recent sample from Rogne.

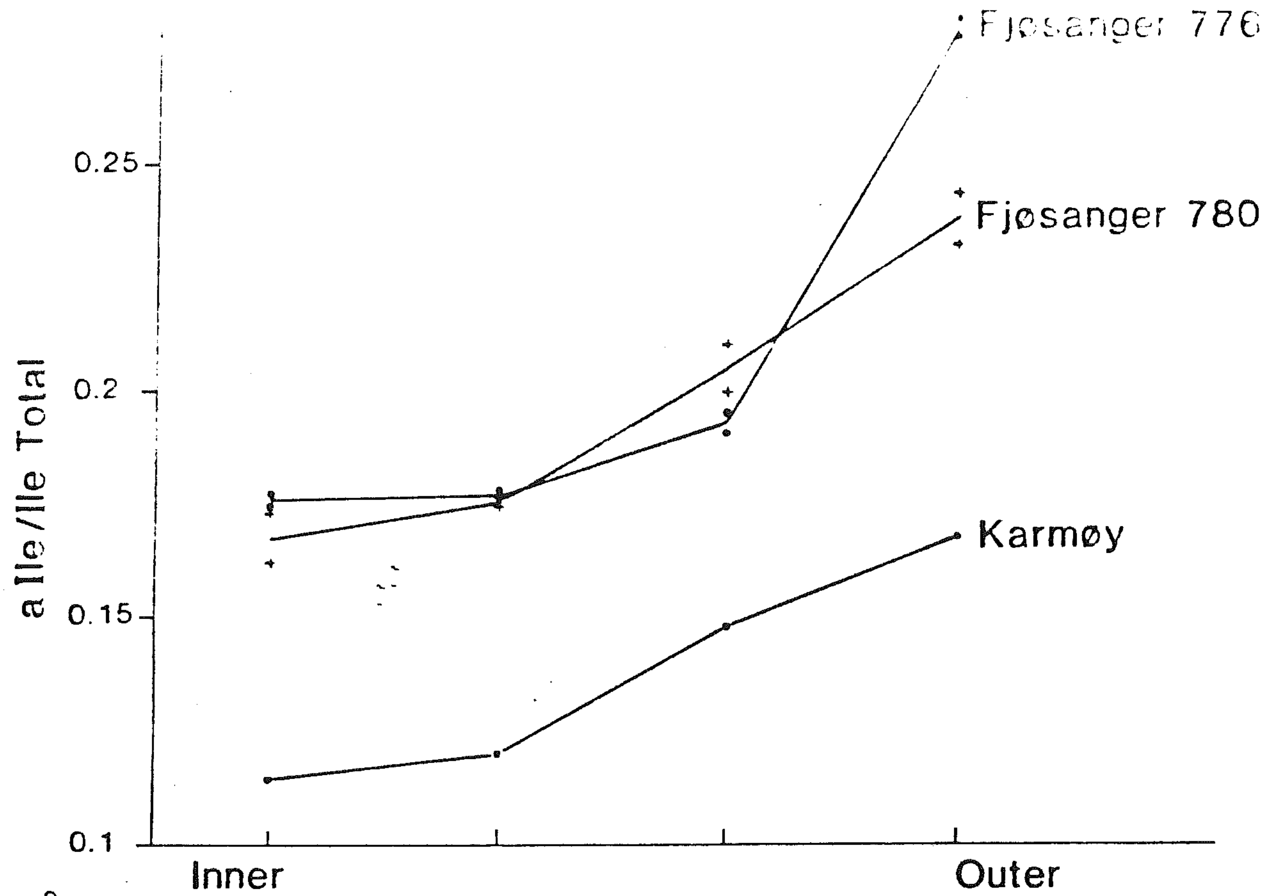

Fjøsanger 776
Fjøsanger 780
Karmøy
0.25
0.2
0.15
0.1
a Ile/Ile Total
Inner
Outer

Fig. 2


Fjøsanger 780
Fjøsanger 776
Karmøy
0.6
0.5
0.4
0.3
a Ile/Ile Free
Inner
Outer

Fig. 3

SEDIMENTOLOGY OF A HIGH LATITUDE POST-GLACIAL CONTINENTAL MARGIN SOUTHEAST BAFFIN ISLAND SHELF

R.T. Gillespie & C.P.G. Pereira

Surficial sediments in the Hekja-Ralegh area of the Southeast Baffin Island Shelf are essentially unsorted pebbly/muddy sands, which indicate a number of influences in terms of sediment source and physical processes. Textural character of the sediment is largely controlled by iceberg scouring and redistribution of the 'original' sediment package.

A model which describes the physical processes which influence and contribute to the sedimentology of this region is described in this presentation.

SETTLEMENT OF THAWING SUBSEA PERMAFROST AT PRUDHOE BAY, ALASKA

T. Matava[1], T. E. Osterkamp[1], A. S. Naidu[2] and W. D. Harrison[1]

[1]Geophysical Institute
University of Alaska
Fairbanks, Alaska 99775-0800

[2]Institute of Marine Science
University of Alaska
Fairbanks, Alaska 99775-1080

ABSTRACT

Settlement of thawing subsea permafrost could potentially provide a significant sediment sink for sediments derived from coastline erosion and contribute to motion of the pore fluids in the sediments above the top of the ice-bonded permafrost. Several experiments were performed to determine the magnitude of thaw settlement occurring in coarse-grained subsea permafrost adjacent to the West Dock Causeway at Prudhoe Bay, Alaska. The experiments were pore pressure measurements in the sediment above the top of the ice-bonded permafrost, placement of nine settlement points at various locations up to 550 meters offshore, Lead-210 dating of a sediment core and clay mineralogy to determine the origin of the sediments. The results of the experiments did not indicate the presence of non-hydrostatic pressure gradients associated with thaw settlement, the Lead-210 based sedimentation rate is too low to measure, settlement points at 10, 100, 200 and 300 meters offshore did not settle in 8.5 months and finally, the clay mineralogy suggests the sediments appear to originate onshore implying the offshore sediments are simply reworked coastal deposits. Based on these experiments it is concluded that the offshore sediments are reworked sediments from the eroding coastline and that thaw settlement does not appear to be occurring in these coarse-grained sediments as the subsea permafrost thaws. These results do not apply to areas where the soils are fine-grained.

Mineral Variability in Central Arctic Ocean Sediments: Potential for Identifying Source and Dispersal Pathways of Arctic Glacial Ice.

Glenn A. Jones
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

Previous studies have shown that texture (i.e. grainsize) can be used to characterize and correlate sediments from widely separated regions of the central Arctic Ocean (Clark et al., 1980). The temporal variations in these textural characteristics have been attributed to variations in the extent and/or intensity of Northern Hemisphere glaciation (Clark and Hanson, 1983). The possible exists that the mineral composition of these sediments can be a valuable means of further identifing the sources and dispersal pathways of glacial ice into the Arctic Ocean. Unfortunately, little work has been done in this area. We will present the preliminary results of an investigation into the temporal and geographic variability of the bulk mineralogical composition of eight central Arctic Ocean cores recovered from a wide range of depositional and geographic locations. The purpose of this investigation is to evaluate if observed mineral variations within the central Arctic sediments reflect changes in the extent of Northern Hemisphere glaciation and/or changes in the major sources of ice-rafted sediment deposited within the central Arctic. Distinct temporal variations in the mineral composition of these sediments is observed. Quartz contents vary from 1% to 40%, feldspar from 0% to 25%, and carbonates (limestone and dolomite) from 0% to 40%. These observed mineral variations do not always correlate with the observed textural changes. This finding suggests that information in addition to that obtained from textural parameters is available. Combining the mineralogical data with the previously studied textural parameters should provide a more valuable index of the temporal and geographic variability of the major sources of sediment input into the central Arctic and to the extent and/or intensity of Northern Hemisphere glaciation. Although we hesitate to interprete this preliminary data at this time, we are none the less excited about the geographic and temporal patterns observed. It is hoped that combining our data with that of field-oriented land geologists can further our understanding of the Quaternary pathways of land-to-sea transport of sediment to the central Arctic.

Clark. D.L. and Hanson, A., 1983. Central Arctic Ocean sediment texture: a key to ice transport mechanisms, in Molnia, B.F. (ed). Glacial Marine Sedimentation, 301-330.

Clark, D.L., Whitman, R.B., Morgan, K.A., and Mackey, S.D., 1980. Strati graphy and glacial-marine sediments of the Amerasian Basin, central Arctic Ocean. Geological Society of America Special Paper 181, 57pp.

DISTRIBUTION AND CHARACTER OF SEDIMENT IN A TIDEWATER GLACIER, SOUTHERN BAFFIN ISLAND, CANADA

Dr. Julian A. Dowdeswell
Scott Polar Research Institute, Cambridge

The distribution, shape and grain size characteristics of sediments in a Baffin Island tidewater glaciers are examined. At the glacier terminus a 0.8-2.9m thick zone of basal debris-rech (14-57 per cent by volume) ice underlies clean ice. Marginal ice flow is extending, and high level debris-rech bands are largely absent. Little supra-glacial sediment is present except as isolated rock-falls.

Measured sediment characteristics were:

1. Clast roundness,
2. Fourier shape of quartz sand grains,
3. Grain size distribution

Modal shapes of basal ice and rock form clasts were sub-rounded and angular respectively.

Fourier analysis showed quartz sand grains from clean ice and rock-fall were more angular and micro-textured than those from basal ice. Grain size envelopes for debis in basal ice, melt water streams, and near shore environments are described and are compared with those from fiord glacio marine sediment. The distribution of sediment within the tide-water glacier controls which mechanism's of debris release are important. This in turn influences the depositonal facies found. Sediment is released mainly by:

1. Direct melting and
2. Sub glacial streams and associated density overflows.

Calving is relatively unimportant. Acoustic sounding revealed three morainal banks offshore of the glacier terminus, probably relating to melt-out of basal debris. A calculated rate of basal sediment supply by melting of 6.1-10 M3 M-1 A-1 is similar to that required to build such banks.

EXTENT OF TERRESTRIAL AND MARINE ICE SHEETS IN THE WESTERN QUEEN ELIZABETH ISLANDS

D.A. Hodgson, Geological Survey of Canada,
601 Booth Street, Ottawa, Ontario, K1A 0E8

Continental glaciers overran or impinged on western Queen Elizabeth Islands several times during the Quaternary. The sparse glacial landforms and deposits also record ice caps centred within the islands. During the Late Pleistocene the Viscount Melville Sound Ice Shelf extended from a grounded continental ice margin across Parry Channel, whereas between the islands, locally generated shelves possibly occurred.

Continental Ice

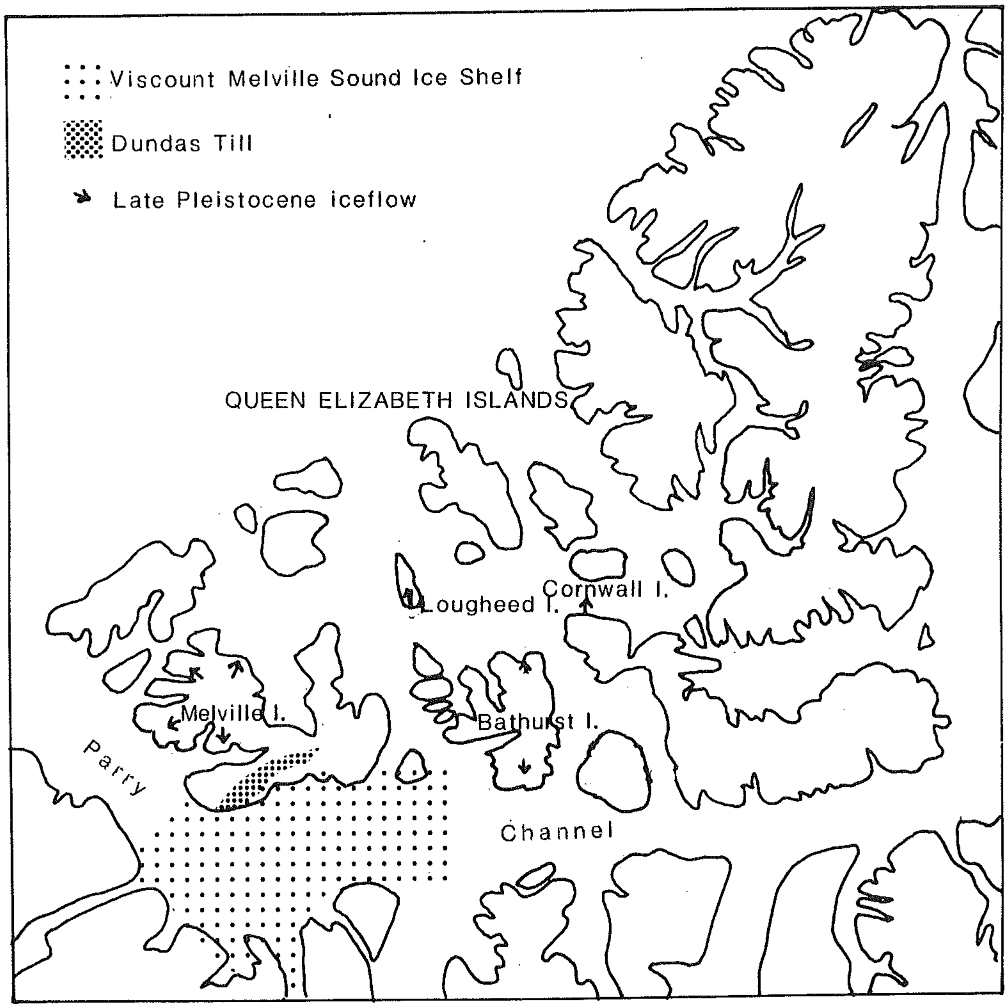
Shield erratics lying above the known marime limit occur on most islands (>500 m a.s.l. on western Melville Island). They are locally abundant in till and glaciofluvial deposits, and indicate inundation by ice of mainland provenance. The lower lying and later Dundas Till of southern Melville Island has been tentatively correlated with the Early Pleistocene Banks Glaciation. No Middle Pleistocene events are known. On southern Melville Island, a shoreline regressing from a maximum sea level at ca. 12 000 BP was overrun at ca. 10 000 BP by an ice shelf thrust from the Laurentide Ice Sheet. This shelf impinged on Byam Martin Island, but resultant calcareous till with abundant igneous clasts has not been seen on islands to the east.

Intra island ice

Radiating ice flow and deglacial landforms are known only from Bathurst and western Melville islands. Retreat of Melville Island ice likely occurred during initial lowering of sea level from the widespread 12 000 BP shoreline (about 50 m a.s.l.). Retreat on Bathurst Island may have occurred while marine limits (>100 m a.s.l.) were abandoned between 10 000 and 8500 BP. However, high early Holocene sea levels possibly resulted from crustal loading by ice in the eastern Queen Elizabeth Islands or by Laurentide ice.

Intra island ice

Till, glacially deformed rock and glaciomarine sediments on Lougheed and Cornwall islands record northward flowing Late Pleistocene ice; possibly this was shelf ice generated on Melville and Bathurst islands.


Viscount Melville Sound Ice Shelf
Dundas Till
Late Pleistocene iceflow
QUEEN ELIZABETH ISLANDS
Lougheed I.
Cornwall I.
Melville I.
Bathurst I.
Parry
Channel

AUTHOR INDEX

Lewis, E.L. 94

Magwood, J.P. 179

LATE SUBMISSIONS

Late Quarternary Depositional Environments of the Canadian Beaufort Shelf

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

The Canadian Beaufort Shelf comprises three main physiographic areas: the western shelf bounded in the east by the Mackenzie Trough; the Mackenzie Trough itself; and the eastern shelf. As a result of oil and gas exploration, the eastern shelf has been the location of extensive high resolution seismic surveys and shallow (100 m) boreholes. Less detailed information is available from the western shelf and the Mackenzie Trough, but high resolution seismic surveys of these two areas were partially completed in 1984. This paper will concentrate primarily on middle to late Wisconsinan depositional environments from the eastern shelf, but preliminary interpretations of presumed Wisconsinan and older sequences from Mackenzie Trough and the western shelf will also be presented.

In boreholes from the eastern shelf, two major types of sedimentary sequence can be recognized. In the very east of the area, thick sequences (up to 40 m) of coarse to fine grained sand predominate and are characterized by a lack of silt or clay interbeds. Analysis of the surface textures of quartz grains from these sands reveals a mixed assemblage of glacial/fluvial, beach and aeolian grains. High resolution multichannel seismic lines in the area show large-scale (5 - 15 m) cross-bedding within the sequences. Linear features of similar scale are seen at the seabed in some areas. The sand sequences are tentatively interpreted to be the deposits of a glacial outwash system. A combination of fluvial and aeolian processes, including channel and dune development can account for the observations described above. Much of the sequence may have been modified by marine transgression resulting in the development of sandy delta and coastal barrier systems.

To the west, along the eastern margin of Mackenzie Trough, the borehole sequences consist of interbedded fine sand, silt and clay. Sand beds rarely exceed 1 m in thickness and make up a relatively minor proportion of the total sediment thickness. On the basis of micro-faunal and -floral evidence, these sequences represent a range of environments including open shelf, shallow shelf, deltaic and lacustrine conditions. The presence of buried channels and prograding (foreset) reflectors in seismic profiles, especially in the outer shelf, supports the interpretation that a delta system prograded across the shelf. The predominantly fine-grained nature of the sequence and high proportion of marine beds suggests a Mississippi - type (fluvial-dominated) delta where distributary channel-migration and switching was a controlling process.

Stratigraphic control on these borehole sequences is based on radiocarbon dates constrained by palynological and seismic data. The thick sand sequences developed in two phases, an older phase prior to 21,000 yrs. BP and a younger phase prior to the last marine transgression (10,000 yrs. BP). The marine and deltaic sequence to the west was deposited between 27,000 yrs. BP and the present. A regional unconformity, noted on seismic profiles across the eastern shelf, provides evidence for a late Wisconsinan lowering of relative sea-level (RSL) which interrupted an overall rise in RSL since 27,000 yrs. BP. During the brief period of RSL lowering, two large valleys (2 - 10 km wide, up to 30 m deep) were incised into the exposed shelf. These valleys have subsequently been drowned and filled as RSL began to rise again. The valley-fill sequences have not been described in detail to date, but seismic profiles indicate a complex infilling pattern, perhaps related to estuarine processes.

In the Mackenzie Trough, the surficial 20 m of sediment consists of bioturbated marine clay. Underlying this thick veneer, a sequence of graded fine sands, very fine massive sands and silt/clay interbeds is observed to a sub-bottom depth of 80 m. Seismic profiles show that these lithologies were deposited in a large-scale delta system. Bottom set, foreset and topset reflectors indicate a large delta prograding to the north. The flat-lying reflector marking the top of this system decreases markedly in amplitude to the north, at a depth below present sea-level of approximately 70 m. The delta system is therefore tentatively correlated with minimum RSL condition during the late Wisconsinan.

On the western Beaufort Shelf, the sedimentary sequences which have been sampled consist primarily of stiff silt and clay. Seismic reflections are generally flat-lying, although shallow incised and filled valley features are observed. The sequence of the western shelf is tentatively correlated to the Pliocene - Quaternary Gubik Formation observed in coastal plain exposures in Alaska (see abstract by Brigham-Grette).

The present understanding of the depositional history of the Canadian Beaufort Shelf during the last 27,000 yrs. indicates that there has been a complex interaction of glacial outwash, delta and marine environments. A more detailed chronostratigraphy is still required to relate the glacial history with the various depositional environments established during this time interval.

DISTRIBUTION AND CONCENTRATION OF HEAVY MINERALS ALONG EASTERN BAFFIN ISLAND FIORDS AND BEACHES

by

M. Emory-Moore and J.V. Barrie
Centre for Cold Ocean Resources Engineering (C-CORE)
Memorial University of Newfoundland
St. John's, Newfoundland, Canada A1B 3X5

Heavy mineral concentrations in excess of 80% occur on the eastern Baffin Island coast. Textural and mineralogical characteristics of sands found on open coastal beaches, side entry beaches, two fiord deltas (sandur) and prodeltas have been examined. Coastal beaches are characterized by well sorted sands with a mean heavy mineral concentration of 30% while the delta/prodelta system varies between fine and medium, moderately sorted sands with a mean heavy mineral concentration of 9%. The heavy mineral concentrations within the nearshore sediments of the study area vary from the north (approximately 80%) to the south (approximately 1-8%). Mineralogy is generally characterized by a dominance of amphibole, pyroxene, opaques and garnet. The heavy mineral composition lacks maturity and is increasingly more variable within the deltas where concentrations decrease. In general the sands appear to mineralogically be in hydraulic equivalence.

Regional variation in heavy mineral distribution is source related. The samples from the northern study area are probably derived from metavolcanics and charnockites rich in pyroxene, garnet and opaques while the central and southern area is dominated by opaques and amphiboles derived from local migmatites and gneisses. The mechanism for selective heavy mineral concentration is not clear but seems to relate to a combination of nearshore wave and aeolian processes acting on locally derived sediments.

DELTA FRONT PROCESSES AND MORPHOLOGY, MACKENZIE DELTA, N.W.T.

C. Peter Lewis
Victoria, B.C.

The subaerial Mackenzie Delta has a surface area of 12,995 km^2 and is fronted by a 6,930 km^2 subaqueous delta front zone extending out to 12 m water depth. As such, it is the second largest delta in North America, exceeded in surface area only by the Mississippi. The large mean annual river discharge of 9,755 $m^3 s^{-1}$ at the delta front, in combination with the low wave energy levels of the microtidal Beaufort Sea, indicate that the Mackenzie, like the Mississippi, is characterized by the dominance of river forces over wave and tidal forces and that its morphology, therefore, should be primarily river-controlled. This river dominance is even further enhanced because of the occurrence of peak river discharge and sediment transport in the spring at a time when marine wave forces are near zero.

River control is verified to some extent by the very low offshore gradient which the Mackenzie has been able to maintain off its delta front, lower even than that off the Mississippi. Unlike the Mississippi, however, the Mackenzie does not have the rapidly advancing parallel distributary levees and digitate outline form that are usually considered typical of a river-dominated situation. Rather it has developed a lobate shoreline configuration with funnel-shaped channel mouths. These appear to result from the absence, at least during significant sediment transport events, of salt-wedge stratification in Mackenzie distributary mouths. The result is that at times critical to channel mouth morphological development, river effluent deceleration and expansion are controlled by jet diffusion and bottom friction rather than the buoyant expansion common off the mouths of major Mississippi Delta distributaries.

This salt water flushing does not appear to be particularly unusual, however. It is known to occur on other Beaufort Sea coast deltas like the Colville and the Babbage which are morphologically similar to the Mackenzie. In fact, it may even be that the modern birdfoot Mississippi Delta, rather than being typical of fluvially-dominated, low gradient deltas, is representative only of a relatively unique situation. The shallow mean subaqueous slope of the Mississippi is actually misleading in that the digitate distributaries considered as characteristic of the delta plain are prograding into water which is much deeper than that which fronts the remainder of the subaerial plain or which fronted older Mississippi lobate-shaped deltas. The salt wedge which is completely flushed from the digitate channels during flood stage is able to penetrate other wide shallow distributary mouths only when the discharge is low.

What is not usual in an apparently river-dominated delta like the Mackenzie, though, is the extensive shoreline retreat which is occurring along the active delta shoreline. Comparison between 1950's and 1970's aerial photography shows little evidence of active progradation, even at many channel mouths, and no evidence of areas which became sufficiently elevated to permit permanent vegetation growth. Even within the protected confines of Shallow Bay, any progradation that might be taking place on the east side of the bay is more than balanced by shoreline retreat on the west. Permafrost thicknesses on the lower delta plain, too, suggest that many of the supposedly recently formed low vegetated alluvial flats have been exposed to subaerial conditions for at least 500 to 1000 years.

This directly contradicts the most common scenario that has been used to account for the development of the modern Mackenzie Delta, a scenario that involves recent rapid progradation in an estuarine environment during a period of relative sea level stability. Modern delta organic sandy silts deposited over the past 5,000 years or so have been hypothesized to overlie fine to medium sands representing an earlier high energy environment. This picture, however, is based on very limited data, primarily from four holes drilled at a lake near Inuvik at the edge of the upper subaerial plain in 1961. Amazingly, these holes remain the only properly cored, logged and analyzed records of subaerial Mackenzie delta plain stratigraphy that penetrate even the Holocene much less the Quaternary section.

Some new stratigraphic information has been collected, however, that also contradicts or does not require a progradational hypothesis. A 1979 hydraulically drilled cross-delta profile anchored on the 1961 site does not confirm the generality of the earlier observed sequence: sandy beds are found scattered throughout the sections and all major changes in stratigraphy can be accounted for by aggradation and by lateral variations in environments of deposition. Offshore, extensive new data suggests that sea level, rather than remaining stable for the past 5,000 years, has continued to rise rapidly. The implication, of course, is that the recent evolution of the Mackenzie Delta front has been controlled more by transgression than by progradation and considerable evidence for this has been reported from offshore. We see here that this evidence is supported rather than contradicted by the onshore situation. It is possible, too, that conditions peculiar to an arctic/subarctic environment are also inhibiting delta front progradation. The presence of bottomfast ice in spring may be turning the 0-2 m zone into one of sediment bypassing at the time of maximum sediment supply.

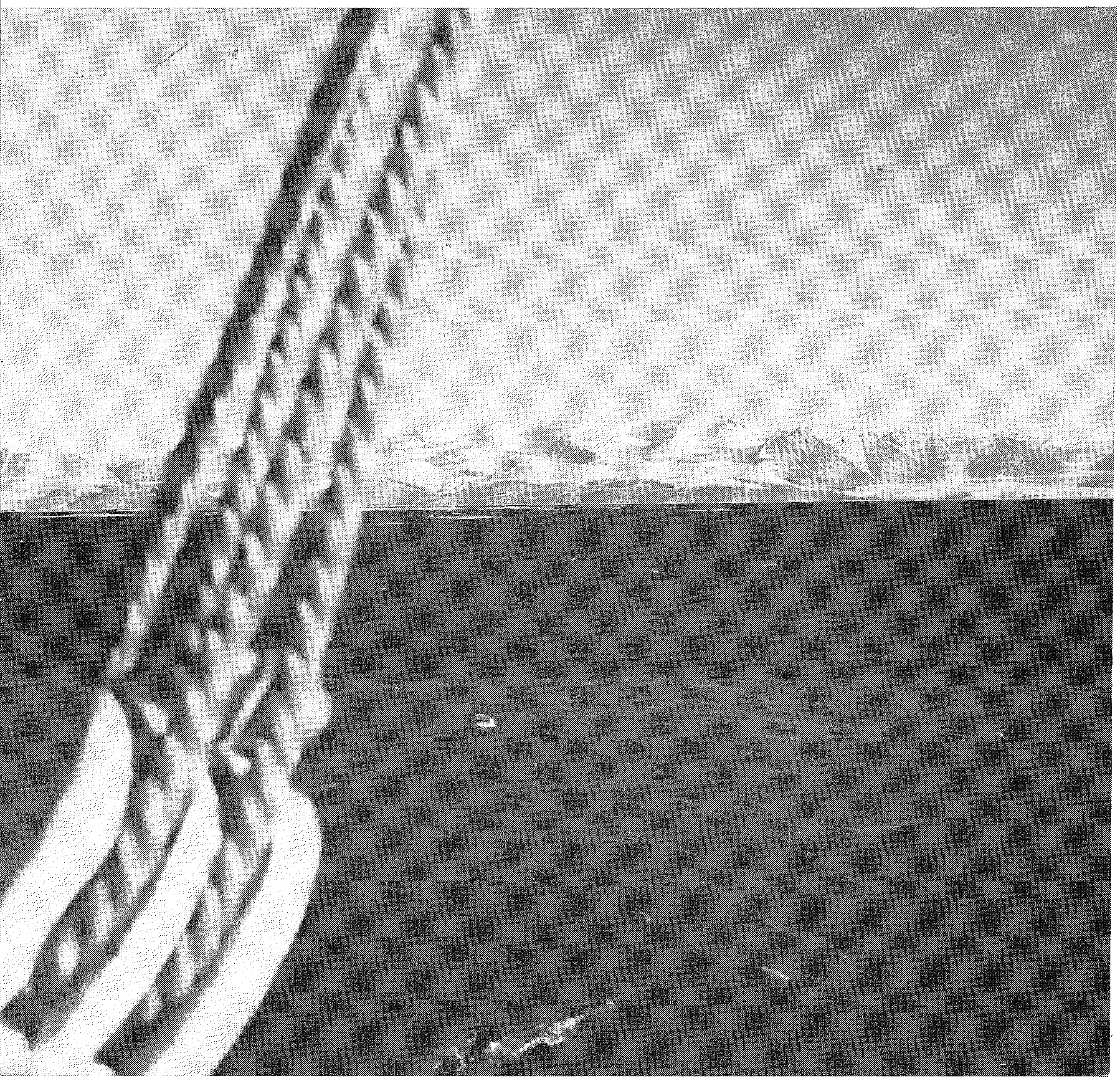
The Mackenzie Delta, then, is not only very different from the classic birdfoot Mississippi model but differs as well from any delta types, even those of similar lobate outline form, which show the coarsening-upward stratigraphy characteristic of delta progradation. It does show evidence of river dominance with its shallow convex-upward offshore slope but it also has been greatly affected by continuing marine transgression and by its arctic/subarctic environment.

14TH ARCTIC WORKSHOP

NOVEMBER 6-8, 1985

ARCTIC LAND~SEA INTERACTION

ABSTRACTS



ALSI

85

Cover photographs by Roger Belanger

Front Cover: Bylot Island from Lancaster Sound

Back Cover: Bedford Institute of Oceanography