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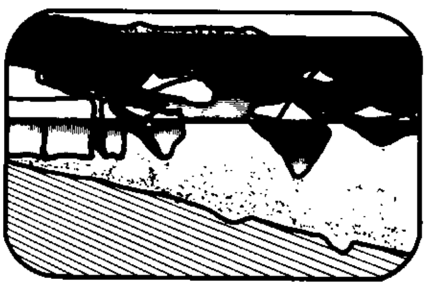

Arctic Land-Sea Interactions

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Introduction

Land-sea interactions involve the exchange of both energy and products originating on land and in the sea. In the arctic, energy exchange processes include: (1) tidal oscillation effects on estuarine circulation dynamics, in an environment of ice cover or ice floes; (2) short-lived events of intense river discharge that provide hydraulic energy to the coastal zone; (3) wind action that may or may not lead to the formation of sea waves, sediment transport and circulation dynamics depending on the presence or absence of sea ice; (4) iceberg production from tidewater glaciers involving both a kinetic and potential energy transfer; and (5) sea ice formation where the reduction of wind-induced turbulence is balanced in part by circulation cells formed as a consequence of the salt rejected during the growth of sea ice. Further, the interaction of these processes takes place along a landscape unique because of intense frost action, a soil cover over permafrost, an incomplete vegetation cover, aeolian storms, and within a framework of glacial dynamics, complex sea level fluctuations, and historically significant climatic fluctuations.

Although the arctic coastline comprises a very large proportion of the world's coastline, the study of arctic land-sea interactions remains in its infancy. The working environment, whether on sea or on land, is demanding. Like other areas of the world, the tools and techniques developed for surveying the nearshore are largely inadequate and this situation is compounded by very limited bathymetric coverage necessary for ship operations. However, petroleum exploration pressures and associated environmental concerns have forced land and sea-based scientists to join forces and develop some initial understanding of the processes that operate in that critical environment.

The 14th Arctic Workshop focussed on the theme of Arctic Land-Sea Interactions and was held at the Bedford Institute of Oceanography, Dartmouth, Nova Scotia, on 6-8 November 1985. The workshop was sponsored by the Arctic Institute of North America, the Centre for Cold Ocean Resources Engineering, the Arctic Petroleum Operators Association, the Geological Survey of Canada, the Institute of Arctic and Alpine Research, the Norske Polar Institutt, the Canadian Department of Fisheries and Oceans, and the Scott Polar Research Institute. Ninety papers and posters were presented. Session chairmen were invited to contribute their ideas, impressions and suggestions for future work on the arctic nearshore. Outlined below are their edited contributions. *Note:* names and affiliations cited in the text are contributors to the Workshop. Their extended abstracts are published in Vilks and Syvitski (1985).

Tidewater Glaciers and Iceberg Dynamics

contribution by Anders Elverhöi (Norske Polar Institutt, Oslo, Norway)

Tidewater glaciers and icebergs are major environmental components in high latitude seas. Their meltwater streams transport large amounts of glacial debris, which may be deposited at rates up to several metres per year in the proglacial environment. Sediments released from icebergs may provide unique markers for hindcasting iceberg trajectories, even though the volume of ice-rafted sediment deposited on the sea floor is of minor importance.

Iceberg calving is an important part of the mass balance for tidewater glaciers and is normally most active in the summer season. Large numbers of bergs are calved during catastrophic events, such as surges within the glacier stream, a feature that is common in Svalbard and some parts of Alaska. The production rate of icebergs is of interest not only to glaciologists, but also to the shipping and the petroleum industries.

Session papers focussed on: (1) the dynamics of icebergs impacting the seafloor, including the interpretation of paleo-events; (2) the sedimentological effects of iceberg calving and ice cap surging; (3) the interpretation of ancient glaciomarine deposits; and (4) ice shelves and their role in cold water formation.

Interesting structures related to ice scouring of the seafloor include: (1) deep (10 m) pits or amphitheatres possibly formed during a grounding or overturning stage in the course of an otherwise drifting iceberg; and (2) a "ribbed" scour pattern within iceberg furrows observed in Hudson Bay and on the Weddel Sea continental shelf. The presence of clays sampled within these "ribbed" scour marks, negate the argument of sand wave origin.

An important step toward determining the origin of these scour marks is the DIGS-85 experiment. This joint government and industry project provides us with the first direct observations of iceberg grounding, combined with *in situ* sedimentological and geotechnical measurements, and supporting meteorological and oceanographic observations. These data have helped to calibrate models used to examine the forces acting on free-floating and grounded icebergs in relation to their size, shape, resultant motion, and to the size of the seafloor scour produced. The petroleum industry has used these models to calculate the risk of icebergs interfering with offshore installations. Ice scouring remains the major industrial hazard along parts of the offshore of Canada's east coast and on the Beaufort shelf (Figure 1).

Research on iceberg dynamics has focussed historically on two basic problems: (1) the prediction of iceberg drift patterns; and (2) their scouring of the seafloor. The session did not deal with drift forecasting, which up to now has been best dealt with using a statistical approach. The DIGS-85 experiment may eventually provide information that will improve drift predictions, essential for our interpretation of the icescour "fingerprints" (C.F.M. Lewis and H.W. Josenhans, Atlantic

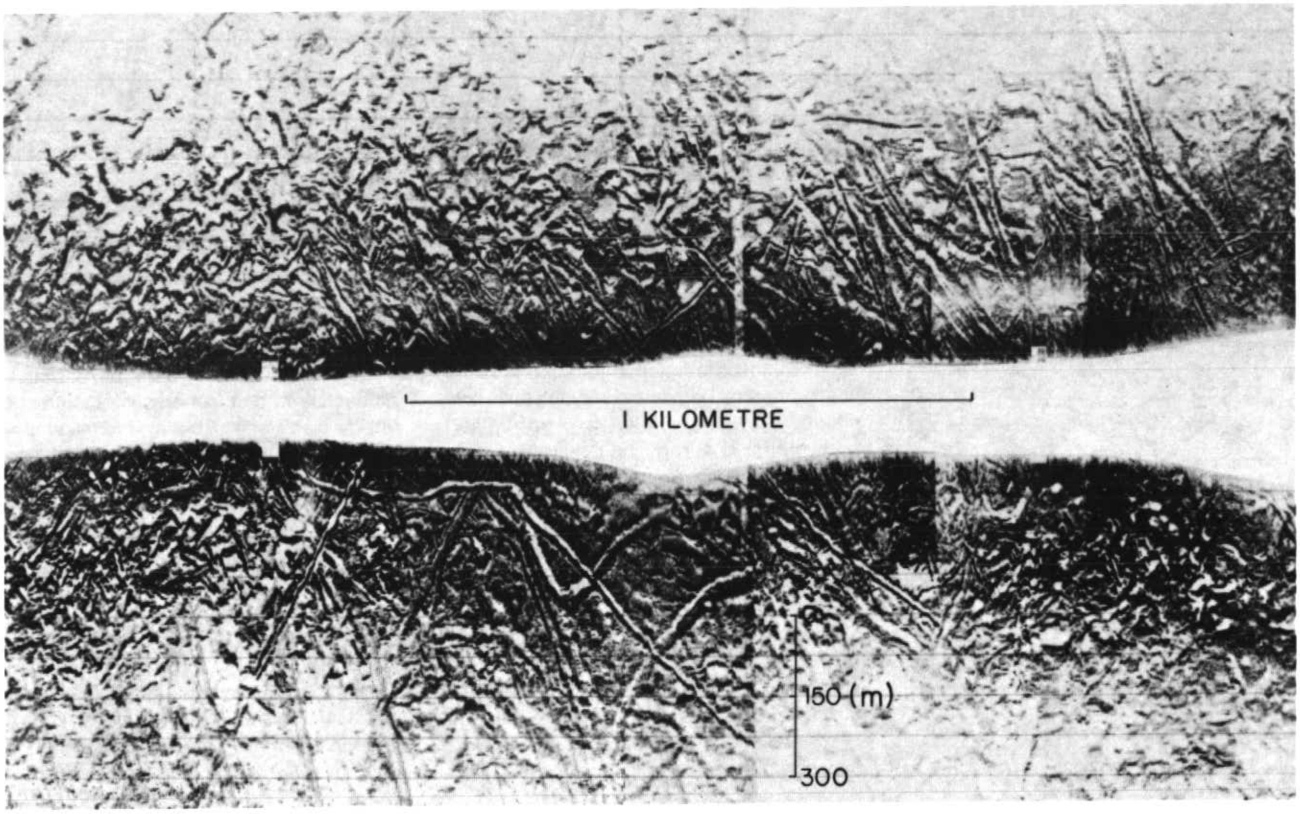

Figure 1 *Typical seafloor along the fjord-shelf interface of Baffin Island, as surveyed using the BIO side scan sonar. Note the many iceberg scour and pit features.*

Figure 2 *Schematic of the various means that sediment may be introduced into the marine environment fronting a tidewater glacier.*

Geoscience Centre, Dartmouth). Future research should also address the movement of icebergs in three dimensions, which may aid our understanding of the formation of the ribbed scour marks.

Iceberg calving may also directly or indirectly influence the seafloor sediments proximal to the glacier. Icebergs, which calve from above sea level, will form a pressure wave as they descend through the water column. These waves could initiate slides and gravity flows and therefore aid in the redistribution of bottom sediments. Interstratified sediments are common in front of tidewater glaciers and the calving process may contribute to the formation of these deposits (R. Powell, Northern Illinois U, Dekalb).

We still lack adequate criteria to differentiate the various glaciogenic sediments deposited in the marine environment (i.e. from beneath grounded ice, in front, or beneath an ice shelf; Figure 2). One recent survey examined the effect of a glacial surge (Braasvellbreen, Svalbard) on the proximal seafloor. The ice has retreated 5 km from its maximum extension in 1938. The striking feature of this recently exposed seafloor are the straight, discontinuous ridges that form a rhombohedral pattern. These ridges may have formed by the squeezing of sediment through crevasses between stagnant ice blocks after the surge (A. Solheim, Norwegian Polar Institute, Oslo). In the future we must learn more about these subglacial processes.

E.L. Lewis (Inst. Ocean Sci., Sydney) discussed the effect of water motion beneath an ice shelf. With increasing pressure, the freezing point is reduced. Thus seawater moving downward will melt ice at depth. As the bouyant meltwater rises, it becomes supercooled with the drop in pressure and ice crystals are formed at higher levels. This process moves ice from deeper to shallower levels in the ice shelf and is essential in melting ice shelves. Areas like the front of the Ross Ice Shelf may melt at up to 6 $m \cdot a^{-1}$.

Session papers on ancient glaciomarine deposits emphasized the advantage of studying complete stratigraphic sections. Studies of exposed ancient glaciomarine deposits have received more attention than their modern counterpart and therein lies the problem, i.e., the inadequacy of actualistic models.

Arctic Fjords

contribution by John Andrews (Institute of Arctic and Alpine Research, Boulder, Co., USA)

Fjords have been characterized as elongate arms of the sea that are situated within the glaciated margins of tectonically uplifted coasts. During the early 20th century there was active debate on whether fjords were tectonic in origin or glacial. Judging from statements in nearly all texts, the glacial origin hypothesis won the day and most people now consider fjords to be the product of glacial erosion. However, there are extremely few papers that attempt to quantify such an argument, or that have looked critically at the evidence. The answer requires the combined attention of structural and bedrock geologists, glacial geologists and sedimentologists. In a talk at the University of Colorado, sometime in the late 1960's, J. Tuzo Wilson directed attention to the fact that the fjord coasts of the world are concentrated in areas that have certain tectonic elements in common; they also have the factor of glaciation in common. What is the relative importance of tectonism, and of fluvial and glacial erosion on the current form of these spectacular landforms? John England (U of Alberta) stressed the tectonic framework of fjords in northern Ellesmere Island and proposed that the major fjords are also located along major faults (grabens?), which may post-date regional glaciations. England points out that once the fjord is formed, the channelling effect will restrict the extent to which ice can thicken and form a regional ice cover.

Fjords constitute important sediment traps in the cascade between terrigenous inputs (glacial, periglacial and fluvial) and eventual storage of sediments in the abyssal plains (Figure 3). In areas that are free of major tidewater glaciers, fluvial inputs frequently result in the formation of large deltas that prograde seaward through time. The supply of sediment to the middle and far basins is often modified by sediment slides from the face of the prodelta and subsequent debris flows or turbidity currents. These flows move along channels that are incised into the seafloor. The slides are a direct result of slope failure caused by locally high rates of sedimentation, and by seismic events that occur along many fjord coastlines.

In fjords that contain active glaciers, the processes of iceberg calving and ice-rafting (including sea-ice rafting) are important, and gravels, sands and even silt-sized particles, are not preferentially stored as in sandur-delta complexes.

Silts and clays are injected into the marine environment with the meltwater plumes that spread down-fjord as part of the estuarine circulation. According to Ron Trites (Marine Ecology Lab., Dartmouth), estuarine circulation in some Baffin fjords can either be enhanced or turned-off by major storms. Gary Winters and others (Atlantic Geoscience Centre, Dartmouth) propose that suspended matter settles very rapidly in these fjords, e.g., the water column may clear in about 30 days for a 500 m deep fjord. Typically concentrations of suspended matter in the Baffin fjords during the autumn season are between 0.5 and 4.0 $mg \cdot L^{-1}$, but can reach 45 $mg \cdot L^{-1}$ near the face of tidewater glaciers. The character of these flocculated particles is highly variable, depending on local mineralogy and biogeochemistry. In fact, even within a single fjord, individual basins can be geochemically unique (Buckley and Fitzgerald, AGC). The relative abundance of detrital carbonate appears to be useful for tracing the exotic input of suspended or ice-rafted sediment in Baffin Island fjords. Peaks in the rate of accumulation of detrital carbonate, as observed in cores, occurred between 10 to 6 ka (Andrews, INSTAAR).

What happens to the fjord basin sediments when climatic conditions cause tidewater glaciers to extend into a fjord remains an outstanding question. We assume commonly that the basin sediment is removed by glacial erosion. However, recent data from Baffin and Svalbard suggests that ice may override the basin muds. The development of

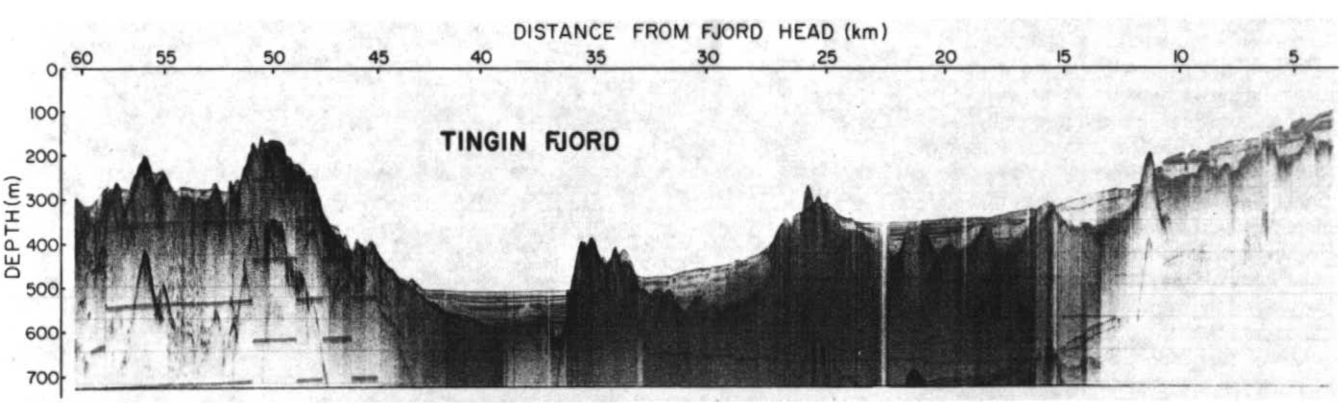

Figure 3 *The effective sediment trap of a fjord as indicated on a 655 cm² airgun reflection-seismic profile.*

actualistic facies models from modern fjord environments allow us to understand the spectrum of possibilities that can be employed as we attempt to reconstruct the environment of deposition in the Quaternary and in more ancient sedimentary sequences.

Sedimentary Processes in Northern Estuaries

contribution by Bruno d'Anglejan (McGill U, Montreal, Canada)

High latitude estuaries are characteristically different from their lower latitude counterparts. The difference is related partly to the alternating ice-bound and ice-free conditions and also to the influence of the storage of snow on the hydrological cycle. Strong seasonality both in the physical environment and in the run-off intensity is a major controlling factor common to subarctic and arctic estuaries, which otherwise may differ in morphology, basin lithology, relief, and in their long-term sea level trend. The effects of seasonality on the sedimentary cycles of northern estuaries are still poorly known; possible areas of investigation are outlined below.

Processes taking place during the winter minimal river run-off and water column quiescence interval are difficult to measure and, for this reason, tend to be ignored. However, recent work off the river mouths of James Bay and Hudson Bay has examined the large areal extent as well as the thickening of freshwater plumes under ice with open water conditions (e.g. Ingram, 1983). These low salinity surface waters are able to propagate offshore over a sharp halocline in spite of reduced run-off. A sharp discontinuity, i.e. the site of covergence, develops at the boundary of the plume and the ambient basin water probably as a result of the lack of wind and wave mixing.

High stratification in the estuaries and offshore is favourable to the development of sharp gradients in suspended sediment concentrations (turboclines or lutoclines). Evidence for midwater suspension flows at density discontinuities in the water column has been obtained in the Gulf of Alaska (Wright, 1971). If these flows persist for several weeks at the end of the winter, they can be important agents for the transport of sediment over large areas of the shelf.

At river mouths, confined flow under ice results in an increase in velocity. In these settings, loose sediment is frequently excavated by the forced flow at the ice edge (e.g. Broadback River in Rupert Bay; d'Anglejan, 1980.) Tidal influences on suspended sediment transport may also be dissimilar under ice, since semi-diurnal oscillations in ebb and flood velocities are made more symmetric by the load of the ice cover (LaSalle Hydraulic Laboratory, Montreal, unpublished results).

Winter suspended loads from rivers are characteristically different (e.g. in their particle size or the composition of the organic-inorganic fraction), as compared to summer loads. Offshore from the river mouth, the vertical flux of particles dispersed horizontally by the above process often contains a late winter organic fraction derived from a brief but intense diatom production under the ice cover. Pelletization by grazing zooplankton represents an effective mechanism of sedimentation at this time. The relative importance of this under-ice marine biological source compared to the inorganic terrigenous source decreases abruptly as winter comes to an end.

Break-up of the ice cover and the rapid rise in discharge from the annual minimum in late winter to the peak value during snowmelt constitute the dominant phase in the sedimentological cycle of high latitude estuaries. Two-thirds or more of the annual sediment load may be transported during this brief interval. Increasing river flow often provokes the retreat of the salt intrusion to the river mouth or further offshore, and the destruction of the winter stratification. Intensification of bedload transport may lead to partial or total flushing of the previous summer and winter deposits from the lower reaches of the estuary, and to the development of a delta front over the inner shelf. The fine organic-rich winter layer may or may not be preserved, although a winter lamination may be found buried under the coarser spring layer. Wave reworking during the summer months may, however, destroy the entire winter-spring record.

The importance of ice as a transport agent of sediment within rivers and estuaries remains unresolved. In the St. Lawrence Estuary, ice along the shores retards rather than promotes sedimentation (Sérodes, personal communication). Ice-rafted sediment is deposited during melting of the ice close to the shoreline. However, only the coarser-grained sediment is likely to remain in place as the river discharge begins to peak. The overall importance of shore-ice fragmentation and dispersal on sediment transport may have been overemphasized because of the conspicuous scour features and microfacies it leaves in the nearshore (Figure 4).

Northern estuaries form integrated assemblages of sediment sources to the continental shelf and latitudinal differences of these assemblages need to be considered. The northward progression of spring melting along a coastline results in delayed sediment output from the more northerly members of a string of related estuaries. The activation time of these various sources may influence the overall shelf transport processes. Satellite imagery recording turbidity and temperature changes at estuary entrances could be used to indicate contrasts and interactions, if any, between discharges issued from dammed and from naturally flowing rivers. Such imaging could also be used to discern differences between estuaries as affected by a change in climate, vegetation and bedrock geology.

Summers, with comparatively stable river flows for several months, represent periods of estuarine readjustment during which salt intrusion tends to be re-established, with a concomittant inshore migration of the turbidity maxima. Deposition takes place on tidal flats and on brackish water tidal marshes after the vegetation is re-established.

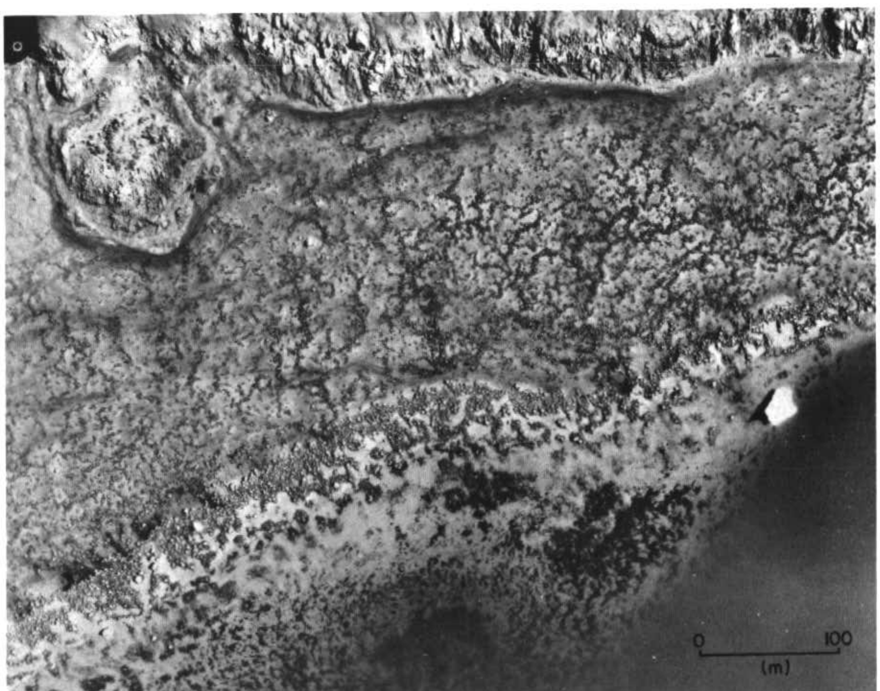

Figure 4 *Vertical air photograph of the expansive tidal flats along Pangnirtung Fjord, Baffin Island. Note the seaward (low tide) boulder barricade.*

An ecologically important seasonal cycle of erosion and deposition dominates these fragile environments, and many details remain to be resolved.

Finally, from contrasts and comparisons between various aspects of estuaries from different climatic zones along northern coastlines, it may be possible to develop models of the evolution of estuarine environments during the deglaciation period.

Permafrost Deltas and Shelves

contribution from S.M. Blasco (Atlantic Geoscience Centre, Dartmouth, Canada) and H.J. Walker (Louisiana State U, Baton Rouge, USA)

There now exists a preliminary geological framework for the Canadian and US Beaufort coast that can be used to judge and assess new information and to focus the direction of future research. Across the Alaskan Coastal Plain, the Gubik Formation spans the late middle Pliocene to late early Wisconsinan at 70 to 80 ka (Brigham-Grette, U of Alberta, Edmonton). The Formation consists of lagoonal, beach and shallow to mid shelf marine, fluvial and aeolian deposits which record six high sea level stands. Through the use of oxygen and uranium isotopes, thermoluminescence and amino acid analyses, the last two transgressive sequences date at 75 and 125 ka, respectively (Carter *et al.*, USGS, Anchorage). The inner shelf area east of Prudhoe Bay has been tentatively correlated with the Gubik Formation of the Alaskan Coastal Plain. There, deposits represent seven and possibly eight late Pliocene to Holocene marine transgressions; two or three intervening deposits record episodes of lower sea level (Smith, USGS, Menlo Park).

On the Alaskan outer shelf there exists a wedge of up to 40 m of recent post-glacial sediment. Seismo-stratigraphy suggests an onlapping sequence of such wedges and these may relate to a series of transgressions correlatable with the global oxygen isotope record over the past 250 ka (Dinter, USGS, Menlo Park). The Alaskan inner shelf is, however, regionally devoid of Holocene sediments. Even the Flaxman Member (75 ka) of the Gubik Formation has been reduced to a lag veneer on the seabed and is being continuously reworked and eroded by the action of ice keel sand currents (Wolf *et al.*, USGS, Menlo Park).

The western Canadian (Beaufort) shelf is also devoid of Holocene sediments, except for thin localized deposits, and sediments of early Wisconsinan age or older are truncated at the seabed. In contrast, the upper 100 m of sediment covering the central Canadian Beaufort shelf have been deposited over the past 25 ka. These deposits consist of a complex of glacial outwash, shallow shelf and progradational deltaic sediments (Hill, Atlantic Geoscience Centre). Shore deposits in the western Canadian arctic, principally Banks Island and the mainland adjacent to the Beaufort Sea, show evidence that a late Tertiary marine transgression was followed by four glacial advances of diminishing areal and temporal extent. The ages of these advances are >730 ka, >128 ka, >64 ka, <23 ka with evidence for largely isostatically induced marine transgression following the earliest and subsequent glacial advances (Vincent, GSC, Ottawa).

In the arctic, ice in one form or another is present throughout most of the year. It plays a significant role in the transport and deposition of arctic sediments. Ice suppresses wave and current action; constricts and accelerates current flow between the ice and the seabed; constrains river flood waters to cause such phenomena as strudel scours offshore; inhibits sediment mobility by the formation of anchor ice on the seabed; and through the action of ice keels, reworks as much as 7.4% of the seabed annually in shallow water (Barnes and Reimnitz, USGS, Menlo Park; Figure 1). By suppressing wave and current action and by causing sediment to bypass the delta front, sea ice has modulated the Mackenzie River flow to create a lobate shoreline with funnel-shaped channel mouths. In the case of the Yukon Delta sediment is discharged through submarine channels under the sea ice during the period of ice breakup. As a result, sediments are deposited tens of kilometres offshore (Dupré, U of Houston). The impact of ice within the Colville Delta complex inhibits the normal hydraulic action of water and affects the reworking and sorting of sediments sufficiently to severely limit the usefulness of textural data in defining depositional environments (Naidu, U of Alaska, Fairbanks). It is interesting to note that the Mackenzie delta, like other arctic deltas that should be river-dominated, is controlled more by marine transgressive processes than by shoreline progradation (C.P. Lewis, Victoria).

Considering the complexity of glacial and relative sea level histories, future research needs include: (1) higher resolution dating techniques for improved correlation between the regional onshore and the offshore and other global studies; (2) a better understanding of arctic paleoecology and climatology to help discern transgressive and regressive depositional environments; and (3) more boreholes to support the available high resolution seismic data in defining Holocene and late Wisconsinan multiple transgression sequences.

Future studies should ascertain the effect of ice (as sea ice, river ice, ground ice, etc.) on delta and shelf sedimentary processes, such as, the rate of channel migration, the rate of sediment transport over and under ice, or the formation of thaw lakes. Deltaic environments associated with permafrost aggradation or degradation need to be clearly understood before the detailed nature and extent of subsea permafrost can be predicted or mapped. In order to thermally model the equilibrium conditions of subsea permafrost, the character of permafrost-affected depositional environments must be known, including details of the local sea level history (Osterkamp *et al.*, U of Alaska, Fairbanks). Further, more research on the nature of barrier island formation, migration and degradation is needed before a proper understanding of shoreline modification along arctic coasts can be realized.

Terrestrial and Marine Ecosystem Interactions

contribution by Susan Short (Institute of Arctic and Alpine Research, Boulder, Co., USA)

Continuous sedimentary records in some marine basins have greatly enhanced research of Quaternary paleo-climatology. However, serious problems still exist in correlating marine and terrestrial records of glaciations and climate. Much deep-sea data are from material collected some distance from the continental margins. These records are of relatively poor resolution for the interpretation of paleo-oceanographic variations on time scales of hundreds of years: a function of slow sedimentation rates and concomittant bioturbation. Suitable nearshore basins are among our best settings for resolving the problem of land-sea correlation. A major problem in using nearshore marine cores is unreliable dating: high rates of inorganic sedimentation reduce the level of dateable carbon which, in turn, may be contaminated with "old" carbon material. Mudie and Guilbault (1982) and Andrews *et al.* (1985) have suggested means to calculate the degree to which the fine-grained organic fraction of the sediment might be contaminated.

Seafloor samples in the eastern Canadian arctic contain significant amounts of pollen which reflect present-day patterns of vegetation, climate and oceanography (Mudie, 1982). Thus a link between terrestrial proxy records of environmental changes and glacial chronology may be resolvable by suitable pollen and "glacial" signatures in the intermediate nearshore sedimentary environment. Marine Holocene records correlate well with the onshore palynostratigraphies. For example, a low arctic tundra vegetation zone, as represented by the shrub *Betula*, was most extensive on southern Baffin Island between 5000 and 2500 B.P. This stratigraphic marker of a warm climatic episode is detectable both in Baffin Island lake sediments (Mode and Jacobs, U of Wisconsin, Oshkosh) and in marine sediments from southern Baffin Bay (Mudie and Short, 1985). Another useful example of how marine basins may mirror land processes is in the abundance of reworked pre-Quaternary palynomorphs in marine sediments. High concentrations are indicative of high terrestrial erosion rates and thus of precursor glacial processes.

Another example of land-sea interaction is the effect of the major water-mass boundary in the northwest North Atlantic that separates the marine arctic and subarctic zoogeographic provinces and the climate vegetation boundary on land between low arctic and high arctic conditions (Andrews *et al.*, 1980). Both the limits of terrestrial plants and those of nearshore marine organisms, particularly molluscs, are correlated with this watermass boundary. Future research should determine if paleo-shifts in the position of the watermass boundary have caused concomittant shifts in the flora, fauna and climate in the terrestrial record.

Lakes that now lie below the post-glacial marine limit are an interesting transitional coastal environment (e.g. Retelle, U of Massachusetts, Amherst; Mangerud *et al.*, U of Bergen, Norway). Marine sections of cores can provide evidence of sea ice breakup and increased runoff during period of glaciation or deglaciation through the analyses of sedimentary parameters and microfossils. In the overlying lacustrine sediments, variations of laminae thickness might reflect changes in runoff from the mid-Holocene to the present. Sedimentological and pollen analyses can provide evidence on whether this is due to climatic cooling or an increase in vegetation in the catchment areas. Finally, dating of the marine/lacustrine boundary can provide information on isostatic emergence rates and on the inception and growth of ice sheets.

Wind-transported material involves both biotic (pollen, plant debris) and abiotic (dust, sediment, volcanic ash) particles in addition to material dissolved in precipitation. Future research should emphasize joint terrestrial and marine coring projects that evaluate the spatial homogeneity of atmospheric deposition, a common input to both terrestrial and marine ecosystems. The study of the deep-sea abiotic and biotic components has already advanced our understanding of the ocean-climate-cryosphere system. The land record may also have a similar level of complexity and ultimate resolution.

A number of session papers focussed on animal-sediment interactions in arctic tidal flats. Aitken *et al.* (McMaster U) showed that several benthic organisms, especially *Arenicola* (lugworm), *Mya truncata* (softshell clam) and *Macoma balthica* (a bivalve), make characteristic traces in the sediments. Outcrops of Pleistocene sandy sediments at Pangnirtung contained enough characteristic traces to determine that the sediments had indeed been laid down in an intertidal environment. Differences in size between modern *Mya* and Pleistocene *Mya* appear to be related simply to their respective substrate environment (Aitken and Risk, McMaster U). Magwood *et al.* (McMaster U) noted the importance of the terrestrial organic matter component to the nutrition of arctic tidal flat ecosystems. They note that the trace analysis of shells could be used as a method to reconstruct fossil food chains. Dale (Queen's U, Kingston) developed a bio and lithologic zonation model for the tidal flats at Frobisher Bay. Such a model could be useful in determining whether tidal conditions have changed over the last 10,000 years along the Baffin coast.

Climate-Water Circulation Interactions
contribution by Thomas Kellogg (U of Maine, Orono, USA) and Charles Schafer (Atlantic Geoscience Centre, Dartmouth, Canada)
Physical oceanographers have made and are continuing to make significant revisions in their thinking concerning mechanisms and source areas for intermediate and deep watermasses of the global ocean. For instance, the arctic shelves are an important source area for Arctic Ocean intermediate and deep watermass formation (Jones and Anderson, Bedford Institute of Oceanography; Midttun, 1985). This is in contrast to the long-held view that Arctic Ocean watermasses include deep water formed in the Norwegian-Greenland Sea, intermediate "Atlantic" water, and a low-salinity surface layer resulting from the melting of pack ice. Newly discovered mechanisms for modern deep- and bottom-water formation, especially deep and shallow open-ocean convection were stressed by Kellogg (U of Maine, Orono). Areas where deep and bottom waters form during glacials now appear controlled by sea-ice extent in the northern hemisphere and by sea-ice and ice-sheet extent in the southern hemisphere (Kellogg, ibid).

Paleoceanographers and paleoclimatologists who fail to take notice of these new findings may discover that they are testing hypotheses and models no longer valid, or that they may be asking the wrong questions. On the positive side, new models of watermass formation provide the means for better understanding microfossil data from deep-sea cores if they can be related, for example, to features such as the newly discovered Arctic Ocean nutrient maximum that has been associated with the halocline (Jones and Anderson, BIO).

Larouche and Galbraith (Champlain Centre for Marine Science and Surveys) investigated the formation and breakup of fast ice in southeastern Hudson Bay in response to temperature (number of degree days), current velocity and wind velocity. They found that a sustained wind velocity in excess of 4 $m \cdot s^{-1}$ contributes to the early breakup of fast ice.

A number of papers on the extent of paleo sea-ice mentioned: (1) an apparent climatic change at about 8,000 B.P.; (2) various evidence for permanent ice cover *versus* open water or light ice cover; and (3) interpretation of "glacial" *versus* "interglacial" climate on the adjacent land on the basis of microfossils and sediment parameters in marine cores. However, the authors of these papers must be cautioned on the lack of adequate stratigraphic control and on distinguishing shelf microfossil variability related to ice cover from bottom water thermal regimes and/or microhabitats.

An early to mid Holocene (pre 5000 to 6000 B.P.) diatom-barren zone in cores off eastern Baffin Island was attributed to permanent sea ice above core sites (Williams, INSTAAR). Osterman (Smithsonian Inst.), using benthic foraminifera in Baffin Island shelf cores, concluded that a relatively warm current flowed southward along the Baffin Island shelf during deglaciation, that a glacial advance occurred at the northern end of Baffin Island between 16 ka and 12 ka, and that glacial advances occurred in the south from 12 ka to 8 ka. Using a variety of tracers in cores collected near and in Clark Fjord, Baffin Island, Jennings (INSTAAR) noted that high rates of ice-rafted deposition occurred between 12.4 ka to 8.4 ka on the outer shelf; thereafter, sedimentation rates increased on the inner shelf as a consequence of the deglaciation of Baffin Island. Sedimentation rates dropped significantly after 7,000 B.P. Dinoflagellates and pollen, from a probable source area in southern Labrador, were reported from mid-Wisconsinan sediments in a transect of cores from Baffin Bay southward to the Labrador Sea (Vernal and Hillaire-Marcel, GEOTOP). No evidence was found for a major input of subarctic water to Baffin Bay at this time.

Miller *et al.* (INSTAAR) argued for repeated ice advances of limited dimensions, derived from local ice caps centered over mountainous regions of the west coast of Spitsbergen. Four advances were recognized, tentatively dated at late Weichselian, late isotope stage 5, stage 5 or 6, and older than stage 6. Chronology was determined using amino-acid data, radiocarbon and U-series dating. Lehman *et al.* (INSTAAR) detailed the presumed stage 5 events at Broggerhalvoya and concluded that deglaciation following these events involved warm waters of an active Norwegian Current system. The biggest uncertainties of these studies involves the timing of recognized glacial events.

A major task facing researchers of arctic paleo-climatology, paleo-oceanography and glacial history, is that of placing observed changes in a reliable regional stratigraphic context. Large uncertainties still exist for radiocarbon dates older than 20 ka. U-series dates have also proved problematic (Szabo *et al.*, 1981). The issue has been complicated by uncritical acceptance of *prime facie* amino-acid evidence. Attempts to calibrate thermoluminescence (TL) dates using amino-acid ratios (Forman *et al.*, INSTAAR) may not bring order to this problem. We suggest that researchers obtain absolute dates and oxygen-isotopic data wherever possible. Until their reliability can be established, TL dates and amino-acid ratios should be limited to local correlations and only after careful calibration with absolute ages from the local area. Until some consensus can be reached on dating problems, we discourage investigators from making poorly supported claims concerning the timing of paleoclimatic and glacial events, and further, to refrain from attempting extra-regional correlations.

Paleoclimatic reconstructions based on microfossils in marine sediments can be reliable only if the environmental tolerances of these taxa are understood. For arctic benthic foraminifera and diatoms in particular, we need quantitative data on modern distributions and the environmental factors that control them. For example, how are benthic foraminiferal species distributions related to sea-ice cover? Is temperature, food supply, substrate type, or some other factor the major control on their distribution? Until quantitative data are obtained, paleoclimatic reconstructions based on microfossils will remain unreliable, often contradictory, and little more than hypotheses. As a prelude to studies of modern tolerances, problems related to taxonomy, such as those associated with key indicator species, need to be resolved and standardized (e.g. Rodrigues *et al.*, 1980).

Transgression-Regression of Sea Level
contribution by Jan Mangerud (U of Bergen, Bergen, Norway)
Mapping and dating of former sea-levels has been a major tool for the reconstruction of Late Wisconsinan/Weichselian ice sheets, notably around the Svalbard archipelago and in arctic Canada. The results are, however, vigorously debated. Future research should be directed toward improved geological mapping and dating of sea-level changes, and possible direct correlation of sea-level to ice-front deposits. A better understanding and knowledge of isostasy, eustasy, and geoidal changes will improve the quality of future reconstructions.

Relative sea-level may, in many cases, provide a link between geological development on the shelves and on the adjacent mainland. Postulated shorelines on presumably glaciated shelves have been reported from considerable depth, which is difficult to understand.

The last few years has seen much interest focussed toward the development of glacial models through the entire last interglacial/glacial cycle. Especially in the arctic, there is a considerable potential for studies of older littoral sediments that may contribute to the synthesis of glacial chronologies. Quantifying these chronologies is crucial for understanding the response of climatic and glacial variations to Milankovitch forcing. The arctic ice-sheets were mainly marine ice-sheets and their timing, with respect to Mid-latitude ice-sheets, is a key issue for glacial-climatic modelling.

Fossils from raised littoral sediments also provide opportunities for paleo-oceanographic reconstruction (temperature, salinity, isotopic composition, etc.) that can be used for correlations between marine and continental sequences. The interplay between oceanographic circulation and the growth/decay rates of ice-sheets is also an important element of the earth's response to Milankovitch forcing.

The Last Word
We have highlighted some of the latest findings and future directions in regard to arctic land/sea interactions. Although the achievements from our northern scientists are significant, work remains if we are to move forward from the present position of fragmentary and general knowledge. The main shortcomings are the lack of winter data in many process studies and the paucity of fossil material for reliable time correlations. Also, more geophysical data (high resolution sidescan and reflection seismics) must be obtained from the shallow coastal regions if we truly wish to correlate the offshore with the onshore story. It is satisfying to know that our knowledge of the interaction of ice on the seafloor, and our ability to map offshore permafrost, has become highly advanced.

Arctic research remains costly and we must continuously improvise using technology and concepts developed for lower latitude studies. Experience still remains the most valuable element in our pursuit of new knowledge. In a recent incident, we discovered that polar bears share our keen interest in science. An inflatable raft used for seismic surveys in the ice leads off Lougheed Island was left unattended for a few hours. On return we found that the bears had damaged the sparker hydrophone eel and the raft. If we could only get the bears to clip their nails and agree to a reasonable salary, we might be able to increase our seismic coverage.

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