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Environmental Atlas of the Beaufort Coastlands

B.R. Pelletier and B.E. Medioli

2014

Natural Resources Canada
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Canada

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ENVIRONMENTAL ATLAS
OF THE
BEAUFORT COASTLANDS

Canada

Environmental Atlas
of the
Beaufort Coastlands

Edited by
B.R. Pelletier
B.M. Medioli

Geological Survey of Canada
Open File 7619

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Symbolic of a new Arctic industry is the eco-tourism ship M/V WORLD DISCOVERER shown in the Beaufort Sea. The tender vessel CANMAR TINGNEAK is tied up alongside (Photo by G. D. Hobson, 1995).

PREFACE

The Beaufort Coastlands, lying adjacent to the southeastern Beaufort Sea, include the northern basin of the Mackenzie River drainage area. These lands are home to more than 7500 people, most of whom are aboriginal residents. Natural conditions, particularly the climate, seriously affect the livelihood of these Arctic dwellers in both a beneficial and calamitous manner. For example, fair conditions can introduce a bountiful wildlife harvest everywhere, but a harsh climate can forestall both land and marine migrations and interfere with hunting activities. This latter event may produce a low yield of much-needed animal resources.

Reports on climate warming are based on observations of a shrinking volume of sea ice, and the drilling records and instrument readings that show a deepening summer thaw of permafrost. Several years of continuous thermistor records, during the last two decades of the 20th century, fully attest to these warming phenomena. These signs of change are not catastrophic at present, nor is the debate on their origin entirely resolved. The period of time in which the warming effect is taking place, as well as its projected length and intensity, are also unknown.

In the matter of slope stability, human livelihoods and wildlife habitats can be adversely affected. Therefore it is essential that many aspects of the terrain such as slope failure, coastal processes involving erosion, coastal retreat, and weather elements including precipitation, air temperatures and wind variables be monitored daily and monthly. To be most useful in monitoring exercises, hazardous natural events and changes to the environment must be recorded concurrently. Wildlife on land, marine mammals at sea and on the ice, and the fisheries and their harvests are the entities that must be included in these environmental studies because of their essential role in the welfare of aboriginal people, as well as their ecological relationships.

More than four million birds visit the area each year for purposes of migratory staging, nesting and feeding. These activities occur along the coastal zone and the lower waterways that empty into the Beaufort Sea, mainly where wetlands, sandbars, inlets, headlands and cliffs provide habitats for avian existence. The entire community of birds must also be considered in plans designed to protect both inland and coastal living niches. It is essential that contingency planning be continued, or introduced in regions that must be protected. This Atlas is designed to serve as a background for such studies that will be beneficial for the occupants and visiting users of this varied suite of habitats.

The infrastructure of the Coastlands must be maintained, expanded and protected due to the growing population. Such necessities as transportation and communications corridors must undergo a similar protective attention in order that the safety and security of the region is maintained. Roads, cable routes and fuel transportation lines all require safe rights-of-way; therefore, to address these potential exigencies and the demand for utilities, the need for safe routes are included in the overall hazards-avoidance plans. These practices will require a cadre of professional and technical specialists, and a pool of workers prepared to perform assignments as required. Such a work force will require considerable background information, some of which is provided in this Atlas.

In the past, the petroleum industry has engaged northerners in training and production programs, as well as in active employment in the exploration of hydrocarbons. Thus, a wage economy for the native community was fostered, and this led to a support infrastructure for the petroleum industry and the community alike. Today some of that infrastructure is devoted to an entirely new industry throughout the Canadian Arctic Archipelago and northern mainland that venture is now called Eco-Tourism (see Frontispiece). Fleets of marine vessels, ice-breaking equipment and search-and-rescue activities may need to be expanded which, in turn, will be a further boost to the economy of the Far North. Should climate warming ensue, this industry may grow; however, it is likely to increase even if present conditions prevail into the near future.

A recreational industry is also thriving in the Coastlands and its surrounding fluvial and hilly regions to the south. This new industry is supported in an administrative sense by the offices of the territorial governments responsible for separate regions such as Yukon, Northwest Territories, and Nunavut. For example, in the matter of publications and the maintenance of an infrastructure, support is afforded for such activities as hiking, fishing, boating, and touring. The recipients of these services and participants in these activities include nature lovers, visitors to heritage and historical sites and museums, entrepreneurs of small commercial ventures, and numerous recreational business people.

Another important aspect to consider in the further development of the Beaufort Coastlands is the issue of governance. This thrust will create its own momentum as local municipalities at the territorial level seek self-government, even though the aegis of the Royal Canadian Mounted Police has provided security for the region since later historical times. Members of this agency are continuing these duties, as self-government is sought and northern municipalities move toward that goal. As eco-tourism and other employment opportunities increase, and should climate warming provide easier access to the marine and coastal areas adjacent to the northlands, the political expedience of self-governance may become less of an option and more of a necessity.

To achieve these progressive goals and adjust to evolving natural hazards, it is necessary to assess the dominant factors in the area that would culminate in these objectives. As a first approach, an inventory of critical information on natural science, sociology, and associated oil-spill problems was achieved by the petroleum and related industries in liaison with the Canadian government during the mid-1970s, when the Beaufort Sea Project was organized and carried out. It resulted in a series of excellent studies and accompanying reports that were published by Environment Canada (Ottawa). This was the beginning of a major effort to address deficiencies in existing coastal offshore technology and the tremendous gap in oceanographic science extant at that time. Two comprehensive works dealing with logistics of oil spill remediation have been published by the Arctic Petroleum Operators Association in 1979, and D.F. Dickens Associate Ltd., and ESL Environmental Science Ltd for Environment Canada in 1987. During this period, several papers dealing with the marine sciences of the Beaufort Sea were published in two atlases by the Geological Survey of Canada (Natural Resources Canada). Since then several hundreds of excellent topical papers by workers in industry, universities and government have contributed to a considerable scientific, sociological and industrial knowledge base of the area. An exceptional collection of papers published in 2000 deals with the physical environment of the Mackenzie Valley and an assessment of its environmental change. This compendium is edited by L.D. Dyke and G.R. `Brooks 2000 of the GSC, Ottawa.

The present volume, an extension of the Marine Sciences Atlas series, deals mainly with natural environmental issues of the Beaufort Coastlands, and has been assembled to assist workers and agencies in various fields who are involved in the protection and the development of the area. A summary of these environmental topics is given in the INTRODUCTION that follows this PREFACE. The full account is presented in the 70 essays, 98 maps, and more than 200 captioned photographs that form the main body of the Atlas.

Collectively the main thrust of this atlas, exclusive of adding to our scientific and developmental inventory, is to signal awareness of potential harm to the physical environment, whether it occurs through economic development or climate change, by outlining potential damage and prevention, and by indicating applicable measures pertaining to restoration and preservation. As well as focusing on the three major settings, which include the inland areas, the coastal features and the immediate inshore of the Beaufort Sea, emphasis is placed on the damage to the land features associated with the profusion of wildlife habitats. All these features must be scrutinized carefully and thoroughly as they represent potential harm to the way of life of the native inhabitants.

B.R. Pelletier
Geological Survey of Canada

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INTRODUCTION: A SYNOPTIC OVERVIEW

Part 1. History and Exploration

This synoptic overview begins with an account of the aboriginal people who inhabited or travelled the Beaufort Coastlands in the extreme northwestern corner of Canada. Commencing several thousands of years ago, the People journeyed from Siberia, across the Bering Strait, and subsequently along the southern and eastern coasts of the Arctic Ocean. These travelers actually reached the modern-day Canadian Arctic Archipelago, and continued further east to Greenland. Although life was nomadic during the beginning of their journey, over the centuries settlements appeared in several places along these island and coastal routes, and inhabiting of the area commenced (Fig. i-1). These activities are described by David Morrison in the first essay of this chapter INUVIALUIT OF THE BEAUFORT COAST; A HISTORY TO 1902.

During the latter part of the 19th century, Morrison notes the tragic experience of the People when they interacted with the early European explorers and traders. Disease from these visitors was a widespread and fatal occurrence that reduced the native population drastically. The introduction of firearms altered hunting activities but was not a threat to the old way of life, which was a subsistence economy that was dependent on living off the land and the sea. Toward the end of this hunting and trading period, Christian missionaries and law-enforcement officers carried out their work within and between the settlements, and a more stable pattern of life settled over the region. Local hostilities amongst different sects of the People subsided, including the rare violent outbreaks between the natives and exploring naval detachments.

A great incentive to the early seafarers in the eastern Arctic was the search for a shorter trading route to the Orient. Whalers were already entering Baffin Bay in the 15th century, and explorers had begun their quest for the Northwest Passage. In the 16th century, the Frobishers began sailing westward to the Arctic Islands hoping to discover the route to the Orient. The overall search involved seamen and explorers from many nations. Significant amongst these voyagers were Norwegian, Swedish, and Danish sailors, as well as numerous contingents of the Royal Navy of Great Britain. In 1845, Sir John Franklin was commissioned by the Royal Navy to seek the unknown passage westerly through the islands of the Arctic that lay ahead. This feat he attempted, and his last message was sent to the outside world in July of 1845. Regrettably he was never heard from again although grave markers of his men were found on Beechey Island, and numerous artifacts of the expedition were found enroute southward to King William Island. After several years, the search for Franklin was abandoned.

A considerable amount of naval exploration was completed in the latter part of the 19th century and included the coastlines of the Beaufort Sea, the northern coasts of the North American continent as well as the coasts of many of the islands to the north and east (Fig. i-2). Importantly, this widespread charting involved mapping the coasts and adjacent waters of the Canadian Arctic Archipelago (see NAVAL HISTORY OF EXPLORATION OF THE BEAUFORT COAST). As the 20th century began, Roald Amundsen had completed a marine route through the southern part of the Archipelago in 1904 over a period of several seasons. This was the first completion of the Northwest Passage by sea, and in 1906 Amundsen reached the Pacific Ocean. Thus the Northwest Passage was finally realized after more than five centuries of effort.

As this era of navigation and discovery closed, another opened. Some of this activity began in the 19th century, and carried on into the period of global hostilities of World Wars I and II. Surveying the land, establishing Christian Missions and related activities, hunting, fishing, and trading involving the Inuit continued as depicted in the photo essay entitled: INUVALUIT ACTIVITIES IN THE EARLY 20th CENTURY. These photos are from the Archives of the Geological Survey of Canada. Much of this activity was due inadvertently to several partially related events such as the following: the abandonment of the search for Franklin, the successful quest for the Northwest Passage, the locating of the North Pole from a dirigible in 1926 and, in more recent times, the surfacing of American nuclear submarines at the North Pole.

During the first half of the 20th century, exploration in the high Arctic declined. In the Archipelago and along the coast of the Arctic mainland, reasonable order was brought to the communities, and the native peoples moved about freely. The old way of life persisted, but now as the 20th century advanced a change emerged. Native people were beginning to live with two cultures: that of their own, and that of the civilization from southern Canada. During the pre-global war years of the 20th century, anthropologists, physical scientists, scholars and many others such as engineers, technical workers and support staff began their studies and operations some of which are ongoing .

After the war years the introduction of the southern Canadian culture persisted with the continuing presence of the Royal Canadian Mounted Police (RCMP) and the introduction of several agencies of the federal government. In 1958, the Polar Continental Shelf Project (PCSP) was organized as one of these agencies and its first field headquarters was established at Isaachsen on Ellef Ringnes Island in 1959 under the direction of Fred Roots. It has since moved several times in order to cover the territory for which it is responsible, and in this interval was led for 25 years by George Hobson until his retirement in 2002.

The PCSP is a multidisciplinary organization of Natural Resources Canada (formerly Mines and Technical Surveys, and subsequently Energy, Mines and Resources, Canada). The original purpose of the PCSP was to serve surveyors, hydrographers, mappers, scientists, and social study specialists even though some of them had been working in the far north since the turn of the 20th century. Foremost was PCSP's support role in matters of logistics, transportation , communications, and numerous day-to-day requests for supplies and emergencies. All the activity supported by the PCSP addressed the sovereignty issue. Parallelling the PCSP, the exploration industry (oil, natural gas, and minerals) was dedicated to the discovery of new wealth. This latter aspect would also underlie the desire to settle land claims with the native people and the federal government.

Changes in the methods of subsistence living for native people included the introduction of the snowmobile into the area around 1960. Food and clothing and other innovations such as vehicles, heavy exploration equipment and the facilities to service them also arrived from the south; thus, a major portion of the cultural change for native people was due in part to industrial activity. Communications were also expanding both inside the Northwest Territories and the rest of Canada, so that new customs and culture were constantly being introduced.

Exploration drew surveyors, geologists, engineers, well drillers and a host of marine experts to the Beaufort region as the search for hydrocarbons extended to the offshore. New demands for services and supplies were being made on the residents of the Beaufort Coastlands and adjacent regions to satisfy the quests and servicing of the ever-growing number of exploration groups and affiliated workers. Oil and gas wells were being drilled at dozens of sites on land and at sea, and optimism abounded (Fig. i-3). However, inordinately difficult navigational conditions produced numerous challenges such as: the presence of huge ice floes; occurrences of large networks of ice in the form of pressure ridges and stretches of new flat ice;

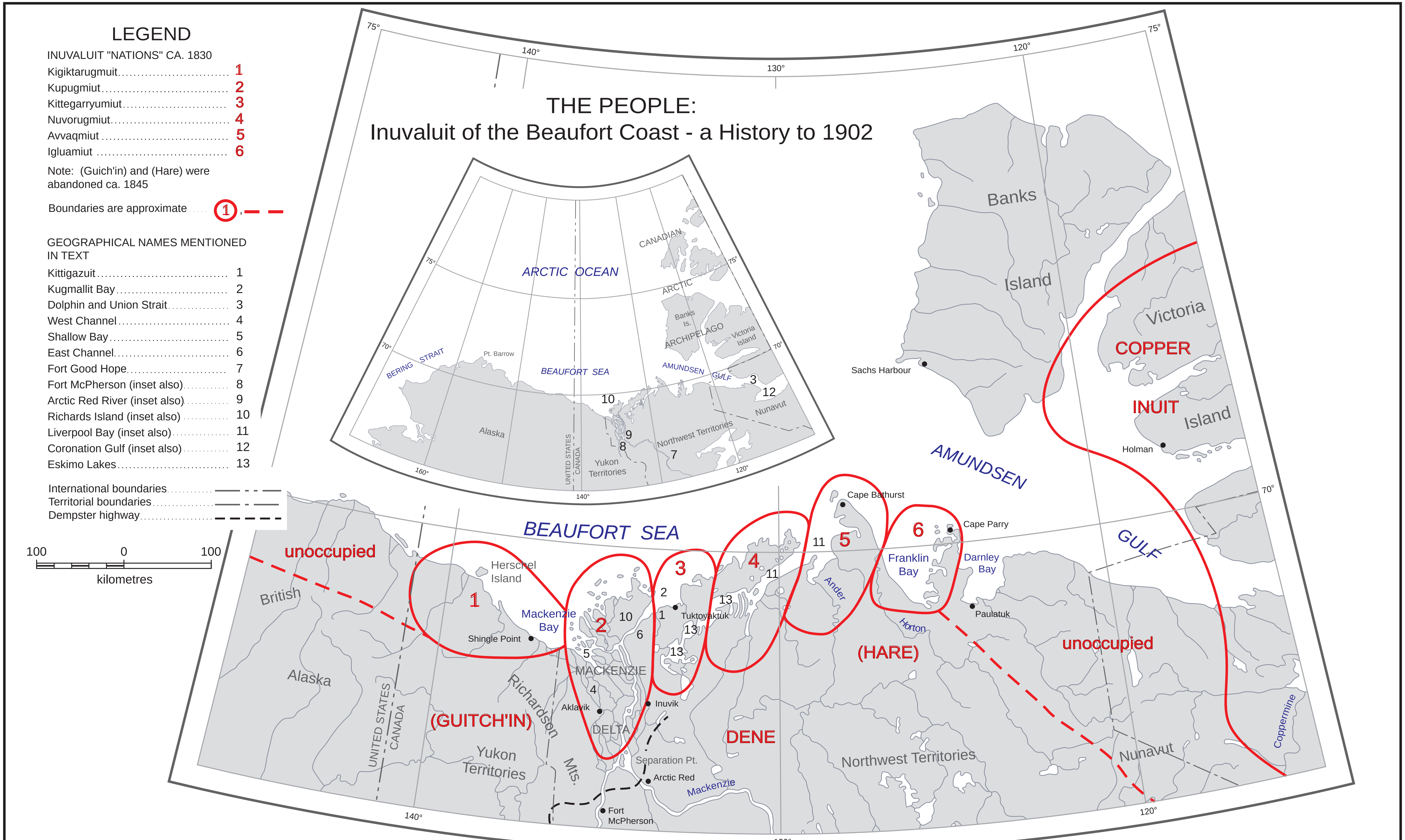

Fig. i-1. Inuvaluit of the Beaufort coast--a history to 1902.

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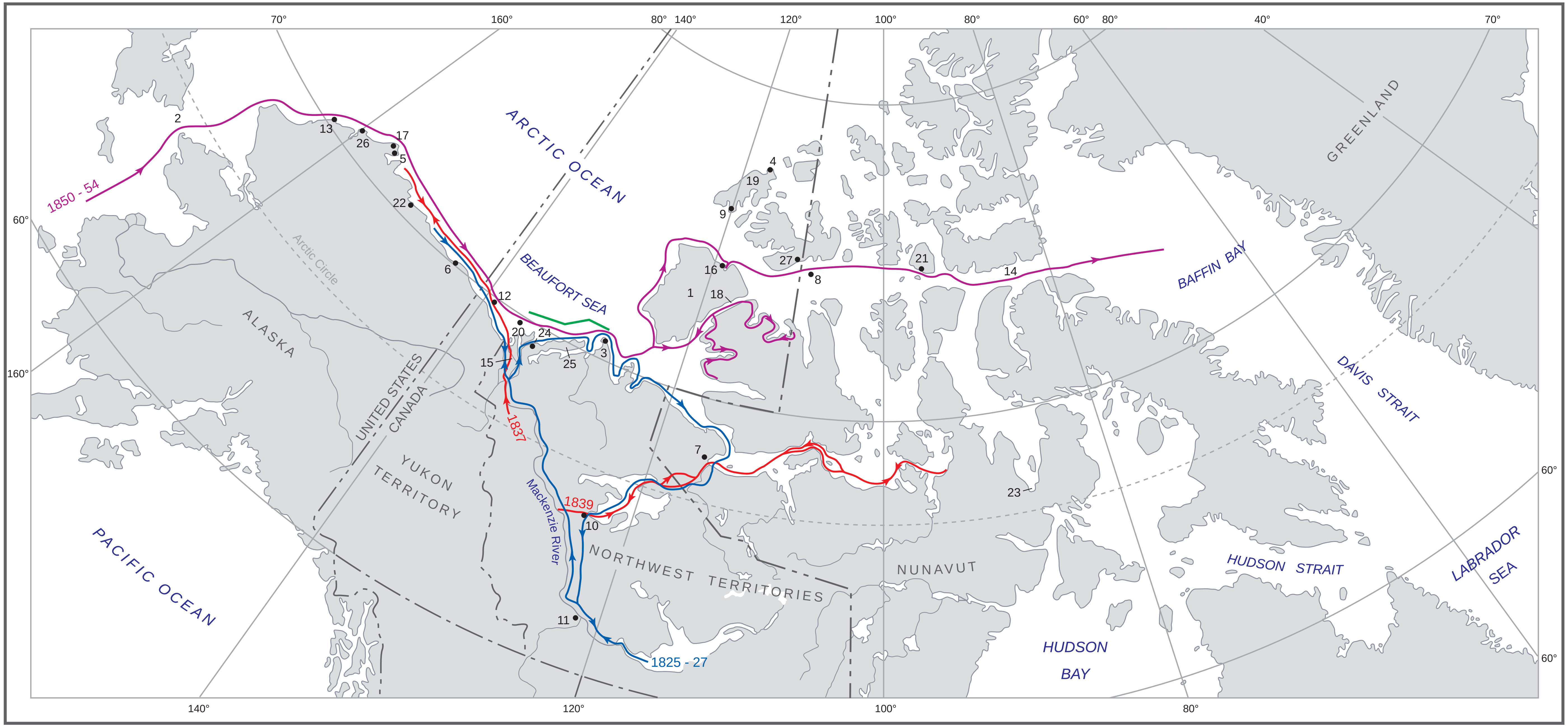
COASTAL MAPPING EXPEDITIONS (1825 - 1982), AND RELATED PLACE NAMES



LEGEND

GENERAL LOCATION OF PLACE NAMES USED IN TEXT

1. Banks Island
2. Bering Strait
3. Cape Bathurst
4. Cape Leopold McClintock
5. Cape Simpson (U.S.A.)
6. Collinson Point (U.S.A.)
7. Coppermine (Kuglutuk)
8. Dealy Island
9. Discovery Point
10. Fort Franklin
11. Fort Simpson
12. Herschel Island
13. Icy Cape (U.S.A.)
14. Lancaster Sound
15. Mackenzie Delta
16. Mercy Bay
17. Point Barrow (U.S.A.)
18. Prince of Wales Strait
19. Prince Patrick Island
20. Pullen Island
21. Resolute Bay
22. Return Reef (U.S.A.)
23. Shepherd Bay
24. Tuktoyaktuk Harbour
25. Tuktoyaktuk Peninsula
26. Wainwright (U.S.A.)
27. Winter Harbour

500 0 kilometres 500

scale 1:15 000 000

COASTAL EXPEDITIONS

Franklin and Richardson	—	1825 - 29
Dease and Simpson	—	1837, 1839
M'Clure	—	1850 - 54
Shipping corridor (CHS)	—	1981,1982

Fig. i-2. Coastal mapping expeditions (1825-1982) and related place names.

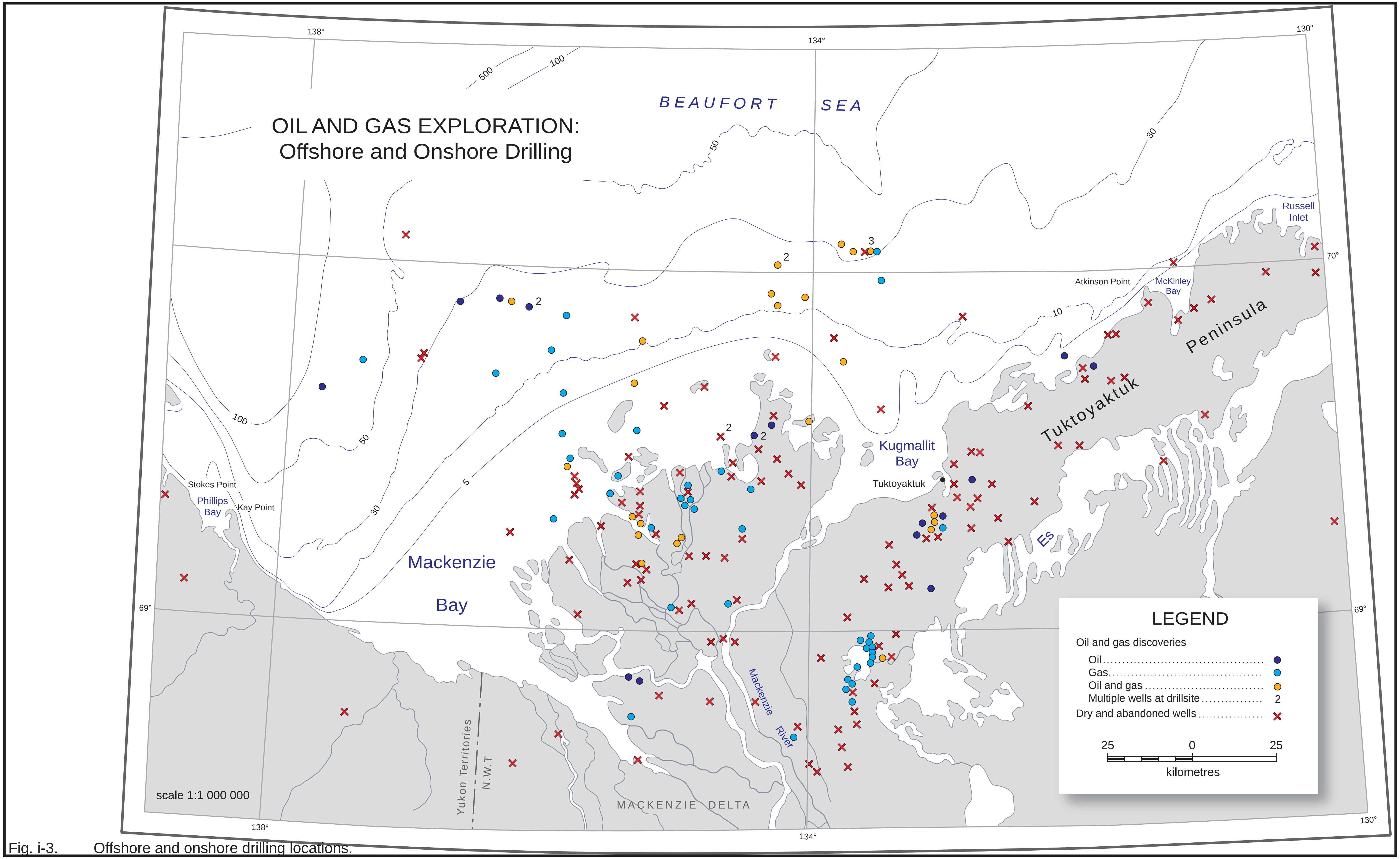


Fig. i-3. Offshore and onshore drilling locations.

and large areas of ice blocks mixed with multi-year old ice floes. At this time in the early 1970s, safeguards to shipping, land travel, human and wild life, and the physical setting became important concerns resulting in a halt to exploration ordered by the federal government.

During this temporary cessation of activities, special projects were mounted to address the difficulties associated with exploration, and to outline remedial measures and strategies in the event of oil spills and blowouts at the wellhead that could be harmful to wildlife habitats. The landmass had been studied for years with regard to engineering hazards such as landslides, permafrost and ground ice. However climatology was foremost on the list of needed studies followed by those on wildlife and oil-spill countermeasures. Many of the latter were directed to the offshore so that oceanography, biology, ice movements and engineering aspects of the seabed were included in the studies. Oceanographers intensified much of their research on ice conditions and the water mass, assisted by numerous vessels of the Canadian Hydrographic Service and icebreakers of the Transport Canada fleet. The seafloor was sounded electronically by hydrographers, and was cored and dredged by geologists and biologists. Geophysicists probed the sub-seafloor with seismic equipment to understand the nature and structure of the geological formations. Most reports were published in the Beaufort Sea Project collection of Environment Canada in 1975, and some in other government departments (e.g. NRCan) and the open literature.

Satellite imagery obtained from the Canada Centre for Remote Sensing (CCRS) proved of immeasurable value at this time. From the imagery of the early Earth Resources Technology Satellites (ERTS) in the late 1960s to the imagery of its successor, Landsat, in the 1970s and beyond, sea-ice types and their distribution and movements were mapped successfully (Fig. i-4). Ensuing analyses of meteorology, ice, and ocean conditions enhanced planning operations, and provided a large factor of safety. Navigators and scientists of many disciplines kept pace in their work with these new developments in satellite imagery particularly as thematic satellites and those using various wave bands were able to provide a new range of imagery such as radar, false-colour imagery, and ultraviolet heat sensors.

The discovery of sub-sea pingos alerted the hydrographers to a new type of hazard in the form of conical shoals occurring singly or in clusters. The Canadian Hydrographic Service addressed the problem by charting a shipping corridor that would guarantee vessels of 'tanker' depth draught a safe passage through or around these shoal waters. Also widespread on the floor of the Beaufort Sea was the presence of ice-scoured grooves. Whereas the pingos presented a hazard to shipping, these grooves could interfere with the laying of pipelines or other seabed installations. The locations of these grooves would have to be mapped, and followed up with engineering studies that would assist in the safe installation of equipment and instruments on the seafloor. With the double hazard of pingos and ice scour, the problems of avoiding collisions, groundings and oil spills had to be met. This was accomplished and numerous recommendations were made to protect the seafloor, coastal areas, shipping, and wildlife habitats. Because of the overall content of the Beaufort Sea Project reports in which seafloor studies and a great range of scientific, hydrographic, and engineering concerns were addressed satisfactorily, drilling were continued.

During the 1960s and 1970s, the search for aggregates (gravel, sand and admixtures of coarse sediments) for drilling foundations and other engineering projects continued at sea and onshore (Fig. i-5). Toward the end of the 20th century, offshore exploration and hydrographic surveys diminished; however, the sea ice studies assumed greater significance from a climatological standpoint. The winning of hydrocarbon resources was still in the minds of those in the petroleum industry. At the same time, governments with shipping in mind were interested in navigational prospects across the entire central Arctic Ocean, including the channels of the Canadian Arctic Archipelago. Such marine passages would depend on the existence of open water, or at least the occurrence of ice navigable water. The reality of such expectations would depend on the prospect of climate warming.

Before the 20th century closed, great strides in the settling of native land claims north 60° latitude culminated in the splitting of the former Northwest Territories into two new political entities: the larger portion of the central and eastern Northwest Territories became ‘Nunavut’, and the western Arctic lands retained the name ‘Northwest Territories’. This occurred on April 1, 1999.

Part 2: Environmental and physical settings

Situated in the extreme northwestern part of Canada, the Beaufort Coastlands are subjected to a wide variety of environmental conditions that are altering the interior as well as the coastal landscape. Continuous permafrost and particularly the presence of ground ice, is the single most important factor controlling the evolution of the landscape (Fig. i-6a, b). Coastal erosion is promoted by the exposure of massive ice beds and lake drainage can be initiated by the thaw of ice wedges to form drainage channels. Landscape change along the coastline and in the interior will continue due to the warming trend in the climate over the past century or so. Storm surges, changes in current flow, and a reduced volume of sea ice will accelerate coastal retreat. These processes must be taken into account in the planning of any kind of landuse.

Climate is one of the most important aspects of nature that defines any region but it is significantly affected by topography. Features such as mountains, valleys, and lowlands all play characteristic roles in their interactions with the elements of the weather. For example, the flow of air is influenced by the obstructions of mountains and ridges and may cause up-drafts; also, the flow of air may be funnelled by the course of confining valley walls and be re-directed horizontally. Additionally, the presence of valleys and lowlands may induce thermal conditions locally. All these phenomenon are described under the heading: OROGRAPHY AND WEATHER. This range of effects is one of the reasons that the geographic boundaries of this atlas have been set some distance inland of the Beaufort Sea; this boundary permits the inclusion of terrain that could produce weather effects subsequently affecting the Coastlands to the north.

In the Beaufort Coastlands, the climate is characterized by the extended period of cold weather in winter, offset by the short cool summer that occurs from late June to early October. The average monthly winter temperature varies from -10°C in October, reaches its coldest interval of -30°C in February, and rises to -5°C in the seasonal spring during the month of May. Summer temperatures vary from 5°C in late May and reach their peak of 12°C in July (the hottest month), then decrease to -5°C in the early fall of late September.

In the latter part of the year, the overall weather patterns of predominant high-pressure cells originate north and west of the Beaufort Sea. These cells form in the region of Siberia (Russia), and are accompanied by flows of cold air to the south and east of the Beaufort Sea.

During winter in the southern part of the Beaufort Sea, the ice cover has fully developed, and continues to move in a clockwise circulation within the Beaufort Gyre. This rotation dominates the surface

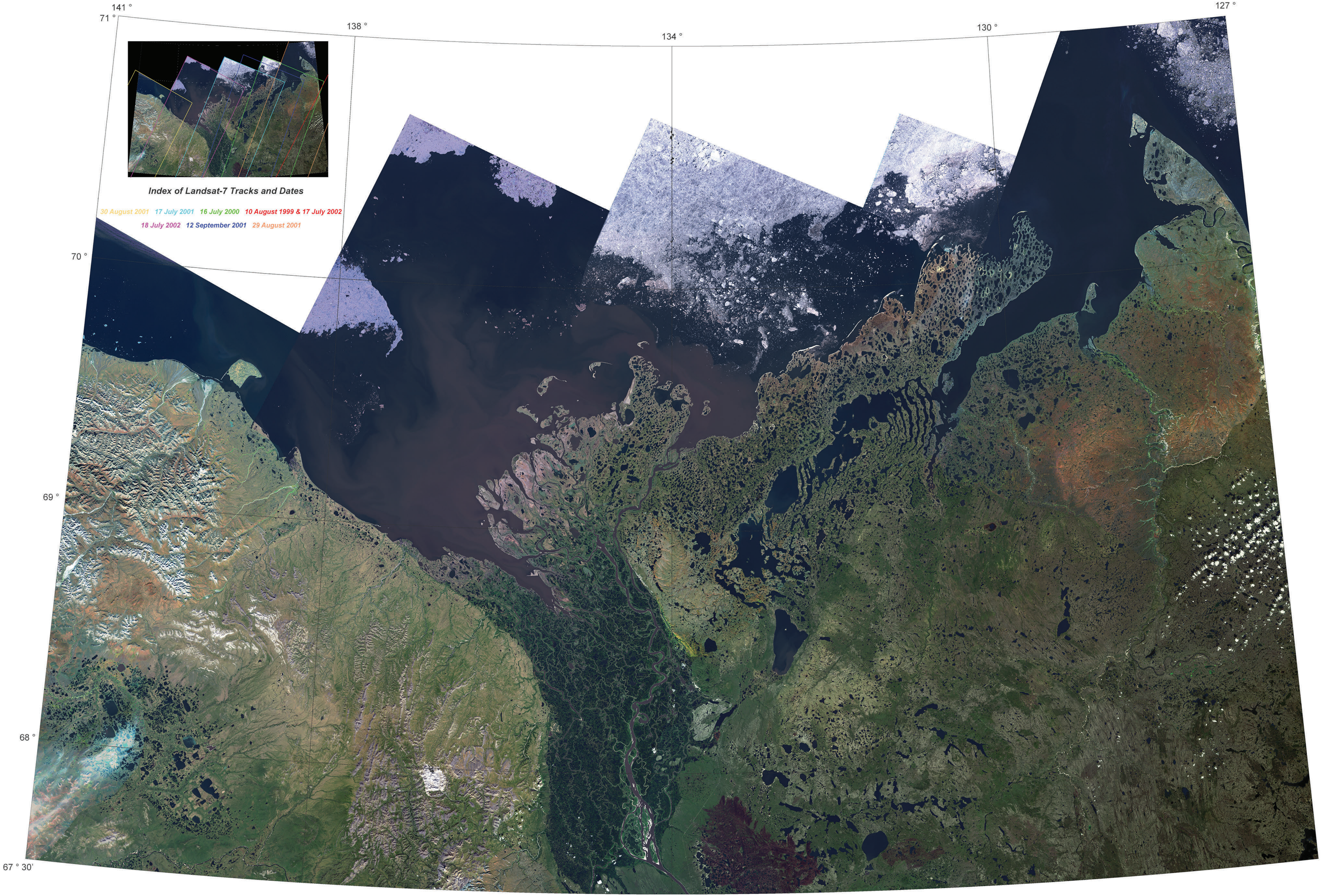


Fig. i-4. Satellite image of the Mackenzie Delta (Photo courtesy of Paul Budkewitsch, AANDC).

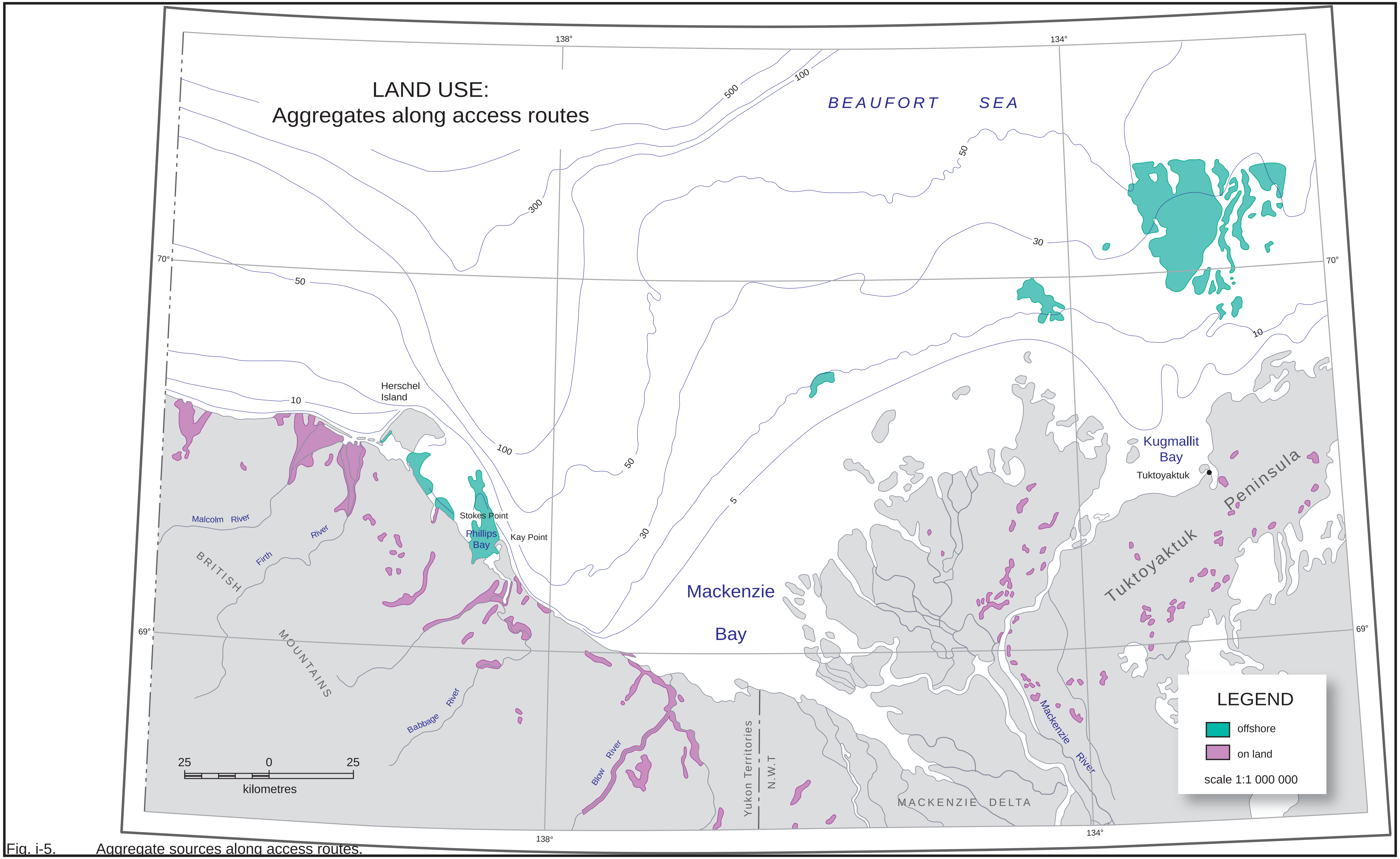


Fig. i-5. Aggregate sources along access routes.

LEGEND

5MH Moderate to high ice content due to the presence of ice lenses
¥ Alluvial terrace deposits: silts and silty clay
¥ Colluvial blanket deposits: fine grained diamicton containing some lenses and beds of sand, gravel and rubble
¥ Bedrock ereas of low resistance to erosion in unglaciated areas

5LH Low to high ice content in sandy sediments, as wedges; moderate to high ice content in silty and clayey sediments, as lenses and reticulate veins; massive ice commonly occurs at depth and in pingos
¥ Lacustrine and marine deposits as plains and intertidal lagoons: interbedded silt, clayey silt, Ê and silty sand; locally underlain by diamicton

5LM Low to moderate ice content, as lenses and reticulate veins, higher ice content with depth; massive icemay be present at base of diamicton and in underlaying sediments
¥ Alluvial deposits as fans, plains, and terraces; sands and isolated silty layers
¥ Morainal and colluvial blanket deposits: stony clay diamicton: may overlie marine and glaciofluvial deposits 1,2
¥ Glaciated upland and piedmont complex: mainly till and disintegrated bedrock; overlies ereas of moderate to low slope
¥ Veneered bedrock: diamicton overlying low rounded hills ridges of unglaciated bedrock
¥ Exposed bedrock: varied bedrock types

5NL Nil to low Ice content, as wedges
¥ Alluvial deposits: coarse sand and gravel3
¥ Glaciofluvial deposits as outwash plains, kames, and eskers: sand and interbedded sand and gravel 1,4
¥ Colluvial deposits as blankets and veneers: coarse diamicton; may overlie areas of unglaciated bedrock
¥ Glacially deformed marine deposits: clay and silt, thin beds of fine sand may be present Ê

4LM Ice content low to moderate where material frozen, as thin seams, reticulate veins, lenses and wedges; massive ice may occur at depth
¥ Morainal and colluvial deposits as veneers and blankets: diamicton
¥ Alluvial deposits as floodplains, terraces, and fans; fine grained sand and silt1
¥ Glaciofluvial and glaciolacustrine deposits as outwash plains and terraces; gravel, sand, and silt1,3,7
¥ Glaciated upland and piedmont: disintegrated bedrock

3LM Low to moderate ice content where material frozen, as thin seams, lenses, and wedges
¥ Morainal and colluvial blanket deposits: diamicton
¥ Alluvial deposits as floodplains, fans and aprons, deltas and terraces: interbedded silt, sand, and gravel 1,3
¥ Glaciofluvial deposits as outwash plains, fans, and terraces: sand and gravel with a veneer of silt or fine grained sand
¥ Marine deposits as tidal flats: interbedded silt, clayey silt, and sand; generally high in organic content

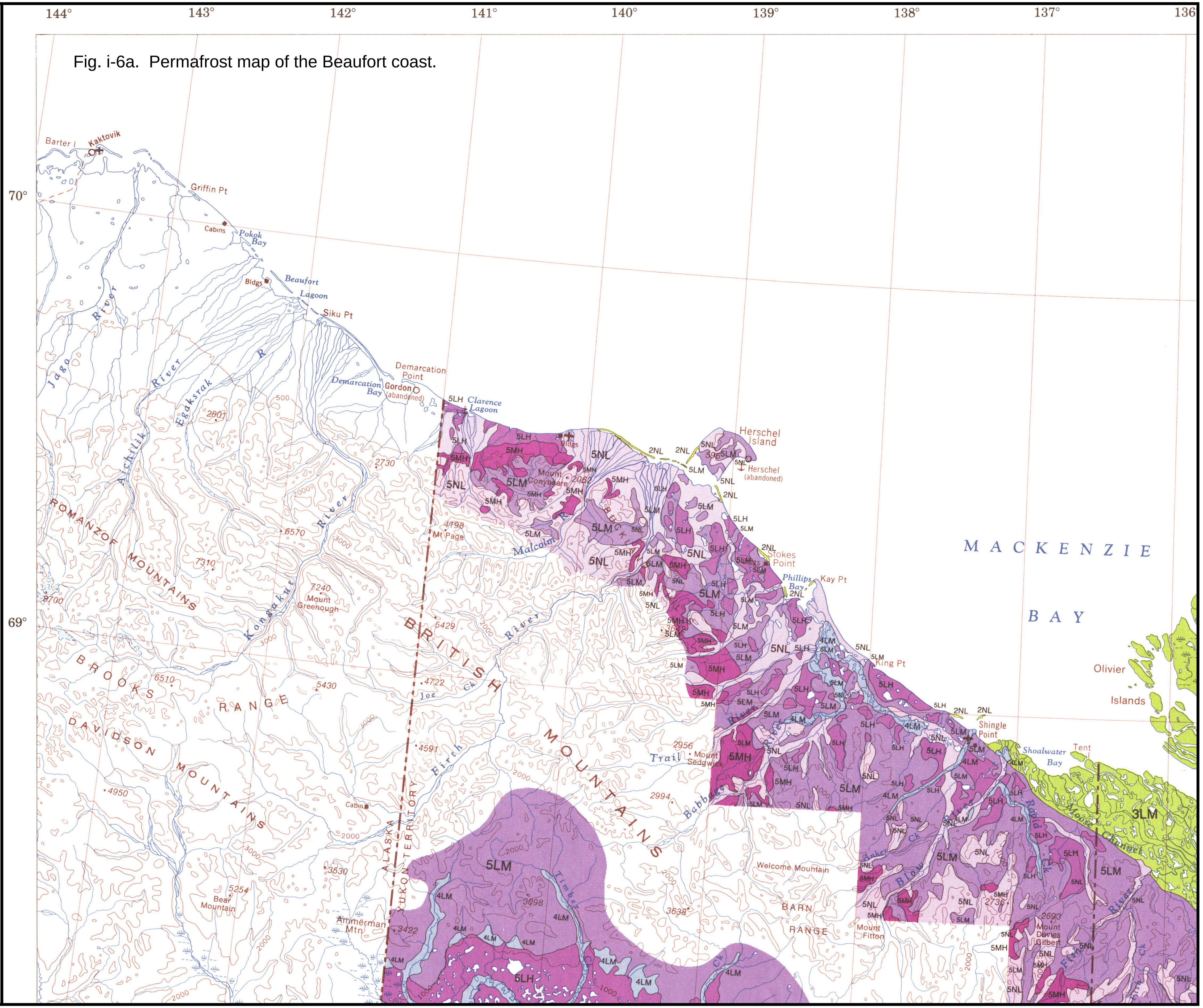
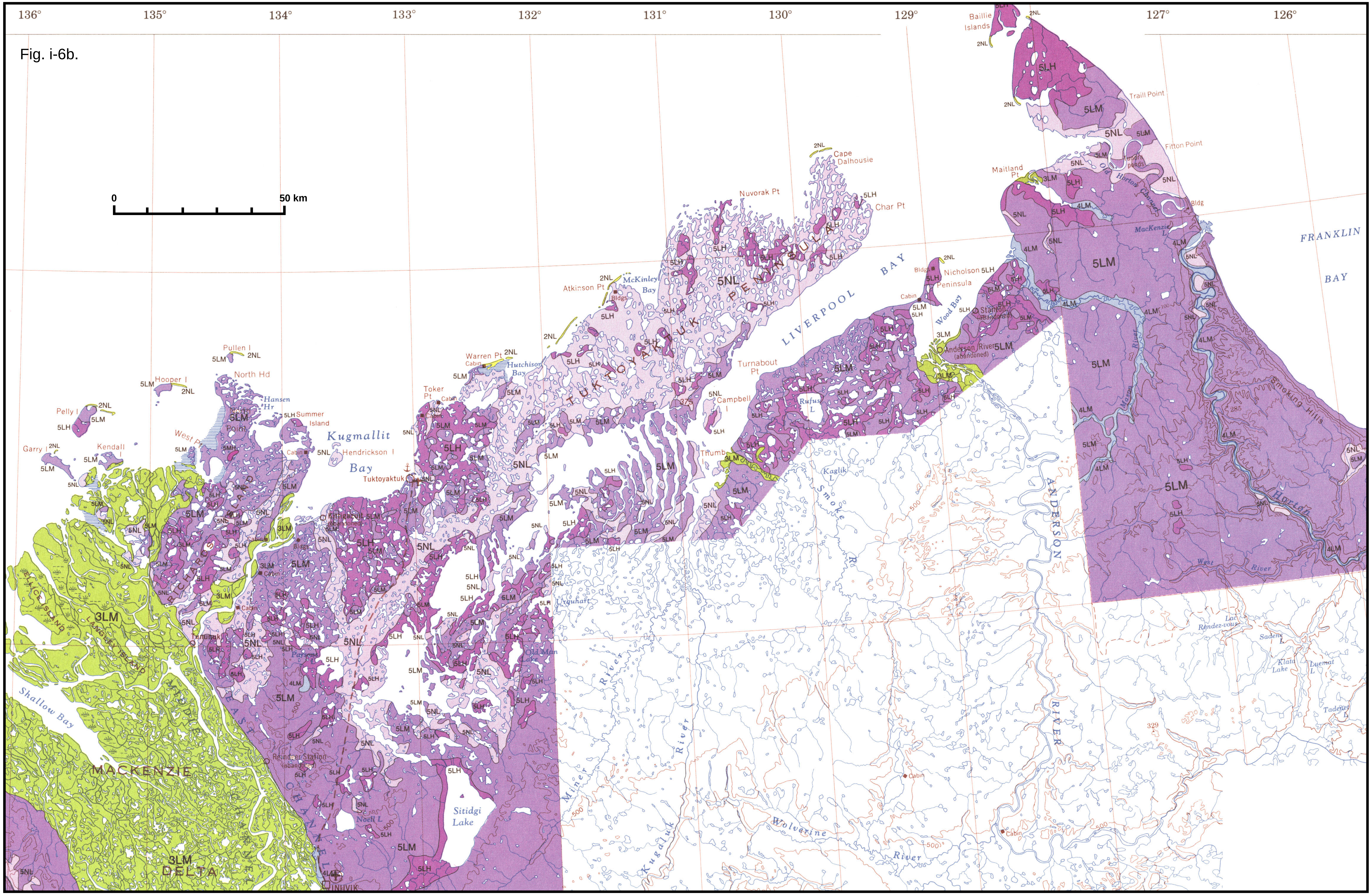


Fig. i-6a. Permafrost map of the Beaufort coast.

Fig. i-6b.



136°
135°
134°
133°
132°
131°
130°
129°
127°
126°
0
50 km
Baillie Islands
Traill Point
Fitton Point
Maitland Pt
Horton
FRANKLIN BAY
Cape Dalhousie
Nuvorak Pt
Char Pt
LIVERPOOL BAY
Nicholson Peninsula
Wood Bay
Stanton
Anderson River (abandoned)
MacKenzie L
Smoking Hills
Horton River
West River
Atkinson Pt
McKinley Bay
TUKTOYAKTUK PENINSULA
Turnabout Pt
Campbell I
Rufus L
Thumb
Kaglik L
Smoke R
ANDERSON RIVER
Warren Pt
Hutchison Bay
Toker Pt
Pullen I
Hooper I
North Hd
Hansen Hr
Summer Island
Kugmallit Bay
Hendrickson I
Tuktoyaktuk
Pelly I
Garry I
Kendall
West Pt
Kittigazuit (abandoned)
Urquhart
Old Man Lake
Sitidgi Lake
Noell L
Reindeer Station (abandoned)
INUVIK
Shallow Bay
ELLICE ISLAND
LANGLEY ISLAND
RICHARDS ISLAND
MIDDLE CHANNEL
EAST CHANNEL
MACKENZIE DELTA
Miner River
Kugaluk River
Wolverine River
Lac Rendez-vous
Sadene L
Klaila Lake
Luemat L
Tadenet
Cabin
Bldgs
5LH
5LM
5NL
4LM
3LM
2NL

circulation of the ocean in the vicinity of northwestern North America and eastern Asia. On the outer fringes of the Beaufort Gyre, the polar pack ice is pressed against the landmass adjacent to the eastern and southern shores of the Beaufort Sea, and remains fixed as landfast ice during the winter. In the shallow inshore waters of all coasts, sea ice is also held fast to the seabed during the winter.

With the approach of spring, warmer air flows northward from Canadian southern regions, and breakup of the landfast sea ice commences. As spring advances into summer, landfast ice fractures and huge flows and blocks of ice created by this break-up move into the ice-infested, clockwise circulation of the Beaufort Gyre.

At this time marine mammals such as seals, polar bear, arctic fox and whales return to the region in their annual migration; other animals live ashore exclusively, especially along the sea coast and river courses. This wildlife includes caribou, grizzly bear, smaller game, and land and shore birds. All wildlife provides food for the native people whether it is ashore, in the water, or on the sea ice.

Fishing and hunting activities commence in late spring and persist through most of the summer. At this time the vegetation thrives and provides shelter for birds and small animals; also, food is available for grazing wildlife. With the onset of late fall, freeze-up commences and winter conditions prevail again both on land and at sea. Wildlife is also a major attraction for sight-seeing travellers who visit the area seasonally from southern Canada, as well as from more distant regions abroad.

In this Atlas the Beaufort Coastlands are not rigidly defined, but are outlined here to serve as a focus for the lands affected directly by the water and ice of the Canadian portion of the southeastern Beaufort Sea. The area includes the physiographic setting southward from the sea to regions near the Arctic Circle. This extension of the land embraces the highlands and drainage systems directly affecting the Coastlands, permiting a broader view of the natural processes operating in the Beaufort region.

In general terms the Beaufort Coastlands are distinguished by a low-lying coastal plain extending a few kilometres inland to the lower portion of an upland rising about 200 m in elevation, thence to a rolling upland with higher elevations up to 500 m above sea level. Mountainous terrains are common in the eastern and western portions of the uplands, both areas being separated by the broad expanse of lowlands and flood plains adjacent to the Mackenzie River. The British Mountains to the far west, and the Richardson Mountains directly paralleling the course of the Mackenzie River on its western side, are the major ranges in the western part of the area. The Travaillant Uplands bound the east side of Mackenzie River. These physiographic divisions are described from the works of the late Hugh Bostock of the Geological Survey of Canada.

Drainage of the entire region shown on the maps is dominated by the Mackenzie River as it flows from the south to empty into the Beaufort Sea in the north. The Mackenzie River is a major transportation corridor, as well as an important support system of life and livelihoods in northwestern Canada.

In that portion of the lowlands lying between the mountains and the sea, (see THE COASTLAND MAPS) numerous streams flow northerly and debouch into the Beaufort Sea. Small deltas are common at the river mouths and may create marshy conditions. These streams are as follows: Clarence River, Fish Creek, Malcolm River, Firth River, Spring River, Babbage River, Deep Creek, and Running River, all of which transect the lowlands lying adjacent to the coast and occur west of the Mackenzie River Delta. Those streams east of the Delta also transect the northernmost mainland of the Northwest Territories. For example: Moose and Snake rivers flow directly into Liverpool Bay; Anderson and Mason rivers empty into Wood Bay; Old Horton Channel ends at Harrowby Bay, and Horton River flows northerly into Amundsen Gulf, just south of Old Horton Creek. Small streams less than a few tens of kilometres in length flow northerly in erratic courses across the mainland into the Beaufort Sea. This is particularly applicable in regions of thermokarst lakes, many of which have internal drainage patterns. However larger lakes such as Sitidgi Lake and Eskimo Lakes are present, and their associated feeders and outlets are larger with courses more regular than those linking thermokarst lakes.

The Eskimo Lakes are shallow and the overall plan of their basin is related to the occupation and passage of glacial ice. Numerous transecting, linear ridges extend in a north-south direction at the eastern and central portions of the Lakes, and are the products of the infilling of crevasses in the toe-ward portion of the ancient glaciers by sediment carried by the glaciers themselves. These ridges, named The Fingers, are the remains of the lag deposited when the glaciers melted. They are one of the best lines of evidence of former glaciers in the area.

Across and along geologic structures the drainage patterns are trellis, but in all lower portions of the hilly country the predominant drainage patterns are dendritic. The numerous thermokarst lakes prevailing in the lower elevations of the Coastlands are interconnected by short streams that are characterized by occurrences of irregular water courses. These lakes are a prominent feature the outer coastlands near the sea, particularly along the Tuktoyaktuk Peninsula where the absence of transecting streams is noticeable throughout that region.

All streams are important because they are the heart of the local inland fishing industry and serve as routes for water-borne transportation. Hunting and fishing camps abound on many river and lake shores, as well as along the shores of the Beaufort Sea, on smaller deltas, and around several inlets and bays adjacent to these marine coastal sites. Therefore, the fate of these streams is crucial to maintaining the native livelihood as well as to supporting all life in the region.

The dominating factor of the landmass in the Coastlands is the presence of permafrost, a thermal condition that occurs in rocks and soil whereby ground temperatures less than 0°C persist for the winter, through the following summer, and into the next winter. Surface thawing takes place in summer to depths of approximately one metre, producing the active layer. Deeper thawing commonly accompanies the disturbance of ground surface vegetation, triggering the following phenomena: soil creep on slopes, landslides, and thawing of ground ice in its many forms including massive ice, ice veins, reticulate ice, pingo ice, and ice wedges. Infrastructure damage and drainage disruptions may also occur. Although pingos grow and form as intrapermafrost mounds, they may also subside and collapse altogether under the effect of warmer summer temperatures inland and under a combined effect of thermal and mechanical erosion along the Beaufort coast.

Evidence for an increasing depth of the active layer indicates that a warming of temperatures has occurred during the last decades of the 20th century, an event which has also led to soil and slope instability (see THE ACTIVE LAYER). Recent thermistor monitoring of these conditions lately has revealed that cooling air temperatures are also occurring along the coastline and deltaic regions.

Several types of soil dislocation along the coast are common. These processes are typified as block-toppling, regressive thaw flow slides, and erosion by means of massive undercutting and subsequent transportation of the sedimentary debris due to the sequential action of waves and longshore currents. The thawing of ice wedges and exposed massive ground ice along the coast are also causes of additional soil removal.

Beaches and sand flats, as well as other depositional features that occur in the lee of eroded headlands, alter the shape of the coastline significantly. These natural constructional features may provide additional habitat for wildlife of the region. Wave-breached coastal areas are characterized by inlets, promontories, and adjacent thermokarst lakes. These changes take place in decadal time intervals and affect the most significant aspect of the coast: it is an important habitat for birds and land mammals not to mention the threat to the livelihood of the native people.

A major feature of this Atlas is devoted solely to documenting the physiography of and biological characteristics of the coastal zone of the Beaufort Coastlands. A series of 27 maps at a suitable working scale of 1:150 000 has been constructed of the entire coastal region because of its relationship to native livelihoods and the possible future importance to the petroleum industry, particularly if these latter natural resources are developed in the near future. Hunting and fishing are the significant activities of the native people and these maps will provide valuable information on natural conditions and site locations of interest to them. These maps will be of interest to workers carrying out environmental studies aimed at assessing the impact of oil and natural gas exploration as well as offshore production facilities such as pipelines and supporting, marine transportation services that will follow.

All maps are drawn at the same scale (1:150 000) and each map is supported by a descriptive essay. In each map and accompanying essay, the following significant topics are outlined: surficial geology and processes including engineering hazards and drainage features; hydrographic elements such as soundings, bathymetry, current directions; sediment transportation directions and the locations of sediment sinks, deltas, and breached lakes along the coast, accompanied by the occurrences of additional coastal features such as inlets, spits and bars, and, finally; hunting and fishing sites, as well as the location of hydrocarbon explorations.

Some of the indicators of climate warming are discussed in the Atlas but, because they form a significant portion of the text dealing with parallel aspects of climate warming in the region, they are presented here without additional discussion (Fig. i-7). Some of these indicators are as follows: the warming effect of greenhouse gases including carbon dioxide, carbon monoxide, methane, water vapour, and nitrous compounds; direct solar effects such as rising air temperatures and subsequently increasing ground temperatures; additional moisture in the atmosphere caused by a changing maritime effect due to air-temperature rise; variations in oceanographic effects in that oceans warm and expand, and sea level rises from the internal oceanic expansion as well as from the increase in water volume from melting glaciers on land; sea ice thins and its aerial extent becomes smaller and covers less ocean, thus exposing more ocean water to solar heating; ice shelves may shrink and collapse, thus reducing albedo effects and intensifying solar insolation. However, these are topics beyond the scope of this atlas, particularly as they warrant full, global inspection and consideration.

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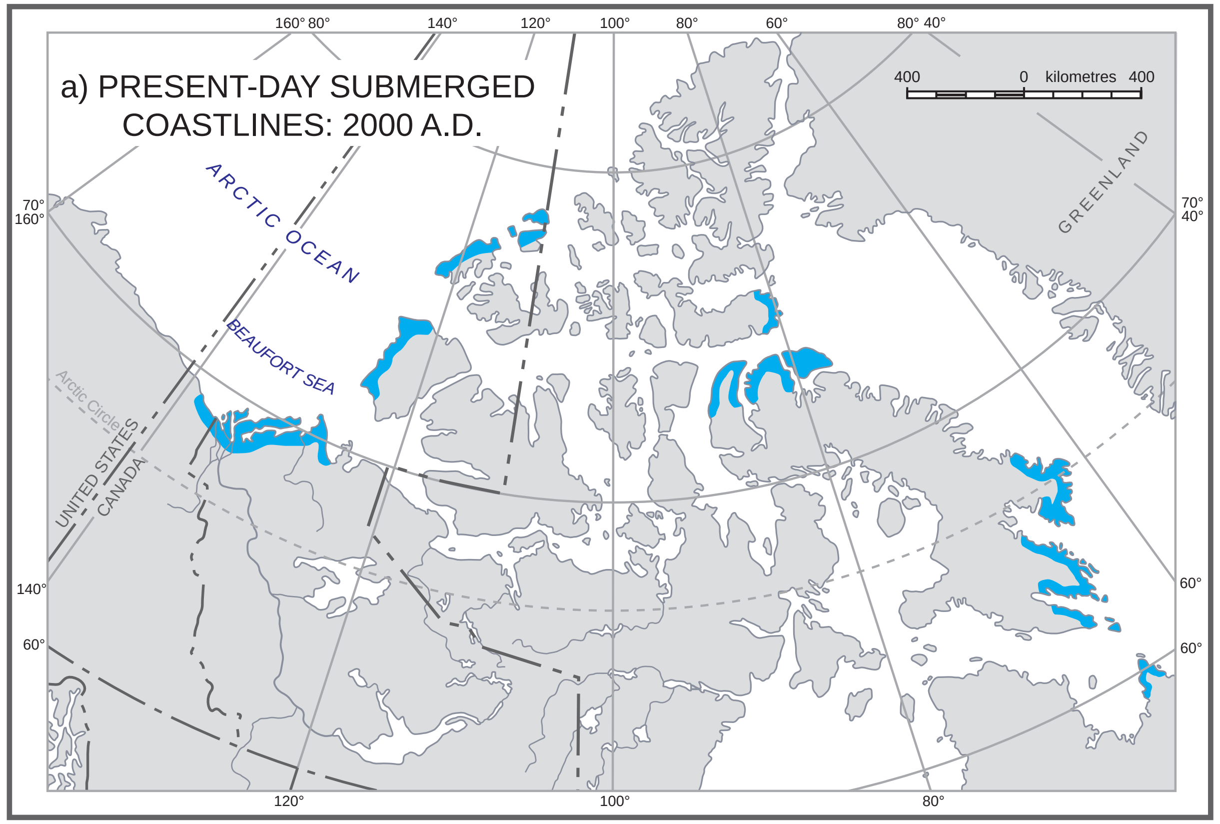
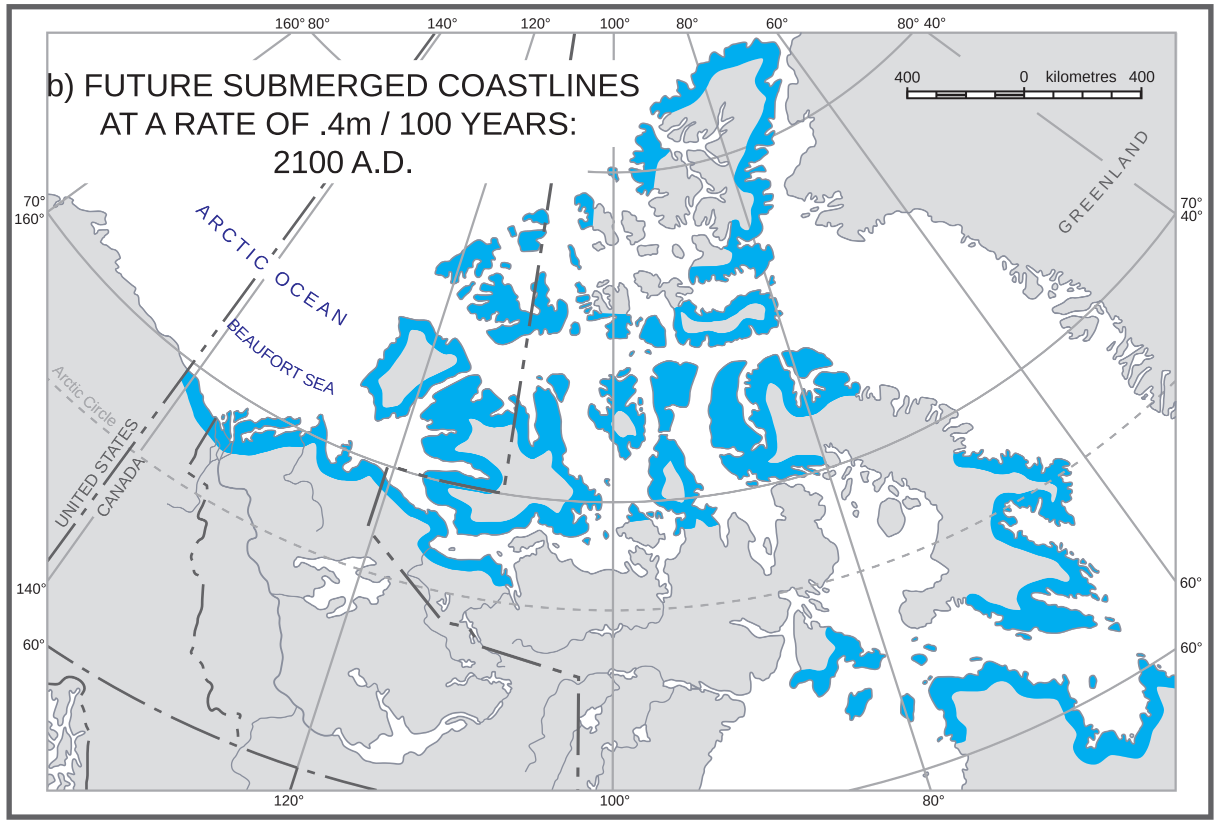
IMPACT OF GLOBAL WARMING IN ARCTIC CANADA:
The rise in sea level

Note: In Fig.i-7a, most of the coastline is submerged in the southern Beaufort Sea and along the southern and western portions of Banks Island due to post-glaciation adjustment . The northern and central southern portions of the Canadian Arctic Archipelago has not undergone any inundation because of post-glacial rebound. However in the eastern part of the Archipelago, sea level is rising which is true for all shores around Hudson Bay. The scenarios in Figs.i-7b and i-7c, indicate that submergence is continuing along nearly all coasts. In Fig. i-7b, a submergence rate of 0.4m per century is indicated and more than two thirds of the coast would be inundated after a period of 100 years. In Fig.1c, which shows a rate of submergence of 0.6m per century, inundation of the coast in all areas of Arctic Canada would have taken place after a period of 100 years. In terms of millennia, inundation would be in the range of several metres. For example, in the scenario of Fig. i-7b, if the rate of inundation remained constant for a period of 1000 years, sea level would stand 0.4m higher than it is today. In the scenario of Fig. i-7c and if the rate of inundation remained constant for a 1000 years, then sea level would be 6m higher than it is today.

Data and sketches after P.A. Egginton and J.T. Andrews


a) PRESENT-DAY SUBMERGED COASTLINES: 2000 A.D.


b) FUTURE SUBMERGED COASTLINES AT A RATE OF .4m / 100 YEARS: 2100 A.D.

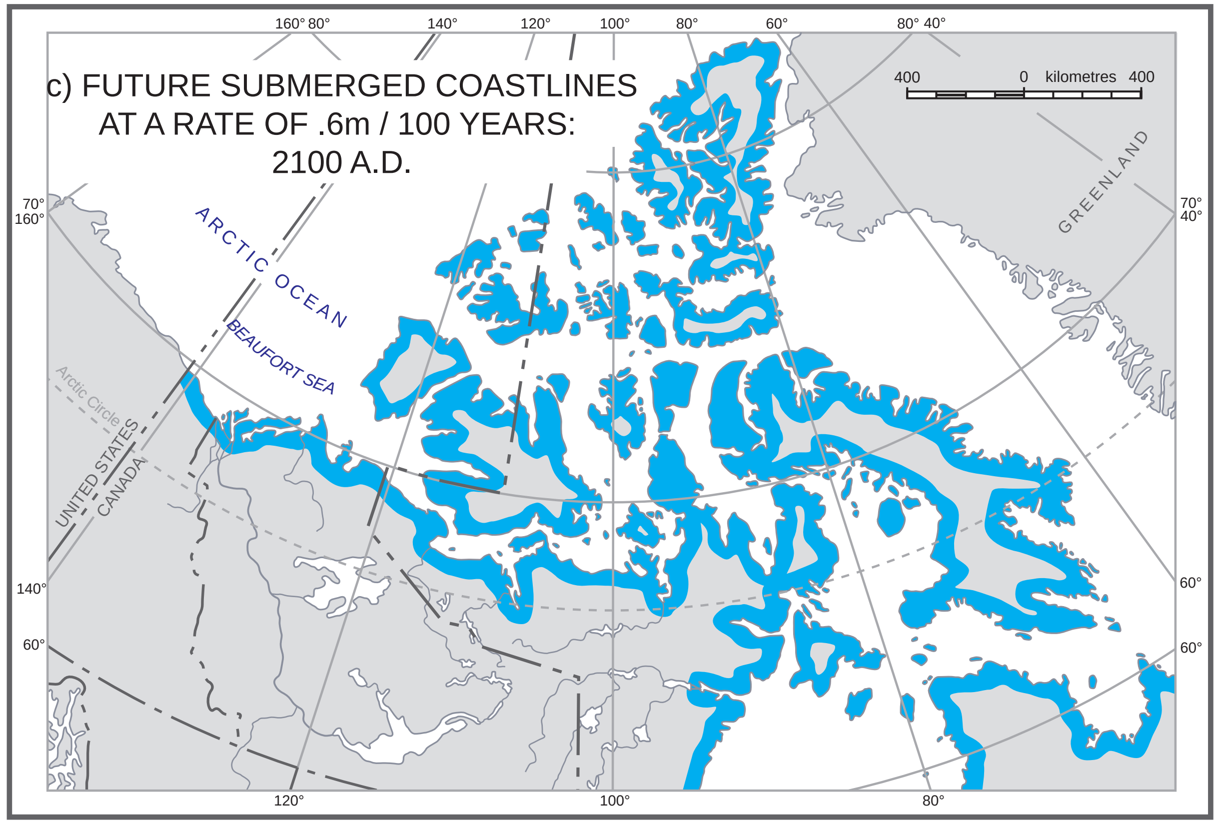

c) FUTURE SUBMERGED COASTLINES AT A RATE OF .6m / 100 YEARS: 2100 A.D.

Fig. i-7. The impact of global warming in Arctic Canada witha focus on rising sea level.

CHAPTER 1
THE PEOPLE

THE PEOPLE

The Inuvialuit of the Beaufort Coast: A History to 1902

The Inuit living along the Canadian portion of the Beaufort Sea coast call themselves "Inuvialuit" or "real human beings". Their homeland stretches from the Alaskan border east to Amundsen Gulf and the western edge of the Canadian Arctic Islands, centering on the great delta of the Mackenzie River. In recent decades this homeland has seen rapid economic and social change, with the collapse of fur markets, the rise and fall of oil and gas development, the extension of the Dempster Highway to Inuvik, and the on-going evolution of local self-government. But it has an ancient history too, one which long pre-dates the arrival of Europeans. The traditional culture of the Inuvialuit was shattered by European infectious diseases in the late 19th century. What can be reconstructed of events and institutions before that date is pieced together from traditional oral histories, archaeological research, and the writings of the various 19th-century explorers, fur traders, and missionaries who visited the western Arctic.

Society

At the time of European contact in the early 19th century (Fig. 1-1), the Inuvialuit were divided into half a dozen distinct territorial groups or "nations". Most seem to have had a main village from which they took their name, with the added suffix "...miut" meaning "people of". Thus the Kittegaryumiut were the "people of Kittigazuit", a large village near the mouth of the Mackenzie River, while the Avvagmiut were the "people of Avvak", a village at Cape Bathurst (see Morrison 1997a). Inuvialuit nations varied in size from a few hundred to nearly a thousand people (Fig. 1-2). All told there were about 2500 Inuvialuit in the early 19th century (Usher 1971; McGhee 1974). They lived in perhaps the richest area of wildlife resources in northern Canada, with a population density many times that of the Central Arctic. With their elaborate villages, permanent log-and-sod houses, and powerful chiefs, the Inuvialuit considered their Inuit neighbours to the east to be (in the words of an early missionary) "outright savages" (Savoie 1970: 215).

Inuvialuit villages typically consisted of a group of large log-and-sod houses dug partially into the ground for warmth (Arnold and Hart 1992). They were often multi-family houses built in a cross-shaped pattern, but single-family dwellings were also used (Fig. 1-3e). Walls were made of vertical poles stuck into the ground and slanted in slightly toward the top, so that the sod insulation stacked against it remained in place. Floors were recessed below ground level to help conserve warmth, and the primary entrance was through a "cold trap" tunnel framed in driftwood. Heat and light were supplied by oil lamps, well attested from historical sources, while many archaeologically-excavated houses also give evidence of large interior hearths. Villages could range in size from a single house to as many as thirty, with three to ten houses being fairly typical. These were primarily winter houses although some of the better-drained examples probably sometimes did double duty in summer as well, when they offered a cool, dark respite from the mosquitoes and the endless midnight sun (Fig. 1-4a). But most people coming to a major village for the summer hunt would have had to live in tents, since their winter houses were elsewhere. As the explorer Stefansson (1914: 323) described it, "Kittegaryuit (i.e. Kittigazuit) was a large village only in summer. In winter the people scattered....".

As well as dwellings, major villages also included "dance houses" or *karigi*. These buildings are described as being about 15 to 20 metres in length, framed in driftwood, with an entranceway covered by a beluga skin, a large central hearth, and a bench which ran around the inside wall (Stefansson 1914: 170). They were the location of important ceremonies, and were used for dancing and the repair and manufacture of tools.

Inuvialuit also lived in snowhouses, particularly later in the winter when their autumn food stores had been consumed (Richardson 1851: 257).

Inuvialuit nations probably functioned much like those of their better documented western neighbours, the Inupiat, as the Inuit or Eskimo of northwestern Alaska are called (Burch 1975, 1980). Here each *karigi* was built and operated by a single large extended family, often numbering fifty or more people. Each had a family head or chief known as an *ataniq*, or "boss". A successful, wealthy *ataniq* was called an *umialiq*, a "rich man".

Among both the Inupiat and the Inuvialuit such leadership positions depended very much on the skill, generosity, and family connections of the individual involved. Inuvialuit kinship rules were flexible and included people related by marriage as well as those related by blood. The more successful and the more generous an *ataniq (*or *umialiq*), the larger the extended family he headed could become, as more people chose to join it. By the same token, a successful *umialiq* (or *ataniq*) was not merely shrewd and personally competent, he was someone with a large potential following; a man with many relatives. There was thus a tendency for the office to be hereditary, since a capable oldest son could sometimes step into his father's shoes. If the umialiq managed the family well it prospered, and as long as it prospered he naturally had first call on the wealth produced. This wealth resulted both from the hunt and from inter-regional trade, which was largely controlled by *umialit* (the plural form). On the other hand, an unsuccessful *umialiq* could easily lose his following.

The powers of *umialiq* were sometimes considerable. The missionary Whittaker (1937: 38) described a "strange Eskimo" moving into Kittigazuit who had to make a payment to the "chief" in order to be able to hunt. Similarly, it was reported that *umialit* had the power to boycott trade with whaling ships, and to demand a payment from whaling captains who wished to hire "their" people (Stefansson 1914: 166). Mangilaluk, who lived at Tuktoyaktuk and died in 1940, is generally considered to be the last true *umialiq* in Inuvialuit tradition (anon. 1991: 11-12).

The economy of the Inuvialuit was geared towards hunting and fishing, and both activities were the focus of considerable technological sophistication. Adept sea mammal hunters, the Inuvialuit had two kinds of boat; the fleet single-man kayak, and the roomy umiaq, used for both transportation and hunting. Beluga hunting was done from a kayak, often with dozens of men forming a line across the mouth of a bay, driving a pod of beluga before them. The frightened animals would ground themselves in the shallows, where it was simple matter to lance them to death. The shape of Kugmalit Bay off the village of Kittigazuit was particularly well suited for this kind of hunting (Nuligak 1966).

Bowhead whaling was another matter, involving deeper waters and larger boats. The umiaq was the preferred craft here, propelled by six or eight paddlers, often women, with a harpooner in the bow, and the *umialiq* himself as the sternsman (Stefansson 1914: 168). The mid-19th century explorer Robert McClure (1969: 93) witnessed a whale hunt off Cape Bathurst

> "The harpooner singles out a fish [whale], and drives into its flesh this weapon[a harpoon], to

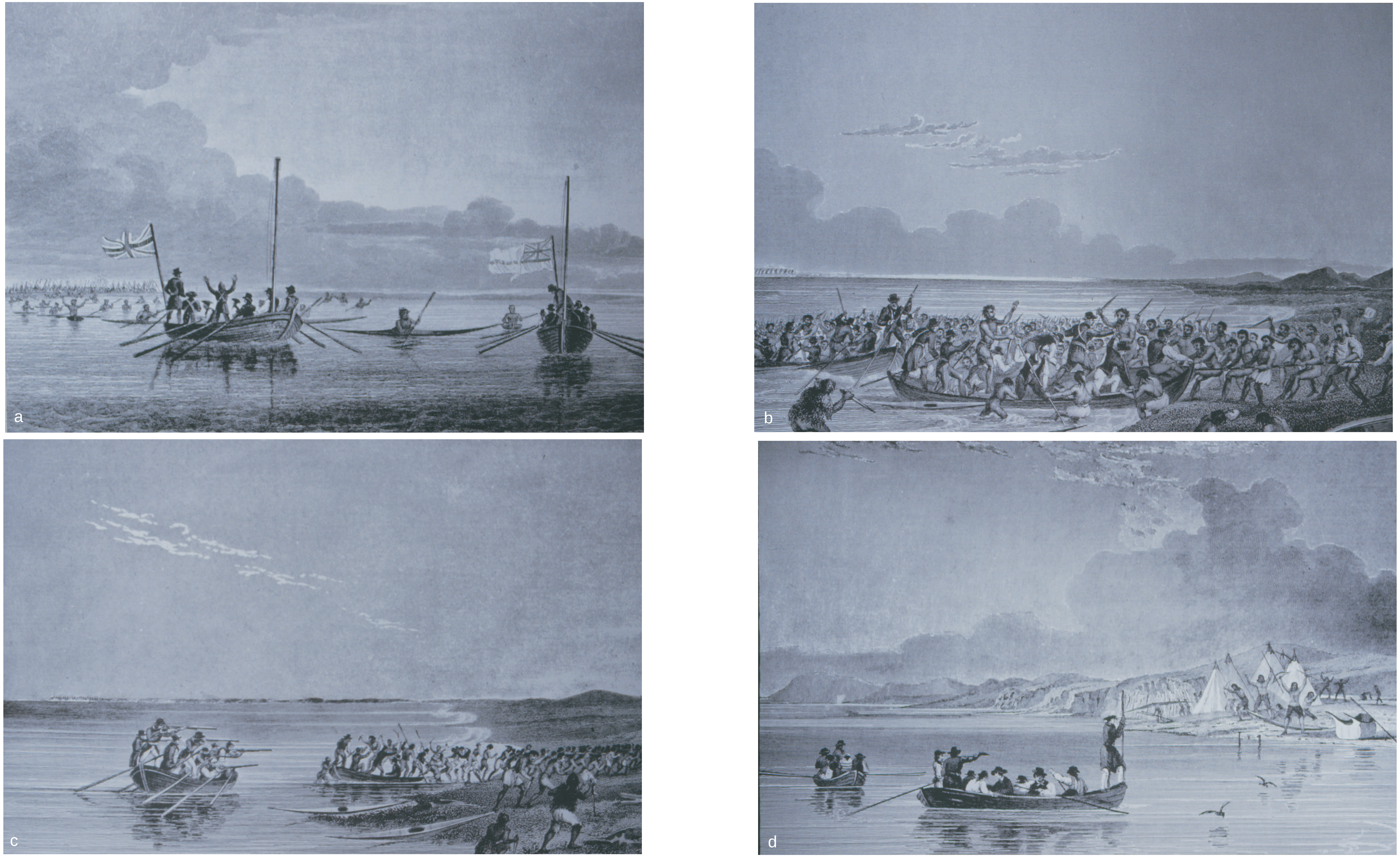


Fig. 1-1. a) The Royal Navy meets the Inuvialuit, Shoalwater Bay, 1826 (Franklin 1828); b) "The Esquimaux pillaging the Boats" (Franklin 1828); c) "The Boats getting afloat" (Franklin 1828); and d) "Esquimaux Encampment on Richard's Island" (Franklin 1828).

Fig. 1-2. a) Inuvialuit man; notice the broad cheek ornaments, called "labrets" (Franklin 1828); b) Inuvialuit woman (Franklin 1828); c) Inuvialuit couple, by Emile Petitot (Savoie 1970); d) Inuvialuit kayakers (Public Archives of Canada); and e) Inuvialuit men and boys (Public Archives of Canada).

Fig. 1-3. a) modern beluga camp ("Rick's Camp"), near Shingle Point, Yukon coast (D. Morrison); b) An Inuvialuit drum dance at Fort MacPherson (Petitot, 1981); c) "Noulloumallok-Innonarana, Chief of the Kragmaliveit Eskimos of Liverpool Bay" by Emile Petitot (1981); d) Modern Inuvialuit laying out fishing nets, Eskimo Lakes (D. Morrison); and e) plan of cruciform Inuvialuit winter house (Franklin 1828).

Fig. 1-4. a) Archaeological excavations begin at an Inuvialuit winter house, near the delta of the Horton River (D. Morrison); b) archaeological excavation of an Inuvialuit fishing site, Eskimo Lakes (D. Morrison); c) recent Inuvialuit house ruin; and d) the modern Hamlet of Tuktoyaktuk.

> which an inflated seal-skin is attached by means of a walrus-hide thong. The wounded fish is then incessantly harassed by men in kayaks with weapons of a similar description, a number of which, when attached to the whale, baffle its efforts to escape, and wear out its strength, until in the course of a day, the whale dies from sheer exhaustion and loss of blood."

Seal hunting was a less dramatic pursuit. A number of techniques were used, including harpooning in open water from a kayak, or at breathing holes through the winter ice. Seals were also taken with nets.

Nets were also used for fishing. Made of baleen or sinew, they were set under the ice of winter, or in open water, suspended from bark floats. In warm weather, special poles twenty or thirty metres or more in length were used to set the nets from shore. Fish were also speared, and taken with hooks through the ice. Most Inuvialuit archaeological sites abound with fishing gear, and with fish bone (Fig. 1-4b).

Caribou were the most important land animal, valued for their meat, and especially for their hides, which were necessary to make warm winter clothing. Hunting techniques included stalking with bows, communal drives, and spearing at water crossing, again using kayaks (see Morrison 1997b). The best caribou hunting was in the foothills of the Richardson Mountains, to the west of the Mackenzie, and in Eskimo Lakes-Anderson River-Cape Bathurst area, to the east. Groups like the Kittegaryumiut who spent the caribou-hunting season hunting beluga had to trade for hides (Stefansson 1914: 355).

From Ancient Times...

Biologically, culturally and linguistically the Inuvialuit are Inuit, closely related to all other Inuit people living across the top North American from Bering Strait to Greenland. All share a recent common origin in a culture which archaeologists call "Thule," which arose in northwestern Alaska about 1000 years ago (Ford 1959). Over the course of the next few centuries, Thule pioneers spread rapidly east throughout the Arctic in a series of migrations which changed the ethnic map of the North American Arctic (McGhee 1984; Morrison 1999). The earliest well-attested Thule site in Canada is located on southern Banks Island and dates to about the year A.D. 1000 (Arnold 1994). Within less than two centuries Thule hunters had spread as far as northern Greenland (McCullough 1989).

They were not entering an unoccupied land. Most of Arctic Canada and Greenland was the home of an eastern "Palaeoeskimo" people known to archaeologists as Dorset (see Maxwell 1985). Within a few decades, or at most a few centuries, they disappeared entirely, apparently pushed into oblivion by the more vigorous and more accomplished newcomers. Dorset culture, however, is known only as far west as Dolphin and Union Strait and the western coast of Victoria Island. No archaeological sites dating to the immediate pre-Thule period are known from the Inuvialuit homeland, so we have no clear idea who (if anyone) the first Thule immigrants met there.

These first Thule ancestors of the Inuvialuit are themselves known more by conjecture than direct evidence, in large part because land subsidence seems to have destroyed almost all of the relevant archaeological sites. Of over three hundred sites documented between the Alaskan border and Franklin Bay, only two clearly date to the Thule period. Fortunately, Thule culture is very well known from most other areas of the Arctic, so that certain general statements can be made about local Thule culture despite the dearth of local information.

It is clear that traditional Inuvialuit culture shared a number of important traits with its Thule ancestor. Like the Inuvialuit, Thule people enjoyed a relatively elaborate hunting culture, with permanent sod-house winter villages, karigis, and at least the beginnings of social complexity. There are also clear differences. Thule sites are rare or absent even from upland areas unthreatened by coastal subsidence, areas well-endowed with later Inuvialuit sites. It seems reasonable to suppose that the Thule population was significantly smaller than that of the Inuvialuit, and that it was more restricted to coastal margins, where erosion and subsidence have been most active.

Other important differences include an absence of fish-netting gear in Thule culture, and an Inuvialuit commitment to the communal kayak-based hunting of beluga whales which transcends anything seen in Thule. The adoption of both seem to have been pivotal in the transition from Thule to Inuvialuit culture, an event which the earliest Inuvialuit radiocarbon dates suggest happened sometime in the late thirteenth century A.D.

Inuvialuit culture proved remarkably successful and stable, apparently much better adapted to the riverine environments of the western Canadian Arctic than its Thule predecessor. From its origins about seven hundred years ago to the time of European contact five hundred years later, very little in the way of cultural change is apparent in the archaeological record. But changes were just around the corner.

To 1902

The first European to visit the land of the Inuvialuit was the Scottish fur trader and explorer Alexander Mackenzie, who in 1789 journeyed down the Mackenzie River to the Beaufort Sea(Mackenzie, 1970). His Dene Indian guides were careful that they not meet any Inuvialuit, though he did see some abandoned camps. Dene and Inuvialuit were traditional enemies, and once in Inuvialuit lands (which traditionally began at Point Separation at the upper end of the Mackenzie Delta), his guides became very cautious, steering Mackenzie clear of the well populated East Channel of the river, toward the maze of the middle delta.

In 1826 the British Royal Navy, intent upon finding a Northwest Passage, sent a party under the command of Lt. John Franklin down the Mackenzie River (Franklin 1828). At Point Separation they split into two parties. One, under Franklin himself, took the West Channel of the river to Shallow Bay, and then coasted west in an attempt to reach Point Barrow. The second party, under Dr. John Richardson, took the East Channel, and then travelled east to the Coppermine River. Both encountered a fairly hostile reception from Inuvialuit, and avoided bloodshed only with considerable difficulty. We owe our earliest detailed written descriptions of the Inuvialuit to this second Franklin expedition, and especially to Richardson, who was an intelligent and sometimes sympathetic observer.

The next flurry of exploration in the area was a consequence of the third Franklin expedition, launched in 1845 and considered missing by 1848. John Richardson returned to the western Arctic in a vain search for his former commander, descending the Mackenzie River and travelling east again to the Coppermine (Richardson 1851). He was followed by captains M'Clure, Pullen, and McClintock, all of whom met Inuvialuit and left published journals. By the early 1850s, the Inuvialuit coast lines were well explored (although the existence of the Eskimo Lakes was still hotly debated) and radical cultural change was just over the horizon.

European trade goods were already widely available through indirect trade. Russian iron goods were in circulation by the late eighteenth century, brought east from Bering Strait by Alaskan Inupiat intermediaries (Mackenzie 1970: 208). By the late 1820s this was supplemented by Hudson's Bay Company wares, traded downriver from Fort Good Hope (established in 1826) by Hare Indian traders (Franklin 1828: 91-93; Krech 1979).

In 1840, the Hudson's Bay Company established Peel's River Post (later called Fort MacPherson) on the lower Peel River just upstream from Point Separation. For the post's first ten years of existence it attracted only Gwich'in, the Inuvialuit remaining aloof from direct trade. But during the early 1850s they began to visit the fort in ever-increasing numbers. One early and beneficial effect of this trade was a suspension of hostilities between Inuvialuit and Gwich'in, although the two long remained suspicious and distrustful of one another (Krech 1979).

Most of this new-found trade consisted of white and red fox pelts, given in exchange for items such as metal fish hooks, glass beads, metal pots (often cut up as a useful source of metal), iron knives, hatchets, and above all tobacco (HBC, B/157/d/6: 1-25; Whittaker 1937: 230-232).

In 1861, the Hudson's Bay Company expanded its operations in the area, opening Fort Anderson on the Anderson River, aimed exclusively at the Inuvialuit trade (Stager 1967). It was an attempt, and a successful one, to bring eastern Inuvialuit into the direct orbit of the Company. These eastern Inuvialuit "dreaded their turbulent countrymen" living around the Mackenzie Delta and had continued to depend on indirect trade with the Hare rather than visit Peel's River Post. Now they visited Fort Anderson, and the post did well for its first few years. In 1866, however, it was abandoned due to declining revenues and a difficult overland supply route from Fort Good Hope. The orders to abandon it were issued in secret, Chief Factor Hardisty noting that because of Inuvialuit anger "care should be taken that the Esquimaux receive no intimation of our designs before they leave for the Sea Coast" (HBC, B/200/b/35: 75).

Reasons for this anger are not hard to find. The previous year the Anderson River area had been hit by a major infectious disease epidemic, probably measles. According to the missionary Emile Petitot, "…because of the measles, all the Eskimos, fleeing the shores of Anderson River, sought refuge on the shores of Liverpool Bay and Franklin Bay.... There were 28 deaths from the measles on the Anderson River...and no one can say how many died around the shores of the Arctic Sea" (Savoie 1970: 140). The Hudson's Bay Company reported that "the Esquimaux were exasperated against the Whites, on account of the number of their people who had died of the Measles, which they imagined was caused by the "bad medicine" of the Whites" (HBC, B/200/b/35: 94).

The closing of Fort Anderson seem to have caused some real economic disruption to those now accustomed to the Hudson's Bay Company and what it had to offer. Instead of reverting to a small-scale trade with the Hare, even eastern Inuvialuit now began making the annual trek to Peel's River Post. In 1866, the year Fort Anderson closed, Petitot counted 250 "Anderson Esquimaux" at Peel's River Post (Savoie 1970: 136). Group identity seems to have been blurring, and by the winter of 1869/70, the "Mackenzie River and Anderson bands" were reported wintering together, both suffering from disease and "camped on the ice hunting seals" (HBC, B/200/b/38: 22). The following year they were victims of a smallpox epidemic (Bompas 1871: 333), and year by year the toll increased. "We are all dying," reported an Inuvialuit chief in the 1870s, "we are getting snuffed out day by day" (Petitot 1981: 193).

It was during this period that the Inuvialuit were first introduced to Christianity, although it is doubtful if they recognized this fact. The Roman Catholic missionary Emile Petitot made several brief attempts to proselytise in the 1860s and 70s, to no apparent effect (Petitot 1981). An Anglican missionary, William Bompas, also visited the Inuvialuit (in 1870?) "as a spy searching the land" (Bompas 1871: 333).

Despite an extensive economic involvement with the Hudson's Bay Company and several major disease epidemics, the Inuvialuit were still in many respects very much aloof from the outside world as late as the 1880s. They had been only very rarely visited on their home ground by outsiders. In their dealings with the Hudson's Bay Company, for instance, it was the Inuvialuit who did the travelling, since Peel's River Post and even Fort Anderson were located outside of traditional Inuvialuit territory. The English Earl of Lonsdale, a fraudulent explorer in most respects, was probably the first European to set foot in Kittigazuit, as late as 1888 (Morrison 1989). But this relative isolation was not to last.

In 1889, the year after Lonsdale's visit, the first whaling ship entered western Canadian Arctic waters, part of the American Beaufort Sea whaling fleet based in San Francisco (Bockstoce 1986). They reported that bowhead whales were "as thick as bees", and by 1894 fifteen whaling ships were wintering at Herschel Island. Smaller numbers wintered as far east as Cape Bathurst and Franklin Bay, and in the 25 years from 1890 to the First World War they took about 1500 bowhead whales from Canadian waters. In so doing, and despite often friendly intentions, they destroyed the traditional culture of the Inuvialuit and almost obliterated them as a people. With the whalers, the isolation of the Inuvialuit was shattered.

The impact of the whalers could be felt in nearly every aspect of life. They were able to import large quantities of inexpensive trade goods, completely outflanking the Hudson's Bay Company and its interior supply routes. In 1893 (?), the traveler Frank Russell (1898: 141-142) met Inuvialuit west of the Mackenzie who had been trading with the whalers at Herschel Island. They had several large bags of flour ("as much as some northern posts receive for a year's allowance"), a new cloth tent, and syrup and coffee ('articles quite unknown in the interior"). Whale boats rapidly came to supplant traditional umiaqs, repeating rifles were in wide use, and even clothing was imported. Russell describes Inuvialuit on Herschel Island dressed in broad brimmed sombreros, and with "tight fitting red flannel drawers over their deerskin trousers." Alcohol was enthusiastically embraced, and Herschel Island rapidly became a "hive of debauchery" (Jenness 1964: 14).

At the same time, the animals which supported the traditional economy were being decimated. Bowhead whales, a staple for some Inuvialuit, almost disappeared, and local caribou herds went into a steep decline (Martel et al 1984). Fortunately neither fish nor beluga stocks were seriously threatened, and there was little outright starvation.

Along with the whalers came large numbers of Alaskan Inupiat, known as Nunatamiut ("inland people") since many came from interior north Alaska. Most came with the whalers as caribou hunters, employed to keep whaling ships supplied with fresh meat when wintering over. The need was so great that during the winter of 1894/95 most of the inhabitants of Point Barrow, Alaska, and nearly 100 people from nearby Point Hope, were employed by the whalers at Herschel Island (Bockstoce 1986: 274). Many "Nunatamiut" were also fleeing a collapse in the west Alaskan caribou population, a disaster they seemed to bring with them.

Relations between the Nunatamiut and the Inuvialuit were strained at first. The Nunatamiut were resented for using poison in trapping, and violent reprisals were considered although never undertaken (Stefansson 1914: 173). A traditional Inuvialuit story dating from this period relates how the Inuvialuit first noticed Nunatamiut moving east through the Mackenzie Delta (anon. 1991: 36). They were afraid that the Nunatamiut would discover the excellent hunting offered by the Bluenose caribou herd east of the River, so an Inuvialuit shaman diverted the herd so that it could not be found. Unfortunately, he hid it too successfully, and it was many years before the animals returned to their former haunts.

Missionaries, too, arrived on the heels of the whalers, mainly Anglicans, and ultimately more successful in their endeavors than Petitot and Bompas had been a generation earlier. In 1892 the Rev. Stringer began visiting Kittigazuit on a regular basis, and beginning two years later he and his successor, Charles Whittaker, established permanent missions at Kittigazuit, Herschel Island, Shingle Point, and other locations (Peake 1966; Whittaker 1937). The teachings of the missionaries soon had a profound effect on native belief systems, and by 1898 Stringer had a congregation of twenty to thirty people at Herschel Island. The first baptism, however, did not take place until 1909.

Inevitably, the whalers also brought disease. Although the details are poorly documented, the Inuvialuit seem to have suffered a number of epidemics during the 1890s, culminating in two devastating measles outbreaks in 1900 and 1902 (Jenness 1964: 14). Kittigazuit and other major villages were abandoned at this time, and police reports indicate that the Inuvialuit population had fallen from an estimated 2500 people in the early nineteenth century to 250 people in 1905, further reduced to 150 by 1910 (Usher 1971: 175). One survivor, Nuligak (1966: 27), remembers,

> That summer the Kitigariuit (sic) people fell ill and many of them died. Almost the whole tribe perished, for only a few families survived. During that time, two of the Eskimos spent all their time burying the dead.... Corpses were set on the ground uncoffined, just as they were. Since I could not count at the time I shall not attempt to give a number; but I know that when the people left for Kiklavak [on the east coast of Richards Island] they were but a handful compared to the number they had been. It was 1902....
>
> Winter came, and one day we saw a huge pack of wolves out at sea on the ice, heading east. There were so many of them that the last ones were still in front of us when the leaders had disappeared on the eastern horizon. It was said that they had feasted on the bodies left on the Kitigariuit land.

Postscript

The Inuvialuit survived, and with better medical facilities, some very hard-won natural immunities, and a great deal of Nunatamiut and more exotic inter-marriage, the population has rebounded to about 3000 people, probably a few more than lived in the area at the time of European contact a hundred and fifty years ago. Most if not all modern Inuvialuit are of mixed Alaskan and local descent, although some families and communities identify more with one heritage than the other. The aboriginal Inuvialuit dialect (*Siglitun*), for instance, survives best in more easterly communities like Tuktoyaktuk, Paulatuk, and Sachs Harbour, while the dialect of the Alaskan newcomers - *Uummarmiutun* - is spoken primarily in Aklavik and Inuvik (Lowe 1984a&b). Recently these five communities, along with the Central Arctic hamlet of Holman on Victoria Island, have joined together in a land claim agreement with the Canadian federal government. Called the Inuvialuit Final Agreement, it was signed in 1984 and governs essentially the entire Western Canadian Arctic. For the first time in a century, the Inuvialuit once more rule their own land.

David Morrison,
Canadian Museum of Civilization

Modern Activities of the Inuvialuit

Historical Aspects

The first human occupants of northern North America may have migrated from Siberia between 18,000 and 10,000 years ago. People of the Arctic Small Tool Tradition spread from Alaska to Arctic Canada and Greenland about 5000 to 3000 years ago; these people are the ancesters of today's Inuit. People had definitely moved into the Beaufort Coastlands area by 1,000 years ago, perhaps even by 2,000 B.C., when the climate was warmer than today. This area was occupied by the Arctic Small Tool Tradition people between 2000-800 B.C., and may not have been occupied by the Dorset Culture of 800 B.C.-1000 A.D. We can be quite confident that the Thule Culture and Inuit occupied the area during A.D.1000-1600. In the general Beaufort Sea area of this atlas, there are presently only two communities: Sachs Harbour on Banks Island, and Tuktoyaktuk in the Mackenzie Delta.

House ruins indicate that Inuit lived on Banks Island about 500 years ago, but later there was a period of some 200 to 300 years when the island was unoccupied. Modern history records that the north coast of Banks Island was sighted in 1819 by members of W.E.Parry's expedition aboard HMS HECLA and GRIPER; this expedition overwintered at Winter Harbour on Melville Island. Captain Frederick William Beechey was the first white man (qallunaat) to sight the south coast of Banks Island in 1825 when he was in command of HMS BLOSSOM exploring the northwestern Alaska coast, and searching for the Northwest Passage. Then Captain Robert McClure over-wintered his ship, HMS INVESTIGATOR, in 1851-52 in Mercy Bay on the north shore of Banks Island while searching from the west for Sir John Franklin's lost expedition. When his ship was not released from the ice, McClure was forced to abandon the INVESTIGATOR with all its stores and hardware, resulting in an influx of Copper Inuit who came to salvage iron and wood over the next 20-30 years. Stefansson, in 1913, gave the community the qallunaat name of Sachs Harbour after his ship MARY SACHS. This ship was part of the Canadian Arctic Expedition, which was led by Stefansson. The MARY SACHS spent the first winter in the ice offshore at the place now known as Mary Sachs Creek, which is a few kilometres west of present Sachs Harbour. The keel of the MARY SACHS is on the beach, as are a few remnants of the expedition. The first permanent occupation in this region began when three Mackenzie Delta families sailed to Sachs Harbour in 1920. However, the Royal Canadian Mounted Police (RCMP) detachment was established much later in 1953.

Tuktoyaktuk, which means "crossing place of the caribou", was formerly called Fort Brabant. This location was named Fort Brabant in 1934 when people assembled there as their place of choice, and renamed it Tuktoyaktuk in 1950. In 1826, Dr. John Richardson, who had been with Sir John Franklin on his second voyage of discovery, investigated the coast between the Mackenzie Delta and Coppermine River, while Franklin explored west to Prudhoe Bay in Alaska. Richardson met many people living in large family encampments at Kittigazuit, Atkinson Point and Cape Bathurst, where there were populations as great as 1000 people. In the period 1890 to 1910, whalers from the San Francisco area operated in the Beaufort Sea and Amundsen Gulf areas, wintering at Herschel Island in the west and Baillie Islands to the east. This invasion of qallunaat into the area with the "mingling" that inevitably took place was disastrous for the native people as epidemics of many types were passed about. In the 1920's, some Alaskan Inuit and some white traders and trappers migrated into the area of the Mackenzie Delta. Inhabitants of Tuktoyaktuk and Sachs Harbour document their birth-place as "somewhere in the delta", and Tuktoyaktuk became the "port of choice" on several occasions.

The following series of events led to the development of Tuktoyaktuk as a settlement. The Inuit of Herschel Island moved to Tuktoyktuk after an influenza epidemic in 1928; the Hudson's Bay Company opened a store and Anglican and Catholic missions were founded in 1937; the Anglican Mission school was built in 1947; the RCMP post was established in 1950; the Distant Early Warning (DEW) line site was built in 1955; the Pentecostal Mission was established in 1957; and several other meaningful events led to the permanency of Tuktoyaktuk

The hamlet of Paulatuk on Darnley Bay dates back to the 1920's when a number of Inuit decided to settle at that location; it was called Letty Harbour at that time. Paulatuk means "place of coal" or "soot of coal" referring to the coal that was found there. The Roman Catholic Mission was opened in 1935, and a DEW Line site was established in 1955.

Although the accompanying photograhs (Figs. 1-5 to 1-10) cover the period of the early 20th century, and specifically the interval of World War I, many of the activities portrayed actually carried through to at least World War II. At that time the high-powered rifle was in use, but the snow-mobile had not arrived. Accounts by explorers, surveyors, employees of the Hudson's Bay Company, the Royal North West Mounted Police (later called the Royal Canadian Mounted Police), the clergy, the native people, and the traders were all participants in the events of the day. A clear memory of these activities has been passed on to those who followed, and so the stories became well-remembered lore. Many of these activities are shown in the fine series of photographs povided by the Geological Survey of Canada from its archives. The descriptions of the People and their occupations are given in the captions in the usage of the times, and all photo credits and numbers are included.

Several photograhs have been selected in order to represent activities of individuals and their groups, and the divisions of work they portray. Contacts with the People and the traders are included, and clearly shows the association of those from the south with the People of the north; yet, the aboriginal way of life was maintained throughout this historical period.

B.R. Pelletier

Fig. 1-5. a) a. Eskimo boy at Point Woolaston in 1916 (Photo by J.R. Cox ; GSC 39687) ; b) "Mary Sacks" leaving Herschel Island NT in 1913. (Photo by J.J. O'Neill ; GSC 38433); and c) Eskimo grave at King Point, Yukon, in 1914. (Photo by J.R. Cox ; 34586)

Fig. 1-6. a) Copper Eskimo drilling bone with bow drill in 1916 at Copper; (GSC 39674); b) Eskimo woman shaping sealskin for slippers about1915, NWT (Photo by J.R. Cox; GSC 39638); and c) Lunch, Mackenzie Delta, NWT, circa 1915 (Photo by J.J. O'Neill; GSC 38440).

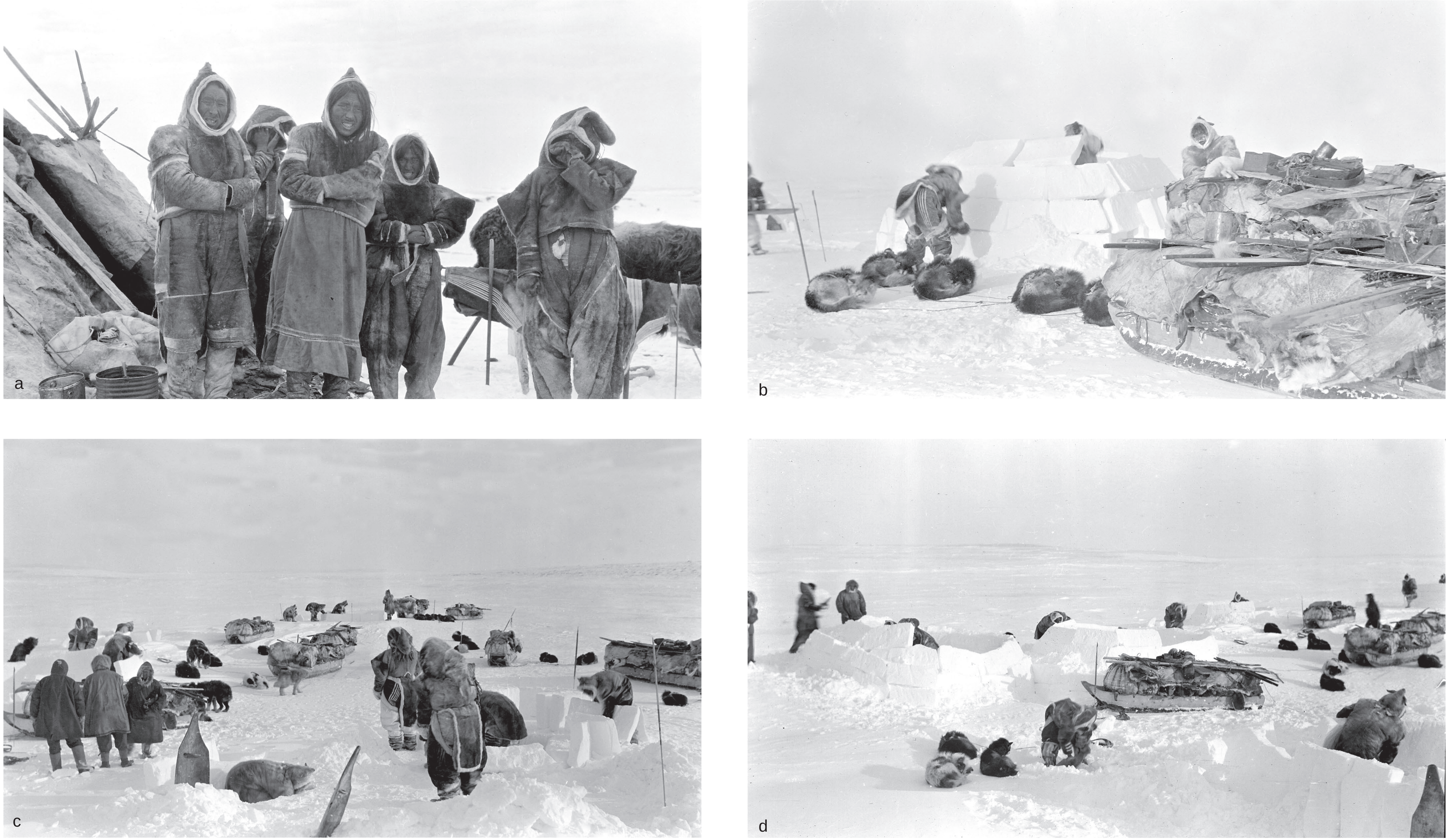


Fig. 1-7. a) Copper Eskimo group at Point Wollaston, NWT, in 1916. (Photo by J.R. Cox; GSC 39686); b) Copper Eskimo packing camp, NWT, around 1915. (Photo by K.G. Chipman; GSC 39641); c) Copper Eskimo building snow village at Bernard Harbour, NWT, in 1915. (Photo by J.R. Cox; GSC 39701); and d) building snow village at Bernard Harbour, NWT, in 1915. (Photo by J.J. O'Neill; GSC 38544).

Fig. 1-8. a) Copper Eskimo packed up and prepared to leave snow village at Bernard Harbour, NWT, around 1915 (Photo by J.R. Cox; GSC 39707); b) Copper Eskimo hammering cut copper arrow heads at the mouth of the Coppermine River, NWT, in 1916 (Photo by J.R. Cox; GSC 39673); c) Eskimo sleds at Cape Woolaston, NWT, on their way inland for the summer in 1915 (Photo by J.J. O’Neill; GSC 38577); and d) Four women in camp at Cape Woolaston, NWT, around 1915. (Photo by J.J. O’Neill; GSC 38585).

Fig. 1-9. a) Shipping at Herschel Island, Yukon, during a gale in 1913 (Photo by J.J. O'Neill; GSC 38436); b) the fleet of the Canadian Arctic Expedition at Herschel Island, Yukon, in 1914 (Photo by J.J. O'Neill; GSC 38668); c) Iglukitakok in the Mackenzie Delta, NWT, around 1915 (Photo by K.G. Chipman; GSC 43228); and d) a detachment of the Royal North West Mounted Police and the photographers survey parting Yukon and Northwest Territories 1915. (Photo by K.G. Chipman; GSC 43211).

Fig. 1-10. a) Lunch on the Mackenzie Delta, NWT, around 1915 (Photo by J.J.O'Neill; GSC 38440); b) Eskimos at church by Shingle Point, Yukon, in 1914 (Photo by J.J. O'Neill; GSC 38426); c) earth slides and the wreck of the BORRANZA at King Point, Yukon in 1913 (Photo by J.R. Cox; GSC 39587); and d) the BELVEDERE reloading whale bone at Herschell Island, Yukon, around 1915 (Photo by J.J. O'Neill; GSC 38428).

Photographic Essay and Descriptions

Note: Some of the accompanying photographs were taken at Repulse Bay and Resolute; however, situations similar to those portrayed could very well have taken place on the ice and shores of the Beaufort Sea (GDH).

Fig.1-11a Two young parents with their first baby in Resolute, 1978. The mother in this photograph is the daughter of a lady, a resident of Resolute, who worked as the cook for several seasons in the kitchen at the Polar Continental Shelf Project (PCSP) base camp at Resolute. Before marriage, this young lady was the assistant to the cook (her mother). One can just hear their words: "what a beautiful first baby".

Fig. 1-11b Another beautiful child in Tuktoyaktuk in 1979.

Fig. 1-11c A young couple at Sachs Harbour in 1975. We see a boy on a scooter and a girl talking about "something important". Note the caribou-skin coat and the pink, knitted bonnet worn by the girl. It is a combination of aboriginal and modern dress. We also see the natural landscape around this community, and the gravel surface covering the permafrost layer which is immediately below that surface in summer (perhaps at a depth of 0.6 m), but at the surface the rest of the year. The total depth of the permafrost under Banks Island is about 650 m.

Fig. 1-11d Two children enjoying the Beluga Festival in Tuktoyaktuk in 1975. Like other children in Tuktoyaktuk, these children dress to celebrate the Beluga Jamboree which is held every summer to celebrate the arrival of the warm season when the sea ice has melted and birds and sea life have returned to "our" land. Various contests are held during this weekend, such as typical Arctic Games and contests for boiling tea and baking bannock; something for everyone! It is a time of celebration for the community. The girl is dressed in a modern blouse and skirt, while the boy is dressed in a Navy uniform complete with shirt and tie; note the enscription on his cap "Victoria, B.C., Canada".

Fig. 1-12a An outdoor camp near Inuvik in the Mackenzie Delta in 1979. On such an occasion, elders will pass traditional knowledge to the younger generation regarding, in this instance, how to survive on the land, and their relationship with the environment. At this camp they will learn much: where and how to gather wood, how to operate a boat, to build a fire, to cook meals and to sleep in a tent.

Fig. 1-12b This activity begs the question "How high can I go?". We see a young athlete competing in an Arctic Games "high kick" competition. The foot that is last on the ground must be that which touches the target, a very difficult requirement of this sport. The target is traditionally a seal bone hung by a piece of string or gut tied to an adjustable extension arm from a vertical pole secured in the ground or on the floor of a school gymnasium. Heights exceeding 2.5 m can be reached in this competition.

Figs. 1-12c and 1-12d Two sketches selected from a series of 24 sketches that were drawn to tell the story of a family going by boat to a favourite caribou hunting area; they were successful. Fig. 1-12c shows father, mother, 3 children, and a caribou that has been spotted. The boat has been pulled up on land and the father, with his rifle, has taken off up the hill towards the caribou. Different types of rock are shown on the surface of the ground. Fig. 1-12d shows the father taking aim at one caribou. The family will then return to their camp or community, and share the meat with others in the community, or dry the meat for winter consumption.

Fig. 1-13a A lady contemplating at Mackenzie Settlement, ca 1988. This photograph, taken from a magazine, depicts an elder who lived in a small community just upstream of Inuvik on the shores of the Mackenzie River.

Fig. 1-13b A friendly little girl probably in the same community as the lady in Fig. 1-13a; maybe they are related. This little girl is wearing a homemade purple cloth parka, seal-skin kamiks (boots) and bright red, cloth-covered mitts. She is standing just outside the house, obviously enjoying having her picture taken on some special occasion.

Fig. 1-13c A male elder probably taken on the same occasion as the previous two photos. He is dressed for this event in a knitted sweater.

Fig. 1-14a The process of moving camp before motor toboggans were generally available. This is probably in the Mackenzie Delta area, ca. 1950. The dogs and komatiks (sleds) and camping gear indicate that this group of people are just setting out to move camp, or just arriving at a new campsite. They may be moving from a more permanent winter residence to an area familiar for hunting seals. It is obviously at a time before motor toboggans could be purchased or even desired by this family. Note that the eyeglasses on the male person are not the older slit-type but are the more modern dark-coloured lenses. We also note that there may be a baby in the pocket of the amouti (parka) on the back of the female person.

Fig. 1-14b Moving camp in summer in the Mackenzie Delta, ca. 1950. When a family moves to another fishing or hunting camp, everyone carries their share. Here we see a mother with a backpack, a father with flooring material for the tent plus a son on his shoulders, one dog with a pack, and other dogs hauling or carrying packs as well.

Fig. 1-14c The NORTH STAR at Tuktoyaktuk ca. 1980. The ship has been pulled up on the spit of beach sand which confines the harbour and was taken out of the water for the winter season to avoid being crushed in the ice and sunk. This ship travelled everywhere in the Beaufort Sea, moving people and material, and conducting scientific work and various other jobs as required by people at shore communities.

Fig. 1-14d Travel by dog team off the south coast of Banks Island, 1973. The favoured and sometimes the only available, means of travel was by dog team and komatik sled. In this formation, there is always one lead dog and then two, three or four pairs, depending on how many dogs you own or can borrow. Another formation sets out the dogs in a fan so that each dog has its own track. Here we see the team and driver travelling over sea ice adjacent to the south coast of Banks Island in almost white-out conditions. The driver of this team is Mary Carpenter who was born in Sachs Harbour.

Fig. 1-15a The ship OUR LADY OF LOURDES at Tuktoyaktuk in 1973. The ship had been pulled up on shore, was restored in 1967 and in 1979 was mounted on the concrete pad and supporting forms by Dome Petroleum when that company had a base camp at Tuktoyaktuk while searching for oil and gas in the Beaufort and Mackenzie areas. This ship had carried supplies onward from Inuvik to communities along the coast east and west of Tuktoyaktuk. The Roman Catholic church can be seen behind the forward section of the vessel. The ship is still at this location in Tuktoyaktuk and Father LeMeur, a local priest from France, is buried within a small white picket fence beside the ship. The ship can still be used by tourists who wish to enjoy a bit of history. For example, you may sleep in the wheelhouse overnight, and larger groups may go down into the hold which is accessible from the wheelhouse. There is a small box readily available for your

Fig. 1-11. a) Their first baby; Resolute, 1978 (G.D. Hobson collection); b) just wondering what is going to happen; Tuktoyaktuk, 1979 (Photo by F. Bruemmer); c) a young couple on a spring day; Sachs Harbour, 1979 (Photo by Mary Carpenter); and d) enjoying the Beluga Festival at Tuktoyaktuk, 1975 (Photo by F. Bruemmer).

Fig. 1-12. a) Outdoor camp in the Mackenzie Delta near Inuvik, 1975 (Photo by Mary Carpenter); b) How high can I go? Scene at the Northern Games, Tuktoyaktuk, 1979 (Photo by F. Bruemmer); c) and d) "And hunting we shall go", from a series of 24 sketches (G.D. Hobson collection).

Fig. 1-13. a) A lady contemplating at Mackenzie River settlement, ca. 1980 (G.D. Hobson collection); b) a friendly child in a Mackenzie River settlement, ca. 1980 (G.D. Hobson collection); and c) an elder in a Mackenzie River settlement, ca. 1980 (G.D. Hobson collection).

Fig. 1-14. a) Moving winter camp in days before the motor Toboggan, probably in Mackenzie River area, ca. 1950. (G.D. Hobson collection).; b) moving camp in the summer; note dogs back-packing, ca. 1950 (G.D. Hobson collection); c) "North Star" pulled up on a beach at Tuktoyak for the winter, ca. 1980 (Photo by Mary Carpenter) and d) travelling by dog team off the south coast of Banks Island, 1973 (Photo by Mary Carpenter).

Fig. 1-15. a) "Our Lady of Lourdes" Ship at Tuktoyaktuk, 1973 (Photo by Mary Carpenter); b) dog teams prepared to race at Sachs Harbour, 1976 (G.D. Hobson, collection); c) two styles of travel; motor toboggan and dog team near Sachs Harbrou, 1976 (Photo by Mary Carpenter); and d) a successful sea hunt near Sachs Harbour, 1976. (G.D. Hobson, collection).

contribution to the church for your overnight, or longer, shelter.

Fig. 1-15b Dog teams ready to race at Sachs Harbour in 1976, during the spring festival; it is getting warmer, the sun is shining longer and the ice will soon disappear. Dog-team races are a part of the festivities. This photo was taken on the east side of the community. The big boat pulled up for the winter is probably the NORTH STAR, the same vessel described in Fig. 1-14c above.

Fig. 1-15c Two styles of travel, motor toboggan and dog team, near Sachs Harbour in 1976. We see an early model of motor toboggan, probably made by the Eliason Company, pulling a heavy load of gear. There is a dog team coming along behind. It may be that they are travelling to an igloo which has been out on the ice for some time, perhaps used by other families as an overnight shelter or a rest area for lunch. Igloos built on the ice are built for anyone's and everyone's use for whatever purpose.

Fig. 1-15d The result of a successful seal hunt near Sachs Harbour,1976. There may be as many as 20 or 24 carcasses on this komatik. We see broken sea ice piled up in the background, a location where seals would surface for air. The komatik is a native-designed sled pulled by dogs or motor toboggan, with runners generally of 2 x 8 inch lumber (in modern times) on edge, and ice on the runners for easier pulling. Breakfast porridge has even been applied to the runners and then shaved down to provide a smooth running surface. Today, the runners are probably covered with plastic or steel, while in the original models, every part was bone recovered from animals such as caribou. The cross-pieces are of 1 x 3 or 1 x 4 inch wood, traditionally held to the runners by leather (seal thongs) for flexibility. Komatiks are still commonly used.

Fig. 1-16a Caribou hunting near Repulse Bay in 1978. This photograph shows two hunters with a skidoo and komatik on river ice, probably having used a rifle to fell the one animal on the ice.

Fig. 1-16b Caribou meat hung to dry near Sachs Harbour in 1975. In this hunting field camp, we can deduce that there are no dogs around because the meat would not be hung so close to the ground above the two oil drums.

Fig. 1-16c A typical hunting camp at Toker Point, Tuktoyaktuk Peninsula, in 1973. We see drift wood that has floated down the Mackenzie River, not an unusual site along the shores of the Mackenzie Delta. When geese, or caribou or whales etc. appear in traditional hunting areas, everyone who can do so goes hunting whether it is for the weekend or a few days, taking time off from work if it is required. Hunting is still very much a part of life in the Beaufort area.

Fig. 1-16d Drying fish at Sachs Harbour in 1976. Fish, when caught, may be filleted, cut up and hung to dry for future use or fed to the dogs. Note the barren rocky landscape. Seals, fish and beluga whales are the favourite natural foods in the western Arctic.

Fig. 1-17a Jigging for Lake Trout at Repulse Bay in 1978. Lake trout are a good-sized, delicious fish that are caught at such a typical location. The procedure is to cut a hole in the ice, drop in a hook- and -line and wait quietly for the "bite". The waiting period is loosely defined as: "until one catches something".

Fig. 1-17b Fox skins hung to dry on western Banks Island in 1978. This would have occurred in late winter/early spring. Hunting fox and other animals for their skins and meat was financially productive for Arctic aboriginal peoples before the onset of public outcry against fur harvesting. However, it is coming back in some small measure.

Fig. 1-17c Stretching of seal skins at Lake Harbour in 1978. Seals are usually caught in late spring and skinned carefully with an ulu knife to prevent causing any holes in the skin, then stretched on a frame to dry and cleaned carefully. Seal skin was used to make clothing such as parkas and trousers, shoes (kamiks) and mitts. More recently, the skins have been used for lady's purses or even brief cases.

Fig. 1-17d The process of cutting up a beluga whale at Sachs Harbour in 1978.The whale has been shot in the water, pulled ashore, then cut up for muktuk and meat.

Fig. 1-18a The catching and tagging of a caribou in the Mackenzie Delta in 1973. A Canadian Wildlife Service officer with native assistance in a boat comes alongside a caribou swimming across a river, captures the animal by the antlers, puts a tag around the neck and releases it, all without harm to the animal.

Fig. 1-18b Putting a radio transmitter on a caribou in the Mackenzie Delta area in 1973. The caribou has been sedated by a dart from a rifle and tagged with the radio transmitter around its neck, thus allowing scientists to follow its migration path and rate of movement with no harm to the animal.

Fig. 1-18c The marking and refloating of a beluga whale in the Mackenzie Delta in 1977. As some whales decide to do for unknown reasons, this beluga has beached itself; scientists of the Canadian Wildlife Service take the opportunity to tag the animal and refloat the stranded whale into deeper water either by pushing the animal by hand or waiting the tide to come in. The tag identifies the animal as to where and when it was in trouble.

Fig. 1-18d A new license plate being installed at the Polar Continental Shelf Project base camp at Tuktoyaktuk in 1988. Bill Presley, in the red shirt, is the mechanic and Eddie Chapman, the other person, the Base Manager. The building is the garage at the logistical centre for scientific research in the Beaufort Sea and adjacent areas; the base was in operation from 1968 to 1997.

Fig. 1-19a Father LeMeur's grave at Tuktoyaktuk in October 1985, which simply states: "In Loving Memory of Father Robert LeMeur, O.M.I., born 1920, died 1985". Father LeMeur is buried beside the ship OUR LADY OF LOURDES of Fig. 1-15a, very near to his home and church. Father LeMeur was born and raised in northern France. He would serve his church community by travelling in the 1940's and 1950's by dog team from Tuktoyaktuk, to Paulatuk and Sachs Harbour, until more recent times when those communities welcomed other "men of the frock" to the individual communities. Father LeMeur was inducted into the Order of Canada in 1988. One had to remember to watch his face to see the facial reaction to a question that required a simple yes or no answer; raising and lowering your eyebrows said "no", while twitching your nose said "yes", in Inuktitut.

Fig. 1-19b The altar in Sachs Harbour church in 1978, showing the communion rail to the right side. "The Last Supper" is easily recognized on the front of the altar. However, contrary to all appearances and first reactions, it is not a painting; the scene is carved in seal skins, maybe 8 or 10 skins have been sewn together and then carved by an ulu knife to remove the hair from the dried skins. The natural pattern of the seal skin can be recognized.

Fig. 1-19c Kamiks hung to dry in a Sachs Harbour home in 1978.These boots are made of seal skin and

Fig. 1-16. a) Caribou hunting at Repulse Bay, 1976 (Photo by F. Bruember); b) caribou meat being hung to dry near Sachs Harbour, 1976 (Photo by Miller); c) a typical hunting camp at Toker Point on the Tuktoyaktuk Peninsula, 1975 (G.D. Hobson collection); and d) drying fish at Sachs Harbour, 1976 (Photo by Mary Carpenter).

Fig. 1-17. a) Jigging for lake trout at Repulse Bay, 1978 (Photo by F. Bruemmer); b) fox skins hanging out to dry on western Banks Island, 1978 (Photo by Mary Carpenter); c) stretching seal skins at Lake Harbour, 1978 (Photo by F. Bruemmer); and d) cutting up a beluga whale at Sachs Harbour, 1988 (Photo by Mary Carpenter).

Fig. 1-18. a) Catching and tagging a caribou in the Mackenzie Delta, 1973 (Courtesy of The Canadian Wildlife Service: G.D. Hobson collection); b) putting a radio transmitter on a caribou in the Mackenzie Delta, 1973 (Courtesy of the Canadian Wildlife Services: G.D. Hobson collection);c) marking and re-floating stranded beluga whales near the Mackenzie Detla, NT, 1977 (Photo by F. Bruemmer); and d) putting on a new license plate at Polar Shelf base camp at Tuktoyaktuk, 1988 (Photo: G.D. Hobson collection).

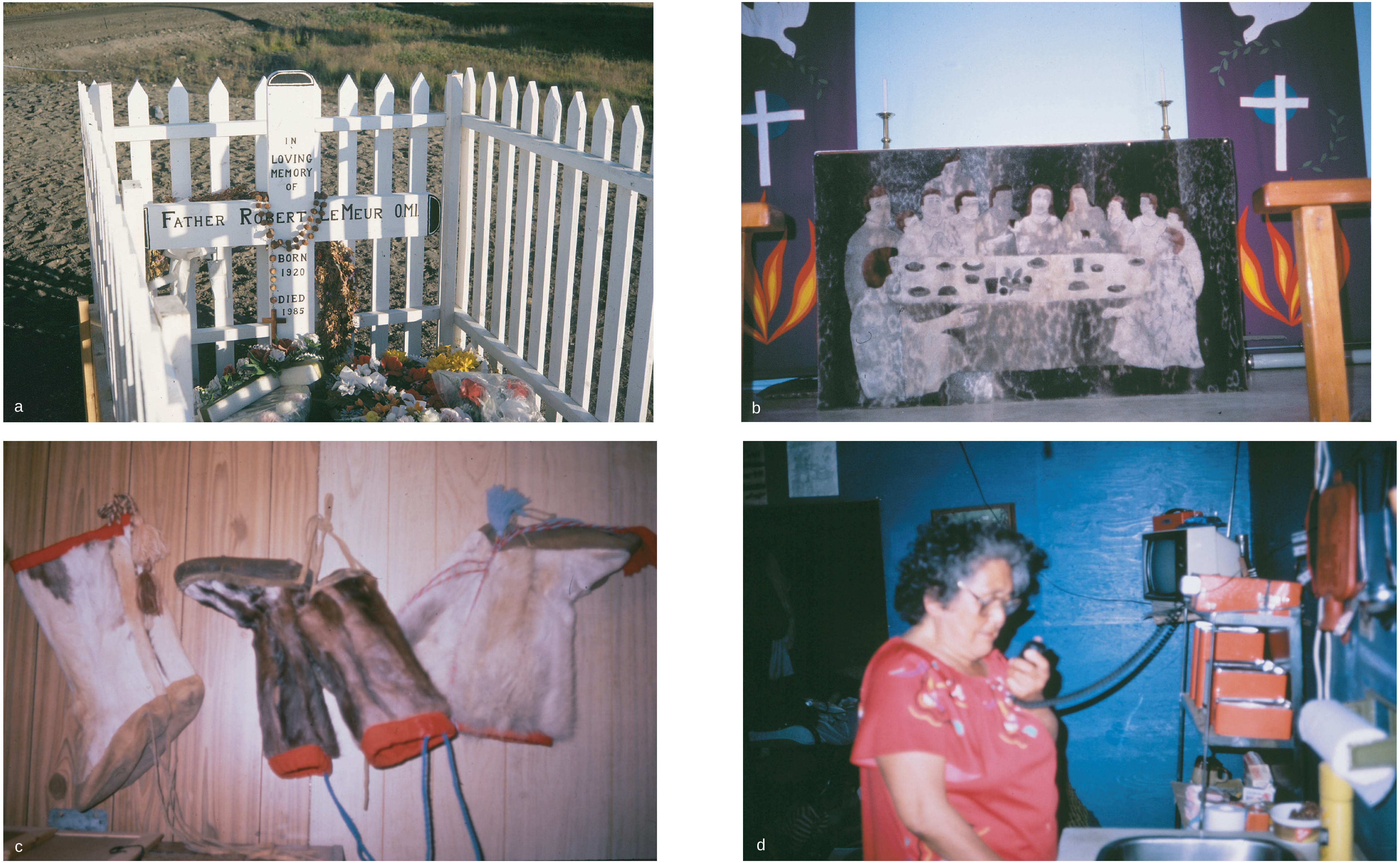


Fig. 1-19. a) Father Le Meur's grave at Tuktoyaktuk, 1985 (G.D. Hobson collection); b) the altar in Sachs Harbour Church, 1978 (Photo by Mary Carpenter); c) kamiks hung indoors at Sachs Harbour, 1978 (Photo by Mary Carpenter); and d) modern communications at Sachs Harbour, (1977) (Photo by Mary Carpenter).

are excellent protection in cold Arctic weather - but do not get them wet!

Fig. 1-19d Modern communications in Sachs Harbour in 1977. You know that this photo was taken in more recent times when you recognize the modern communication system and television in the background. The native people have been allocated a specific radio frequency which allows conversation between field camps, or field camp to home in a community. The lady in this figure is the same as in Fig. 1-17d.

George D. Hobson, former Director
Polar Continental Shelf Project, 1972-1988

Note: Photographs have been taken by George D. Hobson unless otherwise noted.

CHAPTER 2
EXPLORTION AND RESOURCES

EXPLORTION AND RESOURCES

The History of Naval Exploration of the Beaufort Coast

The history of exploration of the Beaufort Sea is an integral part of the history of the search for the Northwest Passage. This search for a shorter sea route to the Pacific Ocean from Europe was a dream of seafarers for centuries. Initially the search was motivated by commercial interests, but in the nineteenth century this incentive swung from the merchants to the scientists in an aspiration to explore and investigate the complexities of the north.

The Beaufort Sea lies on the south side of the Arctic Ocean adjacent to the northern coast of Alaska and the northwestern coast of Canada. It is bounded at its western end by Point Barrow, Alaska, and at its northeastern end by Prince Patrick Island. This wedge-shaped area, lying as it does at the western end of a northwest passage, became the goal of the explorers from the east and later the starting point for explorers attempting a west-to-east passage over the same route.

To place the immensity of the area in perspective, it is somewhat larger than the combined area of the Great Lakes, with Great Slave and Great Bear lakes included for good measure. It was named in 1826 by Sir John Franklin, R.N., for his friend Captain (later Admiral) Sir Francis Beaufort, Hydrographer to the British Admiralty, who was the same Beaufort that gave us the Beaufort wind scale and who was one of the greatest figures in the history of the navigational sciences.

By the mid-eighteenth century a succession of failures from the east to find the Northwest Passage had discouraged further efforts, and it fell to Sir John Barrow, Secretary of the British Admiralty, supported by Sir Joseph Banks of the Royal Society, to re-arouse interest during the early nineteenth century. This interest was scientific rather than exploratory, and in the period 1818-1849 a number of scientific expeditions produced more knowledge of the Arctic than had been achieved previously.

The first major expedition to the Beaufort Sea was headed by Captain John Franklin, R.N., accompanied by Lieutenant Back, R.N., Dr. Richardson, and Mr. Kendall. This was Franklin's second expedition to the Arctic, and it left (the United Kingdom) in 1825, returning in 1827. Their objective was continued exploration of the coast from Coppermine, Canada to Icy Cape, Alaska, where Captain Beechey's HMS BLOSSOM was expected. The party travelled to New York, thence overland to Fort Chipewyan and followed the Mackenzie River to its mouth, arriving there on 18 August 1825. They wintered at Fort Franklin on Great Bear Lake, and the following year Franklin and Back went west from the Mackenzie Delta to Return Reef in Gwydyr Bay, Alaska, while Richardson and Kendall in the boats DOLPHIN and UNION, journeyed east to Coppermine and thence to Fort Franklin on foot. The intended rendezvous between Franklin and Beechey did not take place as Franklin turned back at Return Reef six days before a boat from BLOSSOM reached Cape Barrow, some 160 miles to the west.

In 1826 the Hudson's Bay Company (HBC) decided to send out two of its experienced men, Peter Dease and Thomas Simpson, to complete the survey of the mainland coast. After a 2,000-mile overland journey from Fort Garry (Winnipeg) on the Red River, Dease and Simpson reached the mouth of the Mackenzie River and pushed westward along the coast past Return Reef until stopped by ice at Cape Simpson, this cape being named after George Simpson, Governor of all the HBC Territories. From Cape Simpson, Thomas Simpson set out on foot with a small group and reached Point Barrow on foot on 4 August 1837. Thus the survey of the mainland coastline of the Beaufort Sea from Cape Barrow to Cape Bathurst was completed.

In 1845 the Admiralty mounted the Franklin expedition to attempt the navigation of the Northwest Passage. It was realized that the Passage was of negligible commercial value, but that nonetheless considerable prestige would accrue from its successful navigation. However, the learned societies in England welcomed and supported the opportunity of obtaining extensive Arctic observations, and a considerable quantity of scientific instruments was aboard the ships of the expedition for that purpose. The expedition was equipped for a three-year stay in the Arctic, so serious concern over its failure to return was not felt until 1849. Then public interest began to mount and numerous relief expeditions were launched until 1859, when definite news was discovered to explain the fate of the Franklin party. Although the principal object of the voyages launched during this period was the search for Franklin, they added an immense amount of new knowledge to the cartography of the Canadian Arctic. The Franklin expedition was last sighted making for Lancaster Sound on 26 July 1845, and in 1848 a search was begun.

The 1848 expedition included HM ships HERALD (Captain Kellet), and PLOVER (Commander T. Moore), who were sent to survey Bering Strait and to send boats eastwards to search for Franklin. Boats from PLOVER under Lieutenants Pullen and Hooper left Wainwright, Alaska, in July 1849 and reached the Mackenzie Delta in September of that year. They wintered at Fort Simpson and the following year reached Cape Bathurst.

After the unsuccessful search expeditions of 1848, a further six search parties were sent out in 1850, including, to the west, by way of the Straits of Magellan, the Pacific Ocean and Bering Strait, HM ships ENTERPRISE (Captain Collinson), and INVESTIGATOR (Commander McClure). HMS PLOVER (Captain Kellet) remained in Bering Strait to serve as a depot ship for the expedition. From the time Collinson's two ships passed Icy Cape, Alaska, nothing was heard of this expedition until 1853.

On passage, the ENTERPRISE and INVESTIGATOR became separated in the Pacific. McClure reached Bering Strait a scant week ahead of Collinson and pressed on into the Arctic. He coasted to Cape Bathurst and then headed northeast and was beset in Prince of Wales Strait. Spring sledge parties surveyed the northeastern coast of Banks Island. The ship was released from the ice in July 1851 but was unable to proceed farther north through Prince of Wales Strait, and so McClure came south and west about Banks Island, reaching the north shore of Banks Island in September, where the ship was frozen in permanently in Mercy Bay. McClure sledged to Winter Harbour on Melville Island in April 1852 and there he left a message which eventually saved him. The ship was iced in all that year and scurvy broke out. As the crew was about to abandon ship and sledge out to the east, Lieutenant Pim of HMS RESOLUTE, one of the search ships which came in from the east, arrived. The INVESTIGATOR was abandoned and the crew was evacuated to the RESOLUTE and thence eastwards to England, thus accomplishing the Northwest Passage, albeit partly on foot. Despite claims and counterclaims, McClure and his crew were awarded the Admiralty prize of 2,000 pounds Sterling for the discovery of the Northwest Passage. Thus by 1852, the only remaining unsurveyed coastline of the Beaufort Sea was that of Prince Patrick Island.

That year the British Government sent out its last and greatest search expedition under the command of Sir Edward Belcher, a Canadian. The objectives were twofold: primarily, the expedition was to continue the search for Franklin (Fig. 2-1a, b), and secondly, it was to search for Collison and McClure, for whose safety there was mounting anxiety. HM ships RESOLUTE and INTREPID under Captain Kellet, late of

Fig. 2-1. a) Grave marker on Beechey Island of one of first sailors to die on the Franklin Expedition ca 1846. Monument erected by Belcher (1852-54). (Photo by B.R. Pelletier in 1968, BIO); b) ruins of Northumberland House on Beechey Island; original was erected by Belcher ca 1852-54 (Photo by B.R. Pelletier in 1968, BIO); c) the icebreaker shown is CCGS LABRADOR while on seabed studies in Kane Basin. In 1954, she was the first ship to circumnavigate North America (Photo by B.R. Pelletier in 1963, BIO); and d) the tanker MANHATTAN shown off Resolute in 1969 was the first commercial vessel to make the Northwest Passage (Photo by K. Williams of the CHS, 1969).

HMS PLOVER, were to proceed to Winter Harbour, Melville Island, but due to ice only got as far as Dealy Island. During the fall of 1852 Lieutenant Meecham, laying down caches for spring surveying and search parties, discovered McClure's message, giving his location on Banks Island, which eventually saved the crew of INVESTIGATOR.

In the spring of 1853, Meecham, on a sled journey of 1,006 nautical miles, became the first European to set foot on Prince Patrick Island and charted the island south to Discovery Point. Lieutenant McClintock of the same party, on an epic sled journey of 1,200 nautical miles, travelled north about the island as far as the northwest point, Cape Leopold Mc Clintock. By 1859 the Franklin search had come to an end and the period of intensive surveying of the Canadian Arctic also ended Most of the firsts had been achieved, and in particular, the Beaufort Sea coastline had been almost completely charted. McClure had proven the existence of a Northwest Passage, but at that time its commercial application was worthless and no further major expeditions were outfitted. However the challenge of making the passage by ship remained for the explorer, and in 1903 Roald Amundsen sailed from Norway in a forty-seven ton herring boat, the GJOA and eventually completed the Passage in 1906.

During the period 1913 to 1918 the Canadian Arctic Expedition under the leadership of Vilhjalmur Stefansson set out from Collison Point, Alaska, late in March 1914. The party made a 96-day journey on sea ice and eventually reached shore near the northwestern extremity of Banks Island. From their landfall, they travelled south and en route corrected many errors of McClure's chart. They wintered near Cape Kellet, Banks Island. The following spring they struck out over the ice again and reached latitude 76:30 N., and longitude 133 W., before returning east to reach Prince Patrick Island. Here, they surveyed between Discovery Point and Cape Leopold, thus closing the final gap in the Beaufort Sea coastline.

Due to illness Stefansson had to leave the expedition in 1917, and the following spring Storker Storkerson and a party camped on a large ice floe about 180 miles off the Alaskan coast. For six months they drifted in the Beaufort Sea, returning to land in November. These expeditions by Stefansson and Storkerson disproved the existence of any land in the Beaufort Sea.

There was little activity in the Beaufort Sea between World Wars I and II, though Tuktoyaktuk Harbour was surveyed in 1930-32, and some reconnaissance sounding was done between Herschel and Pullen islands in 1933. During World War II, the Royal Canadian Mounted Police schooner ST. ROCH (Sergent H.A. Larsen) completed the Northwest Passage from west to east on a duty patrol. It took two years to make the voyage and, in 1944, the same ship and master made the return voyage from Halifax to Vancouver in a single season.

The United States Coast and Geodetic Survey began detailed hydrographic surveys of the Arctic coast of Alaska in 1949, and completed the work in 1952.

The first deep draught ship to make the Northwest Passage was the Canadian icebreaker HMCS LABRADOR (Commodore Robertson), which in 1954 made the west to east passage ; incidentally, she became the first vessel to circumnavigate the North American continent Fig. 2-1c).

From information provided by masters in the Hudson's Bay Company, the Canadian Hydrographic Service published several large-scale charts of the more important harbours and anchorages in use in the early 1950's.

This slow approach to charting the Beaufort Sea was changed in 1955 when military considerations of the defense of the North American continent dictated construction of a defense warning system across the Arctic. The Distant Early Warning (DEW) line sites had to be built and supplied, and the inadequacy of existing charts necessitated prompt action. The main impetus was American. In addition to the United States Hydrographic Office which surveyed the approaches to the DEW line sites, the USS REQUISITE and the USCGS STORIS sounded the proposed shipping route from Herschel Island east to Shepard Bay at the southwestern end of the Boothia Peninsula. By 1957, the charts of the Beaufort Sea showed a safe shipping track east from Point Barrrow, and the CHS had completed a two-season standard survey of Tuktoyaktuk Harbour.

In 1960, the Canadian icebreaker CCGS CAMSELL commenced operations in the western Arctic and hydrographers onboard added to the charts of the Beaufort Sea while the ship carried out her icebreaking duties in support of the supply ships. However, in 1962, the CHS commissioned its own ship, CSS RICHARDSON for work in the Arctic. For the first time the CHS hydrographers had their own vessel from which to conduct hydrographic surveys, and no longer had to depend on other agencies providing ship time on an opportunity basis.

Mention must also be made of the efforts of the Polar Continental Shelf Project (PCSP) of the former Energy, Mines and Resources Canada (EMR) and now Natural Resources Canada (NRCan), which was established in 1959, and which developed methods of sounding through the ice in areas inaccessible to ships; also, the PCSP pioneered the use of hovercraft as sounding vehicles where its advantages in working on exposed coasts, subject to frequent changes in weather and ice conditions, made it an ideal craft for carrying out this work.

The passage of the supertanker MANHATTAN in 1969, from the east to the oil fields of the Alaskan slope to test the feasibility of the commercial use of the Northwest Passage, heralded yet another era of activity in surveying the Beaufort Sea (Fig. 2-1d, 2-2a). Her escort, the Canadian ice breaker CCGS SIR JOHN A. MACDONALD (Fig. 2-2b), discovered a previously uncharted shoal (subsequently identified as a pingo, or pingo-like feature on the sea floor; in the Beaufort Sea, which until then had been considered a safe area for normal draught vessels. The use of deep draught vessels called for a re-evaluation of the existing charts, and in 1970 the CHS mounted a major surveying effort in the area. The CSS PARIZEAU and CSS BAFFIN, with their nine survey launches, worked offshore north of the Tuktoyaktuk Peninsula. This program continued with PARIZEAU alone, working out of Victoria, British Columbia, for the 1971 and 1972 field seasons.

Oceanographic research and natural resources charting were also undertaken during this period, and continued for the remainder of the twentieth century. This work commenced in 1970 when CSS HUDSON (Fig. 2-2c) on the penultimate leg of her historic Hudson '70 cruise, worked the Beaufort Sea.

At this time, particularly during the 1980s, more advanced navigational and charting aids came on line which increased the speed and accuracy of seabed charting (Fig. 2-4a, b, c, d). The need for upgraded charts was fulfilled during this time, while exploration for petroleum and natural gas continued over a span of several years. Soon drill ships, artificial islands and other drilling platforms and their tender vessels appeared in the Beaufort Sea. The safe positioning of these ships and installations was due in large part to the efforts of the CHS. At this time, extended charting was required in the search for safe anchorages and

Fig. 2-2. a) Map of the Canadian Arctic Archipelago and adjacent mainland showing the route of MANHATTAN through the Northwest Passage in 1969; b) SIR JOHN A. MACDONALD is escorting BAFFIN (left) through ice fields in the western Northwest Passage (Photo by R. Belanger of BIO, 1970); c) HUDSON is shown above as she carried out her part of a scientific survey off the Beaufort coastlands in 1970 (Photo by R. Belanger of BIO); and d) MACDONALD is seen escorting BAFFIN and HUDSON easterly toward Resolute on their joint transit of the Northwest Passage in 1970 (Photo by R. Belanger of BIO).

Fig. 2-3. a) Hovercraft carrying out high-speed sounding operations in the Beaufort Sea coastal areas during the 1980s (Courtesy of the CHS); b) hovercraft carrying out sounding operations over very shallow waters along the Beaufort coast (Courtesy of the CHS); c) changing launch crews and refuelling from HUDSON during sounding operations off the Beaufort coast in 1981 (Photo by B.R. Pelletier, BIO); and d) high-speed sounding from CHS launches in the Beaufort coastal zone in 1981 (Courtesy of CHS).

Fig 2-4. Crew members of the CSS HUDSON erecting a commemorative plaque near Resolute in 1970 (Photo by B.R. Pelletier, Courtesy of BIO).

sites for the over-wintering of drill ships along the coastline.

Another significant discovery on the seabed of considerable engineering interest was made and investigated by RICHARDSON, BAFFIN, and HUDSON in 1970. These new features comprised grooves that occurred singly or in parallel groups with a single orientation. The linear grooves, later identified as ice-scour marks, were formed by keels of ice floes (single tracks) and pressure ridges (multiple tracks) that were driven into the seabed under the impetus of the wind, water currents and surrounding ice floes that were already in motion. Found in water depths of 50 m or less, they are not a threat to navigation, but may present a geotechnical endangerment to pipelines or other seabed installations. Considerable effort has been undertaken recently to establish the extent of these seabed features.

It is of interest to note that BAFFIN and HUDSON completed the Northwest Passage from west to east virtually together. Although on different dates, both ships sailed from their shared home port at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia. BAFFIN proceeded southwest to the Panama Canal, and then west to the Pacific Ocean; HUDSON also proceeded southerly out of Dartmouth but toward the Drake Passage lying between South America and Antarctica, and then west to the Pacific Ocean via the Strait of Magellan. Baffin had completed her portion of the Northwest Passage just prior to Hudson steaming out of Lancaster Sound on her final leg of the voyage of the HUDSON 70 Cruise. The honour of the first circumnavigation of the American continents fell to HUDSON on this remarkable cruise. A metal plaque was erected on a small elevation overlooking Resolute Bay, Cornwallis Island, by members of the ship's company in early September of 1970 (Fig. 2-4).

Modern technology has eased the task of the navigator, hydrographer, and scientific explorer in the Arctic. Satellite navigation, electronic surveying positioning systems, ice reconnaissance flights, weather reports, radio communication, and the workhorse of the Arctic, the helicopter are standard requisites for most work. But the isolation, the logistics problems, the rapidly changeable weather, and ice conditions, still have to be met and dealth with.

R.W. (Sandy) Sandilands and B.R. Pelletier
Geological Survey of Canada

CHAPTER 3
THE ENVIRONMENT

THE ENVIRONMENT

Orography and Weather

The major physiographic elements in the region consist of lowlands, uplands and mountains. These features are delineated by means of arbitrarily selected topographic contours, as shown on the accompanying map (Fig. 3-1). In this display the uplands and mountains are prominent, and their potential effects on weather systems can be visualized. This is particularly relevant to the mountains in Yukon Territory and Alaska in the western part of the region. To a certain extent the moderate elevations of the uplands in the east, together with the flow-confining mountains in the west, may induce a channeling of northerly and southerly winds along Mackenzie Valley. Therefore to understand the weather patterns in the Beaufort Coastlands, the orographic setting and its effect on prevailing winds must be considered

The smoothed orography depicted in Fig. 3-1 is used as a basis for presenting the seasonal climate maps displayed in the following pages. Generally, mountains may cause both vertical and horizontal deviations in wind flow. In the Mackenzie Valley—Beaufort Sea area , the air flow is influenced by mountain barriers lying across the paths of the prevailing winds. Such obstructions engender local winds that are anomalous in that the following phenomena may be produced: lee, or mountain waves, and chinooks form; winds are re-directed along valleys; diurnal winds such as warm upslope, anabatic flows may arise, as well as cold downslope, katabatic air streams; and coastal winds may be produced from local thermal gradients and eddies, particularly near warm bays and adjacent cold lands.

Westerly winds across the region may create mountain waves over the British and Richardson mountains, thereby causing subsidence and turbulence along the valleys of the Blow, Babbage and neighboring rivers on the northern flank of the British Mountains. The same effect would be produced along Rat River Pass, situated on the lee side of the Richardson Mountains. Easterly winds crossing the region may produce a turbulence along the Mackenzie Valley, as they pass into the lee of the Franklin Mountains and nearby hills.

Along the Arctic coast north of the escarpment that parallels Amundsen Gulf and the mainland coast to the east, southerly flows are disturbed by the obstructional presence of the higher elevations. As a result of this disturbance, strong downslope winds and severe turbulence are produced on the lee slope of the escarpment. Although prevailing weather systems may be guided by the weather aloft (e.g. the 500-mb level), orographic features must be considered as a contributing factor in creating local, anomalous patterns.

B.R. Pelletier
Data after Environmental and Atmospheric Services
Environment Canada

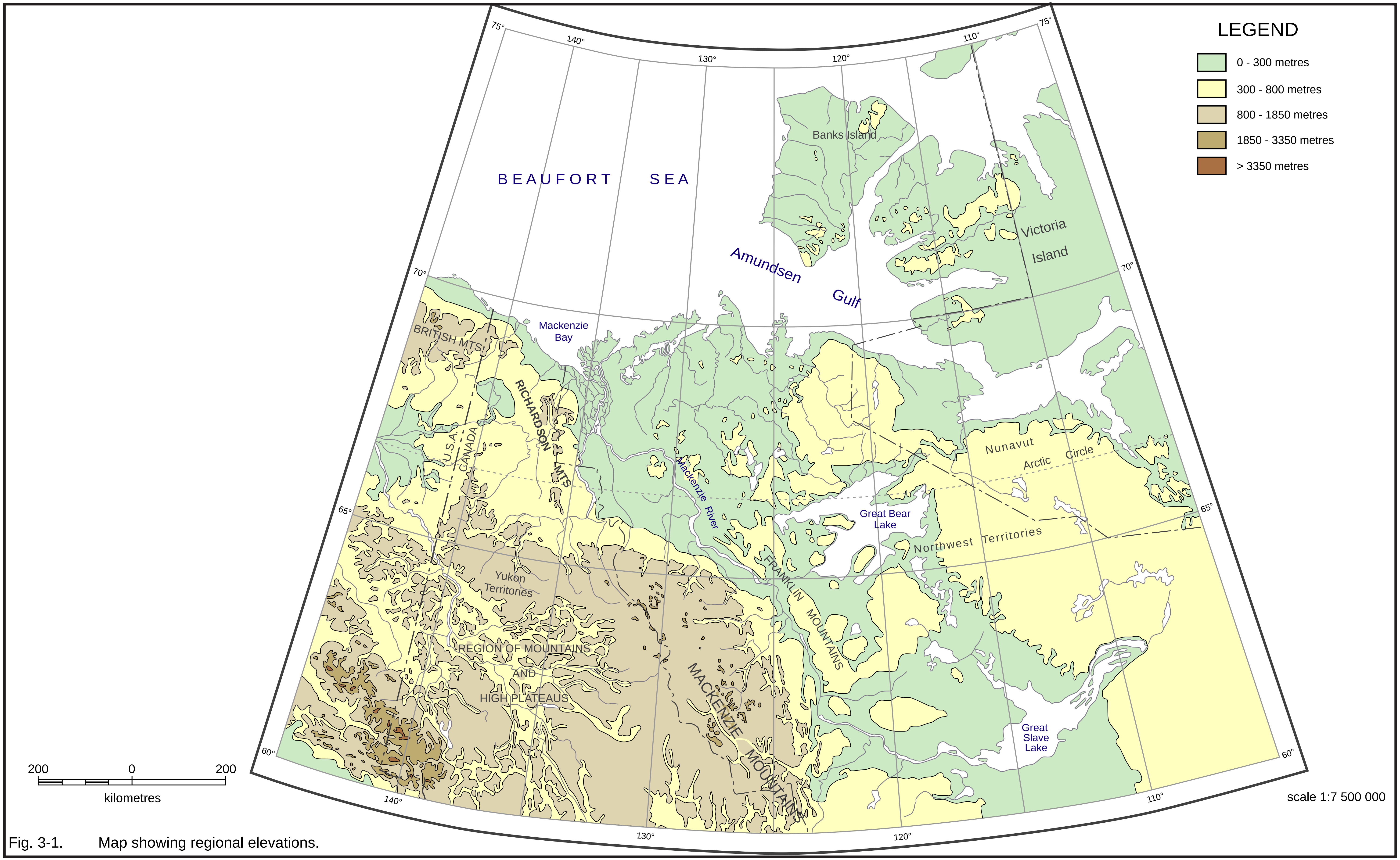


Fig. 3-1. Map showing regional elevations.

LEGEND

Weather stations
(period of record: elevation in m.)............ ●

TEMPERATURES (C)

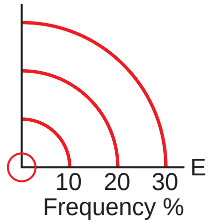
Extreme maximum, mean daily maximum.. -○-, -○-
Extreme minimum, mean daily minimum.... -●-, -●-
Mean daily.. -●-

PRECIPITATION		Sept.	Oct.	Nov.
Rain (mm), trace..................	R	0.3	0.7	0.3
Snow (cm)..........................	S	0.5	18.0	8.0
Total (mm).........................	T	19.7	18.7	8.3

WINDS

Wind roses.........................N

Mean hourly wind speeds
(km/h) by directions:
(Table to accompany
wind roses (see insets))



Direction	AKLAVIK			CAPE PARRY		
	Sept.	Oct.	Nov.	Sept.	Oct.	Nov.
N	11	11	9	19	20	15
NE	8	8	5	19	21	20
E	7	9	5	25	27	27
SE	11	9	9	20	22	20
S	10	9	6	17	18	16
SW	10	9	7	16	19	14
W	9	8	6	22	24	21
NW	15	14	12	22	23	20
all	12	11	9	20	22	19
Max.speed Direction	51 NW	48 NW	51 NW	52 E	56 W	55 E

OROGRAPHY

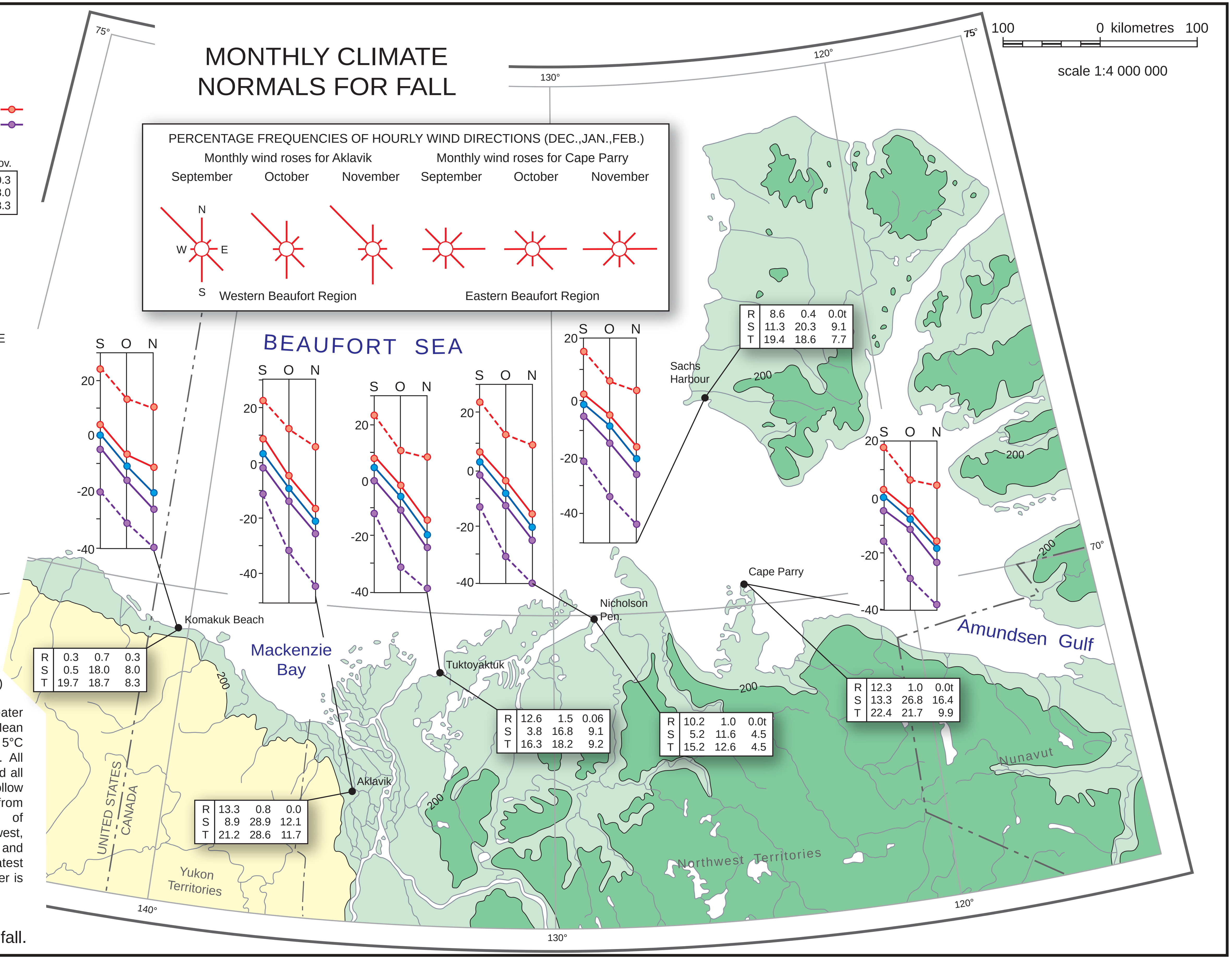
200m topographic contour......................—200—

🟩 Lowlands (below 200m)

🟩 Uplands east of Mackenzie Delta
(200-500m, and exceptionally 800m)

🟨 Uplands and mountains west of Delta
(200-2000m, and exceptionally to 2800m)

Note: Wind regimes are consistant with greater speeds in the east than in the west. Mean daily temperatures decrease steadily from 5°C in September to about -17°C in November. All daily mean maximums (8°C to -20°C), and all mean daily minimums (-3°C to -26°C) follow this trend falling temperatures from September to November. Amounts of precipitation decrease from 28mm in the west, and 22mm in the east, to 4mm in the west and less than 5mm in the east. The greatest snowfall occurs in early fall, and November is the driest month of the season.



Komakuk Beach

R	0.3	0.7	0.3
S	0.5	18.0	8.0
T	19.7	18.7	8.3

Aklavik

R	13.3	0.8	0.0
S	8.9	28.9	12.1
T	21.2	28.6	11.7

Tuktoyaktuk

R	12.6	1.5	0.06
S	3.8	16.8	9.1
T	16.3	18.2	9.2

Nicholson Pen.

R	10.2	1.0	0.0t
S	5.2	11.6	4.5
T	15.2	12.6	4.5

Cape Parry

R	12.3	1.0	0.0t
S	13.3	26.8	16.4
T	22.4	21.7	9.9

Sachs Harbour

R	8.6	0.4	0.0t
S	11.3	20.3	9.1
T	19.4	18.6	7.7

Fig. 3-2. Monthly climate normals for fall.

LEGEND

Weather stations
(period of record: elevation in m.) .... ●

TEMPERATURES (C)
Extreme maximum, mean daily maximum... -●-, —●—
Extreme minimum, mean daily minimum...... -●-, —●—
Mean daily... —●—

PRECIPITATION

		Dec.	Jan.	Feb.
Rain (mm), trace..................	R	0.0t	0.0t	0.0t
Snow (cm)...........................	S	5.4	5.2	5.4
Total (mm)...........................	T	5.4	5.2	4.1

WINDS
Wind roses..........................N

Mean hourly wind speeds
(km/h) by directions:
(Table to accompany
wind roses (see insets))

E
10 20 30
Frequency %

Direction	AKLAVIK Dec.	AKLAVIK Jan.	AKLAVIK Feb.	CAPE PARRY Dec.	CAPE PARRY Jan.	CAPE PARRY Feb.
N	13	7	8	16	16	15
NE	5	6	5	17	17	16
E	5	6	6	26	25	25
SE	8	11	9	19	20	21
S	6	8	7	19	18	16
SW	7	6	7	14	19	15
W	4	11	8	22	22	23
NW	11	13	15	29	14	23
all	10	10	9	15	15	18
Max.speed Direction	80 NW	63 NW	48 NW	57 E	55 W	53 E

OROGRAPHY
200m topographic contour......................—200—

🟩 Lowlands (below 200m)

🟩 Uplands east of Mackenzie Delta
(200-500m, and exceptionally 800m)

🟨 Uplands and mountains west of Delta
(200-2000m, and exceptionally to 2800m)

Note: Data indicates two different wind regimes are present:(1) in the west, wind directions conform to mountain trends;(2) in the east, wind directions parallel the coast. Mean hourly wind speeds are greater in the east than the west. Mean daily temperatures are low everywhere (-25°C to -30°C), with the coldest record in February. Mean daily maximums are -15°C to -25°C and minimums are -30°C to -35°C. Precipitation is steady and low all winter. Lowest amounts fall along the coast (3 to 8.6mm), with slightly greater amounts (6.9 to 9.0mm) inland. Snow is less in late fall, and averages about 5 to 11cm monthly over the winter.

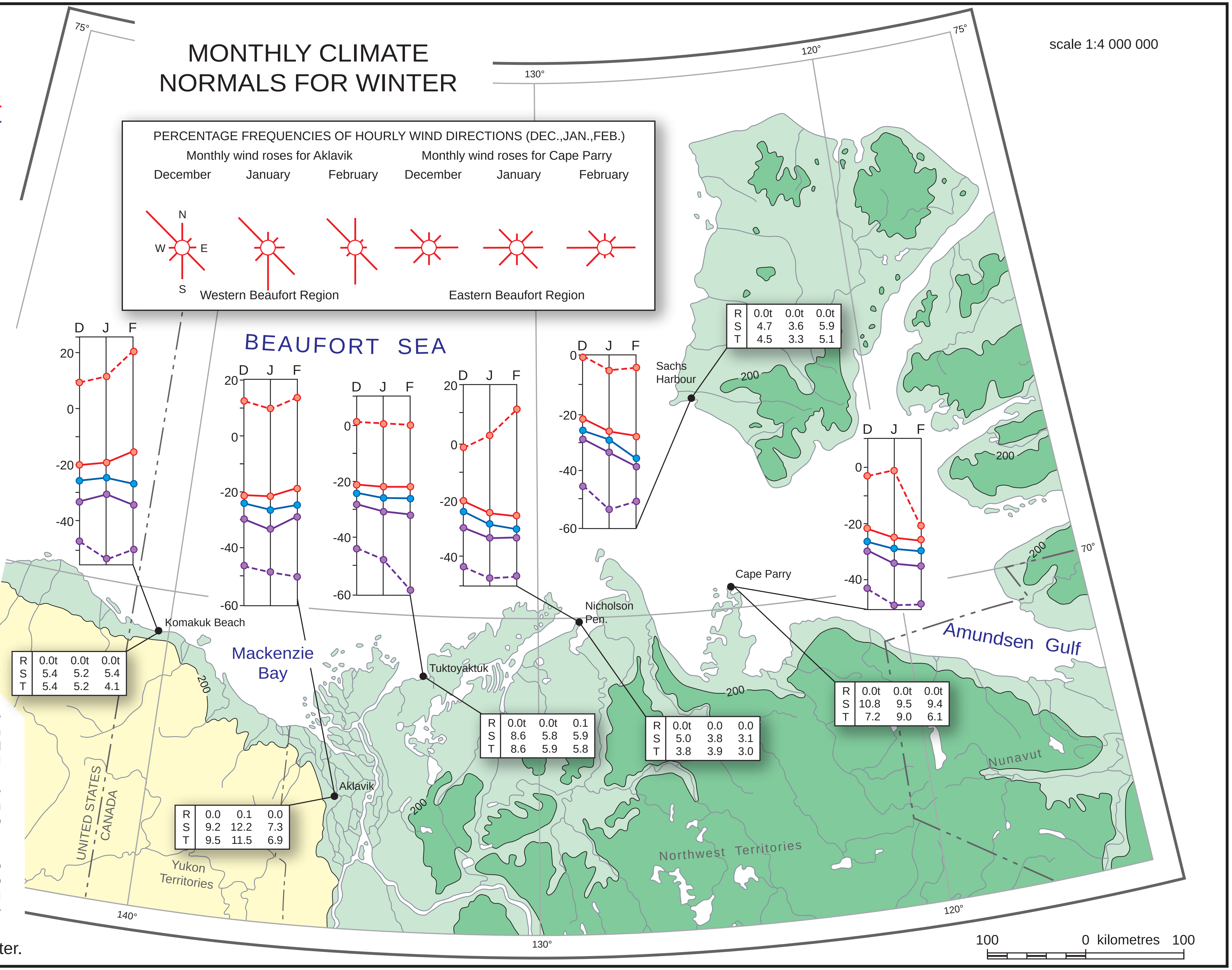
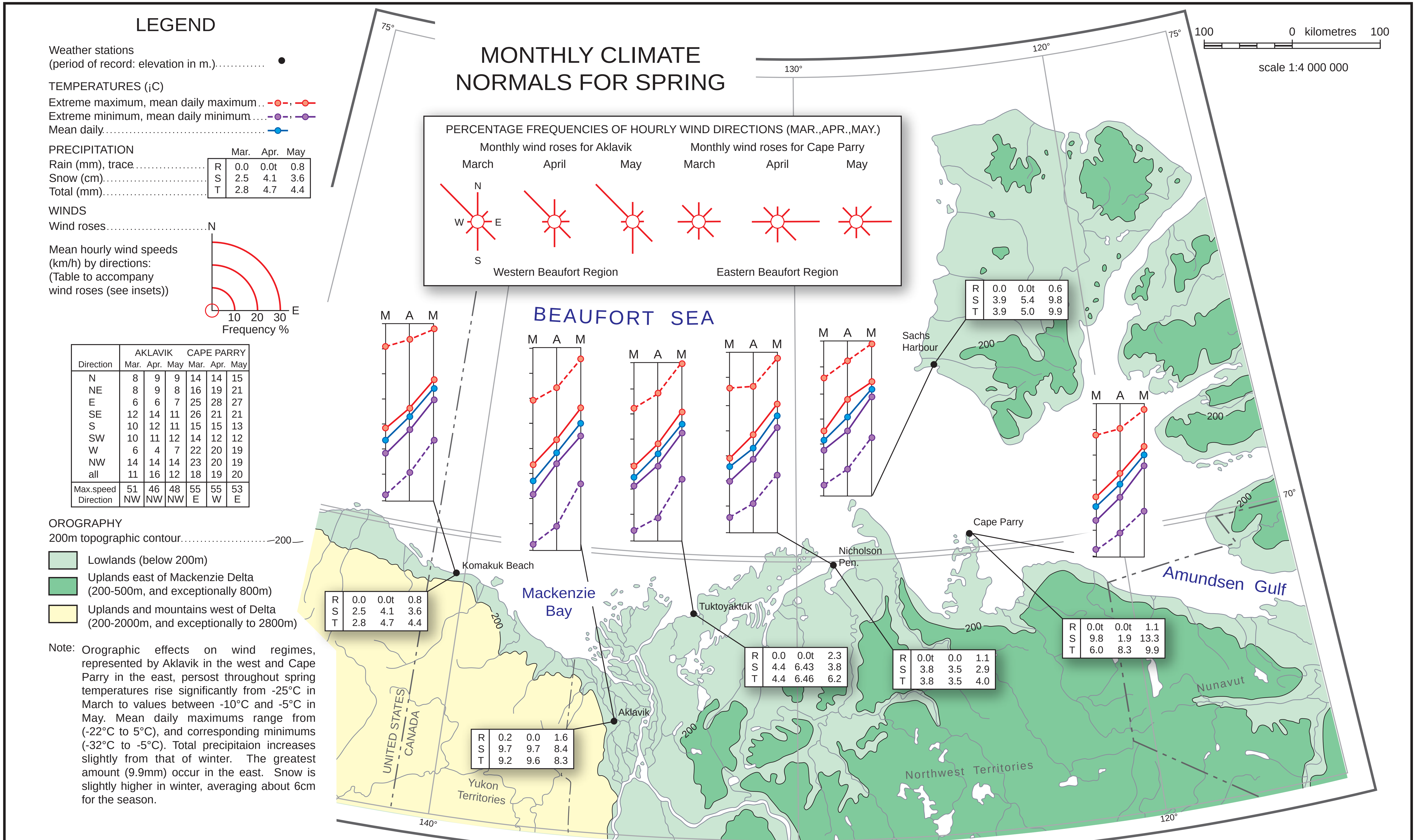


Fig. 3-3. Montly climate normals for winter.



Direction	AKLAVIK Mar.	Apr.	May	CAPE PARRY Mar.	Apr.	May
N	8	9	9	14	14	15
NE	8	9	8	16	19	21
E	6	6	7	25	28	27
SE	12	14	11	26	21	21
S	10	12	11	15	15	13
SW	10	11	12	14	12	12
W	6	4	7	22	20	19
NW	14	14	14	23	20	19
all	11	16	12	18	19	20
Max.speed Direction	51 NW	46 NW	48 NW	55 E	55 W	53 E

Note: Orographic effects on wind regimes, represented by Aklavik in the west and Cape Parry in the east, persost throughout spring temperatures rise significantly from -25°C in March to values between -10°C and -5°C in May. Mean daily maximums range from (-22°C to 5°C), and corresponding minimums (-32°C to -5°C). Total precipitaion increases slightly from that of winter. The greatest amount (9.9mm) occur in the east. Snow is slightly higher in winter, averaging about 6cm for the season.

Fig. 3-4. Montly climate normals for spring.

LEGEND

Weather stations
(period of record: elevation in m.) .... ●

TEMPERATURES (¡C)
Extreme maximum, mean daily maximum ... -○-, -○-
Extreme minimum, mean daily minimum ..... -○-, -○-
Mean daily .... -○-

PRECIPITATION

		Jun.	Jul.	Aug.
Rain (mm), trace	R	12.9	28.8	32.0
Snow (cm)	S	2.5	0.8	3.9
Total (mm)	T	15.4	29.6	35.9

WINDS
Wind roses .... N

Mean hourly wind speeds
(km/h) by directions:
(Table to accompany
wind roses (see insets))

10 20 30 E
Frequency %

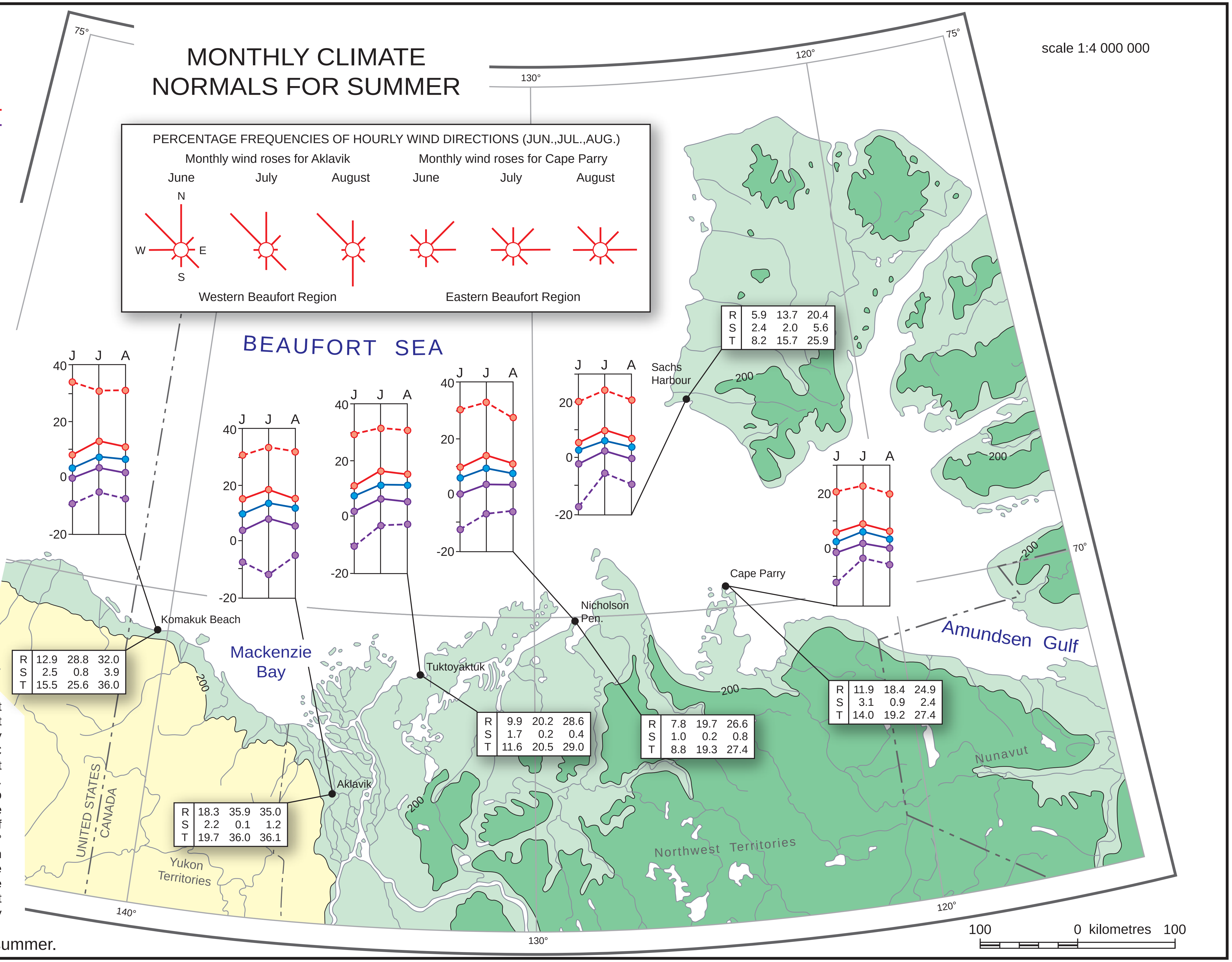
Direction	AKLAVIK Jun.	Jul.	Aug.	CAPE PARRY Jun.	Jul.	Aug.
N	11	11	9	15	16	16
NE	8	10	8	20	16	18
E	8	8	7	26	21	23
SE	10	12	11	20	19	18
S	11	10	9	13	12	16
SW	12	8	9	12	12	16
W	8	9	9	20	20	22
NW	15	14	16	20	20	21
all	12	11	11	18	18	19
Max.speed Direction	45 NW	37 NW	48 NW	49 E	45 W	50 E

OROGRAPHY
200m topographic contour .... —200—

🟩 Lowlands (below 200m)

🟩 Uplands east of Mackenzie Delta
(200-500m, and exceptionally 800m)

🟨 Uplands and mountains west of Delta
(200-2000m, and exceptionally to 2800m)



Note: The wind regimes for the western Beaufort coastlands (Aklavik) and the eastern Beaufort (Cape Parry) persist all summer. Mean daily temperatures rise considerably from about 5°C in June to about 12°C in July (the hottest month), all fall to yet positive values in August. Range of the mean daily maximum is 10°C to 20°C, with the lower value in June and the higher on in July. Corresponding range of mean daily minimum temperature is 8°C to -2° C, for June and July respectively. Precipitation increases in summer to a total of 36mm in the west, and 27mm in the east. August is the wettest month due mostly to more abundant rainfall because snowfall is minor - generally less than 3cm.

Fig. 3-5. Monthly climate normals for summer.

SEASONAL WEATHER: Surface pressure patterns for fall (October)

LEGEND

CONVENTIONS
See SEASONAL WEATHER MAP for winter

AIR PRESSURE AND AIR FLOW NOTATION

Mean pressure in mb (1/10 hecto Pascal)............	● 1011.8
Sea-level pressure isobars (mb)........................ (Dashed over water and mountainous regions)	━━━ ━ ━ ━
500 mb conour (see CONVENTIONS).................	━ ━ ━
Air pressure cells (high, low)...........................	H,L
Flow of air (direction)....................................	➡

Note: By September and October, an area of high pressure begins to build into the area establishing a northwesterly flow of cold air over the Mackenzie Basin. (At this time the arctic seas are in their freeze-up mode). Out breaks of cold arctic air behind the fall cyclones become progressively colder. As the dome of cold arctic air begins to cover an ever-increasing area, the high pressure builds. Without the influx of solar radiation, air masses over the area continue cooling and become progressively colder as winter sets in. With disappearance of the sun, the air continues to radiate its heat to space and becomes progressively cooler. (See CLIMATE NORMALS for fall).

Map adapted after B.M. Burns*
commentary: Heather Auld*

* Atmospheric and Environmental Services
Environment Canada

200 0 200
kilometres

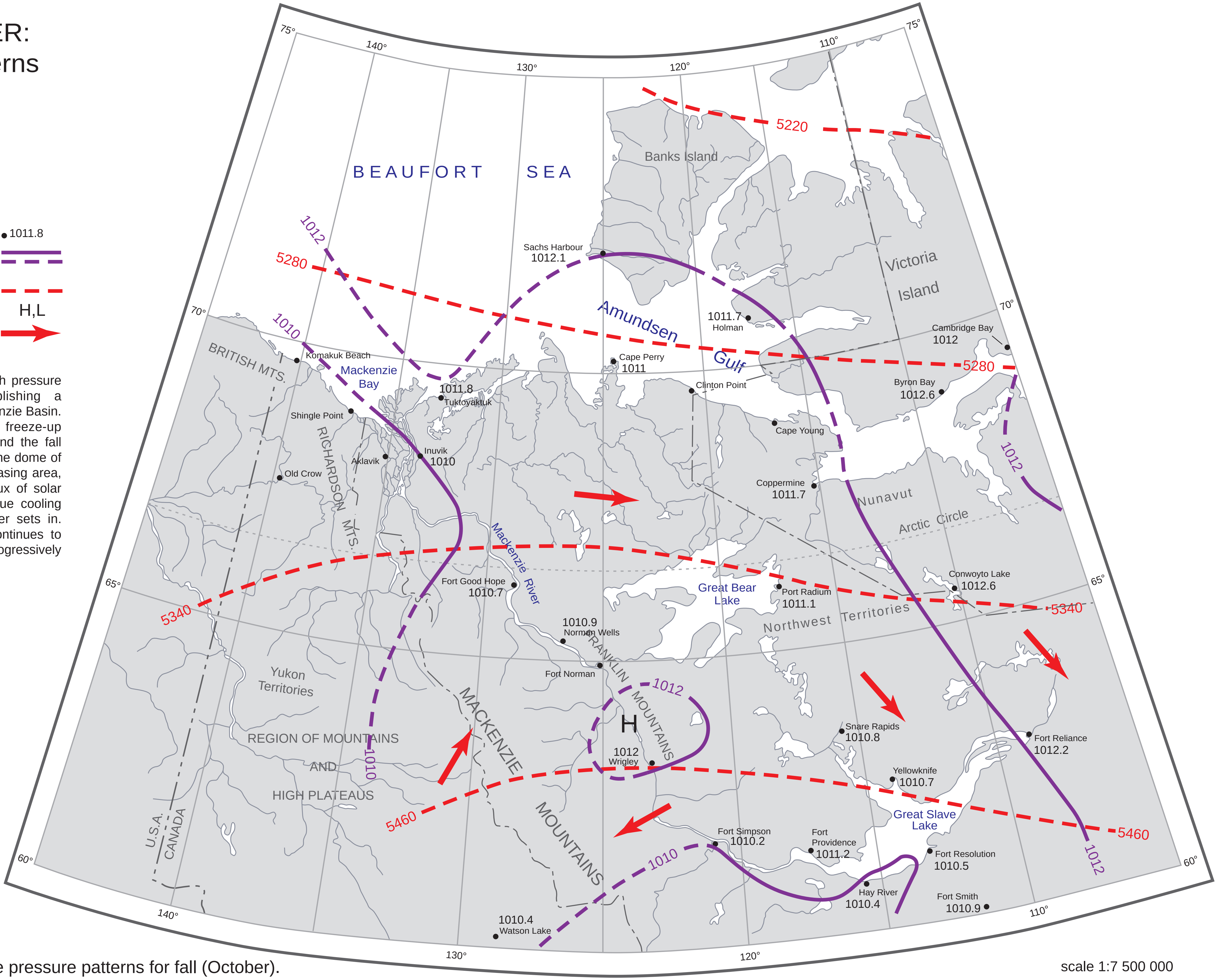


Fig. 3-6. Seasonal weather: Surface pressure patterns for fall (October).

scale 1:7 500 000

SEASONAL WEATHER: Surface pressure patterns for winter (January)

LEGEND

CONVENTIONS

The isolines marked with values in the thousands (e.g.1018) refer to sea level pressure values in millibars (one tenth of a hecto Pascal). The pressure conours (isobars) are very useful in indicating the direction and relative speed of airflow. The red, dashed contours (▬ ▬) indicate upper level flows. In the accompaning maps, these contours are for the 500-millibar (mb), or 18 000-foot level and describe the height above sea level in metres to reach a constant pressure of 500 mb in the atmosphere. These upper level flows are useful for a number of reasons including the fact that the upper level winds tend to steer the surface weather systems.

Aloft a relatively strong, mean northwesterly flow tends to dominate in winter. This flow aloft then weakens in spring and becomes more westerly.

Note: Wind, or flow direction is given by the direction of the wind source.

AIR PRESSURE AND AIR FLOW NOTATION

Mean pressure in mb (1/10 hecto Pascal)............ ●1021.8
Sea-level pressure isobars (mb)........................ ▬▬▬ / ▬ ▬ ▬
(Dashed over water and mountainous regions)
500 mb conour (see CONVENTIONS)................. ▬ ▬ ▬
Air pressure cells (high, low)............................ H,L
Flow of air (direction)..................................... ➜

Note: During January, the Mackenzie basin region is dominated by large areas of high pressure that often persist for a considerable periods of time. these cold, high pressure areas originate over the Beaufort Sea, and more southwesterly along the Mackenzie valley. See CLIMATE NORMALS for winter.

Map adapted after B.M. Burns*
commentary: Heather Auld*

* Atmospheric and Environmental Services
Environment Canada

200 0 200
kilometres

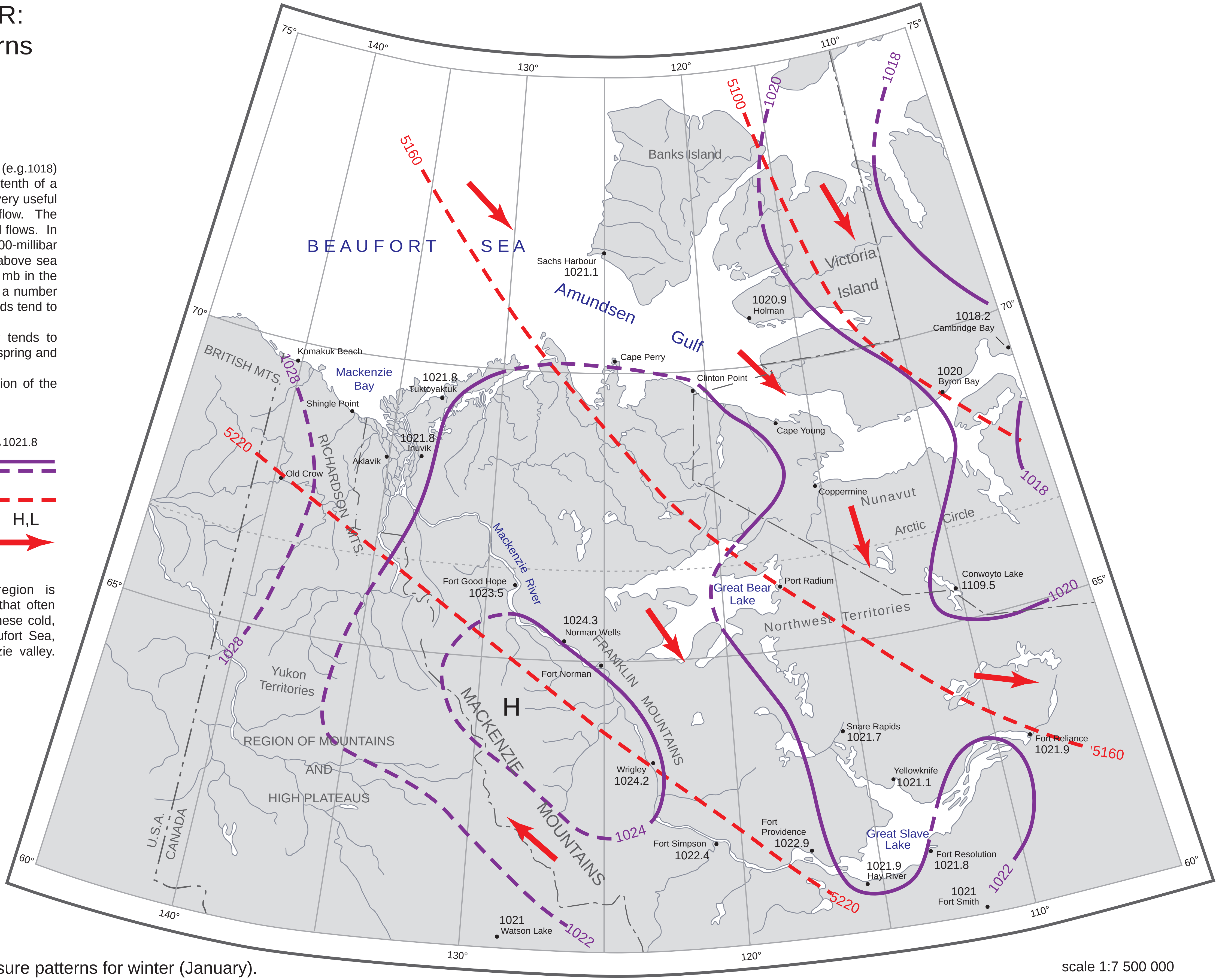


Fig. 3-7. Seasonal weather: Surface pressure patterns for winter (January).

scale 1:7 500 000

SEASONAL WEATHER:
Surface pressure patterns
for spring (April)

LEGEND

CONVENTIONS
See SEASONAL WEATHER MAP for winter

AIR PRESSURE AND AIR FLOW NOTATION

Mean pressure in mb (1/10 hecto Pascal)............ ● 1019.5
Sea-level pressure isobars (mb)........................ ▬
(Dashed over water and mountainous regions)
500 mb conour (see CONVENTIONS)................ ▬ ▬
Air pressure cells (high, low)............................ H,L
Flow of air (direction).................................... ➡

Note: The high pressures that tend to stagnate over the Mackenzie Valley in February, begin to migrate eastwards and westwards in March so that their trajectories lie well east of the valley by April and May. The air masses that are associated with these highs are cold and dry. Northerly winds on the east side of the high in winter maintain a continuous supply of frigid Arctic air that covers extensive areas of the Mackenzie and Keewatin districts of the Northwest Territories. In spring, with the high pressure areas to the east, a southeasterly flow begins to establish itself over the region, bringing warmer air with it from areas further south. (See CLIMATE NORMALS for spring), and OROGRAPHY AND WEATHER for physiographic background.

Map adapted after B.M. Burns*
commentary: Heather Auld*

* Atmospheric and Environmental Services
Environment Canada

200 0 200
kilometres

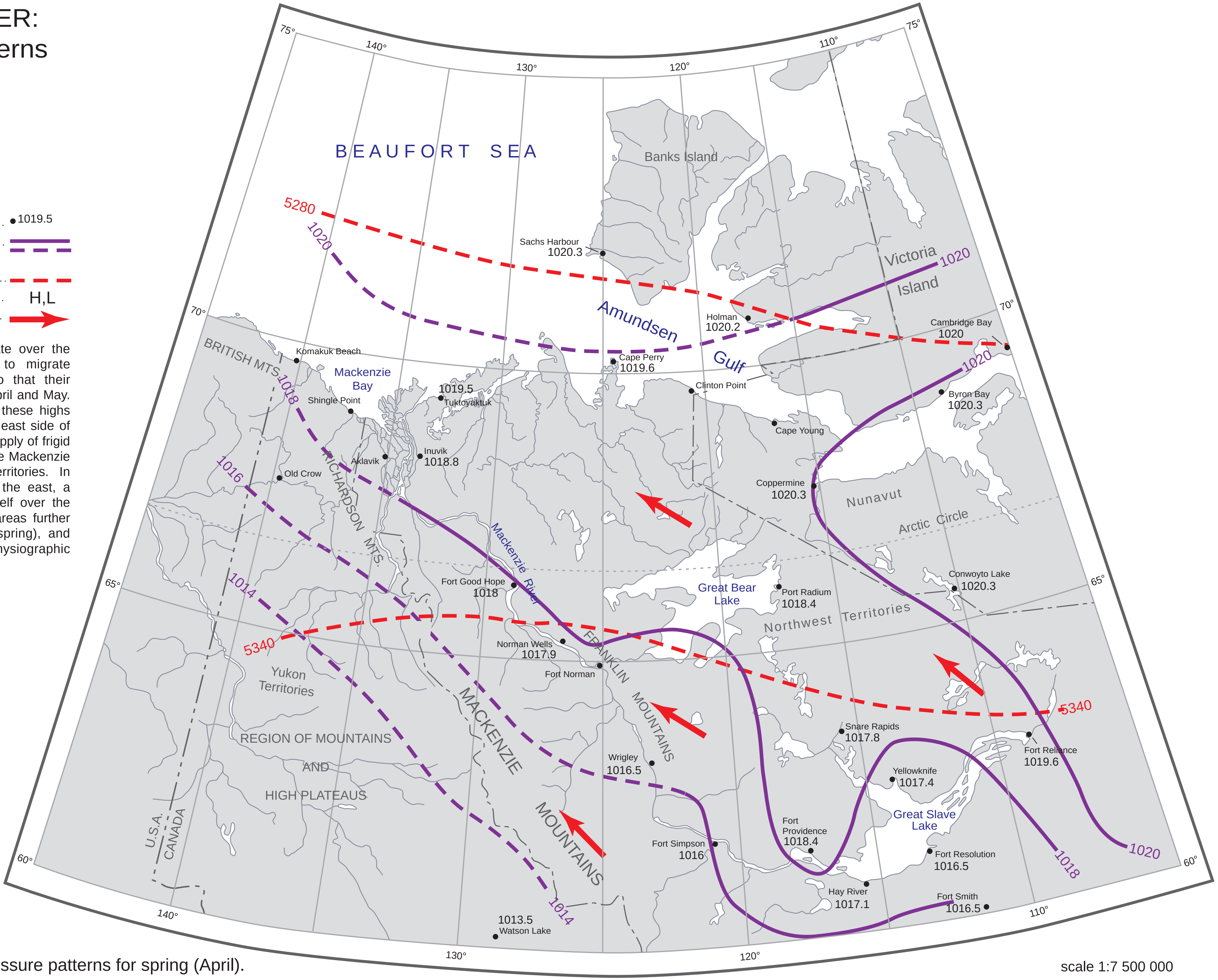


Fig. 3-8. Seasonal weather: Surface pressure patterns for spring (April).

scale 1:7 500 000

SEASONAL WEATHER:
Surface pressure patterns for summer (July)

LEGEND

CONVENTIONS
See SEASONAL WEATHER MAP for winter

AIR PRESSURE AND AIR FLOW NOTATION

Mean pressure in mb (1/10 hecto Pascal)	● 1011.8
Sea-level pressure isobars (mb) (Dashed over water and mountainous regions)	▬▬ ▬ ▬
500 mb conour (see CONVENTIONS)	▬ ▬
Air pressure cells (high, low)	H,L
Flow of air (direction)	➡

Note: The warm southeasterly flow, which settles over the region during late spring, and the return of the sun bring warmer temperatures to the Mackenzie Valley. By July, this region has warmed considerably. Low pressure areas dominate in July and August, often tracking from the central Yukon southeastward along the Mackenzie Valley. Other times, low pressure areas form anew, favouring their development in the Norman Wells area in the lee of the mountains. Cyclonic systems are most frequent (active) during the summer period. While cyclones develop and track across the area in winter, the cold dome of Arctic air, which dominates the winter season, forms a block to migrating cyclone systems so that they seldom penetrate the region. (See CLIMATE NORMALS for summer).

Map adapted after B.M. Burns*
commentary: Heather Auld*

* Atmospheric and Environmental Services
Environment Canada

200 0 200
kilometres

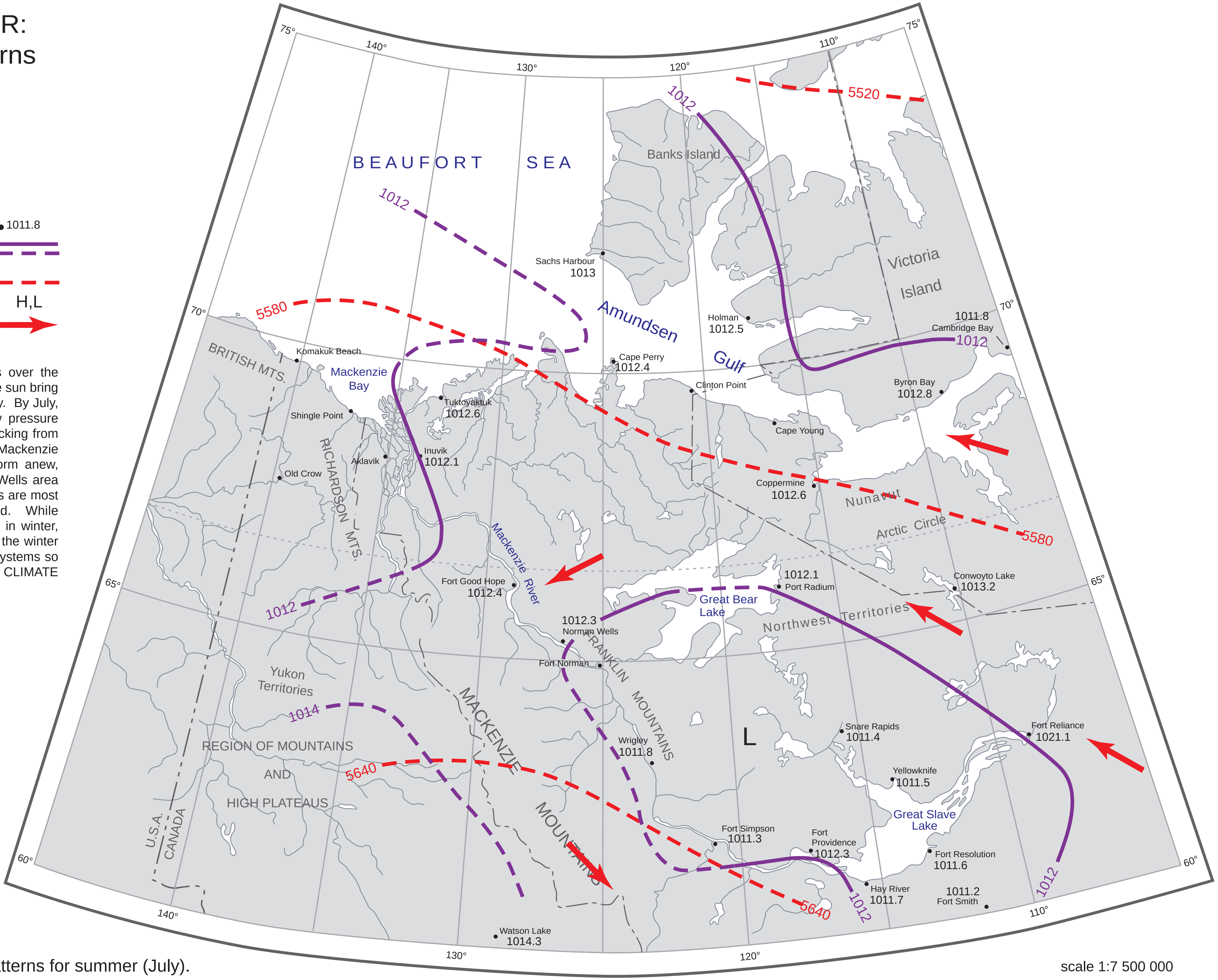


Fig. 3-9. Seasonal weather: Surface patterns for summer (July).

scale 1:7 500 000

Mean Monthly and Annual Degree Days, Rainfall and Snowfall

Human activities, ecological niches and physical settings are affected directly by these climatic normals on a daily basis. However the degree of influence of these phenomena are understood to greater advantage when they are studied on a monthly basis, or over a longer period such as a year. For purposes of comparing observations at a given station, as well as from station to station, inspection of mean annual values may be more expedient.

Degree Days

The concept of degree days has many applications, as follows: for business and home dwellers because of heating needs; for outdoor works such as industrial needs, construction, engineering projects, transportation, and agriculture; and for environmental and development concerns dealing with soil disturbance involving landslides, foundations and drainage. Degree days are defined as the amount that the daily mean temperature departs from some reference temperature, such that a one-degree departure from that reference is called a degree day. If the number of frost degree days is to be determined when the mean daily temperature is -18, the reference is 0°C and the number of frost degree days is 18. Degree days are cumulative over an arbitrary period of time such as a month, or a year; the graphs on the facing page show both. The curve representing the mean monthly air temperature is added for reference, and is read horizontally for each station from the scale on the right hand side of the page (Fig. 3-10a).

In the accompanying graphs, four types of degree days are illustrated for three weather stations listed from north to south as follows: Cape Parry (70°10'N, 124°41'W); Tuktoyaktuk (69:27 N; 133°00'W); and Inuvik (68°18'N, 133°29W). The selected degree days are heating (H), frost (F), thaw (T) and growing (G). Heating degree days are based on the reference of 18°C, and relates to all the outside air temperatures whose daily means are below that value. These degree days are accumulated monthly and annually and, because of the importance to communities and businesses, the amount of fuel required for heating can be calculated from these totals. Frost degree days include those data in which the daily mean temperature falls below 0°C. The calculations from these 0°C measurements are important to outdoor industry mentioned above, because of the deleterious effect on humans and materials. Thaw degree days refers to those days whose mean daily temperature rises above 0°C. These degree days have important relevance to engineering projects, industrial and domestic construction because of foundation problems, transportation corridors and pipelines because of freezing and thawing, and to various agencies involved in the study of ground disturbance due to thaw. Because all these activities take place in areas subjected to disturbance or dislocation of the active layer, which overlies the permafrost, the appreciation of frost degree days is essential in order to plan remedial measures that may assist in circumventing accidents, hazards, and perhaps disasters. Growing degree days, which are those degree days whose mean daily temperatures rise above 5°, are cited because of their relevance to agricultural practices. Applications of these calculations comprise an expedient means of determining the length of the crop season, and the likeliest times of the year for harvesting.

Similar to the observations of most climate normals at weather stations in the region, the amount of degree days is partly a response to the latitudinal positions of these stations. The annually accumulated number of heating degree days is greatest at Cape Parry (10972), intermediate at Tuktoyaktuk (10914), and least at Inuvik (10049); again, the number of frost degree days is greatest at Cape Parry (4887), intermediate at Tuktoyaktuk (4744), and least at Inuvik (4719). Conversely, the annual number of thaw degree days is least in the northerly station at Cape Parry (201), intermediate at Tuktoyaktuk (883), and greatest at the southerly station at Inuvik (1250); again, the number of growing days is least at Cape Parry (121), intermediate at Tuktoyaktuk (410), and greatest at Inuvik (682). These latitudinal trends are also observed in the amplitudes of the troughs for both heating degree-day, and the frost degree-day curves; they are highest for Cape Parry, and lowest for Inuvik. Conversely, the peaks of both the thawing degree-day, and growing degree-day curves are lowest at Cape Parry and highest at Inuvik. All such troughs and peaks of the degree-day curves coincide, inherently, with the amplitude of the curve representing the mean monthly air temperatures. This climatic indicator is the foremost influence on all parameters explained above, and generally, is inseparable from the latitudinal indicator already demonstrated; that is, the more northerly stations are colder and the southerly sites are warmer. This is shown in the following observations on the mean annual temperatures: at Cape Parry it is -12°, at Tuktoyaktuk it is -10.5°, and at Inuvik it is -9.5°C.

Rainfall and Total Precipitation

In the accompanying graphs depicting the mean amount of rainfall and total precipitation (including snow) on a monthly basis, the latitudinal aspect is pronounced (Fig. 3-10b). Total precipitation is least at Cape Parry, and is greatest at Inuvik. The mean annual amount of rain and total precipitation, respectively, for the three stations indicated in the graph are as follows: Cape Parry receives 69.8 mm of rain and a total precipitation of 160.3 mm; Tuktoyaktuk receives 75.4 mm of rain and a total precipitation of 142.1 mm; and Inuvik receives 116 mm of rain and a total precipitation of 257.4 mm.

At Cape Parry, rainfall occurs at various intervals over a five-month period beginning in June and ending in October. Similar occurrences of rainfall are experienced earlier in the year at both Tuktoyaktuk and Inuvik; at Tuktoyaktuk, rainfall begins in May and carries through to October, whereas at Inuvik rainfall begins in May but continues to November. Trace amounts of rain occur during all other months, everywhere in the region. All stations receive their heaviest rainfall in August, which is one month later than the warmest time of the year. In the months characterized by trace amounts of rain, the amount of snowfall is greatest. This is also manifested in the slight asymmetry of the temperature curve in that it is skewed away from the greatest occurrences of total precipitation.

Snowfall and Month-End Snow Cover

The amount of monthly snowfall and month-end snow cover are plotted on another series of the accompanying graphs (Fig. 3-10c). Snowfalls occur each month of the year and, generally, tend to accumulate at the end of the non-summer months in the form of a snow cover on the ground. As expected the greatest snowfall is in winter, but early fall is also a time of extraordinary snowfalls. In all areas the least amount of snow falls in summer, which is also the period when a snow cover is absent. The graphs show that this dearth of snow has an obvious inverse relationship to the peak of the air-temperature curve.

The northern station at Cape Parry receives less snow (129.6 cm) than at Inuvik (175.5 cm); however, the amount of snow at Tuktoyaktuk is only 68.5 cm. The amount of snowfall and the month-end snow cover is almost twice as much in the Inuvik area, as it is in Cape Parry. This difference is snow accumulation may have a number of reasons: the Inuvik area receives more precipitation than the northern part of the region. The actual amount of snow that accumulates on the ground is also dependent on the ground surface environment. A lack of vegetation in the north produces an area unprotected from winds that tend to scour the snow that has already fallen; considerable growth near, and south of treeline provides

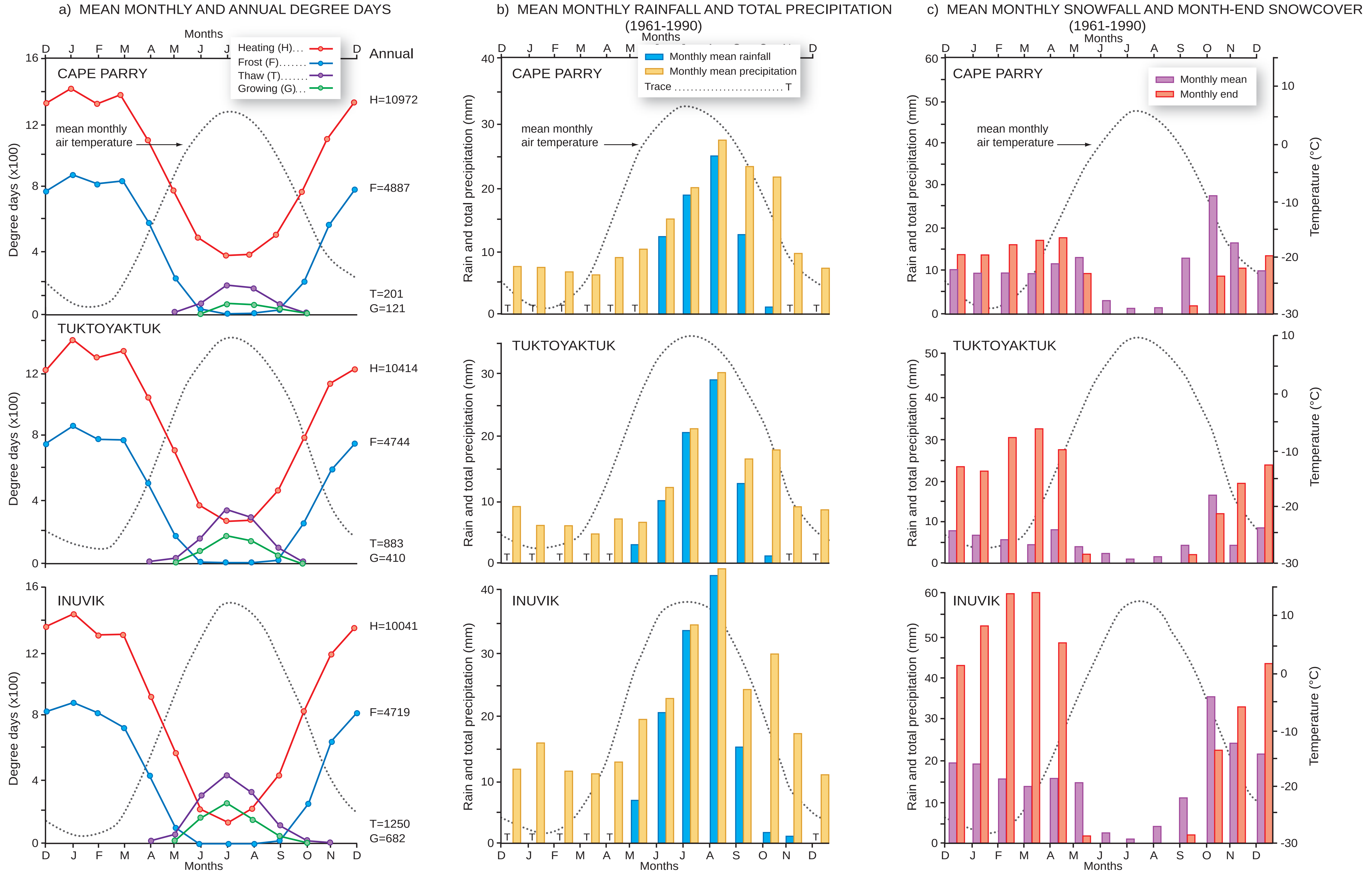


Fig. 3-10. Mean monthly and annual degree days, mean monthly rainfall and total precipitation (1969-1990), and mean monthly snowfall and month-end snowcover (1961-1990).

both protection from the wind and induces entrapment of falling and blowing snow; the southern regions are warmer and moister and, consequently, more favourable to the development of a protecting growth of shrubs and trees.

B.R. Pelletier
Data after Atmospheric and Environmental Services
Environment Canada

Ice Break-up; Zonation and Movement in the Beaufort Sea

A significant aspect of ice break-up in the Beaufort Sea is the disappearance of landfast ice in the coastal zone, and the immediate impact of this event on the start of hunting, fishing, marine transportation, local weather patterns, and the botanical and zoological cycles both offshore and on the coastlands (Fig. 3-11). Marine coastal erosion, local slope failures and sedimentation begin at this time, and subsequently alter the configuration of the coastline. Such processes continue to be effective during the ensuing months of summer and early fall.

In 1972 Landsat (formerly, ERTS) was launched into polar orbit, thus giving scientists the opportunity to study meteorology, oceanography, geosciences and other disciplines by analyzing imagery from space. This procedure was used extensively in the examination of the break-up of landfast ice along the Canadian Arctic mainland and Arctic Archipelago. These contributions are given sequentially because of their overall relevance to the environment and ecology of the Beaufort Coastlands.

Landsat Imagery

A broad view of ice distribution and movement was obtained in Landsat imagery, which was transmitted from an altitude of 800 km. above the earth. The satellite was launched into polar orbit, thus producing an east-west coverage of Canada every 18 days. Over the Beaufort Sea the satellite transits merge for a period of 5 days, thus permitting daily observations of this region for 5 consecutive days beginning on every eighteenth day. Because the imagery is gathered over an interval of several days, the incident angle changes from one transect to the next. Corrections for distortion have been made in the construction of the mosaics shown on succeeding pages and, despite any traversing hindrances, the mosaics can be employed for the purpose of demonstrating ice movement and distribution.

Obscuring some surficial features is the presence of cloud covers throughout the region, particularly in the south where the clouds form well-defined, parallel and wave-like ridges. In other areas the clouds are thin and may resemble a misty haze, or they may be displayed in huge air-flow patterns. However, broad areas of differing ice bodies and their attendant fracturing can be discerned easily, specifically where large leads are opened by the action of moving ice under the stress of winds and ocean currents. By matching angular fractures, widening leads and different ice features observed from one transect to the next over successive daily passes of the satellite, the imagery mosaic can be constructed so that the distribution and movement of ice can be measured. These phenomena have been mapped by L.W. Sobczak, as shown in the map on the opposite page and in the mosaics on succeeding pages.

Ice Zonation

During the winter and early spring, ice in the Beaufort Sea has a characteristic zonation which comprises the following: landfast ice, active shear ice, transitional shear ice and the polar pack (see map inset). Landfast ice is newly formed each year, and is about 2 metres thick. It is attached to all coasts, and has a width of several km; however, this width may vary up to 40 km from one year to the next. In some areas landfast ice may obliterate the coastline, and a dusting of snow may complete the camouflage. This would tend to obscure the tide cracks, which are linear features that form in the ice along the coast. These features are a response to vertical stress induced by weak tidal forces in the region.

The shear zone lies adjacent to the landfast ice, and is produced when the moving polar pack shears against the inshore ice that is held fast to the coastal seabed, and shore. A long arcuate lead opens at this time to form an area of open water that may expand or contract, depending upon the prevailing atmospheric conditions. For example, southerly and easterly winds may open the leads, and northerly and westerly winds may close them. Eventually, the shear zone expands into larger areas of open water, and forms a long arcuate pattern whose configuration parallels the coasts of Banks Island and the Arctic mainland of the southeastern Beaufort Sea. A transitional shear zone forms seaward of this active zone, and develops additional, but smaller arcs of open water that are parallel with the first major arc. This shear zone consists of large matching fractures and a profusion of huge ice blocks and multi-year floes. It parallels the same arcuate pattern of the original shear zone, and extends into the polar pack directly.

Polar pack ice lies adjacent and seaward of the transitional shear zone, and comprises thick multi-year ice, frozen leads, rare ice-island fragments and numerous oblique fractures and open leads. Its surface is characterized by ridges and hummocks, and generally has an extremely rough aspect to it. This is in contrast to the smooth, almost featureless surface of landfast ice. The polar pack may be several meters thick, particularly in areas where floes have rafted onto each other. In extreme cases it may be separated from land by a distance of 300 km across open water, but the average separation is about 150 to 200 km.

Ice Movement

Movement of the ice is controlled by atmospheric systems and oceanographic circulation. Surface winds drive the ice canopy forward, and the clockwise motion of the Beaufort Gyre may enhance this movement of ice in the windward direction.; however, a wind blowing in the reverse direction of the gyral flow may impede the advance of the ice and cause it to be retarded or reversed. Eventually the ice will resume its gyral circulation under the influence of the prevailing winds, and continue its course around the Arctic Ocean.

Spring break-up begins when shearing is produced by the moving polar pack as it acts against the stationary landfast ice. Fractures form in this boundary zone, ice floes and blocks are segmented, and all are encompassed by expanding areas of open water containing a mixture of slush and crumbled ice. Further seaward as the season advances, early fractures are enlarged and extend into the zone of polar ice. This movement is measured by noting similar features from one transit imagery to the next. From this examination, the direction of movement can be determined and the rate of separation between matching features can be calculated. This rate is variable, and depends on weather and ocean factors already noted. Generally the ice movement is faster when the pressure gradient of the atmospheric system becomes steeper. Under these conditions, the ice can move at an average speed of 9 km/d; however, during the most active

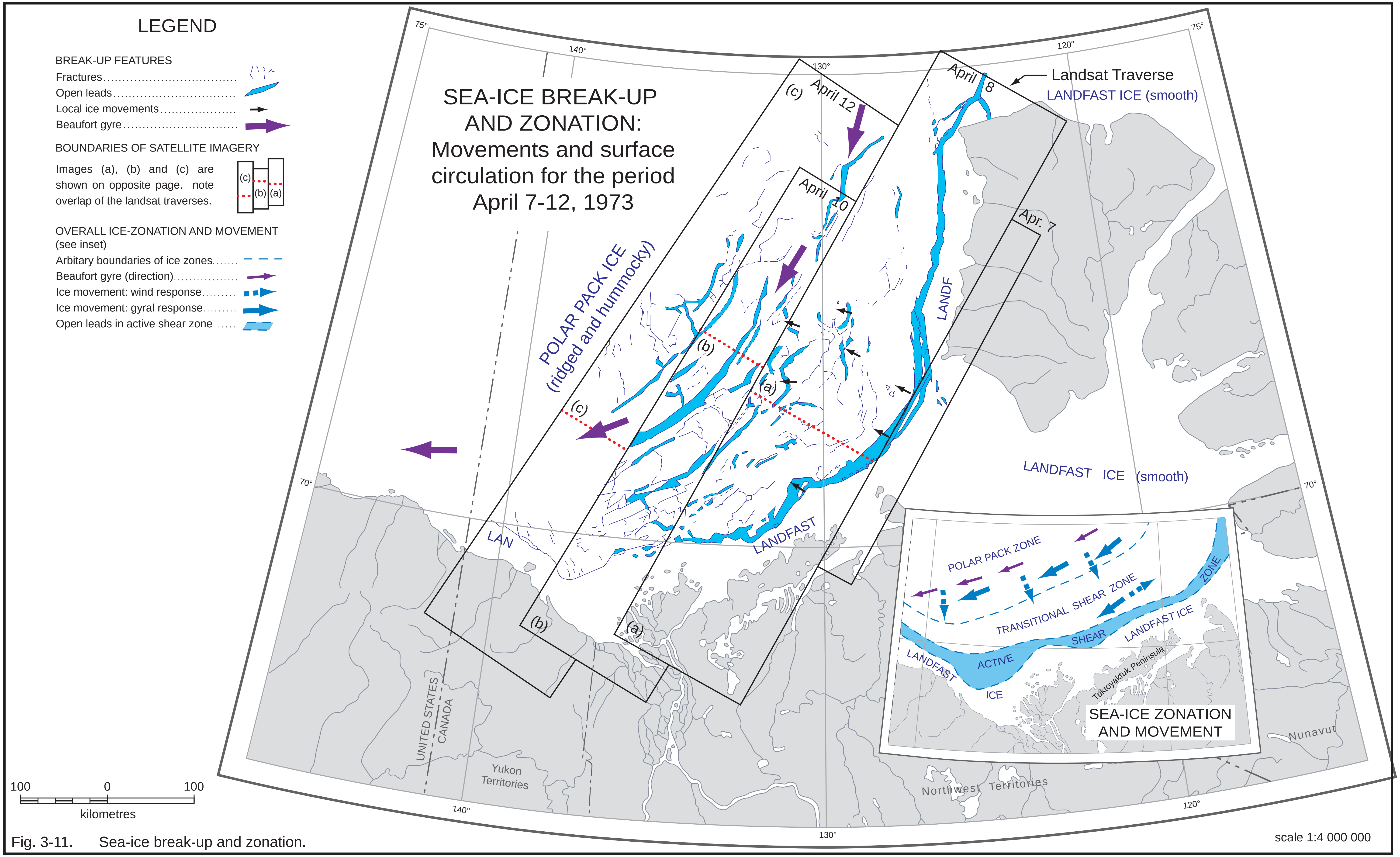


Fig. 3-11. Sea-ice break-up and zonation.

period of the system, it moves at speeds up to 18 km/d. In slow periods of the atmospheric system prior to the formation of the shear zone, movement of the ice may be as little as 0.3 km/d.

B.R. Pelletier
Map after L.W. Sobczak
Data after Canada Centre for Remote Sensing
Natural Resources Canada

CHAPTER 4
WILDLIFE AND HABITATS

WILDLIFE AND HABITATS

Fishes

Fifty eight of the known 108 species of fish that occur in Canadian aArctic marine waters are present in the southeastern Beaufort Sea. The 58 species are taxonomically classified into 37 genera and 18 families and, by their temperature-salinity preferences, are divided into six general ecological categories. These consist of the following:

1. Freshwater category: species which invade coastal waters from the rivers, but only within the discharge area of the river;

2. Anadromous category: species which spend the early part of their life in freshwater, and then go to sea for one or more years before returning to spawn;

3. Semi-anadromous category: species which spend some early stage of their life in freshwater, and go to sea for summer only;

4. Euryhaline-eurythermal category: species that tolerate a wide range of salinities and temperatures;

5. Marine-cold adapted category: species that live in relatively cold to sub-zero temperatures and reasonably high salinities;

6. Marine-warm adapted category: species that live in positive temperatures and high salinities, as occur in depths greater than 300 metres.

Species and ecological type are listed in Figure 4-1 and 4-2. Sampling locations are shown in Figures 4-3a and b, and the sites where adult specimens of fish of local economic importance have been caught. The relative abundance of some species with respect to shore and water depth is shown in Figure 4-4. The coastal area is important to the fisheries resource of the Beaufort Sea. Anadromous species (those which spend their summer feeding at sea and then return to overwinter in freshwater) such as boreal smelt, ciscoes and whitefish, are abundant there. Offshore migrations appear to be restricted (Fig. 4-4).

The boreal smelt, *Osmerus eperlanus* (Linnaeus), has a circumpolar distribution (Fig. 4-5b). They are a carnivorous species which reach about 25 cm in length, and enter freshwater in spring to spawn. Least cisco, *Coregonus sardinella* (Valenciennes), and Arctic cisco *Coregonus autumnalis* (Pallas) are autumn spawners (Fig. 4-5d, 4-7d). The Arctic cisco is important to the domestic fishery.

The Arctic char, *Silvalinus alpinus* (Linnaeus), is a slow-growing fish that is widely distributed throughout the Arctic (Fig. 4-5c). Some of these forms are land-locked, as well as anadromous. Spawning individuals are generally much more brightly pigmented than are the sea run fish.

Two species of flatfish are common to brackish waters along the Beaufort Sea coast. The Arctic flounder, *Liopsetta glacialis* (Pallas), is dull grey-brown on its eyed side and milky white on the underside (Fig. 4-7a). The starry flounder, *Platichthys stellatus* (Pallus), is more colourful (Fig. 4-6d); rows of rough plates are present on the eyed side, and the fins display black and white bands. This species is also taken commercially along the Pacific coast.

The *fourhorn sculpin* , *Myoxocephalus quadricornis quadricornis* (Linnaeus), is camouaged for life on the sea floor (Fig. 4-6a). It is a relatively large marine sculpin that is tolerant of freshwater.

Pacific herring, *Clupeaharengus pallasi* (Valenciennces) (Fig. 4-6c), and saffron cod, *Eliginus navaga* (Pallas) (Fig. 4-6b), are offshore marine species from the Beaufort Sea. The former are laterally compressed fish with large brightly coloured scales. Neither species is fished commercially in the Canadian Arctic.

J. G. Hunter and D.E. McAllister
Data from the following individuals: R. Percy; V.A. Poulin; R.E. Kendel; R.A.C. Johnson; U. Lobsiger; M.D. Kozack; and F.F. Slaney and Company.

FISH: species, feeding types and ecological groups

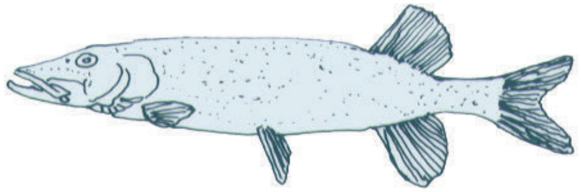
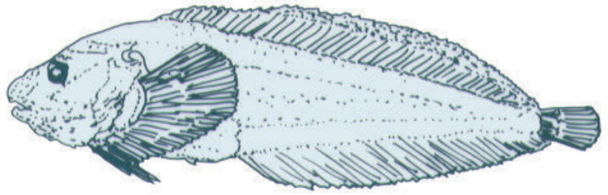
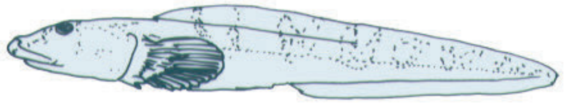
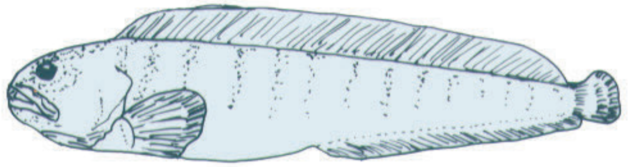
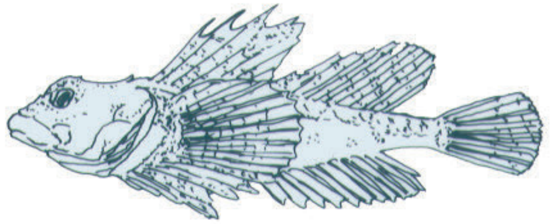
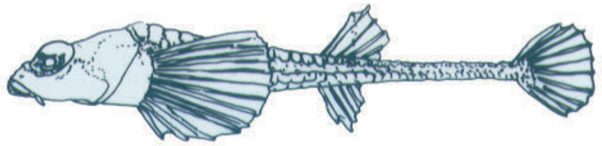
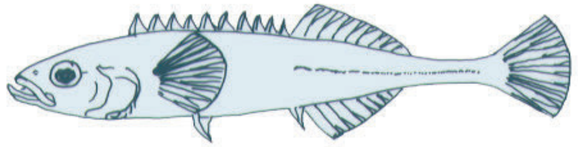
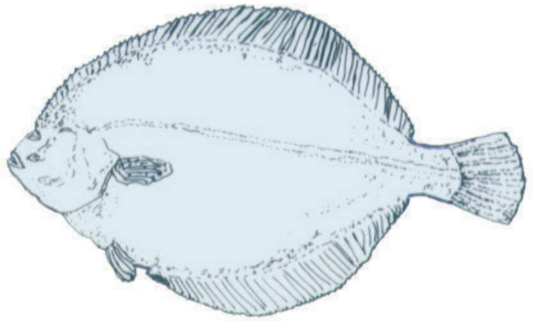
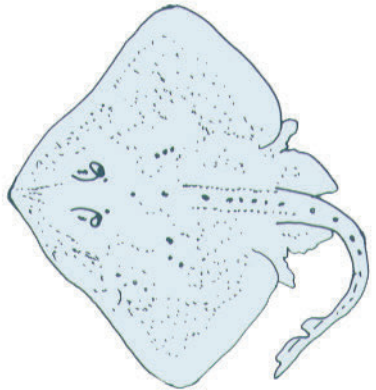
species	feed. type	eco. gp.
 Esocidae (Pikes)		
Esox lucius - northern pike	P	1
 Laparinae (Snailfishes)		
Liparis cyclostigma - dusky seasnail	B	5
L. herschelinus - bartail seasnail	B	5
L. koefoedi - gelatinous seasnail	B	5
L. tunicotus - greenland seasnail	B	5
 Zoarcidae (Eelpouts)		
Cymolus viridis - fish doctor	B	5
Lycodes jugorious - shulupaoluk	B	4
L. mucosus - saddled eelpout	B	6
L. pallidus - pale eelpout	B	5
L. polaris - polar eelpout	B	5
L. ross - threespot eelpout	B	6
L. sagittarius - archer eelpout	B	6
L. seminudus - longest eelpout	B	6
Lycenchyles sp.	B	4
 Anarhichadidae (Wallfishes)		
Anarhicus sp.	B	5
 Stichaeidae (Pricklebacks)		
Acantholumpenus mackayi - backline prickleback	B	4
Anisarchus medius - stout eelbleny	B	5
Lumpensus fabricli - slender eelbleny	B	5
 Ammodytidae (Sand lances)		
Ammodytes hexaplerus - stout sand lance	B - P	4
 Cottidae (Sculpins)		
Artediellus scaber - pough	B	5
Gymnocanthus tricuspis - arctic staghorn sculpin	B	5
Icelus bicornis - two horn sculpin	B	5
I. spatula - spatulate sculpin	B	5
Myoxocephalus quadricornis - four horn sculpin	B	4
M. scorpeoides - arctic sculpin	B	5
M. scorpeus - short horn sculpin	B	5
Triglops nybelini - bigeye sculpin	B - P	6
T. pingelli - ribbed sculpin	B	5
 Agonides (poachers)		
Aupidophoroides drikii - arctic alligator fish	B	5
 Gasterasteidae (Stickleback)		
Pungitius pungitius - ninespine stickleback	P	4
 Pleurenectidae (Flounders)		
Liopsetta glacialis - arctic flounder	B	4
Platichthys stellatus - starry flounder	B	4
 Rajidae (Skates)		
Raja sp.	B	6

Fig. 4-1. Fish species, feeding types and ecological groups.

FISH: species, feeding types and ecological groups

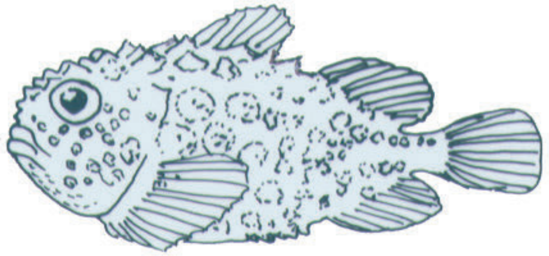
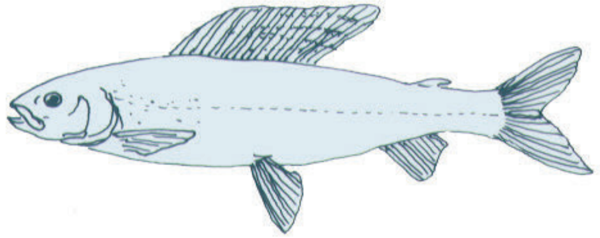
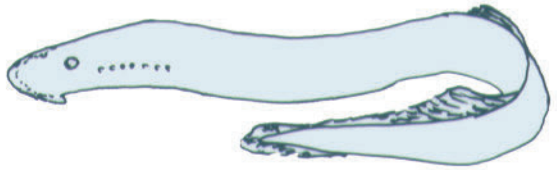
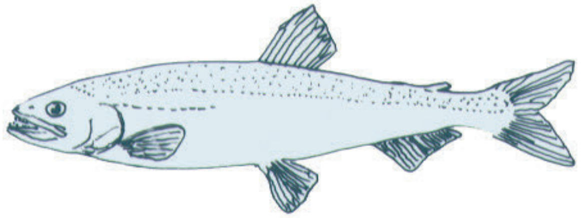
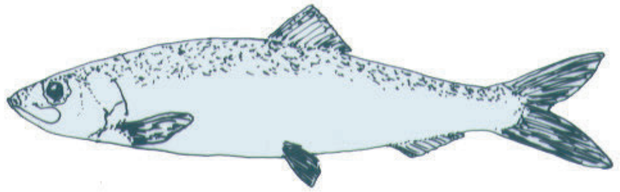
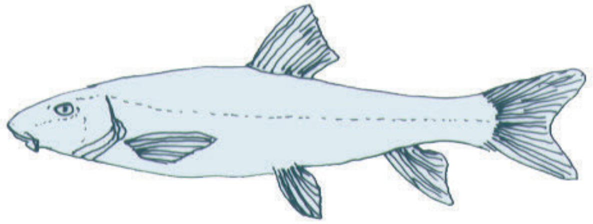
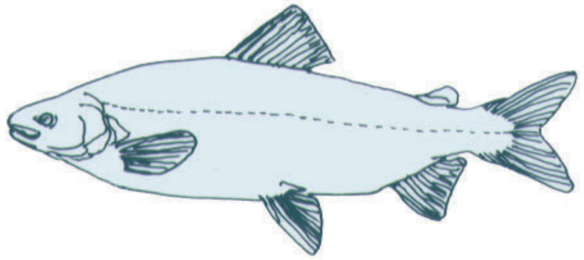
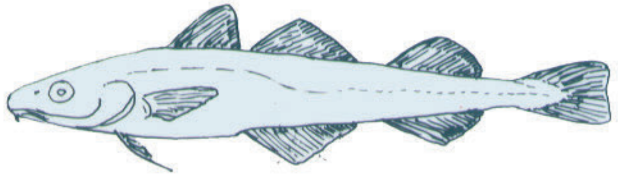
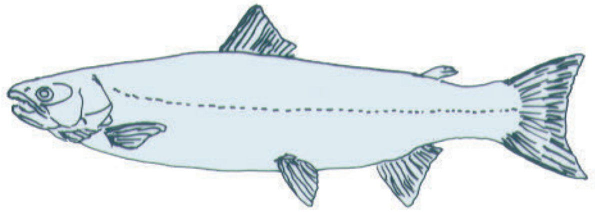
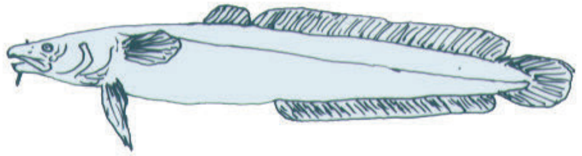
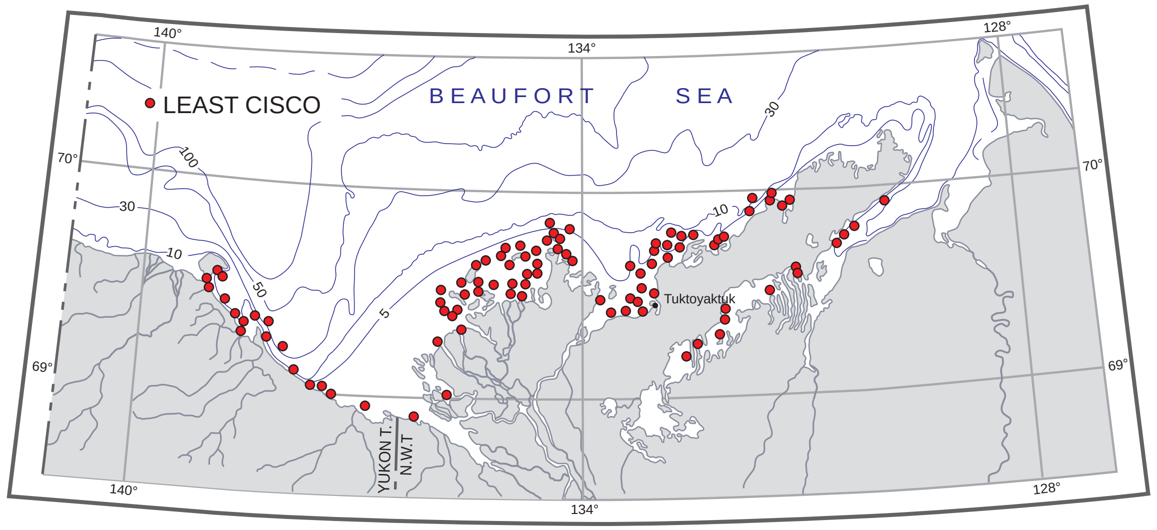
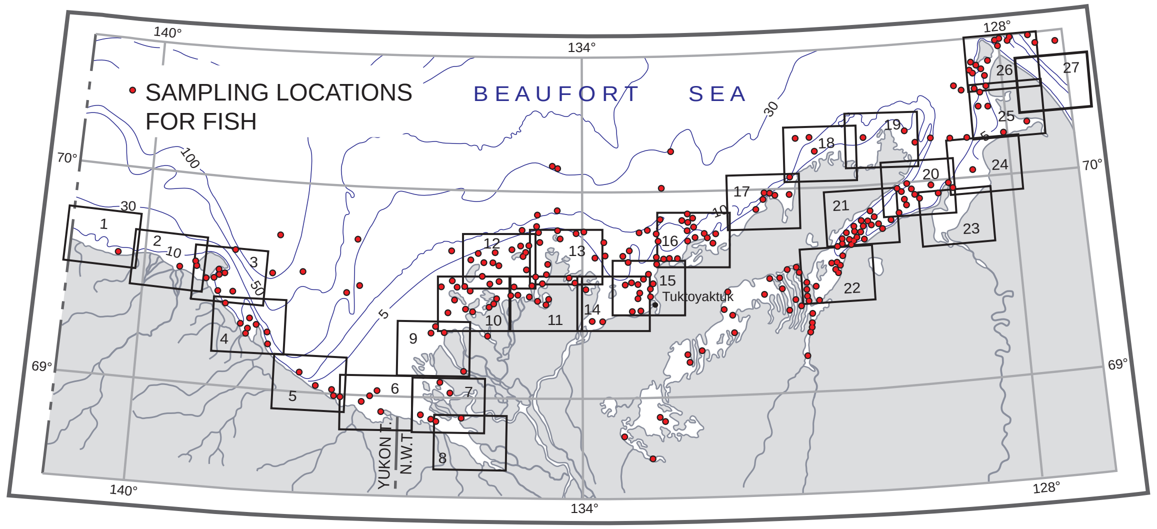
species	feed. type	eco. gp.	species	feed. type	eco. gp.
 Cyclopteridae (Lumpfishes and Snailfishes) Cyclopterinae - lumpfishes Eumicrotremus derjugini - leatherfin lumpsucker	P	5	 Thymalline (Graylings) Thymallus arcticus - arctic grayling	P	1
 Petromyzonidae (Lampreys) Lampetra japanica - arctic lamprey	P	2	 Osmeridae (Smelts) Mallotus villosus - copelin Osmerus mordax - rainbow smelt	P B - P	4 3
 Clapeidae (Herrings) Clupea harengus pallasii - pacific herring	P	4	 Catostomidae (Suckers) catostomus catostomus - longnose sucker	B	1
 Salmonidae (Trouts) Caragoninae - whitefishes Caragonus autumnalis - arctic cisco C. clupeaformis - lake whitefish C. nasus - broad whitefish Prosopium aylindraceum - round whitefish Stenodus leucichthys - inconnu	P B B P P P	3 3 3 3 1 3	 Gadidae (Codfishes) Gadinae - codfishes Arcticgadus borisovi - toothed cod A. glacialis - polar cod Boreogadus saida - arctic cod Eliginus gracilis - saffron cod gradus ogae - ogae cod	B - P B - P B - P B-P-I B - P	5 5 5 4 5
 Salmonidae (Trouts and Salmons) Oncorhynchus gorbuscha - pink salmon O. keta - chum salmon O. nerka - sockeye salmon O. tshawytscha - spring salmon Salvelinus alpinus - arctic char S. namaycush - lake trout	P P P P P P	2 2 2 2 3 3	 Lota lota (Turbot)		

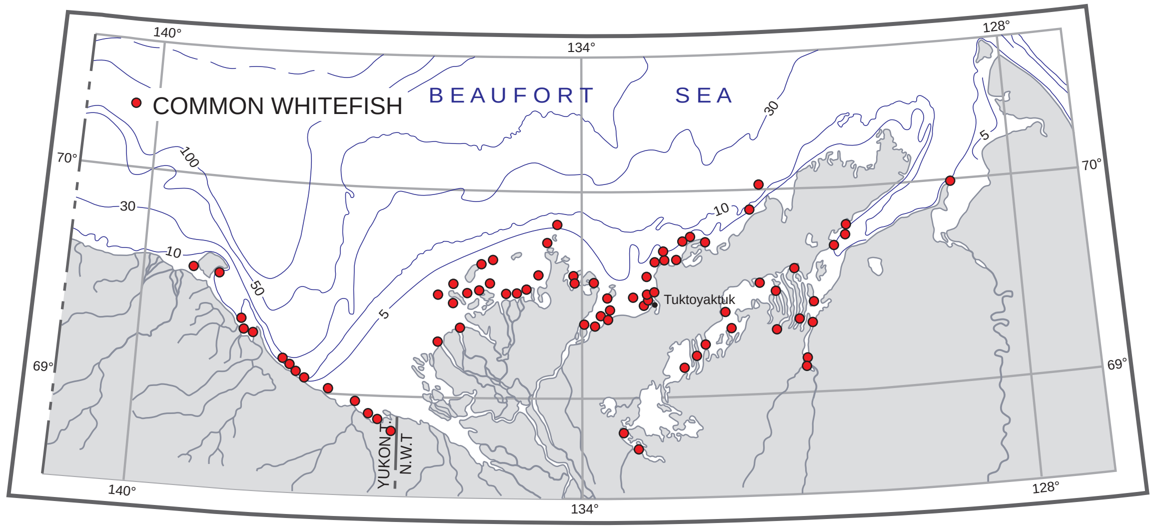
Fig. 4-2. Fish species, feeding types and ecological groups.

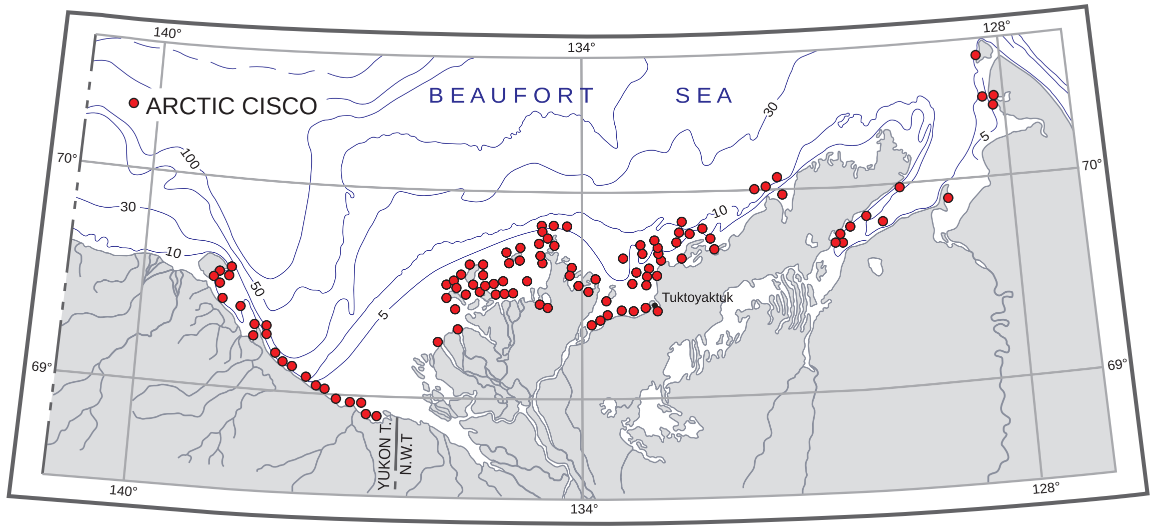
FISH: Important fisheries of the coastlands (arctic cisco, least cisco, common whitefish, inconnu)

Note: The index map shows the sampling locations selected for a seasonal study of the main fisheries occuring along the Beaufort Coastlands. For convenience, the boundaries of the COASTLANDS MAPS are also indicated in order that a geographic reference may be applied to the larger scale maps of the coastal region.
Photographs of these fish and other fish species are in the accompanying pages, together with drawings, ecological information habitat activities, migration routes and feeding types.









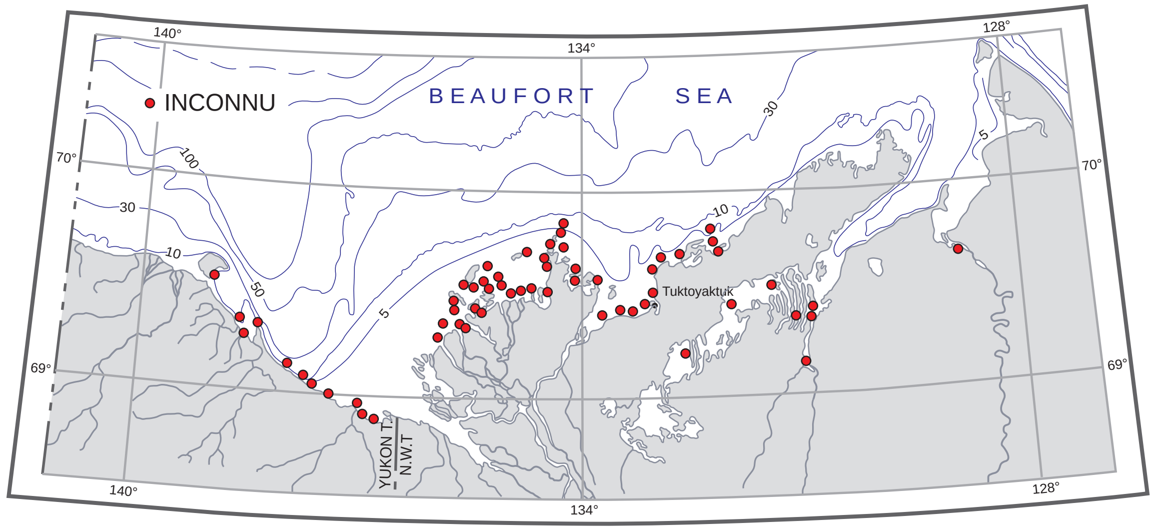


Fig. 4-3a. Important fisheries of the coastlands.

50 0 50
kilometres

scale 1:4 000 000

FISH: Important fisheries of the coastlands (broad whitefish, starry flounder, rainbow smelt, burbot, saffron cod, arctic sole)

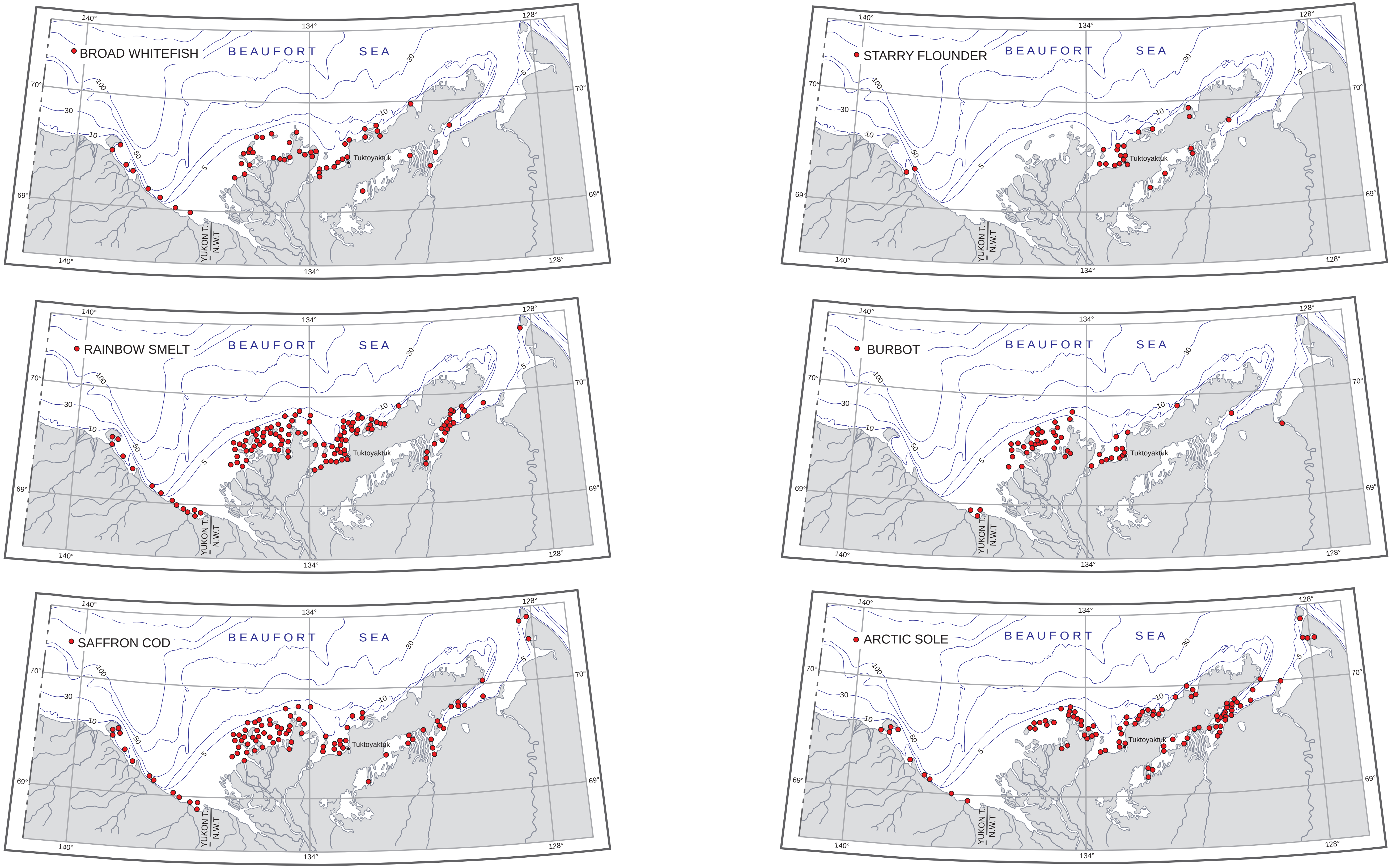


Fig. 4-3b. Important fisheries of the coastlands.

50 0 50
kilometres

scale 1:4 000 000

FISH: areas of different species groups, and migration routes

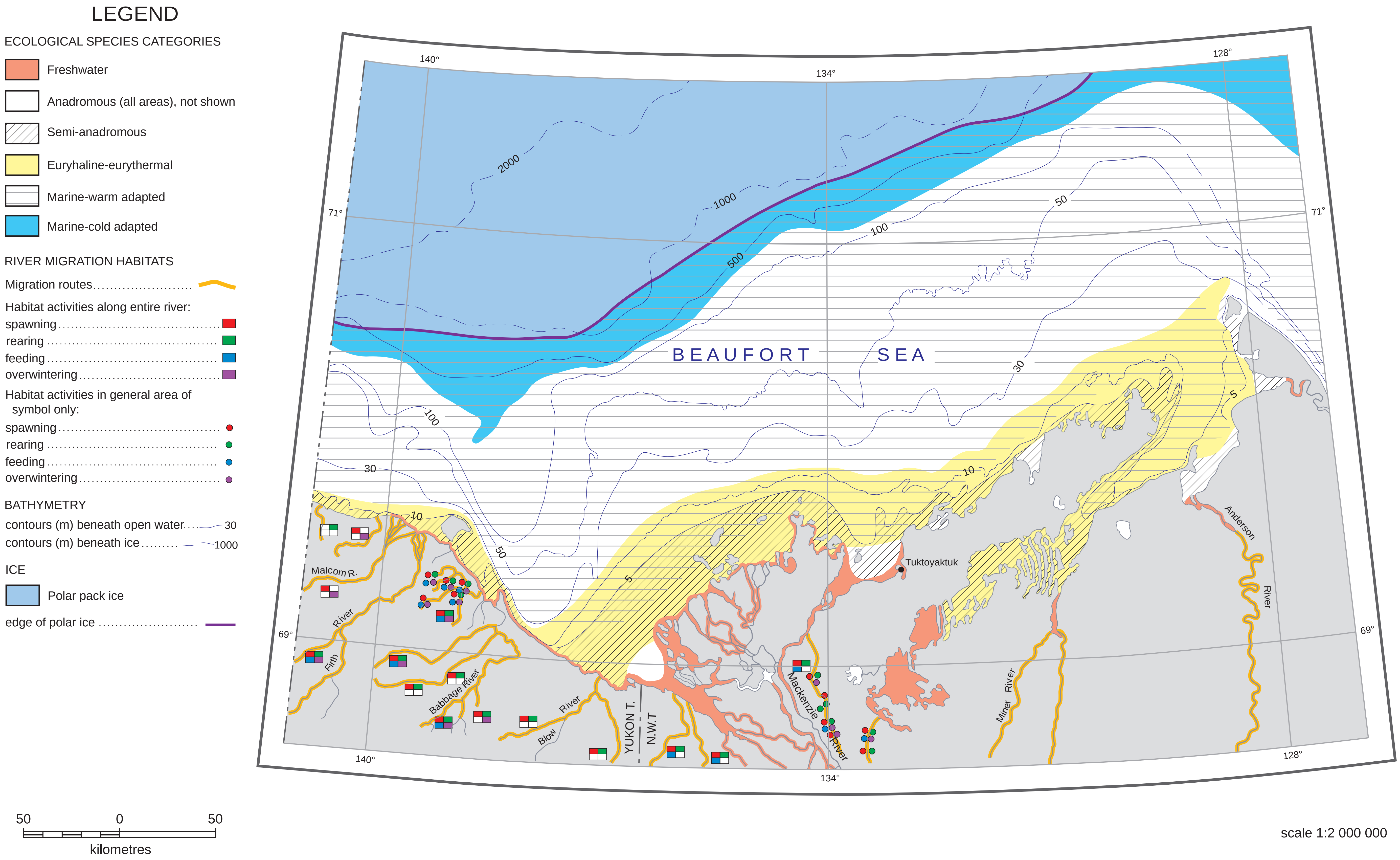


Fig. 4-4. Areas of different fish species groups, and migration routes.

Fig. 4-5 a) Arctic cod; b) boreal smelt; c) Arctic char; and d) Arctic cisco.

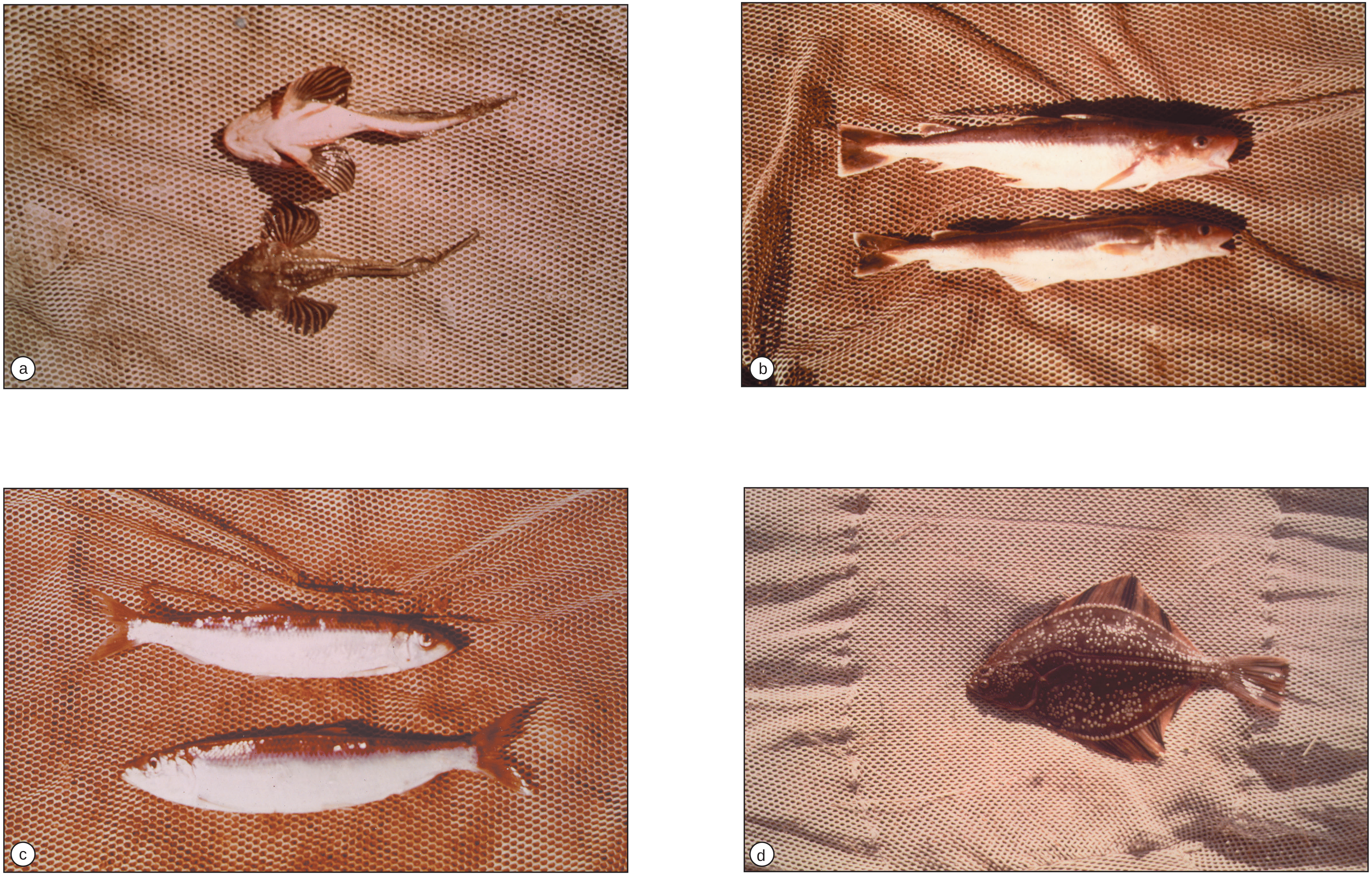


Fig. 4-6. a) four-horn sculpin; b) saffron cod; c) Pacific herring; and d) starry flounder.

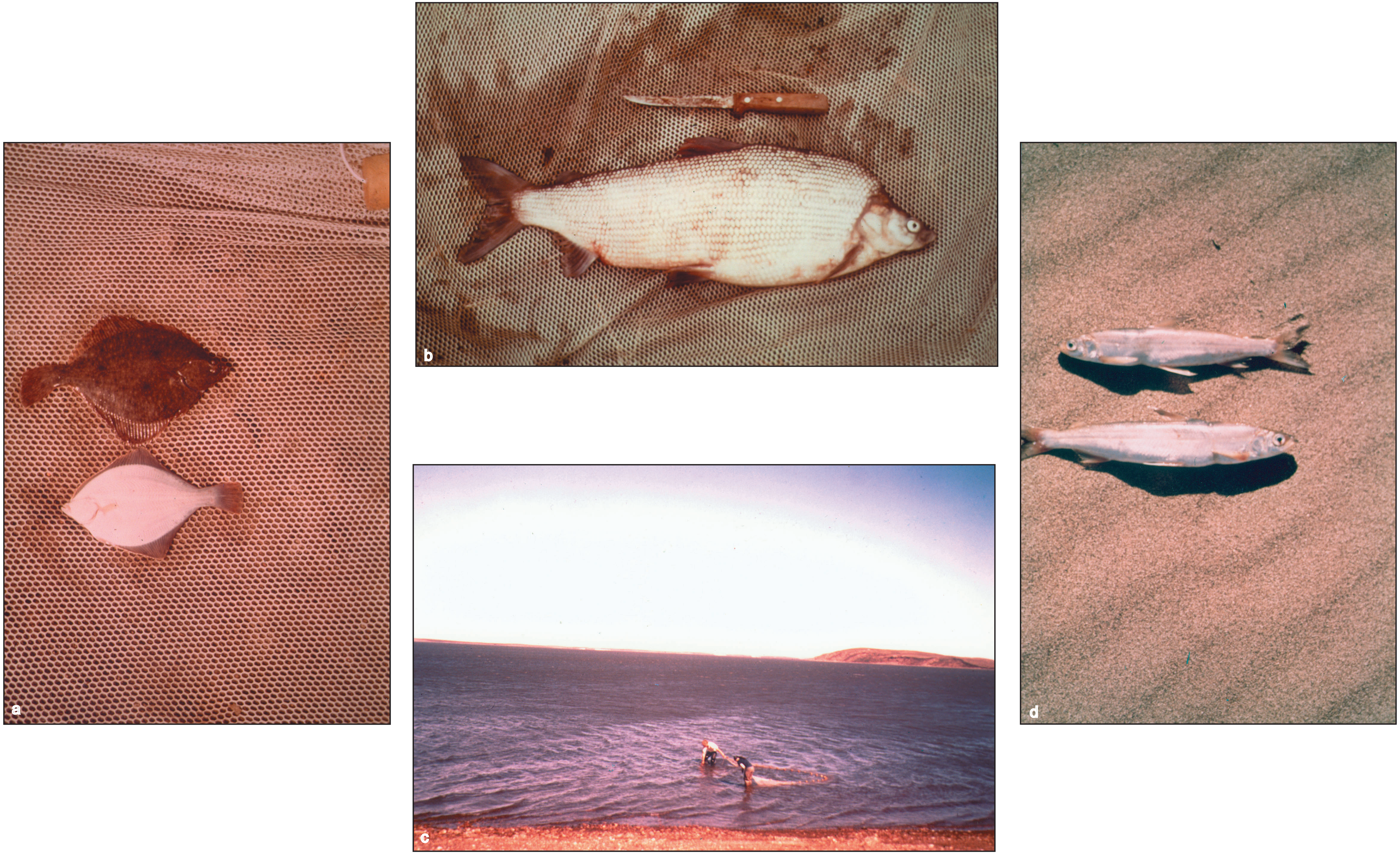


Fig. 4-7. a) Arctic flounder (photo by R. Percy); b) humpback white fish (photo by R. Percy); c) seining along the coast in Masson Bay (photo by R. Percy); and d) least cisco (photo by R. Percy).

Fig. 4-8. a) Creel of lake trout, on Tuktoyaktuck peninsula (Photo by B.D. Smiley); b) Fish (inconnu) drying at Tuktoyaktuk (Photo by B.D. Smiley); c) trout of lake on Tuktoyaktuk Peninsula (Photo by V.N. Rampton); and d) Inconnu catch (Photo by Sam Barry).

Whales

Meteorological and Sea-Ice Conditions

The most important factors contributing to the existence of sea mammals in the southeastern Beaufort Sea are climate and the combined effect of the nature and distribution of sea ice. Both the beluga (white whale) and bowhead whales respond to these conditions (Fig. 4-9a, b, c, d). In the spring of the year, the flow of warm air from the south contributes directly to the occurrence of the annual spring break-up of the ice canopy over the Beaufort Sea. Open water appears along the mainland coast, Amundsen Gulf, and the coastal areas lying off the western and southern sides of Banks Island. All these areas of open water actually lie several kilometres seaward of the landfast ice in the adjacent areas. Because of rising summer air temperatures and the continued flow of warm southern air, fracturing of the sea ice commences and large stretches of open water develop in the vicinities of all the coasts. Subsequently more open water occurs as the ice is driven northerly, and an open seaway appears which provides a transportation corridor for beluga and bowhead whales alike.

Concentrations

Areas of whale concentrations are shown in Fig. 4-10. These are found around Herschel Island , the outer islands of the Mackenzie Delta, and the polyna in the western part of Amundsen Gulf. With an abundance of open water and increased solar insolation, primary productivity for whale-feeding is provided in shallow waters close to shore, and is further enhanced by the warmer, nutrient- and silt-laden discharge from the Mackenzie River.

Marine temperatures also rise several degrees Celsius at this time of year, thereby promoting further ice break-up. This sequence of events produces an increased amount of feeding supplies for whales entering the southern Beaufort Sea from the west. Eventually great numbers of whales (perhaps a few thousand beluga and some hundreds of bowhead according to M.A. Frake, D.E. Sargent and W. Hoek) occupy these feeding areas at one time or another. By the last week in June, whales have reached the coastal waters of the Tuktoyaktuk Peninsula, the Mackenzie Delta waters, particularly Kugmallit Bay, and the sea around Herschel Island. Some whales have entered Liverpool Bay, and others have swum northward to the partially ice-infested waters occurring west of Banks Island. These waters are characterized by an abundance of large ice floes and separated blocks of sea ice.

Harvesting

The hunting of white whales is an important activity of native people living along the coast of the Southern Beaufort Sea. Not only is this occupation a means of gathering food, but it also offers a means of preserving a way of life that has persisted for hundreds of years. It provides an opportunity to maintain a native culture that includes life in hunting camps, and the garnering of so-called country food (Fig. 4-11). This latter aspect of the hunt is a significant factor in preserving the native way of life in the region.

The beluga appears in the area along the Beaufort coast in late June and early July, after which the hunting opens and people move to the camps. These camps are in the vicinity of Mackenzie Delta, such as outer Shallow Bay, Kendall Island, Kugmallit Bay and are found , as well, at many sites along the coast of the Tuktoyaktuk Peninsula. Beluga hunting camps have also been established further east in the vicinity of the Anderson River. Generally the people return to their communities after a few weeks, although some remain to fish at the hunting camps or move to fishing camps elsewhere.

The huge bowhead whale was earlier sought because of its whalebone and, commonly, its baleen plates. The latter are found in the whale's mouth where they are suspended from the upper jaw and serves as food filters. However bowheads are protected by international convention and, therefore, are not part of the hunting scene even though native people are exempt from these restrictions. Because of such restraints, these marine mammals are recovering from their devastating losses due to the hunting that took place up to the first third of the twentieth century. Generally, the movement pattern of the bowhead is similar to that of the beluga; they arrive in early June and July from the western seas such as the Bering, and return by the Beaufort coastal routes in August and September eventually wintering again in the Bering Sea.

Commentary: B. R. Pelletier
Data after: M.A. Fraker, D.E. Sargent and W. Hoek

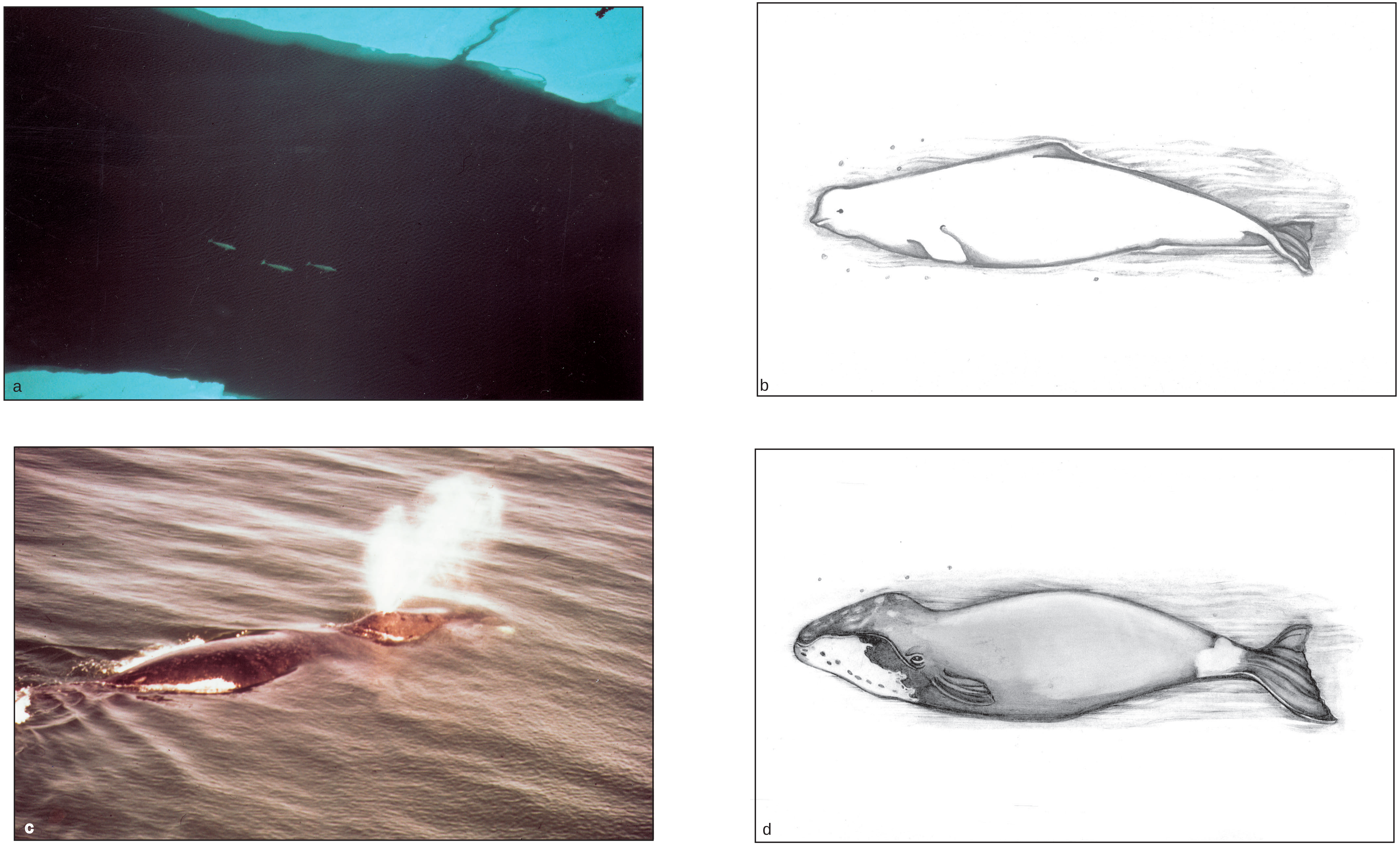


Fig. 4-9. a) Three beluga swimming in an openlead, Beaufort Sea. (Photo by B.D. Smiley); b) profile of beluga. (Line drawing after Ms. Joey Morgan); c) bowhead whale blowing in Franklin Bay. (Photo by W. Hoek); and d) profile of bowhead whale. (Line drawing after Ms. Joey Morgan)

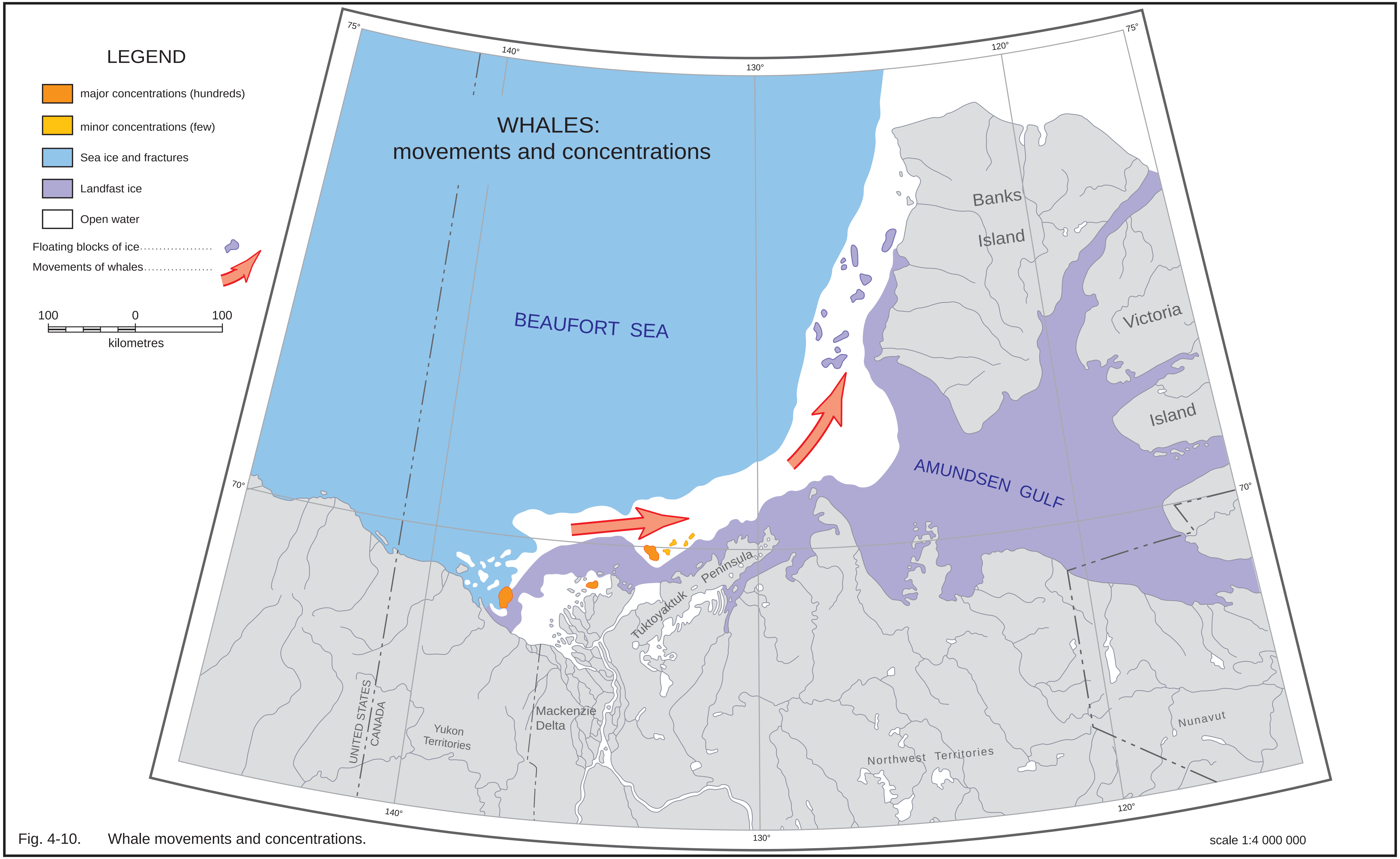


Fig. 4-10. Whale movements and concentrations.

scale 1:4 000 000

Fig. 4-11. a) Beached beluga juvenile, near Tuktoyaktuk (photo by B.D. Smiley); b) beluga camp, Shoalwater Bay, west side of Mackenzie Delta (photo by Sam Barry); c) Muk Tuk hanging to dry at whaling camp, Beaufort coast (photo by R. Percy); and d) whaling camp on barrier beach near Tuktoyaktuk (photo by R. Percy).

Polar Bears, Seals, and Arctic Foxes

The eastern Beaufort Sea has substantial populations of polar bear (*Ursis maritimus*), ringed seals (*Phoca hispida*), and bearded seals (*Erignathus barbatus*). Harbour seals (*Phoca vitulina*) and walrus (*Odobenus rosmarsus*) are seen only occasionally and, therefore, are not mentioned further here. The polar bears, arctic fox (*Alopex lagopus*) and seals are discussed together, rather than as a single species, because they are so closely interrelated ecologically. Hopefully, this arrangement will provide more of an understanding of why their patterns of distribution and abundance in the eastern Beaufort Sea exist.

Ecological Relationships

The factor that has the greatest influence on the distribution of polar bears and seals in the eastern Beaufort Sea is the distribution and type of sea ice (Fig. 4-12, 4-13). Because the distribution of polar bears appears to be influenced most by the distribution of seals, the seals are discussed first.

After freeze-up, adult ringed seals are more concentrated in the bays and areas of land-fast ice along the coast than they are in offshore areas (Fig. 4-12). In these inshore areas, they maintain breathing holes on the last cracks to freeze, or under pressure ridges, by abrading the ice with the heavy claws of their foreflippers. These breathing holes are then covered over and hidden by drifting snow. In March and April, the female ringed seals dig lairs in the snow drifts, above their breathing holes, in which they give birth to their pups. The area of greatest ringed seal productivity known in the western Arctic includes northeastern Amundsen Gulf, Prince Albert Sound, the west coast of Banks Island, Liverpool Bay, Franklin Bay and Darnley Bay.

Offshore from Tuktoyaktuk Peninsula and the west coast of Banks Island, the ice shear zone parallels the coastline line beginning about the 20-m depth contour. From freeze-up to break-up, an abundance of leads, moving ice, and periodic open water persist for varying numbers of kilometres out to sea from the edge of the shear zone before the multi-year polar pack is reached. Just before freeze-up in the fall, there appears to be a migration of young ringed seals along the coast from west to east. Those young of the year and the subadult ringed seals that remain are more concentrated in the areas of offshore moving ice, than in the land-fast ice areas. Presumably this occurs because the adult ringed seals exclude the younger less dominant seals from the preferred fast ice habitat.

When the sea is ice-covered, bearded seals prefer the shallow water depths (25-75 m) in the vicinity of the shear zone although a few are found at much greater depths. Although they are also able to maintain breathing holes by abrading the ice with the claws of their foreflippers, most apparently prefer to remain in moving ice areas where they can usually breathe in open leads or through only minimal thicknesses of young ice. Bearded seals give birth to their young on the bare ice on the edge of a lead in April or May, usually in the moving floes but sometimes in the fast ice areas, such as in Amundsen Gulf, as well.

Recent studies on wild polar bears have shown that the most common method of hunting seals is to wait beside an open, or snow-covered breathing hole and wait for the seal to surface in order to breathe. This is especially true during cold or windy weather when few seals haul out on the ice. Thus, it is obvious that the seals are much more accessible to bears through their relatively exposed breathing holes on frozen leads than they are under heavy snow drifts or pressure ridges. For this reason, it is suggested that the advantage to the polar bear of hunting along the floe edge, and shear zone generally, is that seals are more accessible along the narrow band of small open and refrozen leads that emanate from the ice edge itself. Also, the proportion of younger and possibly more naive seals is greater there than in the fast ice areas: also, studies have shown that more than 80% of the seals killed by polar bears in the spring are less than two years of age. Thus, the concentration of bears is greatest in this key feeding area.

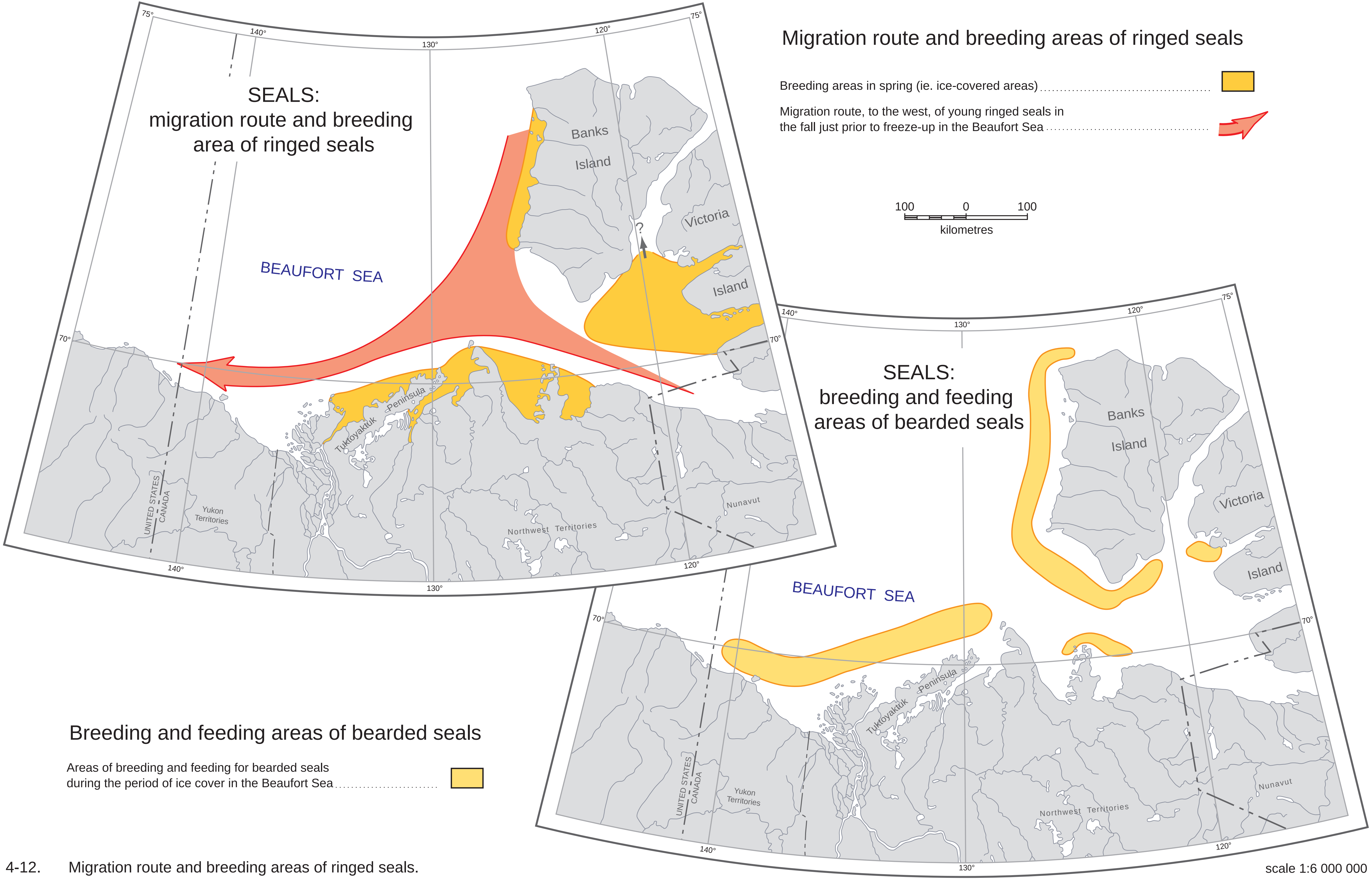
Polar bear cubs are born around the end of December in dens in snow banks on the land, particularly along the coastal areas of Banks Island and to a lesser degree along the mainland coast from Herschel Island to Cape Dalhousie as well (Fig. 4-13). The females leave the dens with their new-born cubs in late March and early April to hunt seals. However, these family groups with young of the year appear to avoid the offshore moving ice areas where older bears in general, and adult males in particular tend to concentrate. Instead, female with cubs of the year, as well as some females with older cubs, tend to hunt more in the inshore fast-ice areas where ringed seal areas are more abundant (Fig. 4-14, 4-15, 4-16a).

The other abundant, but often overlooked occupant of the sea ice is the arctic fox (Fig. 4-16b). Arctic foxes have large litters in terrestrial dens, particularly on Banks Island (Fig. 4-17). Thus, after freeze-up, large numbers of arctic foxes go out on the sea ice to follow polar bears, and scavenge on the remains of seal kills. In March and early May, arctic foxes may also be significant predators of new-born ringed seals in the subnivean birth lairs. In this way a much larger population of arctic foxes survive the winter than could otherwise do so by depending only on terrestrial resources. It appears to be this ecological relationship amongst the polar bear, seals, and arctic foxes that provides the basis of the highly successful Inuit white fox trapping industry of the western Arctic.

Seasonal Movements and Summer Distribution

Polar bears in the eastern Beaufort Sea undertake long spring and fall movements every year because of the large scale seasonal changes in the distribution of sea ice in that area. For practical purposes, all of the polar bears in the eastern Beaufort Sea may be considered as one population although there is a tendency for less exchange between the mainland coast of Banks Island, than there is between either of those areas and Amundsen Gulf. Most bears present in Amundsen Gulf and the southeastern Beaufort Sea appear to move north along, or offshore and parallel to the west coast of Banks Island. Along the mainland coast, some of the bears probably go directly north, while some appear to move further west before going north. Some bears may return via Alaska as well, since there has been about a 5% exchange rate recorded between the eastern and western Beaufort Sea areas as well. To date, only one of the Alaskan tagged-polar bears has been recovered in the eastern Beaufort Sea east of Baillie Islands. However, in general, the polar bears show a high degree of fidelity to their feeding areas between years, independent of where they go during the summer. Each year a small number of polar bears do not leave with the ice and, consequently, spend the summer along the mainland coast or southern Banks Island.

Ringed and bearded seals are pelagic during the open-water period, periodically hauling out to bask on ice floes but only rarely on land (Fig. 4-16c, d, 4-18, 4-19, 4-20). Although there are probably preferred areas and depths, these aspects are unknown during the ice-free period. Some young ringed seals make large scale movements as well, as evidenced by the recovery in Alaska and Siberia of seals branded in the eastern Beaufort Sea. Foxes tagged on Banks Island have been recovered in Alaska, and foxes tagged in Alaska have been recovered on Tuktoyaktuk Peninsula and Banks Island.



Migration route and breeding areas of ringed seals

Breeding areas in spring (ie. ice-covered areas) .... 🟨

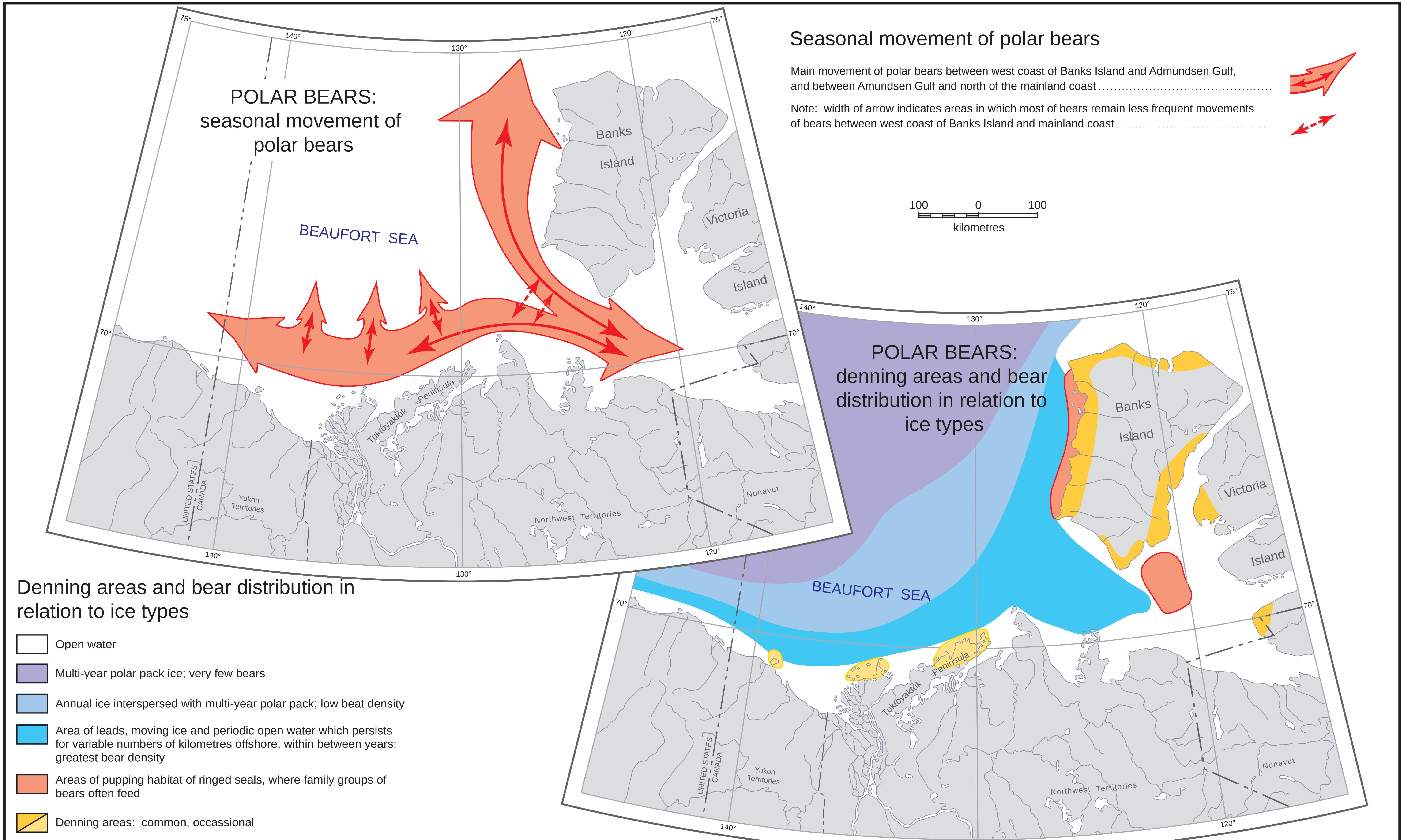
Migration route, to the west, of young ringed seals in
the fall just prior to freeze-up in the Beaufort Sea .... ➚

Breeding and feeding areas of bearded seals

Areas of breeding and feeding for bearded seals
during the period of ice cover in the Beaufort Sea .... 🟨

Fig. 4-12. Migration route and breeding areas of ringed seals.

scale 1:6 000 000



Seasonal movement of polar bears

Main movement of polar bears between west coast of Banks Island and Admundsen Gulf, and between Amundsen Gulf and north of the mainland coast ....

Note: width of arrow indicates areas in which most of bears remain less frequent movements of bears between west coast of Banks Island and mainland coast ....

Denning areas and bear distribution in relation to ice types

- ☐ Open water
- 🟪 Multi-year polar pack ice; very few bears
- 🟦 Annual ice interspersed with multi-year polar pack; low beat density
- 🟦 Area of leads, moving ice and periodic open water which persists for variable numbers of kilometres offshore, within between years; greatest bear density
- 🟥 Areas of pupping habitat of ringed seals, where family groups of bears often feed
- 🟨 Denning areas: common, occassional

Fig. 4-13. Seasonal movement of polar bears.

scale 1:6 000 000

Fig. 4-14. Adult male polar bear in Beaufort Sea. (Photo by I. Stirling)

Fig. 4-15. Adult female polar bear (drugged) with her two newborn cubs. (Photo by I. Stirling)

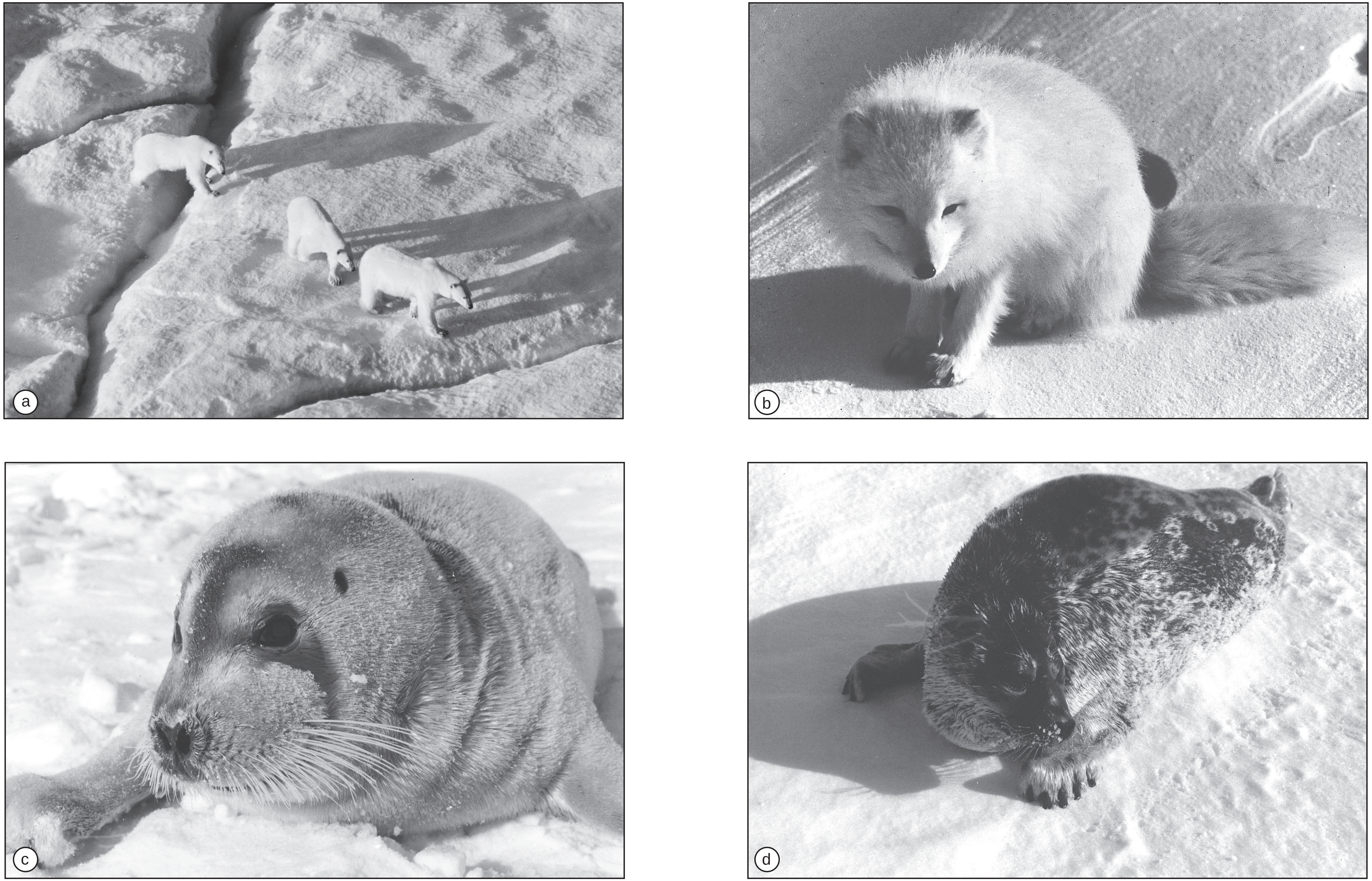


Fig. 4-16. a) Female polar bear with two yearling cubs (photo by I. Stirling); b) Arctic fox (photo by R. H. Russel); c) yearling bearded seal (photo by I. Stirling); and d) adult ringed seal (photo by I. Stirling).

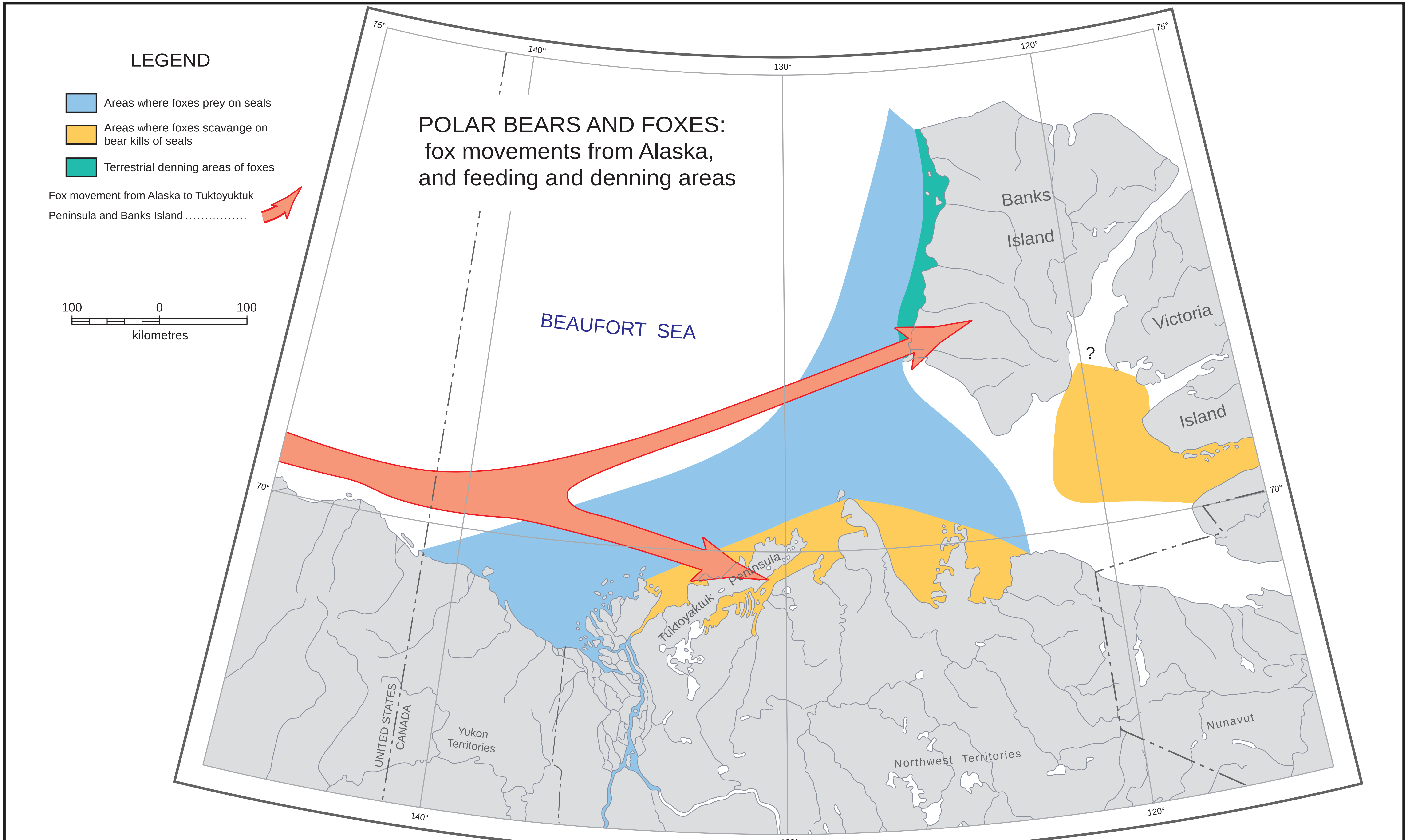


Fig. 4-17. Fox movements from Alaska, and feeding and denning areas.

Fig. 4-18. Subadult bearded seal, Beaufort Sea. (Photo by I. Stirling)

Fig. 4-19. Subadult ringed seal, Beaufort Sea. (Photo by I. Stirling)

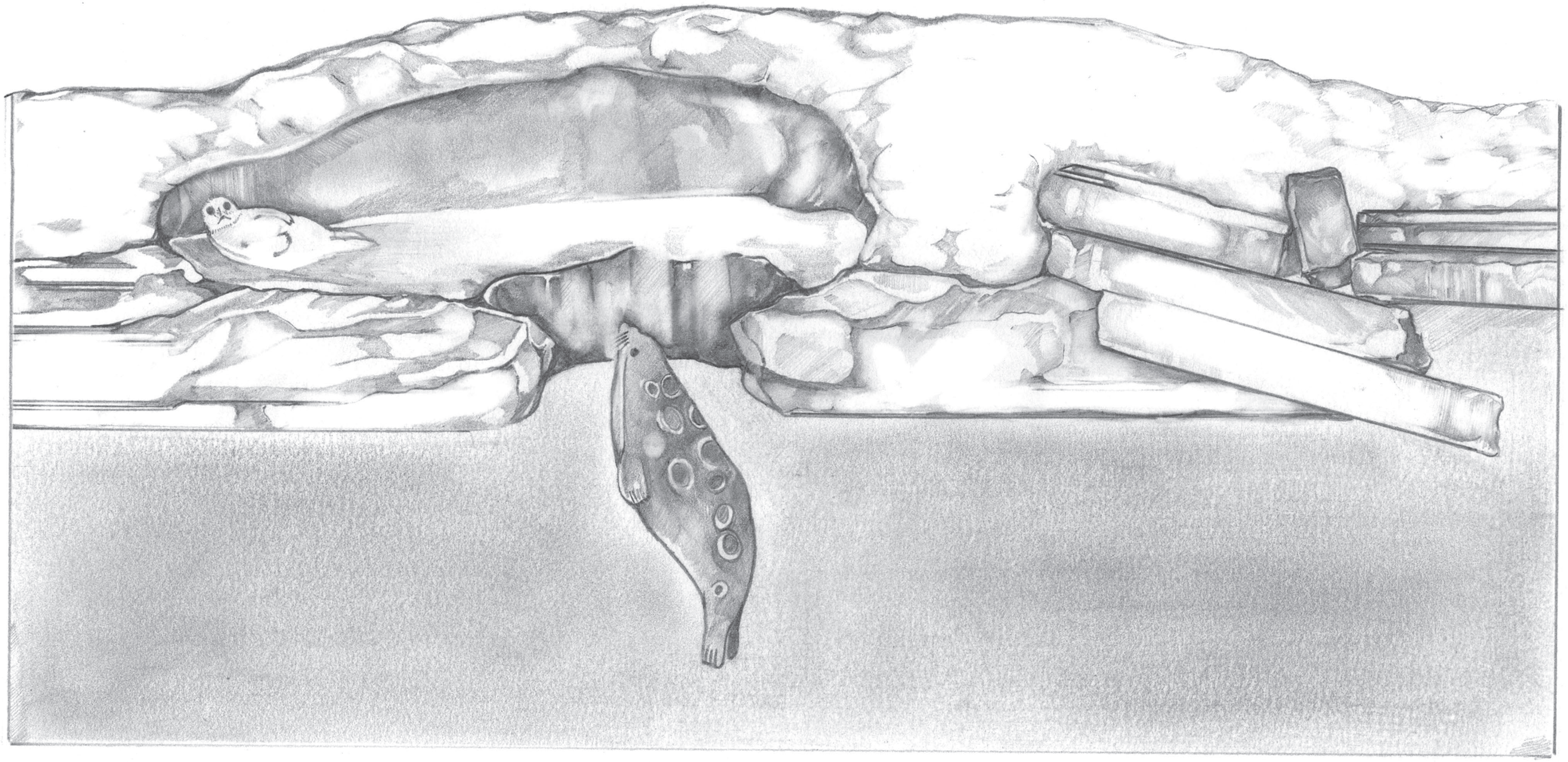


Fig. 4-20. Birth lair (nunarjak) of ringed seal. (line drawing by Joey Morgan)

Population Status

In the spring of 1974 and 1975,after which a population study was made, the numbers of both ringed and bearded seals dropped by about 50% and productivity of ringed seals by 90% from previous levels because of natural causes. Although it is known that numbers and productivity were likely severalfold higher in 1972 and 1973, there are no quantitative data with which to draw accurate comparisons. In response to the reduction in the numbers of seals, the polar bear population also dropped by about one-third by 1975 and the birth rate to about one-half its previous level. In 1977, both the seal and bear populations were still at relatively low levels.

Ian Stirling and Dennis Andriashek

Land Animals

Two of the largest land animals occupying the coastlands along the southern Beaufort Sea are the caribou and the grizzly shown here (Fig. 4-21). This coastal habitat offers relief from the mosquitos and flies, which torment the animals in the spring and summer. Many other coastland and riverine dwellers, some of whom live in low-relief interfluvial and deltaic areas, include foxes, muskrats, beavers, rabbits, minks and wolverines. Black bears, wolves and mooses may also be found in less swampy areas of higher relief. The habitats of all these creatures, together with denning and foraging grounds, are described in the Land Use Information Series of Environment Canada. Similar data on fish, sea mammals and birds, which are illustrated in the present Atlas, are given in the Information Series as well.

This series was produced for Indian and Northern Affairs Canada.

Fig. 4-21. a) Caribou on tidal flats, Wood Bay (photo by Sam Barry); b) caribou on ice to avoid mosquitos and flies, Liverpool Bay (photo by Sam Barry); c) grizzly bear at Maitland Point (photo by V. Rampton); and d) a herd of caribou running in shallow water near Cape Perry, in Amundsen Gulf (photo by F. Bruemmer, 1978).

Birds

Fig. 4-22. a) Swan with young (photo by Sam Barry); b) swans along Beaufort coast (photo by Sam Barry); c) pair of swans at nest (photo by Sam Barry); and d) swan at nest in scrub willow (photo by Sam Barry).

Fig. 4-23. a) Swans (photo by Sam Barry); b) snow geese in flight (photo by Sam Barry); c) snow geese near nest (photo by Sam Barry); and d) snow geese at nest (photo by Sam Barry).

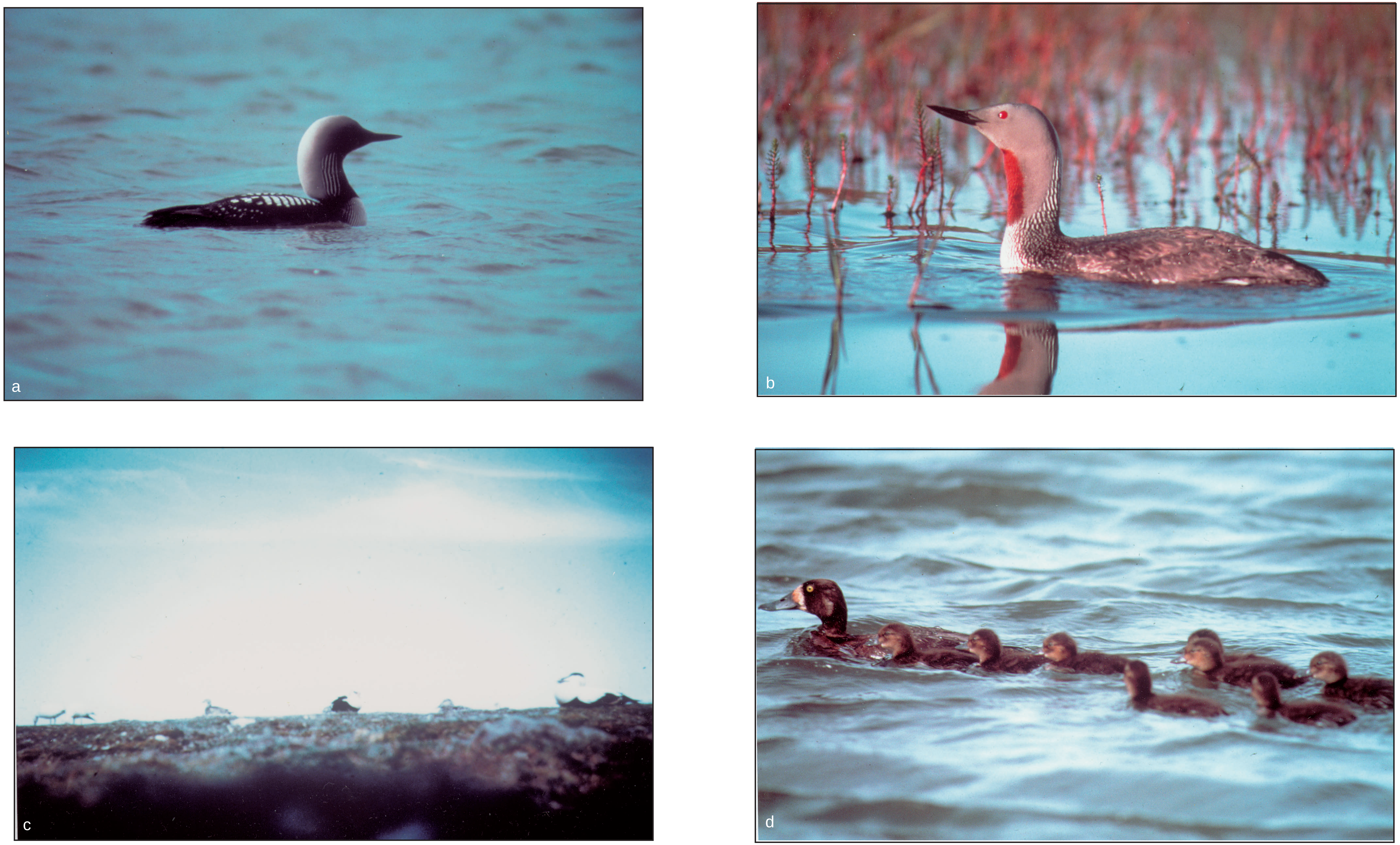


Fig. 4-24. a) Arctic loon (photo by Sam Barry); b) red-throated loon (photo by Sam Barry); c) snowgeese, king eider and common eider (photo by Sam Barry); and d) greater scaup with young (photo by Sam Barry).

Fig. 4-25. a) Arctic tern (photo by Sam Barry); Arctic tern on driftwood (photo by Sam Barry); c) Arctic tern at nest; two eggs in normal clutch (photo by Sam Barry); and d) pair of Arctic tern (photo by Sam Barry).

Fig. 4-26. a) Pair of old squaw ducks (photo by Sam Barry); b) pair of old squaw ducks (photo by Sam Barry); c) old squaw on nest (photo by Sam Barry); and d) golden plover (photo by Sam Barry).

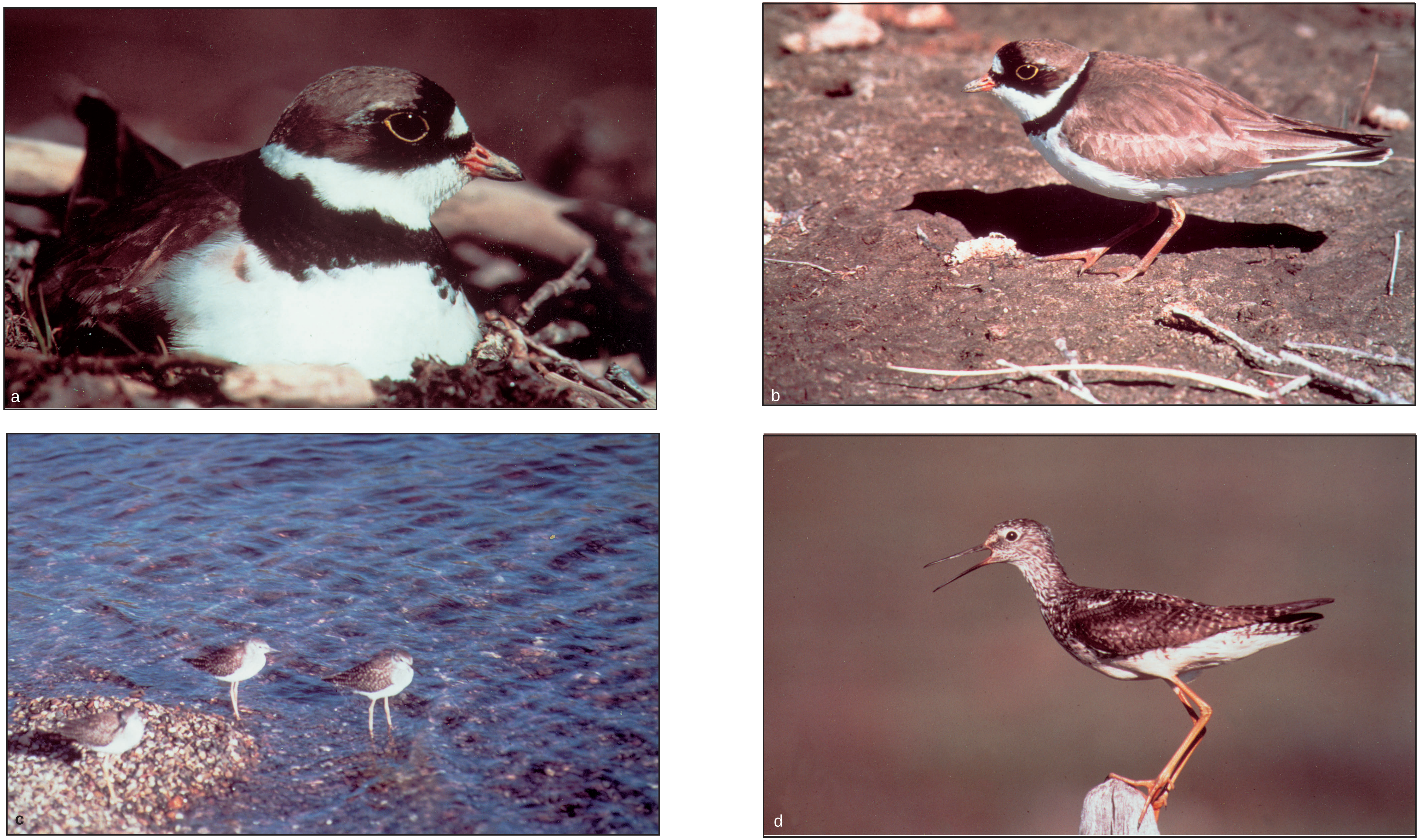


Fig. 4-27. a) Semi-palmated plover on nest (photo by Sam Barry); b) semi-palmated plover (photo by Sam Barry); c) pectoral sandpiper (photo by Sam Barry); and d) lesser yellowlegs (photo by Sam Barry).

Fig. 4-28. a) Northern phalarobe: adult female (photo by Sam Barry); b) Northern phalarobe (photo by Sam Barry); c) Hudsonian godwit (photo by Sam Barry); and d) Hudsonian godwit (photo by Sam Barry).

Fig. 4-29. a) Long-tailed jaeger in flight (photo by Sam Barry); long-tailed jaeger (photo by Sam Barry); c) pomarine jaeger feeding on fish carrion (photo by Sam Barry); and d) pair of paristic jaegers (photo by Sam Barry).

Fig. 4-30. Glaucous gull in flight, Tuktoyaktuk (photo by Sam Barry); b) glaucous gulls on rocks near Cape Parry (photo by Sam Barry); c) glaucous gull feeding on Arctic char (photo by Sam Barry); and d) glaucous gulls on nesting habitat (photo by Sam Barry).

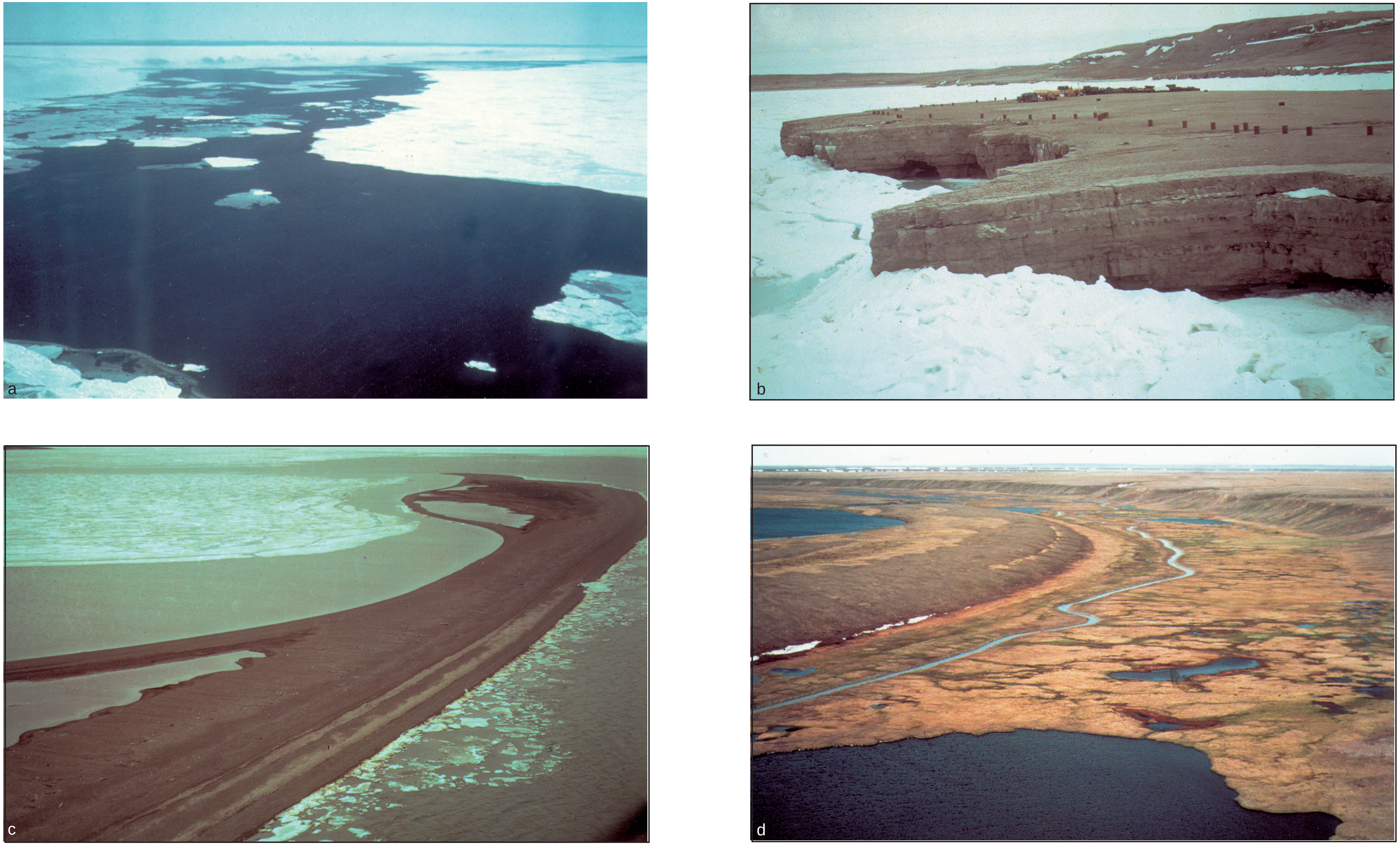


Fig. 4-31. a) Lead in sea ice provides migratory route for sea birds (photo by Sam Barry); b) thicked-billed murre cliff, Cape Pary migratory bird sanctuary (photo by Sam Barry); c) sand spit used by either gulls or terns, Parry Peninsula (photo by Sam Barry); and d) goose and duck habitat, Old Horton River bed, Harroby Bay (photo by Sam Barry).

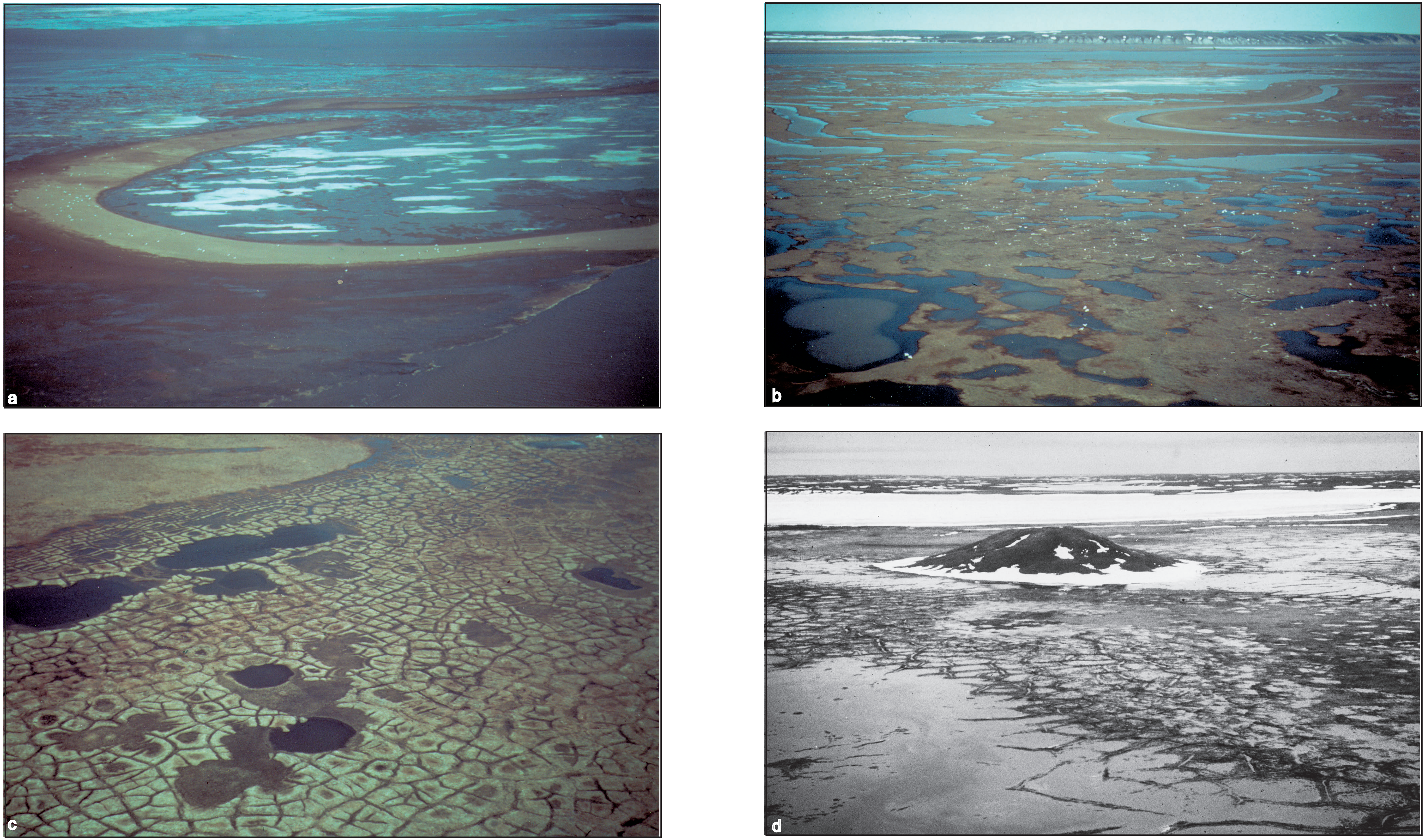


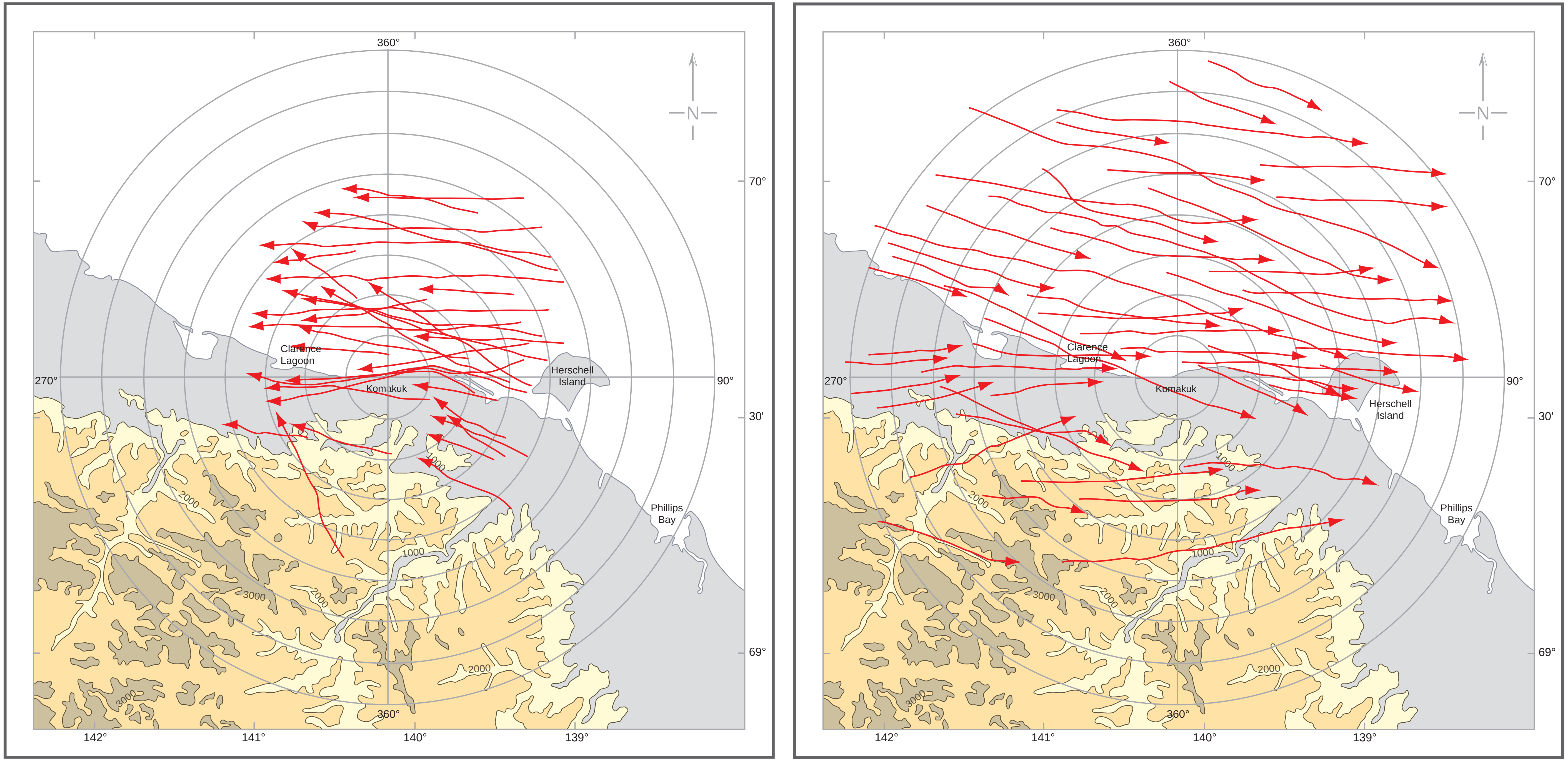
Fig. 4-32. a) Glaucous gull nest island, Mason River delta (photo by Sam Barry); b) snow goose and swan nesting habitats in Anderson River delta migratory bird sanctuary (photo by Sam Barry); c) duck habitat on polygons (patterned ground) near Liverpool Bay (photo by Sam Barry); and d) brant, swan and duck habitats around pingo and polygons on Campbell Island, Liverpool Bay (photo by Sam Barry).

Fig. 4-33. a) Willow ptarmigan on grave post, Beaufort coast (photo by Sam Barry); b) ptarmigan in sea near Nicholson Island (photo by B. Smiley); c) bald eagle nest at Eskimo Lakes, Tuktoyaktuk Peninsula (photo by V. Rampton); and d) bald eagle chick, near Kittigazuit, Tuktoyaktuk Peninsula (photo by V. Rampton).

PATHS OF BIRDS

moving west

moving east



June 16, 1975

July 7-8, 1975

Fig. 4-34. Bird flight paths.

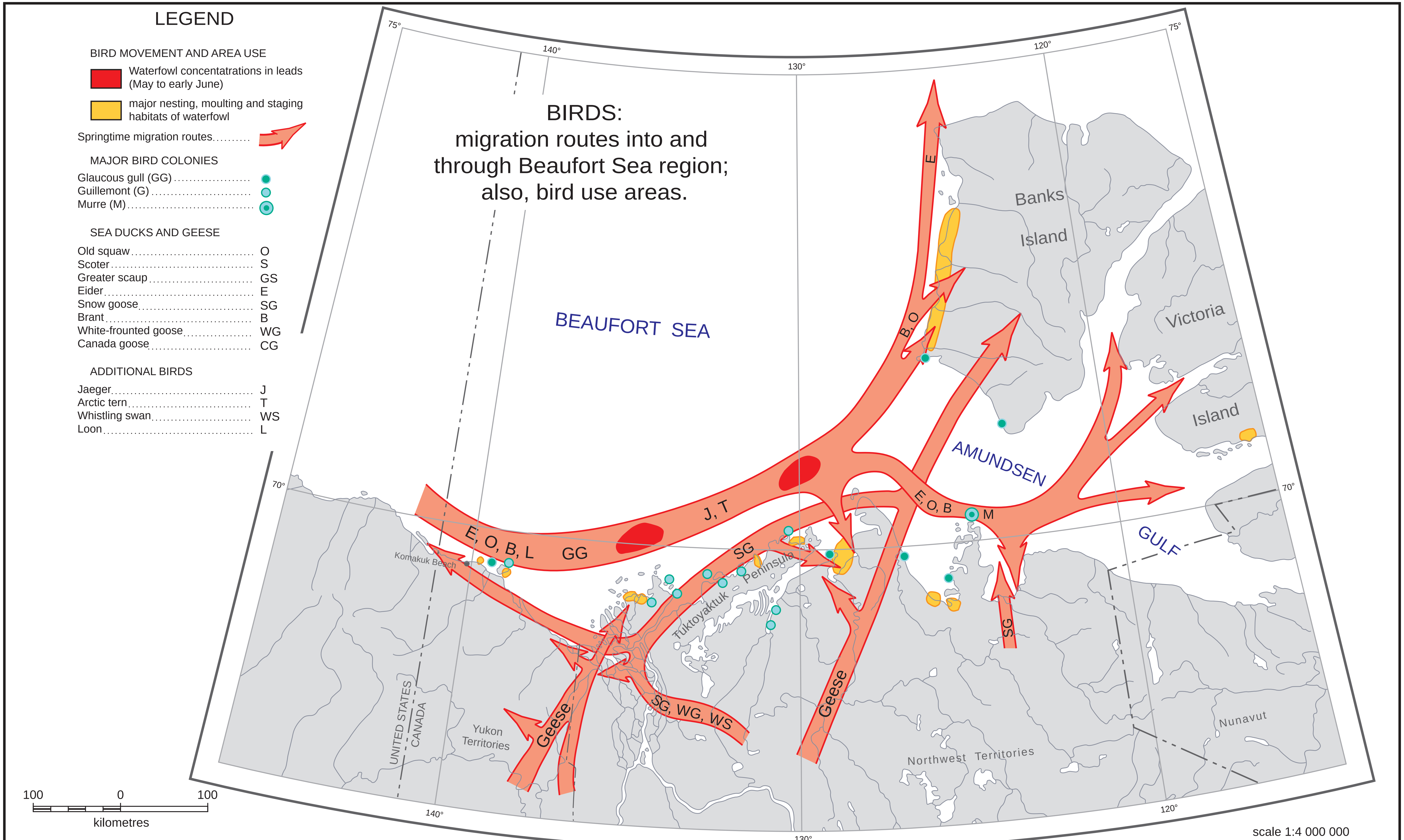


Fig. 4-35. Bird migration routes into and through the Beaufort Sea region.

CHAPTER 5
VEGETATION

VEGETATION

Vegetation Map of the Beaufort Sea Rim

The following account is an explanation of the legend shown on the accompanying map (Figs. 5-1). It comprises descriptions of several Arctic ecosystems (legend items 1-7), the boreal forest-tundra ecotone (legend items 8-11), and the areas of acidic/alkaline soils (see map inset).

Arctic Ecosystems

1. Wetlands:
These are poorly drained terrains with standing or seeping water, abundant shallow lakes, and low-centred ice-wedge polygons. They are rimmed by peat ridges , and dominated by cotton grasses and other sedges. Ground cover is densely bryophitic, and emergent marsh species are common in shallow water around the edges of ponds.

2. High Bush Thickets:
These are found in flood plains beyond the treeline. Tall thickets of deciduous shrubs occur along the deep channels of braided streams and rivers, and on alluvium that is periodically flooded. Thickets are comprised primarily of willows (*Salix alaxensis*), with heights of 2-6 m.

3. Low Bush Tundra and Cotton Grass Meadow:
This ecosystem consists of continuously vegetated tundra that is dominated by low erect shrubs (about 1 m high) such as willows, dwarf birch , and heath. Shrubs commonly occupy about 50 percent of the ground cover. On fine-grained imperfectly drained sediments, shrubs are replaced by continuous cotton-grass tussocks, with occasional occurrences of sedges, grasses, and scattered low erect and dwarf shrubs.

4. Prostrate Shrub-Herb Tundra:
This category contains all but the wettest terrain dominated by dwarf and prostrate shrubs such as arctic willow, low heath and grasses, all of which grow on acidic materials: however, willow and arctic avens mats with legumes and sedges are also present, and all grow on alkaline materials.

5. Cushion Shrub-Herb Barrens:
This ecosystem consists of scattered clumps of willow, heath and grasses (which grow on acidic soils), and willow and arctic avens (which grow on alkaline soil). Herbs are common associates, but a cryptogamic understorey is discontinuous or absent altogether.

6. Herb Tundra and Barrens:
Terrain of this ecosystem is dominated by the presence of herbaceous species; dwarf shrubs, though, may be absent or very local. Purple saxifrage is common on alkaline soils, and grasses and woodrushes are found on acidic terrain.

7. Alpine Tundra:
This ecosystem comprises low matted and cushion plants, as well as sedges and grasses. It also includes both continuously vegetated meadows and sparsely vegetated barrens that occur on the rock and rubble that are found on the mountains above treeline

Boreal Forest-Tundra Ecotone

8. Bog-Muskeg:
This ecotone is found in the terrain south of the treeline, which is too wet for the growth of trees. Thick sphagnum moss deposits, with sedges, solitary cotton grasses and local cotton grass tussocks , are also present. Drier margins and their adjacent terrains have erect shrubs, spruce and tamarack.

9. Scattered Trees in Low Bush Tundra:
All but the wettest terrain that is covered by groves of spruce trees and occasional tree-sized willow, poplar, aspen and alder, all of which occurs in the midst of dense low bush tundra and lichen-heath tundra, is characteristic of this ecotone. Its northern limit is delineated by the treeline.

10. Open Spruce Woodlands:
In this ecotone, spruce trees are present in open-canopy configuration together with groves of deciduous trees. A lower shrub layer of willow, birch, alder, or lichen heath tundra is also found here.

11. Bottomland Forests:
This ecotone is found in valleys on alluvium, lying south of the treeline. Closed stands of spruce occur on the oldest alluvial deposits, and are rarely flooded during spring breakup. Younger alluvium is vegetated by thickets of balsam, poplar, alder and tall willow such as Felt-leaf willow.

S.A. Edlund

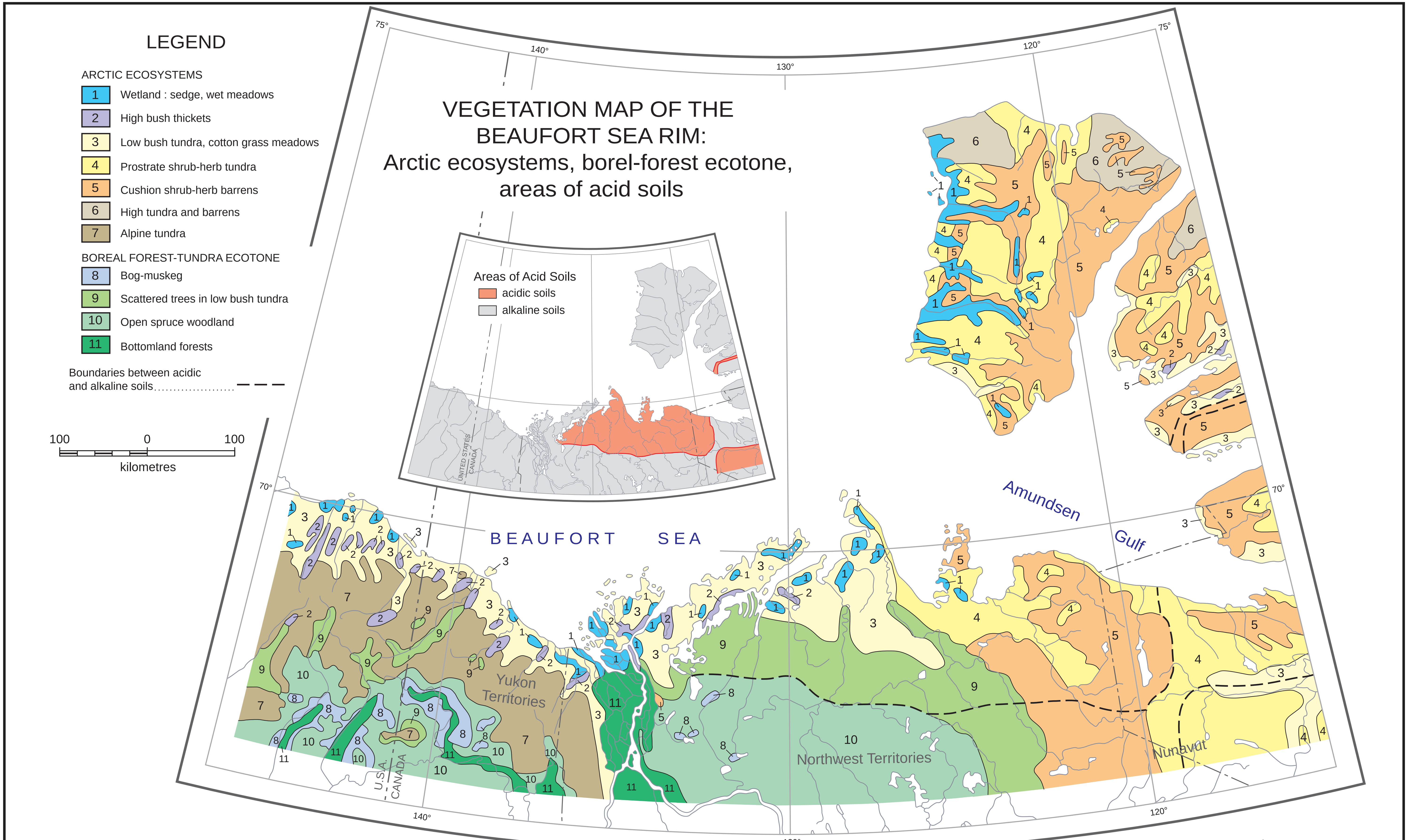


Fig. 5-1. Vegetation Map of the Beaufort Sea rim.

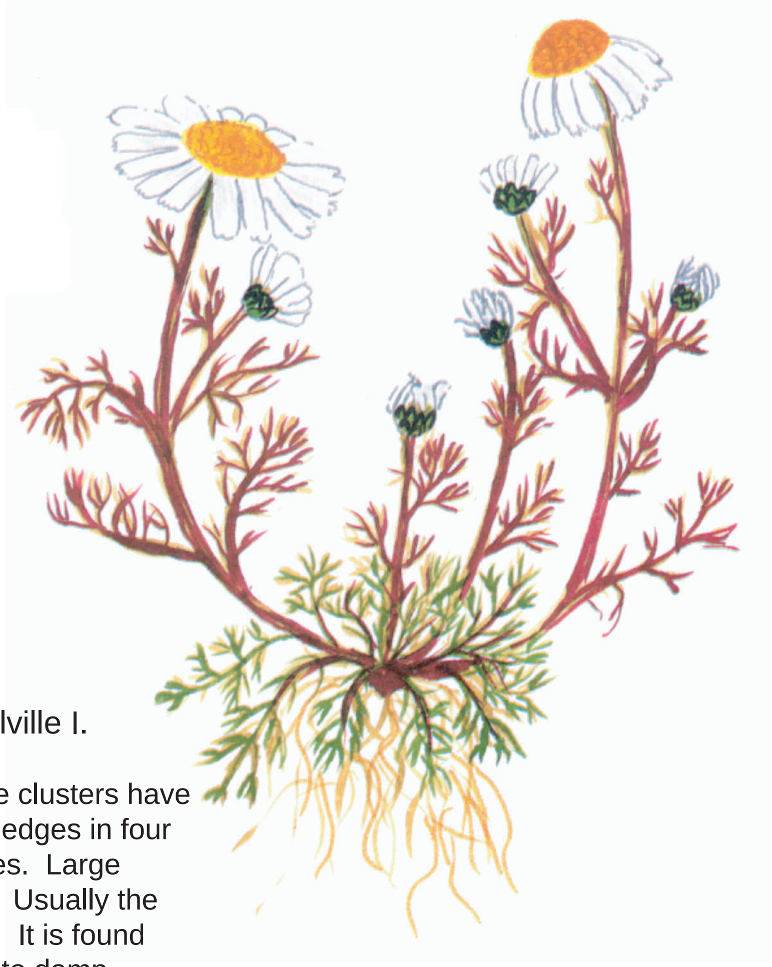
scale 1:4 000 000

Dryas integrifolia
ARCTIC AVENS; MOUNTAIN AVENS
(Low, Mid and High Arctic) Melville I.

This woody, evergreen shrub which is the Territorial flower of the Northwest Territories, forms mats of tiny spade-shaped leaves. Dead leaves remain attached for a long time. Flowers are white or creamy yellow with gold centres, and are borne on a hairy, short, 2-3 cm high stalk. Seeds are carried by wind by feathery attachments. It flowers in late June and July, and generally occurs on neutral to alkaline soil.

Matricaria ambigua
SEASHORE CAMOMILE
(Low Arctic) Victoria I.

This short-lived perennial can reach 10-30 cm high as a simple or branched plant. It has daisy-like, scentless white flowers. It is found in soil near the sea shore and is locally abundant around settlements. It flowers in July and August.



Saxifraga oppositifolia
PURPLE SAXIFRAGE
(Low, Mid and High Arctic) Melville I.

Matted trailing branches or dense clusters have small leathery leaves with bristly edges in four tight or loose rows along branches. Large purple flowers have short stems. Usually the first plant to flower, in early June. It is found on a variety of habitats, from dry to damp, generally on neutral to alkaline soil.

Drawings by S.A. Edlund are reproduced with the permission of the Minister of Public Works and Government Services Canada, 2001 and Courtesy of Natural Resources Canada, Geological Survey of Canada

Fig. 5-2. Arctic wildflowers.

Vegetation Regions and July Climate of the Beaufort Sea Rim

The distribution of vegetation at high latitudes is influenced by summer climate patterns, because summer is that time of year when plants emerge from a state of dormancy to become active biologically. Unfortunately standard climatic information in the north is limited to that gathered from a few weather stations and, informally, from settlements and seasonal scientific camps in the region. Such data are readily available from all these sources in the summer, therefore the mean July temperature of the region is chosen to represent the period of summer warmth. From these observations, congruencies of weather and vegetation patterns can be delineated and their occurrences explained. Some of these relationships are demonstrated on the accompanying map (Fig. 5-3).

Vegetation Regions

The northernmost extent of Boreal Forest and the Forest-Tundra Ecotone in North America occurs in the northern Yukon and adjacent District of Mackenzie. The limit of continuous forest is confined to the valley bottoms of the Mackenzie, Old Crow and Porcupine zrivers, and to the upper reaches of the Firth River (Fig. 5-1). In these areas the northern limit of spruce tree-growth form is marked, roughly, by the occurrence of treeline. Within a short distance north from this boundary, spruce is prostrate and reaches its species limit.

The Low Arctic vegetation region comprises the best-developed, treeless, continuously vegetated tundra communities in the Arctic. It includes plant communities dominated by low-erect and prostrate shrubs such as willow, birch and heath species. In exceptionally sheltered, well-watered habitats, some shrub species reach small-tree heights. The herbaceous associates of the shrub communities may also have tall flowering stalks in this zone. However, the poorly drained terrain dense and diverse sedge wet meadows and cotton-grass tussock meadows.

In the Mid Arctic vegetation region , vegetation is limited to middle and lower slopes, valley bottoms and lowlands. All but the wettest terrain is dominated by low shrubs and herbs, but species diversity and density is much less than the Low Arctic region. Sedge-meadow wetlands, too, are limited in density and diversity.

The High Arctic vegetation region occurs on the northern part of Banks Island and on the uplands of northwestern Victoria Islands. In this region, continuous vegetation is limited to the valley bottoms and lowlands. Dwarf shrubs may be dominant locally, but herbaceous species are generally the most common vascular plants. Sparse sedge and grass wetland occur in this region on poorly drained terrain.

The Alpine area, which comprises the mountainous zone above timberline, starts at elevations of 500-600 m in the British and Richardson mountains. It includes a variety of cushion plants, low and dwarf shrubs and meadow communities, all of which are too complex to map at this scale (Fig. 5-1). The assemblages show affinities to both the more southerly alpine of the Cordillera, and the Arctic ecosystems.

Climate

In these polar regions, the length, intensity and duration of summer warmth has a major influence on the distribution of plant communities and individual species. The northern limit of continuous forest roughly coincides with the 13°C mean July isotherm (Fig. 5-3). Timberline (the altitudinal limit of trees) and treeline (the northern limit of trees) coincides with the 10°C mean July isotherm (Fig. 5-3). The northern limit of low-erect shrub thickets, and the extensive cotton-grass tussock meadows roughly coincides with the 7-8°C mean July isotherm. The limit of woody species capable of erect shrub growth, and also herbaceous species with tall flowering stalks is roughly 5-6°C mean July temperatures. The northern limit of heath roughly coincides with the 5°C mean July temperatures. Dwarf shrubs persists as dominants into the region as cool as 3-4°C mean July temperatures, but are frequently replaced by herbs in many areas (Fig. 5-3).

The Arctic front, marking the southern limit of the air mass originating over the Arctic Ocean and adjacent islands, greatly influences most of the Beaufort Sea region in summer. Only the area southwest of the British and Richardson mountains is significantly influenced by the polar front, which originates in the northern Pacific Ocean and has been modified by its passage over continental Alaska.

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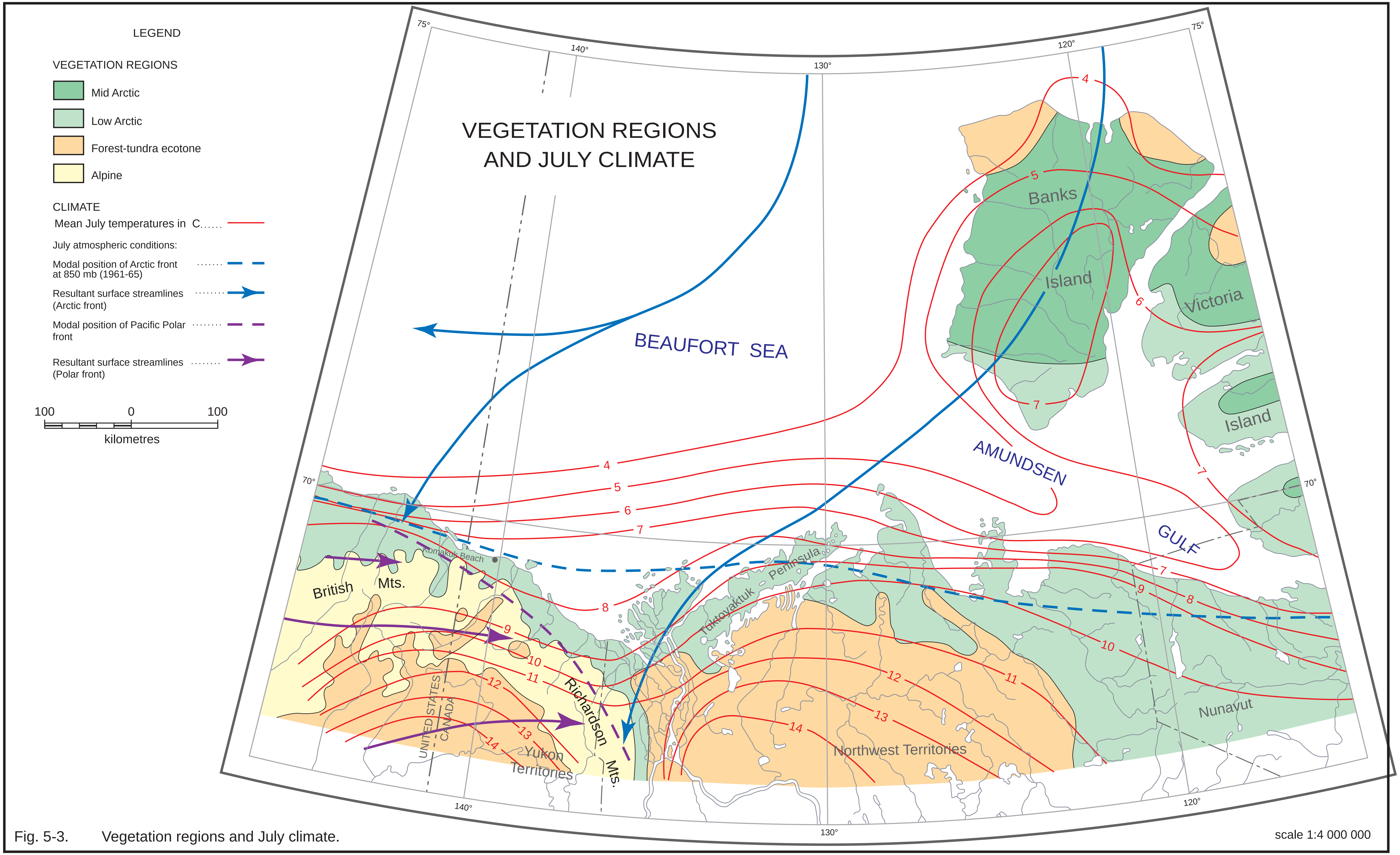

Fig. 5-3. Vegetation regions and July climate.

scale 1:4 000 000

Vegetation Regions and Northern Limits of Legummocege and Ericyceoe

The northern limits of these plant families are displayed on the accompanying map (Fig. 5-5). These boundaries are superposed on the vegetation regions previously described and shown on the maps, also. Photographs of some of the plant species in their natural setting are given in succeeding pages.

Leguminosae (Pea family)

Several members of the Leguminosae are common associates in shrub communities of the Arctic, generally growing on neutral to moderately alkaline terrain. *Lupinus arcticus* (arctic lupine), with flowering stalks up to 0.5 m high, is endemic to northwestern North America and rarely extends beyond the treeline and the zone of dense low erect thickets of shrubs in the adjacent Low Arctic vegetation region (Fig. 5-4b). *Hedysarum* (liquorice-root) is a common tall, stalked associate in dwarf shrub and low erect shrub communities growing on calcareous soils in the Low Arctic tundra (Fig. 5-4c). Densely tufted hummocks of *Oxytropis arctobia* (Fig. 5-4a) and other more compact or prostrate species such as *O. arctica* and *Astragualus alpinus* (alpine milk vetch) are common on well-drained , calcareous terrain in the Low and Mid Arctic regions and, locally, in the High Arctic.

Ericaceae (Heath family)

This family is particularly well represented on acidic to neutral soils, and in regions where soil development has sufficiently leached an upper horizon of alkaline soils. *Ledum groenlandicum* (common Labrador tea) is confined to the Forest-Tundra Ecotone, but its close relative *Ledum decumbens* (northern Labrador tea), aprostrate shrub, extends into the Low Arctic vegetation region (Fig. 5-4d; 5-6). A typically acid-loving species, its range is limited by the alkalinity of the tills on Banks and Victoria islands. *Rhododendron lapponicum* (the Lapland rosebay) occurs in the Forest Tundra Ecotone as an erect shrub (Fig. 5-6; 5-7a), but in the Low Arctic region it adopts a more prostrate form. It, too, is restricted in distribution to acidic soils. *Cassiope tetragona* (arctic white heather) is the only heath species that is commonly found in the Mid and High Arctic regions (Fig. 5-7b). In its southern range, it occurs in extensive mats on acidic soils; on its northern limit, it is confined to sheltered niches on acidic soils, and to local ephemeral snow patches on alkaline soils.

S.A. Edlund

Fig. 5-4. a) *Oxytropia arctica* (silvery oxytrope) (Photo by Sylvia Edlund); b) *Lupinus arcticum* (lupine) (Photo by Sylvia Edlund); c) *Hedysarum albinium* (liquorice-root) (Photo by Sylvia Edlund); and d) *Ledum decumbens* (Photo by Sylvia Edlund).

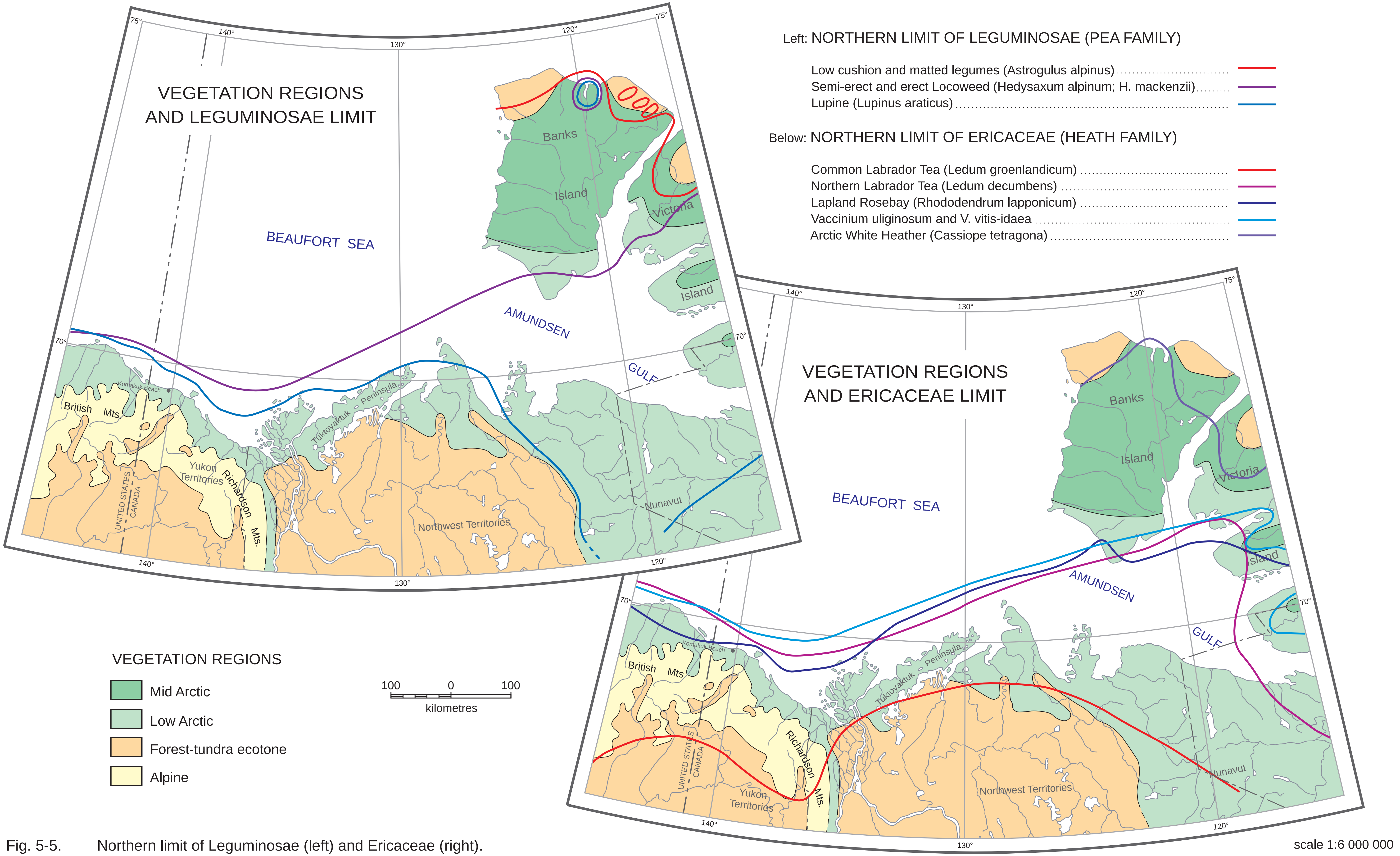

Fig. 5-5. Northern limit of Leguminosae (left) and Ericaceae (right).

scale 1:6 000 000

Ledum decumbens
(L. palustre ssp. *decumbens)*
NORTHERN LABRADOR TEA;
SMALL HUDSON BAY TEA
(Low Arctic) N. Keewatin

This woody, low shrub has leathery, narrow green leaves, with rusty red wood beneath. A cluster of small, white flowers occur at the tips of branches. It is found on damp acid-soil, and can be used as tea or marinate for meat. It flowers in July, and has a flowering branch of 5-20 cm high.

Drawings by S.A.Edlund

Rhododendron lapponicum
LAPLAND ROSEMARY
(Low and Mid Arctic) Eskimo Point

This trailing and semi-erect dward shrub is very branched. Small oval leaves, evergreen, have rusty hairs on underside. Flowering branch 5 - 30 cm high. One to five flowers in cluster at the tips are pink-purple and very fragrant. It occurs on damp, sheltered soils, and tolerates weakly alkaline soils as well as acidic ones. It flowers in late June, July.

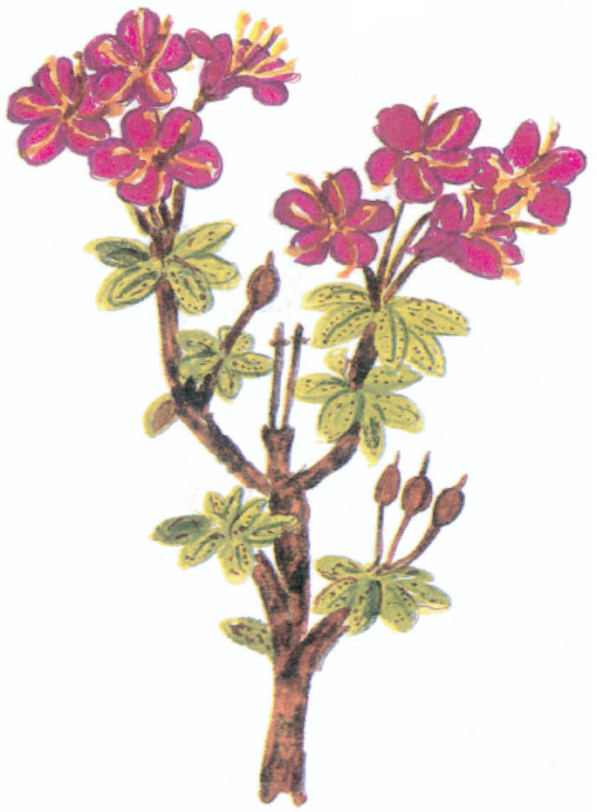

Fig. 5-6. Arctic wildflowers.

Fig. 5-7. *a) Rhododendron labbanicum* (Photo by Sylvia Edlund); b) *Cassiopa tetragona* (Arctic white heather) (Photo by Sylvia Edlund); c) Anaceae (spruce family) (Photo by Sylvia Edlund); and d) Pinaceae at tree line (pine family). (Photo by Sylvia Edlund)

Vegetation Regions and Northern Limits of Betulaceae and Cyperaceae

The northern limits of these plant families are displayed on the accompanying maps (Fig. 5-8). These boundaries are superposed on the vegetation regions previously described (Fig. 5-1), and are shown on the maps also. Photographs of some of the plant species in their natural setting are given on succeeding pages (Figs. 5-9, 5-10) while drawings are in figures 5-11, 5-12 and 5-13..

Betulaceae (Birch and Alder family)

This family reaches its northern limit in the Low Arctic vegetation region (Fig. 5-8). Tree-size and tall shrub birch, such as *Betula papyrifera* (Fig. 5-9a) and *B. occidentalis* occur in sheltered locations in the Forest-Tundra Ecotone and may extend locally beyond treeline. *Alnus crispa* (green Alder) is a small tree-forming shrub that is limited to the zone near treeline. It occurs only in isolated clumps beyond treeline, and forms low dense thickets immediately above timberline in the Richardson Mountains. *Betula glandulosa* (Dwarf Birch) occurs as a low erect shrub in the Forest-Tundra Ecotone, and as a prostrate shrub at its northern limit in the Low Arctic vegetation region (Fig. 5-10d). It occurs only locally on the moderately alkaline tills of the western Canadian Arctic Archipelago.

Cyperaceae (Sedge family)

Sedges and cotton-grass species dominate wetland communities in the Forest-Tundra Ecotone and the Arctic vegetation region. *Carex aquatilis* var. *aquatilis* is common in wetlands in the Forest-Tundra Ecotone, but barely extends into the Arctic Instead, *C. aquatilis* var. *stans* becomes the dominant of wetlands in the Low and Mid Arctic vegetation regions, and portions of the High Arctic. Another sedge, *C. membranacea*, grows on imperfectly drained tundra in the Low and Mid Arctic regions. The tussock cotton grass, *Eriophorum vaginatum* forms hummocky meadows on thick, imperfectly drained , silty sediments and peaty soils in the Low Arctic region (Fig. 5-9c). Although the species occurs locally in the Mid and High Arctic regions, the dense meadows are limited to the Low Arctic.

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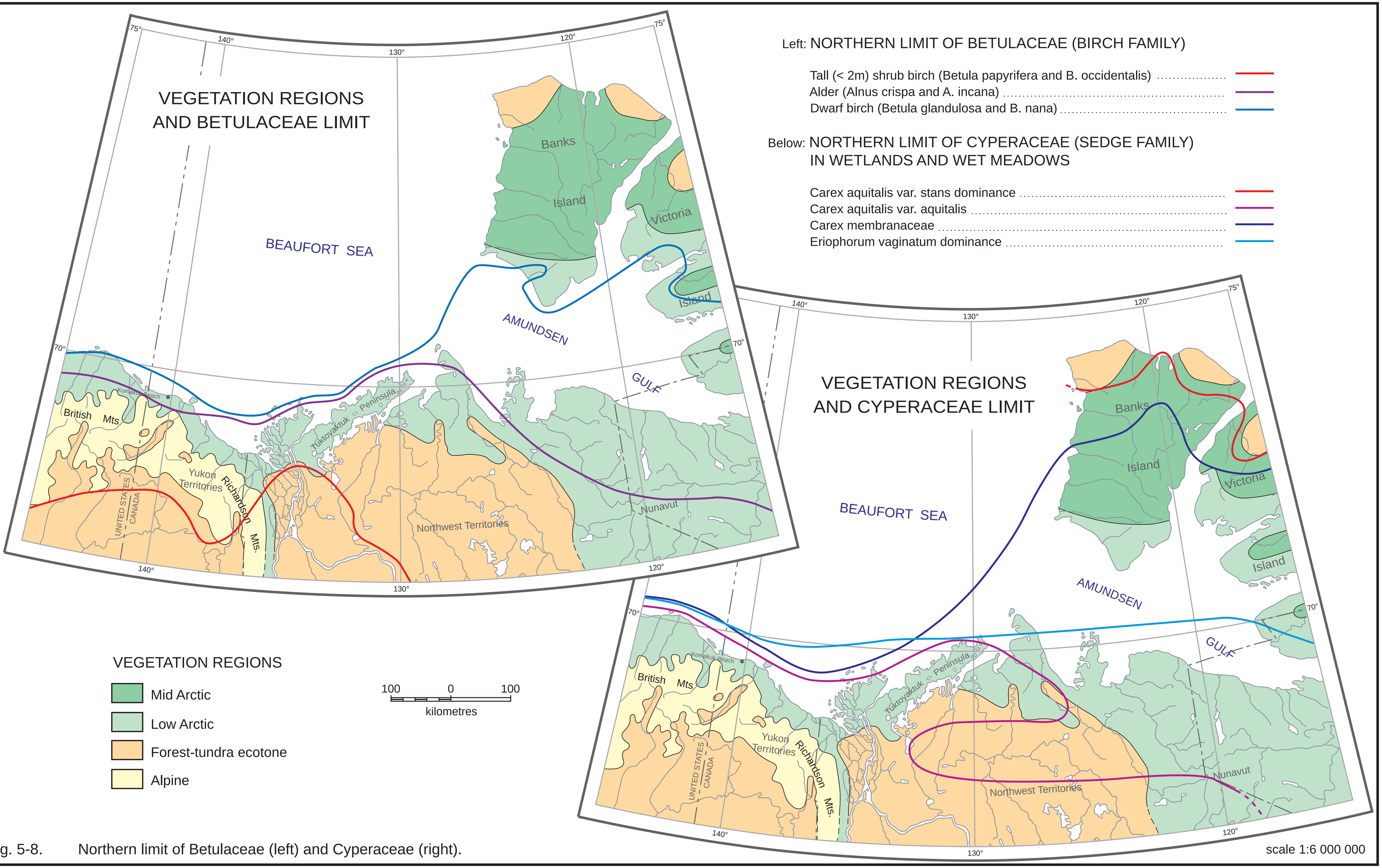


Fig. 5-8. Northern limit of Betulaceae (left) and Cyperaceae (right).

Fig. 5-9. a) *Betula papyrifera* (tree size paper birch) (Photo Courtesy of D.A. St-Onge); b) Cyperracea (cotton grasses and sedges around the pond) (Photo by Sylvia Edlund); and c) *Eriophorum vaginatum* (tussocks of sedges) (Photo by Sylvia Edlund).

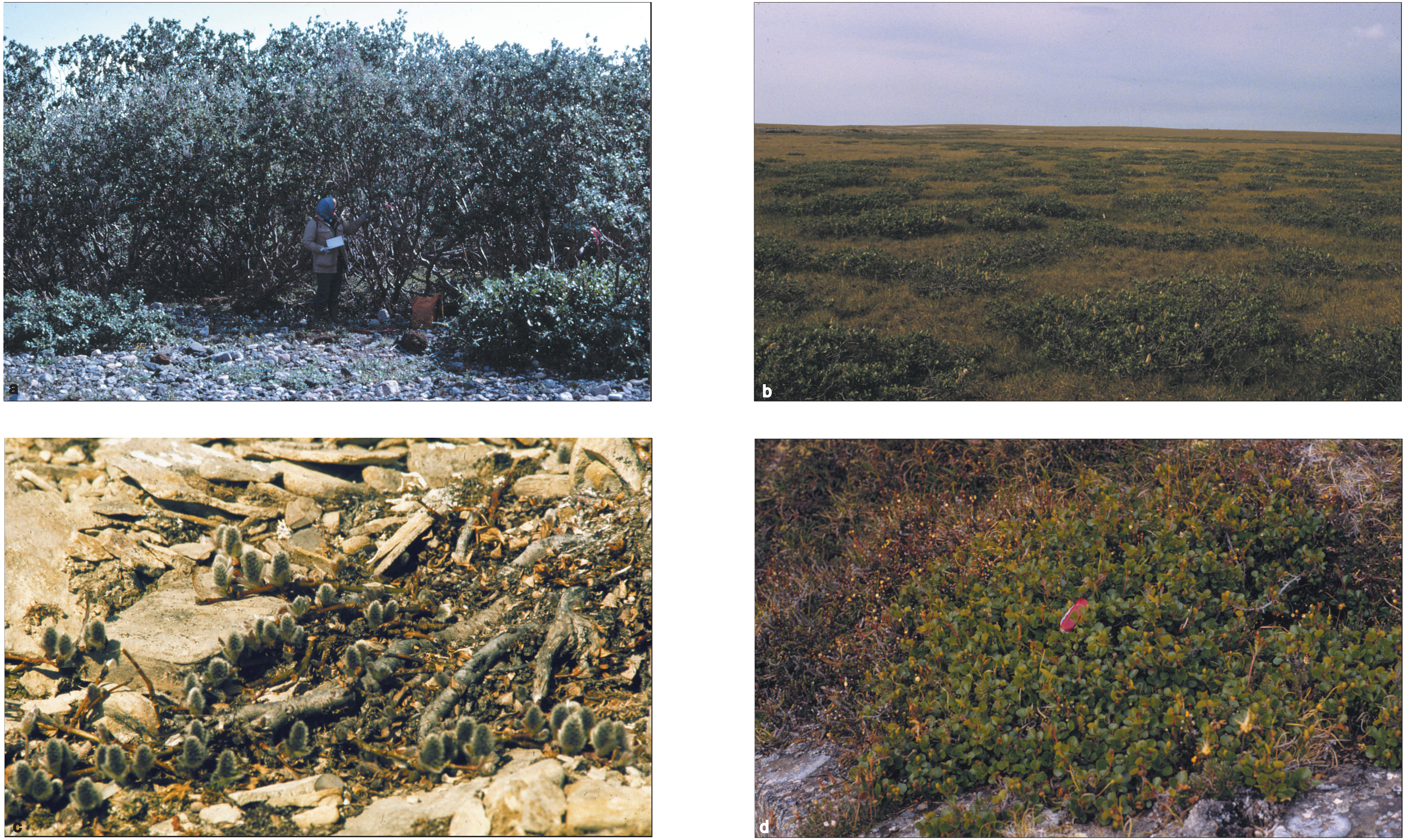


Fig. 5-10. a) *Salix alaxensi* (felt-leafed willowthicket) (Photo by Sylvia Edlund); b) *Salix alnatava* (low exect willow) (Photo by Sylvia Edlund); c) *Salix arctica* (dwarf artic willow) (Photo by Sylvia Edlund); and d) *Betula glandulose* (dwarf birch) (Photo by Sylvia Edlund).

Caltha palustris var. *arctica*
YELLOW MARSH MARIGOLD
(Low and Mid Arctic) Melville I.

The flower with five shiny hellow petals occurs at the tip of trailing, nearly leafless stems. Leaves attached to the base are kidney or heart shapped. it occurs in wet marshy places and in shallow water. young tender leaves can be eaten only if cooked; they are poisonous if not cooked. Flowers July to August.

Ranunculus pedatifidus
NORTHERN BIRDFOOT BUTTERCUP
(Low and Mid Arctic) Melville I.

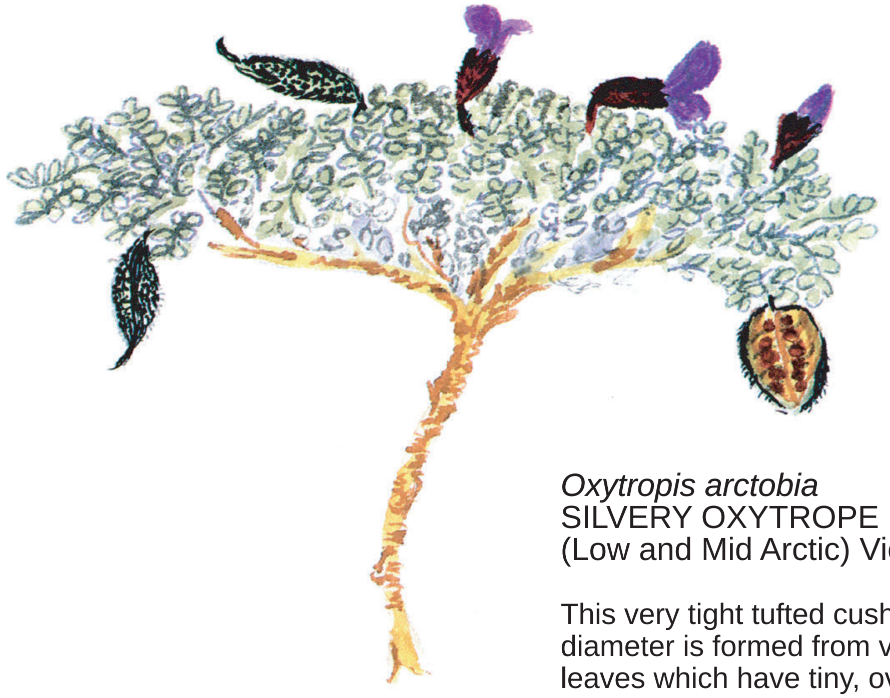
The deeply cut leaves resemble a bird's foot. A single yellow flower grows on an 8-30 cm stem. It occurs on moderately drained alkaline sand and gravel or grassy tundra. It flowers in July.

Ranunculus nivalis
SNOW BUTTERCUP
(Low, Mid and High Arctic) Melville I.

This is one of the first plants to flower after snow melts. It has basal leaves with three-to-five lobes. A single yellow flower occurs at the tip of a 5-10 cm high stem. It occurs in wet areas, particularly snowbed zones.

Drawings by S.A.Edlund

Fig. 5-11. Arctic wildflowers.



Lupinus arcticus
ARCTIC LUPINE
(Low Arctic) Tuktoyaktuk

Silvery green, palm-shaped leaves radiate from a woody base. Large purple-blue flowers form a pointed cluster on a stem 12-60 cm tall. Seeds are poisonous. It is found on moderately drained soils, and it flowers in late June and July.

Oxytropis arctobia
SILVERY OXYTROPE
(Low and Mid Arctic) Victoria I.

This very tight tufted cushion 15 - 30 cm in diameter is formed from velvety grey, wooly leaves which have tiny, oval leaflets. The flower is solitary, rarely paired, and is purple, with a short stem, barely stretching above the cushion. The fruit is a grey pod with black and grey hairs. It is found only in Arctic Canada on alkaline gravel. It flowers in July.

Oxytropis arctica
ARCTIC OXYTROPE
(Low and Mid Arctic) Melville I.

Densely clustered grey-green, wooly leaves have numerous paired leaflets. The flowers are a cluster of showy blue-purple and are strongly scented. The fruit is olive green, sickle-shaped beakedpod. It is found primarily on alkaline soils and flowers in July. Flowering stems are 5 - 10 cm in length.

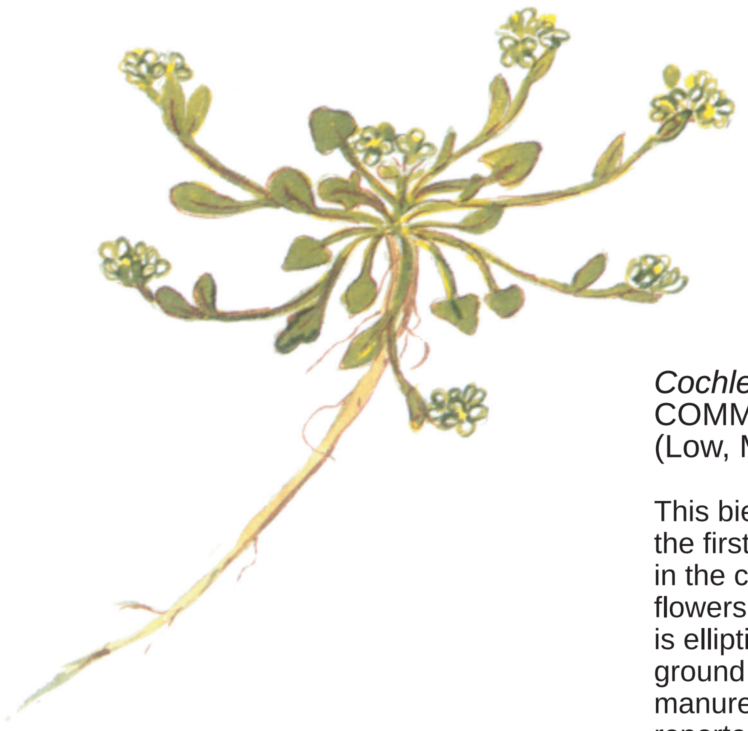
Drawings by S.A.Edlunc

Fig. 5-12. Arctic wildflowers.

Armeria maritima
SEA PINK; THRIFT
(Low and Mid Arctic) Victoria I.

This plant has dense tussock of long, narrow, fleshy green leaves. Flower stalks 10 -20 cm high, ending in a round head of small, papery, rose-pink flowers. It is found on sand and gravel, generally near the coast and on river terraces or lake shores.

Drawings by S.A.Edlund



Cochlearia officinalis
COMMON SCURVY GRASS
(Low, Mid and High Arctic) Melville I.

This biennial plant appears as a small rosette the first year. A cluster of white flowers appears in the centre during the second year. As the flowers mature, the stem elongates; the fruit is elliptical. Occurs on damp and disturbed ground near the seashore and other salty or manured areas. Edible fresh or cooked, it is reportedly rich in Vitamin C.

Fig. 5-13. Arctic wildflowers.

Vegetation Regions and Northern Limits of Pinaceae and Salaceae

The northern limits of these plant families are displayed on the accompanying maps (Fig. 5-14). These boundaries are superposed on the vegetation regions previously described, and are shown on the map also. Photographs of some of the plant species in their natural setting are given in the preceding page.

Pinaceae (Pine family)

This family is restricted to the zone occurring near treeline. *Larix laricina* (Larch or Tamarack) is a small tree that is generally found on alkaline soils. In the District of Mackenzie it generally reaches its northern limit south of treeline; however, in the mountains, its limit is extended to timberline locally. Spruce species such as *Picea glauca* (White Spruce) and *P. mariana* (Black Spruce) are the most common evergreen trees in the Forest-Tundra Ecotone. In this ecotone, white spruce forms both treeline and timberline. Black spruce is found on poorly drained soils and does not quite reach treeline. Low shrubby junipers such as *Juniper communis* (Ground Juniper) and *J. horizontalis* (Creeping Juniper) occur in this region as well. *J. communis* extends some distance beyond treeline into the Low Arctic tundra: however, *J. horizontalis* barely reaches treeline and is restricted to alkaline soils.

Salicaceae (Willow family)

This family is the dominant or major associate on all but the wettest terrain in most of the Arctic. In the Forest-Tundra ecotone tree-sized shrubs occur along some major streams and river channels, as they do in the Boreal Forest. Many of these willow species also occur as dense low-erect willow thickets, less than 1 m high, on uplands in the Forest-Tundra Ecotone and in the adjacent Low Arctic region. Prostrate willows, primarily the dwarf *Salix arctica* and Arctic willow, (Fig. 5-10c), occur in both the Low and Mid Arctic regions and the High Arctic locally.

S.A. Edlund

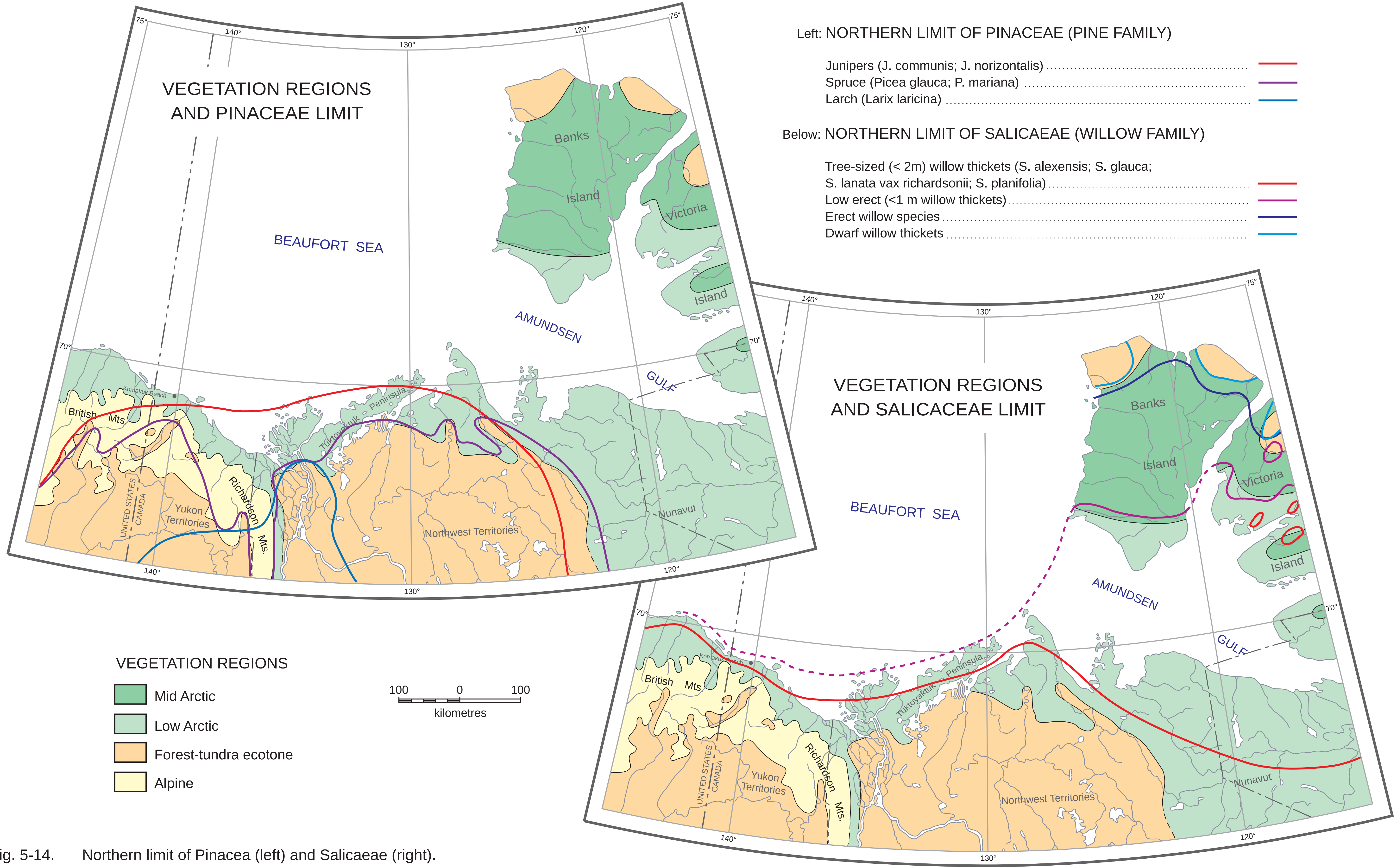


Fig. 5-14. Northern limit of Pinacea (left) and Salicaeae (right).

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CHAPTER 6
WETLANDS

WETLANDS

Wetlands distribution

Physiographic Influence

Wetlands have many important environmental, ecological, and economic attributes, some of which include the following: a data base for the study of ecological matters; a potential forest land for production; possible farmland for agriculture; a nesting, visiting and ecological niche for enormous amounts of water fowl; possible recreational sites, including the enjoyment of observing colourful and exotic flowers; a source of peat fuels for energy use; an important fresh-water storage area for plants and animals and the basis of a related conservation strategy, a source of carbon dioxide for plant production; and an absorbent of carbon dioxide and aerosol pollutants for enhancing atmospheric quality.

Wetlands are defined as land that has the water table at, near, or above the land surface or which is saturated for a long enough period to promote wetland or aquatic processes as indicated by hydric soils, hydrophilic vegetation, and various kinds of biological activity that are adapted to the wet environment. This definition was developed by The National Wetlands Working Group, which has further described wetlands as water-logged soils, peatlands (where more than 40 cm of undecomposed vegetation is present), areas of shallow open water less than 2 m deep, and areas periodically inundated by water when the waterlogged condition is dominant in the ecosystem. Wetlands occur in mid to high latitudes in many countries around the world. In Canada about 14% of the land surface comprises wetlands, and approximately 87% of this is peatland.

Development

The main factors, either solely or in combination, that influence the development of wetlands, are morphology of the landscape and climate. In the lands bordering the Beaufort Sea, low evaporation compensates for the low precipitation and, together with extensive areas of poor drainage, these conditions favour wetland formation. Although permafrost is esssentially continuous in the region, the condition is particularly favoured in wetlands where the water table is below the surface in summer but near the surface in winter.

Major physiograhic elements also exert an influence on the development of wetlands (Fig. 6-1). On flat lands where drainage is slow, water may accumulate to form a wetland; however on sloping surfaces, especially in hilly and mountainous regions, water may never reach surplus amounts to develop a wetland because of rapid drainage. Even though some wetland occurrences may be a response to conditions of temperature and precipitation, the physiographic setting may predominate. For example, the cold winters (-20° to -30°C) and cool summers (14° to 17°C), combined with relatively low annual precipitation (<300 mm), are condusive to the development of wetlands in the lower Mackenzie Valley and Delta. In the mountains, however, the conditions of slightly colder winter temperatures (-33°C) and summer temperatures (14°C) combined with a similar low, annual precipitation (<250 mm), fail to develop appreciable amounts of wetlands because of the occurrence of steep rocky slopes.

On the map illustrating the distribution of wetlands (Fig. 6-1), a fairly good correspondence of percentage cover of wetlands to physiograhic elements is readily apparent. The greater cover of wetlands coincides with the low-lying areas of Mackenzie Valley, Tuktoyaktuk Coastlands, the Coastal Plains, and the lower uplands; the lesser amounts, with the mountains. However, some valleys and flats in the mountains and higher elevations of the upland regions may contain substantial amounts of wetlands. This overall distribution of wetlands can be compared with the generalized physiographic elements shown in the inset, and the shaded relief depicted on the map (Fig. 6-1).

A dynamic situation exists in wetlands because of the continual interaction between biological and physical components in the ecosystem. If climatic influences are unchanged, a steady state or equilibrium is achieved, which leaves the wetland unaltered. However, the climate can change thus creating changes to the wetland environment. In such instances the wetlands is a transitional phenomena, and its development must be studied constantly as it proceeds toward aridity on the one hand, and inundation on the other. Even agricultural practices and artificial construction may affect both the transitional nature and the equilibrium of the wetland. More drastically, natural processes such as flooding, or damming due to land disturbance may contribute to its fate.

Wetland Types

Five types or classes are used to describe the wetlands of Canada. They are based on biotic criteria such as vegetation and peat, and on abiotic factors that include hydrology, water, climate, landforms, drainage, and proximity to water bodies. The five types of wetlands are as follows: bog, fen, marsh, swamp, and shallow water. Importantly wetlands are not synonymous with peatlands, although peatlands are wetlands that are characterized by a layer of peat that is greater than 40 cm in thickness. At this depth most wetland plants are rooted in peat.

Bogs are peat-covered wetlands comprising sphagnum and forest peat, and may have a water table that is raised or level with the surrounding wetlands. The water table may be isolated from mineralized water, thus imparting nutrient-poor and acidic qualities to the bog.

Fens are peatlands that are characterized by a high water table, and slow internal drainage. The dominant vegetation consists of sedges, grasses, reeds, brown mosses, and a sparse cover of trees in some areas. In localities where the derived water is rich in minerals, the fen contains a high nutrient content and a slightly acidic quality.

Marshes are wetlands that are periodically inundated by standing, or slowly moving water. They comprise a peatland with seasonally fluctuating water, which permits the circulation of nutrients because of contact with mineral sources. Under these conditions, a slightly alkaline content is imparted to the water. Marshes are generally wet and are characterized by pools and channels that are interspersed with emergent vegetation consisting of grasses, reeds, rushes, sedges, and peripheral bands of shrubs or trees.

Swamps are a wetland type in which standing or gently moving waters persist for long periods. This condition leaves the subsurface continuously waterlogged and, because these waters are rich in minerals containing magnesium and calcium cations, a neutral to alkaline nature characterizes the water quality. In this type of wetlands coniferous or deciduous trees and shrubs form a dense cover, together with herbs and mosses.

Shallow water types of wetlands represent a transitional stage between lakes and marshes or

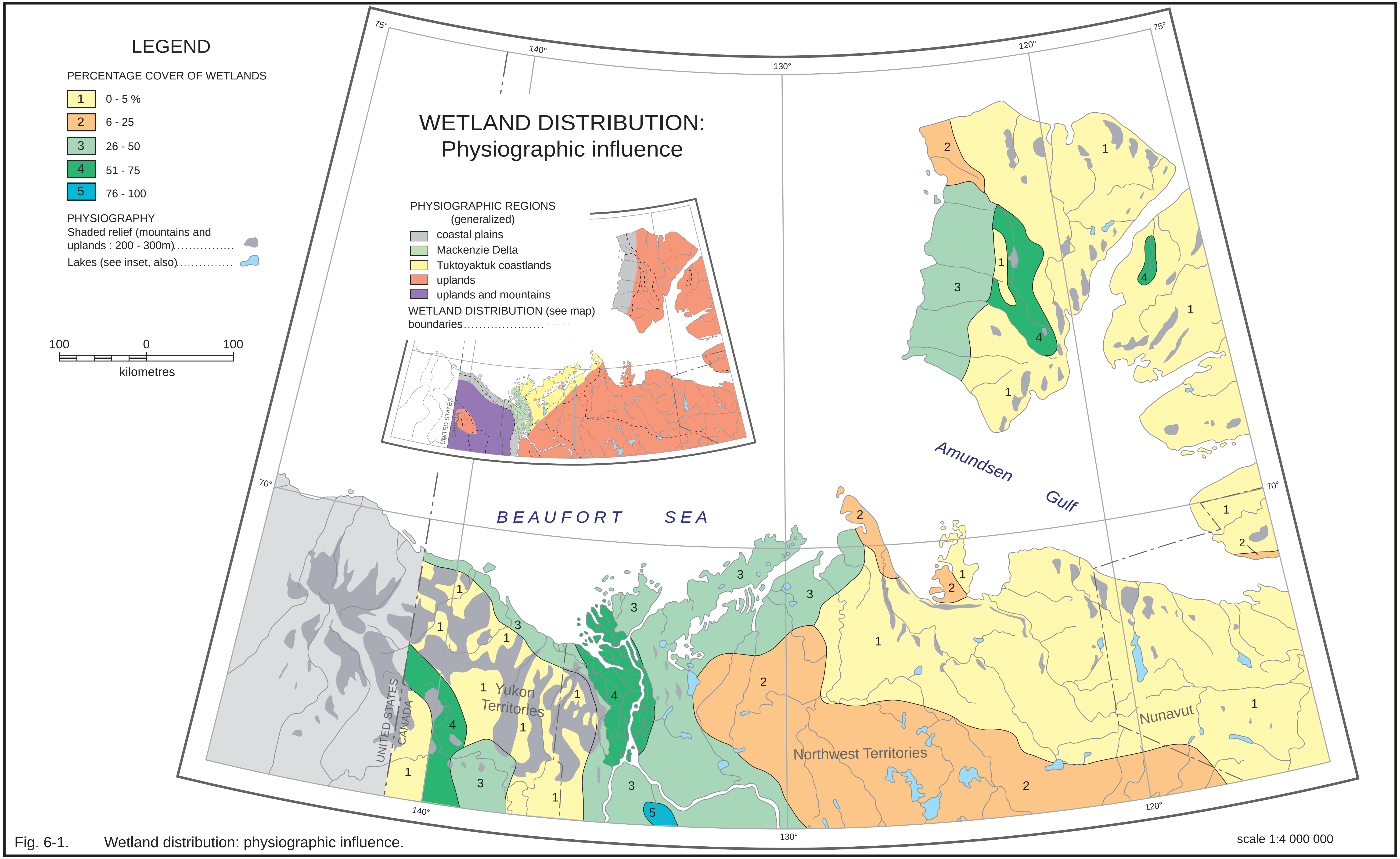


Fig. 6-1. Wetland distribution: physiographic influence.

swamps. They are standing bodies of water with small or large expanse, and are distinguished from deepwater bodies by the occurrences of summer water depths that are less than 2 m; they are also delineated from other wetlands by the fact that they occupy more than 75% of the wetland surface area. An open aspect is imparted to the surface waters, which are free from emergent vegetation, although floating and rooted plants may be present. Areas of open water greater than 8 hectares in extent should be classified separately under shallow water types, regardless of the presence of bordering zones of vegetation. Water depths increase during flooding, and shorelines erode at this time; however, during droughts, these waters recede and expose mud flats. These alternate characteristics of the shoreline delineate, further, the shallow water types from uplands and bordering complexes of wetlands.

B.R. Pelletier
Map: after National Atlas of Canada, Distribution of Wetlands
Natural Resources Canada
Data: after the National Wetlands Working Group
Environment Canada

WETLAND REGIONS

Wetland regions generally occur in broad climatic zones, based on temperature and precipitation. In Canada the temperature gradient, which extends from north to south, is demonstrated clearly in the accompanying map of the Beaufort Coastlands (Fig. 6-2). Temperatures are given as climate normals, and represent the annual mean daily values for the period of record indicated at the given station. Precipitation gradients occur from west to east in Canada (exclusive of the Pacific region), but this phenomenon is less prominently developed in the Beaufort region. However values of annual total precipitation are given on the map and these, too, are climate normals for the given period of record.

Although temperature and precipitation are the chief environmental influences, wetland regions also develop through interaction with various components of the ecosystem. Other factors may involve the nature of the soil, presence of peatlands, type of vegetation, development of the active layer, and occurrences of permafrost. The significance of vegetation is apparent, and is observed when certain wetland regions occupy the area of a dominant vegetation type and the boundaries of that vegetation and the associated wetlands are coincident. Such congruency is common in both peatland and shallow water wetlands that are fringed by shrubs or trees. Permafrost is important because of the cryogenic disturbance of the wetlands that it engenders, and the obstructions to through-flowing water that it presents. Because many of these combined factors are characteristic of a given area, wetlands have been so-divided into different regions. In the Beaufort Coastlands, the main wetland regions are Arctic, Sub-Arctic and Rocky Mountain.

Climatic Influence

Although the interpolation of temperature and precipitation values are derived from various weather maps and tables produced by Environment Canada, several weather stations are selected in order to demonstrate the geographic aspects of these variables (see map). Of these stations, Sachs Harbour on Banks Island is the most northerly and coldest (-13.7° C); on the other hand, Inuvik in the Mackenzie Delta is the most southerly and warmest (-9.5°C). Intermediate stations situated on the coastal mainland have intermediate values. These stations are Cape Parry (-12.0°C), Nicholson Peninsula (-12.0°C), Tuktoyaktuk (-11.5°C), and Komakuk Beach (-11.5°C). The graphs of the mean monthly and annual temperatures for some of these stations (see inset) clearly show that cold winters and cool summers prevail throughout all the wetland regions in the Beaufort Coastlands.

Mean annual ground temperatures obtained from monitoring devices, drilling and engineering crews, and geophysical surveying parties are the bases upon which relevant isotherms have been interpolated. This procedure helped to locate the southern boundary of continuous permafrost in the coastlands. The striking parallelism of both air- and ground-temperature trends is also observed where such trends conform, generally, to the boundaries selected for wetland regionalization.

Patterns of total precipitation may, in part, conform to the boundaries of the regional wetland areas shown on the accompanying map. In the north, aridity is dominant due to a minimal amount of precipitation received annually; to the south, increased amounts of precipitation occurs but these amounts are still considered to be low. A slight variation in the amount of total precipitation prevails from west to east in the Beaufort Coastlands, but these occurrences are generally features that are characteristic of the associated region of Arctic wetlands.

Environmental Boundaries

Certain physical boundaries are used to delineate areas that have a characteristic environment, the latter of which may comprise features of given wetland regions. Because of the inherent environmental quality of such borders, they are referred to here as environmental boundaries. They include the treeline and the southern limits of continuous permafrost on land, and the edge of the polar ice in the southeastern Beaufort Sea. These boundaries are generally stable over periods of several years except for the edge of the polar pack, which may vary from year to year across distances of tens of kilometres.

The trend of the northern limit of treeline partly conforms to both types of isothermal trends, as well as to the borders of regional wetlands. Treeline is clearly an environmental boundary in that the land south of it harbours its own ecosystem and contains its particular soil, while its tree cover affects snow catchment and deters wind erosion of the soil. North of treeline a different ecosystem occurs and the land is subject to blowing snow and subsequent wind erosion. In these respects, treeline provides additional environmental features that are characteristic of wetlands in the region.

The boundary between continuous and discontinuous permafrost conforms to the regional trends of the isotherms, treeline and wetland borders, and is also environmental in nature. North of this boundary, all wetlands are underlain by continuous permafrost and, to the south, by discontinuous permafrost. Occurrences of permafrost partially control movement and disturbance of the active layer, as well as the development of pingos, thermokarst, vegetation and, consequently, the habitats for wildlife. Such permafrost effects add substantially to the nature of wetland regions, and may be delineated partly by the permafrost boundaries where it is recorded or mapped.

A significant environmental boundary is the edge of the polar pack ice. It is unique in that it moves, particularly after breakup, and carries with it certain environmental attributes of the frozen sea. These features, such as low temperatures and vigorous winds, affect the adjacent coastal wetlands and their development. In spring when warm southerly winds pass over the coastlands and drive the ice edge seaward, a renewed cycle in the ecosystem begins that impacts directly on the Arctic wetlands. Flowing water, open coasts, thawing soils and lakes, and a flourishing vegetation are the harbingers of this season. Later in the year, particularly in early fall, the ice edge returns to the coast. The cold, driving northerly winds that originate over the sea ice close the open coastal waters, and inhibit all coastal activity including navigation. Under colder temperature from that of the summer, these Arctic winds blow onto the land where they commence the erosion of the untreed wetlands. An Arctic winter environment is created over the entire reach of the Beaufort Coastlands, as soils, lakes and wetlands freeze, and frost, snow, ice and non-flourishing vegetation become ubiquitous.

Wetland Regions

In the Beaufort Coastlands, the main wetland regions are Arctic, Sub-Arctic and Rocky Mountain (Fig. 6-2). These wetlands are further sub-divided into the following regions: Mid-Arctic, Low Arctic, High Sub-Arctic, Low Sub-Arctic, and North Rocky Mountain wetlands. Although climatic factors are most important, these divisions are based on characteristics that are indigenous to each region. The Mid-Arctic wetland region is the most arid of the Arctic wetlands in the Beaufort Coastlands. The precipitation normal is exemplified at Sachs Harbour where the amount of precipitation is 126 mm annually. Isothermal values for air temperature range from -12°C in southern Victoria Island, to -15°C in the middle portion of Banks

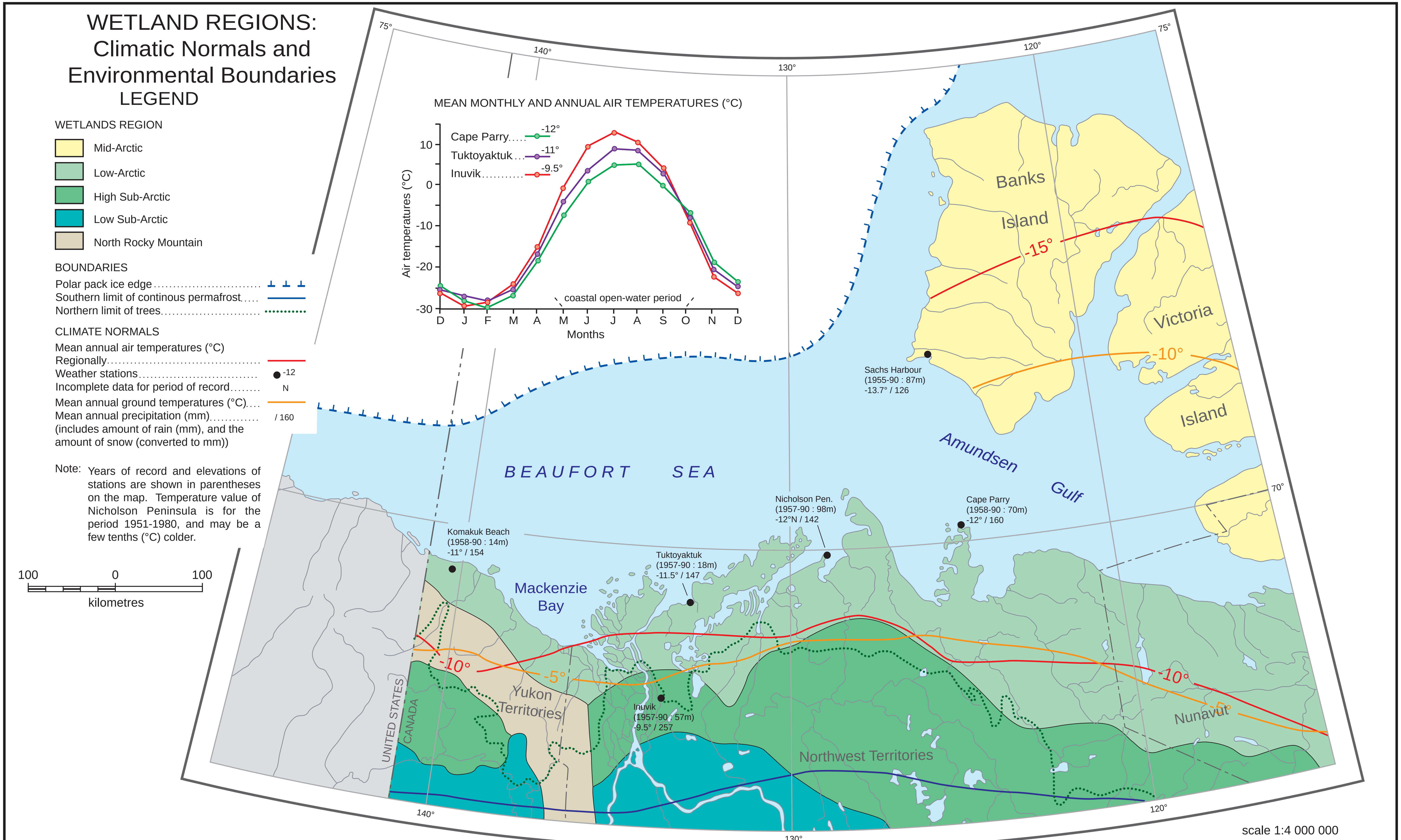


Fig. 6-2. Wetland regions: climate normals and environmental boundaries.

Island. In these wetlands ground temperatures are approximately 5°C warmer than air temperatures, and range from interpolated values of -8°C to -12°C in a south-to-north direction. The -10°C isotherm for ground temperatures is also an interpolated value, and extends across southern Banks and central Victoria islands. Continuous permafrost underlies this entire wetland region, which lies about 300 km north of treeline, and is under the direct and nearby influence of polar-ice winds. Land coverage consists of fens and polygonal development, with marshes along the coast and shallow water in low-lying areas elsewhere.

The Low Arctic wetland region is less arid than its northern neighboring region, but is drier than the Sub-Arctic wetlands to the south. Total precipitation at Komakuk Beach in the western part of the region is 154 mm, and ranges to 176.5 mm at Cape Young in the eastern portion; intermediate values are given for coastal stations from Tuktoyaktuk to Clinton Point (see map). The Low Arctic wetland region lies mostly within the -10°C to -12°C isotherms, based on temperature normals at Komakuk Beach (-11.0°C), Tuktoyaktuk (-11.5 C), Cape Parry (-12.0°C), and Clinton Point (-10.8°C). Ground temperatures are a few degrees colder everywhere, a finding which is interpreted from the -5°C isotherm which extends across this entire wetland region. This region also comprises an area that is generally underlain by continuous permafrost. The wetland surface includes lowland polygonal fens, some of which are occupied by pingos (see next overleaf). High and low coastal marshes and shallow water are also characteristic of this wetland region that lies north of treeline, except for a small area located about 40 km south of Eskimo Lakes.

The High Sub-Arctic wetland region is fairly cold with annual, mean daily temperatures ranging between -8 and -10°C. This is indicated at Inuvik where temperatures are around -9.5°C; in fact, this entire wetland lies south of the -10°C isotherm. Mean annual ground temperatures are colder than -5°C in the north, with slightly warmer values to the south. However, the boundary of continuous permafrost lies almost exclusively within this wetland region. The total amount of precipitation for the year is 257 mm at Inuvik, but is slightly less in the northern part and greater in the south. Almost the entire region lies south of treeline, except for an area in the extreme eastern portion. A distinctive zone of the High Sub-Arctic region lies west of the Richardson Mountains and it, too, is within treeline. Polygonal peat development is common within this region, together with occurrences of shallow water in the Mackenzie Delta; however, pingos are rare.

Low Sub-Arctic wetland regions occupy only a small portion of the Beaufort Coastlands. They are slightly warmer than other wetland regions in that the annual mean temperature is -4°C approximately. Correspondingly the annual mean temperature of the ground is close to 0°C, thus explaining the presence of the continuous/discontinuous permafrost boundary extending through the region in a general east-west trend. This boundary separates an area to the north that is underlain by continuous permafrost, from one to the south that is occupied by discontinuous permafrost. This High Sub-Arctic wetland region is wetter than the more northerly wetlands of the Beaufort Coastlands in that it receives 350 mm of total precipitation annually. Peat plateau bogs and fens are the characteristic wetland types for this region.

The North Rocky wetland region comprises the mountain wetland in the Beaufort Coastlands. It exhibits a vertical range of climatic influences because of the altitudinal factor, but is generally cool and moist. The annual mean daily temperatures are approximately -6°C in the northern part, and -4°C in the south. Ground temperatures, which are based on annual mean values, are slightly colder than -5°C in the north as indicated by the associated -5°C isotherm; however, they increase to positive values in the extreme southern portion of the region where the southern boundary of continuous permafrost crosses the region in an east-west trend. Thus, this region is almost entirely underlain by continuous permafrost. The total amount of precipitation, annually, has a considerable range in values; it is about 300 mm in the northern part, and approximately 450 mm in the south. Wetlands in this region comprise peat plateau bogs in the valleys and lower slopes, and generally small basin bogs and fens in the higher areas.

B.R. Pelletier
Map: after Canada Wetland Regions, National Atlas of Canada
Natural Resources Canada
Meteorological data: after Atmospheric and Environmental Services Environment Canada

CHAPTER 7
TERRESTRIAL PROCESSES

TERRESTRIAL PROCESSES

Physiographic Regions

The main physiographic regions around the southeastern Beaufort Sea were described by H.S. Bostock, according to the following divisions: Arctic Coastal Plain and Continental Shelf, Arctic Lowlands, Interior Lowlands and Cordilleran Region. These regions are segregated as shown in Figure 7-1 and described in the following account; however, other features such as Coronation Hills, Eagle Plains, Keel Range and Old Crow range are omitted in the descriptions.

The Arctic Coastal Plain

This narrow feature extends from Alaska eastward around the Beaufort coast, and then northward to the Canadian Arctic Archipelago where it terminates on Meighan Island (not shown on map). The entire Arctic Coastal Plain is characteristically low-lying, but has regionally distinctive features that warrant a further subdivision into three main segments as follows: Yukon Coastal Plain, Mackenzie Delta and the Island Coastal Plain.

In the west, the Yukon Coastal Plain commences at the Alaskan border and ends at the western edge of Mackenzie Delta. This Plain has elevations of 100 m in its western part, and a narrow width of 10 km where it lies between the mountain foothills and the coast. This portion of the coast comprises co-alesced deltas that formed by sediments deposited from mountain streams flowing from the south. In the eastern part of the Yukon Coastal Plain, the general elevation is greater and rises to 200 m. The coastal width is about 20 km and, thus, it is wider than its western part. Coastal sand spits and bars, thaw-flow features, and the undercutting and collapse of blocks along the coast are common in this portion of the Plain.

Mackenzie Delta is a major physiographic feature which has an elevation of 10 m at its southernmost point, and a surface that descends gradually to sea level at the Beaufort coast. It extends about 200 km along a northwesterly axis from Separation Point, and is generally 65 km wide but somewhat wider at the coast. Its surface is covered with innumerable small lakes, distributaries, cross-linking channels, and numerous pingos in the northern portion. Due to its uniformly low relief, thaw-flows are absent.

J.R. Mackay and V.N. Rampton have distinguished the land east of East Channel from the Delta on the basis of surficial cover; fine-grained Holocene sediments occur in Mackenzie Delta, and coarser-grained Pleistocene sands and gravel are more characteristic of Richards Island (and some outer islands) and Tuktoyaktuk Peninsula. New subdivisions include Richards Island on the northeastern corner of Mackenzie Delta, and the Tuktoyaktuk Coastlands (a name proposed by V.N. Rampton) to include the land east of East Channel. This feature would comprise Tuktoyaktuk Peninsula, and the area south of Eskimo Lakes extending to Cape Bathurst in the east and to Baillie Islands lying north of the Cape. Richards Island and the Tuktoyaktuk Coastlands contain numerous pingos, thermokarst lakes, and thaw-flow features. Higher relief also distinguishes these subdivisions from Mackenzie Delta in that relief to 60 m is observed on Richards Island and to 100 m, at the least, on the mainland where rolling hills are present.

The land boundaries of these subdivisions are easily visible on remote-sensing imagery. For example, a strong geological discontinuity can be observed along East Channel in both Seasat (synthetic aperture radar) and Landsat (false colour) imageries. The continuation of this boundary offshore from East Channel to the Beaufort Shelf can also be detected by these imageries, and confirmed by means of seismic reflection profiling. This undersea extension is observed on the east wall of Mackenzie Trough, where it is called Garry Trough.

The Island Coastal Plain

This feature, lying on the west coast of Banks Island, is part of the northern segment of the Arctic Coastal Plain. It, too, contains Pleistocene and older sands and gravels, and is characterized by the occurrences of rolling hills and physical features rising to 100 m.

Arctic Lowlands

These physiographic features are formed in terrain occupied by flat-lying or gently inclined Paleozoic and late Proterozoic sedimentary rocks. Occurring across the southern portion of the Canadian Arctic Archipelago, Victoria Lowlands is one of these features. Its surface tilts toward the southwest across Prince of Wales Strait from Victoria Island to Banks Island, a direction in which elevations decrease from 600 m to 100 m at a point where the terrain merges with the Island Coastal Plain. A variety of glacial deposits, drumlinoid ridges and belts of thick, rugged moraines occur on the surface of the Victoria Lowlands. Such ridges form irregular hills a few hundred metres high on both Banks and Victoria islands.

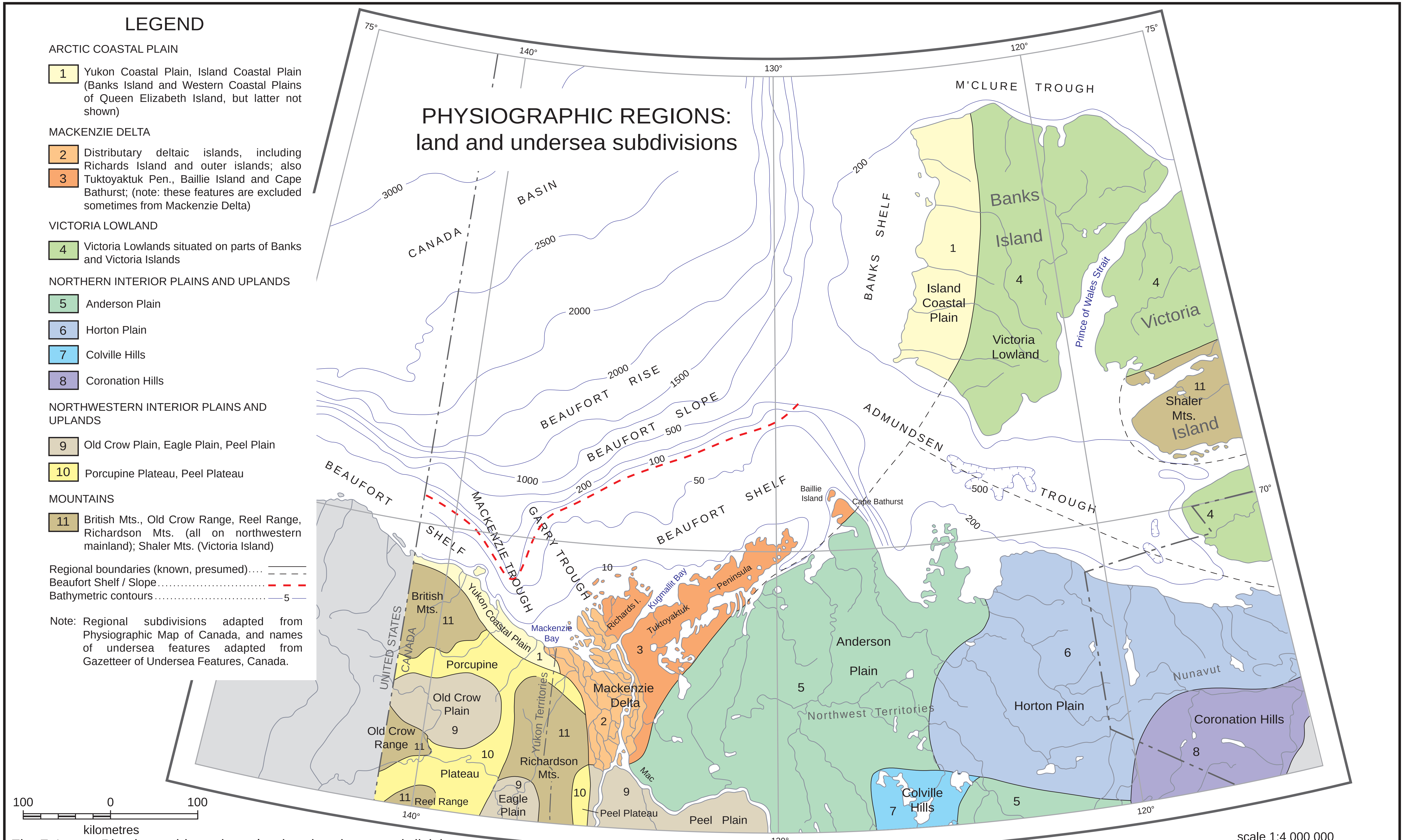
The Shaler Mountains are high hills that occur in the Arctic Lowlands, and rise to about 800 m in elevation above sea level. They are sufficiently remote from the Beaufort region to be excluded from influencing physical processes, but are dominant in an orographic sense in that they can influence coastal weather in the eastern Beaufort area.

Interior Plains

Lying between the Precambrian Shield to the east and the Cordillera to the west, the Interior Plains in northwestern Canada comprise Horton, Anderson and Peel plains, Colville Hills and Peel Plateau. The main slope, which permits drainage to flow directly to the Arctic Ocean, is formed by both Horton and Anderson plains. Horton Plain consists of flat-lying Paleozoic and Proterozoic sediments, and has elevations between 400 and 700 m. On the other hand, Anderson Plain is undulating and covered by glacial drift and outwash. It rises toward the south, although local relief varies from 200 m to 500 m of elevation and exceptionally to 800 m. Long meandering streams and small lakes of non-thermokarst origin occur throughout these plains but, in the north, numerous small thermokarst lakes dot the area. Elevations are sufficiently great to influences local weather, because of accompanying orographic effects.

Colville Hills consist of numerous ridges of Paleozoic strata, which rise above the surrounding plains to elevations of nearly 800 m. Some intervening physiographic hollows contain large lakes that occur within the ridge-like web, and are about 15 km or more in width at elevations of 250-300 m.

Peel Plain is a broad feature about 300 km in length along a northwest-southeast axis, and almost half as wide. In the west, the elevation is about 130 m and rises to 500 m in the east. Mesozoic sedimentary strata underlie the southwestern part of Peel Plain, and Paleozoic rocks form the hilly region in the northern and eastern portions.



PHYSIOGRAPHIC REGIONS: land and undersea subdivisions

LEGEND

ARCTIC COASTAL PLAIN

1 Yukon Coastal Plain, Island Coastal Plain (Banks Island and Western Coastal Plains of Queen Elizabeth Island, but latter not shown)

MACKENZIE DELTA

2 Distributary deltaic islands, including Richards Island and outer islands; also
3 Tuktoyaktuk Pen., Baillie Island and Cape Bathurst; (note: these features are excluded sometimes from Mackenzie Delta)

VICTORIA LOWLAND

4 Victoria Lowlands situated on parts of Banks and Victoria Islands

NORTHERN INTERIOR PLAINS AND UPLANDS

5 Anderson Plain

6 Horton Plain

7 Colville Hills

8 Coronation Hills

NORTHWESTERN INTERIOR PLAINS AND UPLANDS

9 Old Crow Plain, Eagle Plain, Peel Plain

10 Porcupine Plateau, Peel Plateau

MOUNTAINS

11 British Mts., Old Crow Range, Reel Range, Richardson Mts. (all on northwestern mainland); Shaler Mts. (Victoria Island)

Regional boundaries (known, presumed)....
Beaufort Shelf / Slope............................
Bathymetric contours............................ 5

Note: Regional subdivisions adapted from Physiographic Map of Canada, and names of undersea features adapted from Gazetteer of Undersea Features, Canada.

Fig. 7-1. Physiographic regions: land and undersea subdivisions.

Peel Plateau comprises large steps which rise from the east toward the Richardson Mountains in the west, and is bordered by the Mackenzie Mountains in the south. General elevations of the Plateau are between 200 and 500 m, but rise towards the mountain borders. Some of the step surfaces are erosional, and truncate tilted Paleozoic and Mesozoic strata. Other step surfaces consist of nearly horizontal sedimentary beds. Evidence of glaciation, such as drift deposits and meltwater channels, is present.

Cordilleran Region

This region consists of mountain ranges, high-level plateaus and intervening low-lying plains. In the eastern Cordillera (see accompanying map) bedrock comprises folded sedimentary strata in the British Mountains of the northeastern part, and in the Richardson Mountains lying west of Mackenzie River and Delta to the southeast. The British Mountains lie close to the Beaufort coast, where they border the narrowest part of the Yukon Coastal Plain. At elevations of 2000 m, these mountains are highest near Alaska, where they have peaks about 2800 m high. On the other hand, the Richardson Mountains have a somewhat lower elevation, about 1500 m generally, but some rugged peaks reach heights of 1800 m.

The Porcupine Plateau lies like a saddle between the British Mountains to the northwest and the Richardson Mountains to the southeast. It extends to the highland areas in the south and west, which lie about 50 km south of the Arctic Circle. In the north, the general elevation of the Plateau is about 500-600 m, but its greatest relief is in the south where ridges occur at elevations of 800 m. The Porcupine Plateau descends to a piedmont that borders the Yukon Coastal Plain in the north, and to the unglaciated Old Crow Plain in the west at elevations of 300 m.

All Cordilleran features bear a significant orographic effect on local and regional weather patterns. The Cordilleran features in the north are transected by streams that debouch sediments into the Beaufort Sea and form coalescing delta plains, and other constructional forms such as spits and bars along the Yukon Coastal Plain.

Undersea Physiographic Subdivision

The continuation of the Arctic Coastal Plain offshore is manifested as the Beaufort Shelf, Banks Shelf and the Queen Elizabeth Shelf to the north (last named is not shown on present map). Arbitrary topographic boundaries separate the Beaufort Shelf, Slope and Rise, respectively; however, at depth of 2000-2500 m the Beaufort Rise slopes gently into Canada Basin to depths exceeding 3700 m.

Three major undersea depressions bear a physiographic significance to the Beaufort coastlands. Those features are as follows: (1) Mackenzie Trough, which extends as an ancestral valley of Mackenzie River to depths of 400 m, and receives a considerable amount of sediment from the Mackenzie River system; (2) Garry Trough, which transects the Beaufort Shelf along the east wall of Mackenzie Trough and which marks a distinctive geological discontinuity landward between Holocene sediments of the Delta, and Pleistocene and older sediments of both Richards Island and Tuktoyaktuk Peninsula; and (3) Amundsen Trough, which is U-shaped in cross-section, about 500 m deep and is receiving deltaic and coastal sediments transported by easterly longshore currents. Amundsen Trough is presumably an ancient fluvial valley that has been modified by Pleistocene glaciation, and later submerged.

Other minor undersea valleys transect the Beaufort Shelf, and are expressed as re-entrants along the bathymetric contours. Two of these are observable along the 50-m isobath, and lie directly north of Kugmallit Bay and McKinley Bay, respectively. All these undersea valleys together with the parallelism of the modern coastline and the bathymetric contours on the Beaufort Shelf, as well as the innate parallelism of the Beaufort Shelf/Slope break are apparent evidence of a previous Beaufort coastlands offshore. Seismic, sonic and drilling exploration have confirmed this evidence of an earlier coastland. Such a feature existed subaerially prior to a continuing Holocene, and perhaps earlier period(s) of submergence.

B.R. Pelletier
Geological Survey of Canada

Parts of Physiographic Map of Canada: H.S. Bostock
(Natural Resources Canada: formerly EMR Canada).

Bathymetry after The Canadian Hydrographic Service
(Fisheries and Oceans Canada).

Geological Setting

The area under consideration lies in the lower Mackenzie River region and embraces vast tracts of dissected lowlands east of the Mackenzie River mostly, and hilly to mountainous regions in the Richardson and British mountains west of the river. The Mackenzie River generally flows northwesterly, emptying into the Beaufort Sea and draining by far the largest part of the area. It is followed closely in size of drainage area by the Porcupine River in the Yukon, and the Anderson River in the Northwest Territories (see Fig. 7-2).

Bedrock underlying the area ranges in age from late Precambrian to Tertiary (see Legend on Geological Settings, map; Fig. 7-3). It is generally undeformed and flat-lying east of the Mackenzie River, and upturned to varying degrees in the mountains to the west. Time-stratigraphic units within the succession reveal significant gaps in the geologic record, so that continuity of these units across the area is commonly lost. Nonetheless, the rock succession has retained a wide variety of lithologies varying from weather-resistant, cliff-forming limestone and dolomite, to thick successions of recessive weathering, richly fossiliferous shale. Where flat-lying over wide areas, these rocks form plateaus, as in the country north and east of the Richardson and Mackenzie mountains; where upturned, the limestone and quartzite beds within them form ridges and ledges, strikingly outlining the bedrock folds and faults (Fig. 7-5a). One can readily imagine the development of structural and stratigraphic traps for oil and gas buried beneath the Mackenzie Delta, and the occurrence of resistant jointed quartzite or carbonate ridges for the quarrying of construction materials. The latter, however, are favored nesting sites for many species of birds; they are also favored for denning areas of many wild animals.

The rock succession across the area is readily divisible into ten time-stratigraphic units stacked one upon the other (see map Legend on Fig. 7-3) and is well dated by means of fossils or radiometry, so that it is possible to derive a time-stratigraphic map as shown in Figures 7-3 and 7-4. For engineering and/or environmental purposes, the units will be discussed in order from youngest to oldest.

The youngest time-stratigraphic unit is the Quaternary (Q), comprising unconsolidated mud, silt, sand and gravel. This unit covers, by far, the largest portion of the area from the coastal plain, to the Old Crow Plain on the south flank of the British Mountains. Except for gravel in the river beds, little of this unit is of economic value. In the upper Mackenzie Delta region between the settlements of Fort McPherson and Arctic Red River, both of which are immediately south of the map area of Figures 7-3 and 7-4, are large deposits of quartzite pebbles and cobbles that have been derived from the Precambrian Shield. These aggregates continue to be a source of road metal for the construction and maintenance of the Dempster Highway where it crosses the Peel and Mackenzie rivers.

Comprising mudstone, siltstone and sandstone, the Tertiary succession (T) is the highest (youngest) bedrock in the area. It occurs both east and west of the Mackenzie Delta and, despite its limited areal extent, is an important reservoir for oil and gas; it is also a source of low-rank coal in the northern Richardson Mountains. These latter beds are mildly deformed into north-dipping homoclines, making it readily available for coal exploitation and development.

Both marine and non-marine shale, sandstone and conglomerate comprise the Cretaceous time-stratigraphic unit (K). It is widely distributed both east and west of the Mackenzie River, being undeformed generally east of the River and highly folded and faulted west of it. Its ridge-forming character outlines the structural complications among the folds and fault blocks in the mountainous terranes, and the potential for quarrying constructional material in those area.

The Jurassic-lower Cretaceous unit (JK) is dominated by marine, richly fossiliferous shale interspersed with siltstone and sandstone. It occurs almost exclusively west of the Mackenzie River and was doubtlessly a primary source of hydrocarbons before being unroofed and the once-contained hydrocarbons lost to the atmosphere in late Cretaceous and early Tertiary times.

The Permian—Triassic time-stratigraphic unit (PT) embraces the boundary between the Paleozoic and Mesozoic Eras. It consists predominately of clastic rocks in the middle and upper part of the Permian System, and limestone in the middle and upper Triassic. Within the area covered by this atlas, the unit is confined to the Richardson and British mountains. The latter (Triassic) component is homotaxial with the Prudhoe Bay reservoirs north-central Alaska, but have been removed from the subsurface of the Arctic Coastal Plain prior to the deposition of the Jurassic-Lower Cretaceous rocks.

The Carboniferous unit (C), like the Permian-Triassic immediately above it, is confined to the mountainous regions. It is dominated by resistant, white weathering limestone that forms characteristically castellated ridges on the north and south flanks of the British Mountains; however, it is absent to the east in the Barn Mountains.

Unit DC, representing the Upper Devonian-Lower Cretaceous (in part) is dominated by both marine and non-marine clastic rocks, and is widespread in the lower Mackenzie River region as rhythmically interbedded siltstone and shale. It contains high grade anthracite coal in the British and Barn mountains.

Hornblende biotite granitic intrusions (Dg) of Late Devonian age occur locally as small patches in both the British and Barn mountains, and as massive bodies in the Old Crow Range south of the map area (Fig. 7-5b). Rocks of this unit (Dg) are moderately resistant, forming tors in the higher parts of the range. Perhaps the most widespread time-stratigraphic unit in the area is the Cambrian-Middle Devonian (CD), comprising a thick succession of highly deformed limestone and shale in the British Mountains, and a relatively undeformed, graptolitic, shaly limestone succession in the Richardson Mountains (Fig. 7-5c). East of these mountains, it is coeval with the thick limestone carbonate shelf deposits occurring around Inuvik and forming the sedimentary framework for the early and middle Paleozoic of the northern Interior Plains.

The oldest rocks within the area consist of a succession of well bedded mudstone and limestone in the core of the British Mountains, with scattered inliers on the south flank of the range and at Inuvik, immediately east of the Mackenzie Delta. The base of the unit, and correspondingly its contact with crystalline basement in the Inuvik area as determined from seismic reflection surveys, is at a depth of approximately 18 km. This would be the minimum thickness for the unit.

D.K. Norris
Geological Survey of Canada

Data from Norris, D.K. , 1985 . Geology of the northern Yukon and northwestern District of Mackenzie. Geological Survey of Canada. Geological Survey of Canada, Map 1581A, scale 1: 500 000

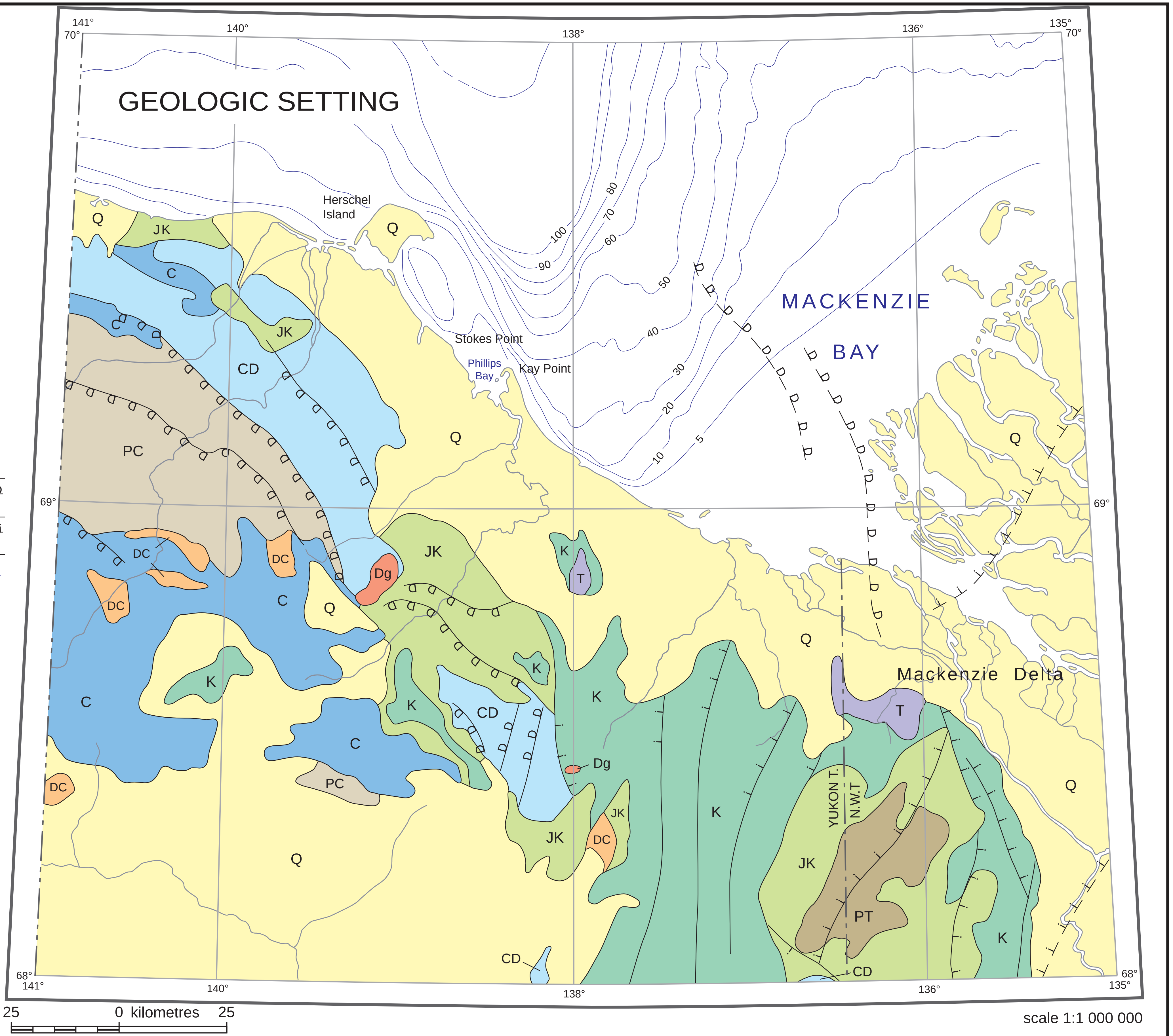
Fig. 7-2. Index map of geographical names for northwestern Canada.

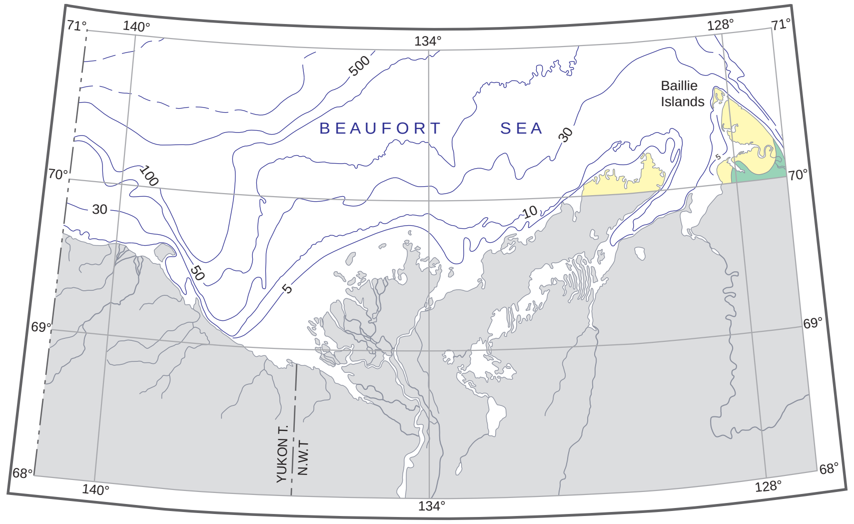
LEGEND

TIME - STRATIGRAPHIC UNITS: LITHOLOGY

- Q QUATERNARY: sand, silt and gravel; marine and non-marine
- T TERTIARY: mudstone, siltstone, sandstone and coal; marine and non-marine
- K CRETACEOUS: shale, sandstone, conglomerate and coal; marine and non-marine
- JK JURASSIC-LOWER CRETACEOUS: shale, siltstone and sandstone; marine
- PT PERMIAN-TRIASSIC: limestone, shale and sandstone; marine
- C CARBONIFEROUS: cherty, limestone and shale; marine
- DC DEVONIAN-CARBONIFEROUS: shale, conglomerate and coal; marine and non-marine
- Dg GRANOTOID INTRUSIONS: hornblende, hictite gneiss
- CD CAMBRIAN-DEVONIAN: limestone, dolmite and shale; marine
- PC PROTEROZOIC-CAMBRIAN: mudstone, limestone and volcanic conglomerate; marine and non-marine

Fault, contraction (known, inferred)
teeth show up thrust side ....
Fault, extension (known, inferred)
dot shows down thrown side ....
Anticline (arrows indicate dip direction) ....
Bathymetry (m) ....





Index map showing boundary of eastern and western portions of geological map, and northern portions of units Q and K (see LEGEND)

Fig. 7-3. Geological setting of the area.

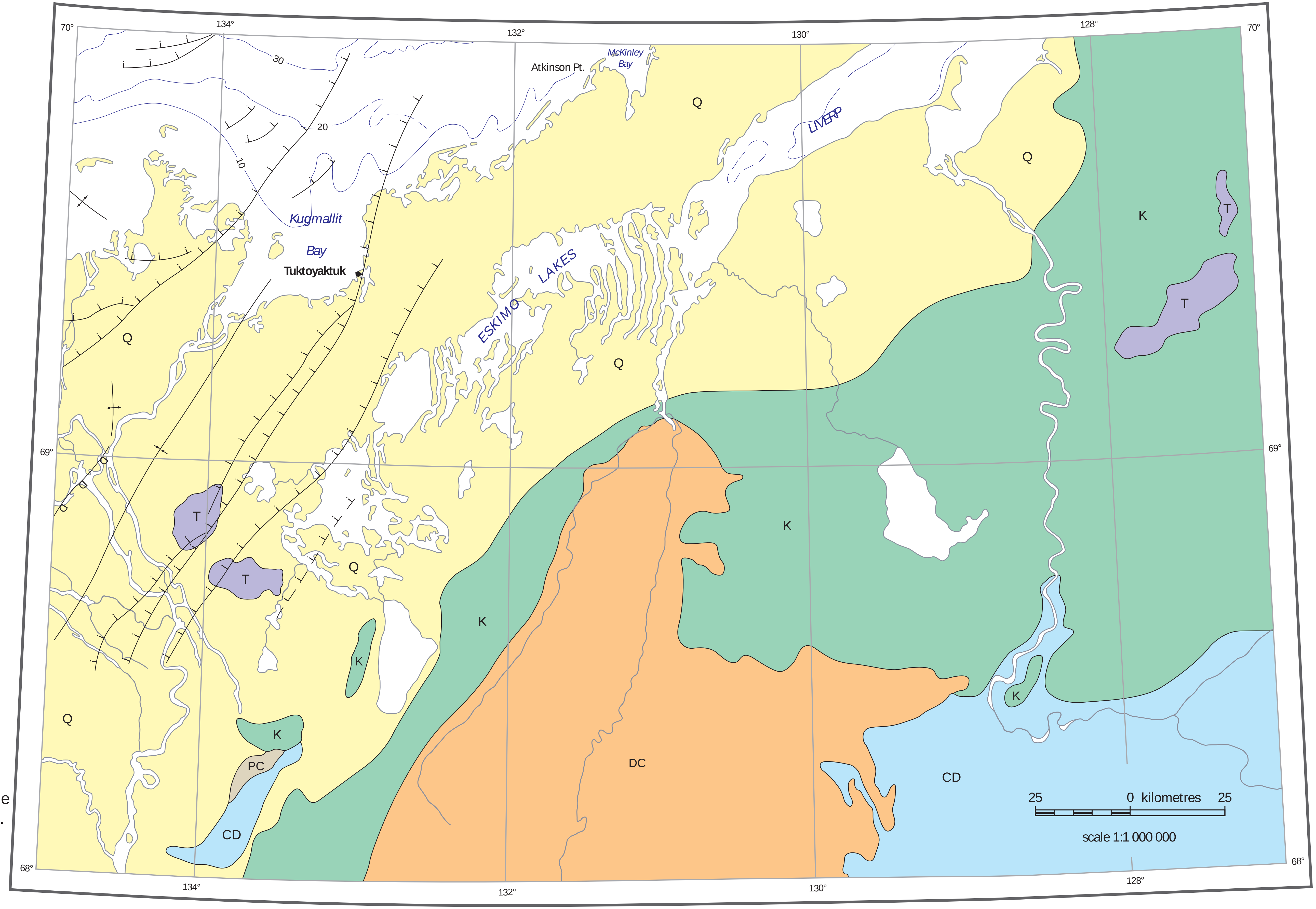


Fig. 7-4. Geological setting of the area (cont.).

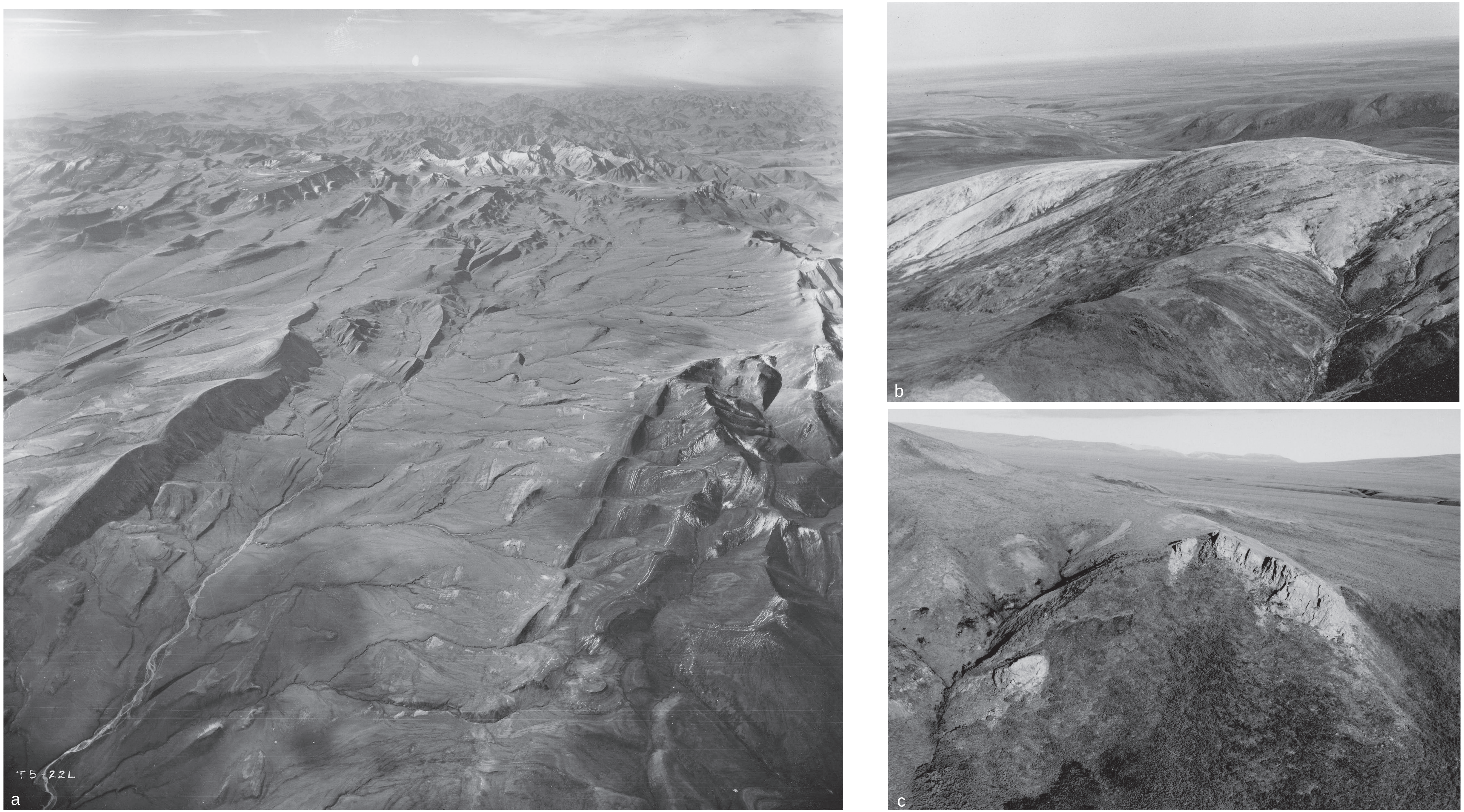


Fig. 7-5. a) Ridge-forming Jurassic and Lower Cretaceous clastics of the northern Richardson Mountains, with a resistant core of white weathering limestone and dolomite comprising the White Uplift. View is to the south (NAPL Photo T5-22L); b) Light-weathering granite of the Mount Sedgwick stock (335 Ma) hosted in Lower and Middle Paleozoic Road River Formation, northern Yukon Territory. View is to NE toward Trail River and Yukon Coastal Lowland in background (ISPG Photo 3566-2); and c) Pale orange weathering limestone of the Upper Shublik Formation resting with angular unconformity upon black cherty shales of the Lower and Middle Paleozoic Road River Formation on the north flank of the Romanz of Uplift (ISPG Photo 2421-206).

Late Quaternary Glaciation and Sea Level Trends

The extent of the Early and Late Wisconsinan glaciations (beginning about 80 000 and 32 000 years ago, respectively) are shown in Figure 7-6. On land, the indications of these glaciations comprise numerous topographic features such as meltwater channels, spillways, and eskers, together with the evidence of moving and eroding ice, which includes such features as hummocky moraines, drumlins, grooving and other lineations. The surficial till deposits are corraborating evidence of the passage of ice sheets over the Beaufort Coastlands. As well, exotic boulders that are present within the glacial deposits, are evidence of the great distances travelled by these huge ice sheets. The signs of long transportation such as facetted sides and worn edges that are present on the boulders, can be observed in river beds and banks, as well as wave-eroded beach and cliff deposits. The entire range of sedimentary particle sizes, from clay to boulders, is present in eskers and moraines that occupy most of the coastlands.

East and south of the area, similar evidence is present, which demonstrates that glaciers advanced from the vicinity northwest of Hudson Bay. These glaciers continued to grow and spread as massive tongues of ice until they spanned most of the northern part of the continent of North America, and reached thicknesses of 2-3 km. These growing ice tongues comprised the Laurentide ice sheet, which spread to the front ranges of the Rocky Mountains; here they abutted montane glaciers flowing from higher elevations. The continental glaciers moved northerly and westerly across the Northern Plains and the southwestern portions of the Canadian Arctic Archipelago toward the Arctic Ocean. On Figure 7-6, the limits of glacier advances are shown, and they include those of the all-time glacial maximum and the Wisconsinan.

Permafrost

Permafrost is a thermal phenomenon occurring in rocks or soils in which the temperature remains at or below 0°C for long periods of time. According to the former Permafrost Subcommittee of the National Research Council of Canada, the minimum period extends from one winter, through the following summer, and into the next winter; most permafrost has existed for much longer times than this minimum, however. At temperatures below 0°C, most of the moisture in the soil occurs as ground ice. Because this ice usually exists at temperatures close to its melting point, thawing is likely to take place as ground temperatures rise. This ground ice occurs as structure-forming ice, *viz,* segregational ice, intrusive ice, reticulate vein ice, ice crystals, and icy coatings on soil particles. Ground ice occurs also as large bodies of more-or-less pure ice, of which three main forms are recognized. All three forms, pingo ice, ice wedges and massive ice, occur within the Beaufort Coastlands. They are discussed in subsequent articles, under the titles of Massive Ice, and Pingos.

Controls on Permafrost

Temperature is the main control on the occurrence of permafrost. Permafrost can exist only in areas where the equilibrium temperature, between the amount of heat lost from the ground in winter and that gained from the atmosphere in summer, plus geothermal heat, remains continuously below 0°C. With regard to subsea occurrences, the permafrost is largely relict, having formed during a period of widespread sea level lowering during the glacial maxima of the Quaternary Period when large areas of the continental shelf, which extended beyond the Laurentide Ice Sheet, were exposed to the intense cold of a glacial climate. During inter-glacial and recent post-glacial times, the exposed shelf has undergone submergence by a cold Arctic Ocean and the subsea permafrost has been preserved (Fig. 7-7).

Beneath the land areas, especially Richards Island and the Tuktoyaktuk Peninsula, the permafrost body is both relict and contemporaneous, in that the upper part of the permafrost is more or less in equilibrium with the climate of the last few decades to centuries, whereas the basal part of permafrost developed during the much colder climate of the glacial era. These events of glaciation and exposure to glacial conditions also affected the development of surface features on the land, with the development of kettle lakes and deranged drainage. Those features were the precursors of a thermokarst topography that exists today. Interestingly, shallow, offshore, seismic profiling records have revealed evidence of a thermokarst development on the Beaufort Shelf.

The upper part of the ground, above the permafrost consists of a soil cover that thaws each summer and refreezes each winter. This is known as the active layer and, strictly, it is not a part of permafrost; it is discussed further in a subsequent account, the Active Layer. The depth to the base of permafrost, and therefore its thickness, is controlled, however, by the balance between the heat emanating from the interior of the earth and the cold atmospheric conditions at the surface of the ground. In Figure 7-7, depths to the base of permafrost have been interpreted as contoured values. These values are derived from borehole data that extend from the ground surface to below the base of permafrost, both on land and beneath the sea. Permafrost thickness ranges from a few tens of metres in the northern portion of Mackenzie Delta and adjacent Mackenzie Trough beneath Shallow Bay, to more than 700 m beneath the Beaufort Shelf and adjacent Richards Island.

Climatic control of permafrost is illustrated further in ground-temperature profiles obtained from Richards Island. The minimum ground temperature near the surface along the Beaufort Sea coast of Richards Island is about -14°C; this increases to -10°C at depths of 12 to 14 m, and this temperature is then maintained, with depth, throughout most of the thickness of the permafrost body, rising to 0°C at the base of permafrost at depths of 700 to 750m. At Tununuk, on southern Richards Island, beside the modern Mackenzie Delta, where discontinuous permafrost occurs, ground temperature data are available from the Imperial Oil Company's Reindeer well. Here the coldest ground temperature is about -8°C and the temperature increases with depth until the 0°C isotherm, which defines the base of the permafrost, is reached at a depth of about 300m. Proceeding southward across the various zones of permafrost, positive ground temperatures are reached at progressively shallower depths. On another note regarding temperature control, annual fluctuations of air temperature may be reflected in ground temperature profiles, but are generally subdued and not readily apparent beyond 10 to 15 m depth.

Other controls on the distribution of permafrost and the nature and extent of associated ground ice include variations in latitude, altitude, climate, topography, geology and vegetation. Colder climates prevail at higher altitudes and more northerly latitudes. Topographic features, such as slope aspect and slope angle, affect insolation, depth of thaw, and runoff and hence moisture content. Taliks, or bodies of unfrozen ground within permafrost, are found beneath rivers and lakes. Vegetation affects permafrost conditions primarily by trapping snow, particularly in areas of heavy growth and abundant trees, and this partially insulates the uppermost permafrost from extreme winter temperatures.

Different geological formations have different thermal properties. For example, rocks with a low thermal conductivity are characterized by shallow permafrost; the same is true for unconsolidated sediments. Different soils, due to a textural control, may contain more moisture than others, which also leads to the development of different amounts of ground ice in the permafrost. Fine-grained soils, such as

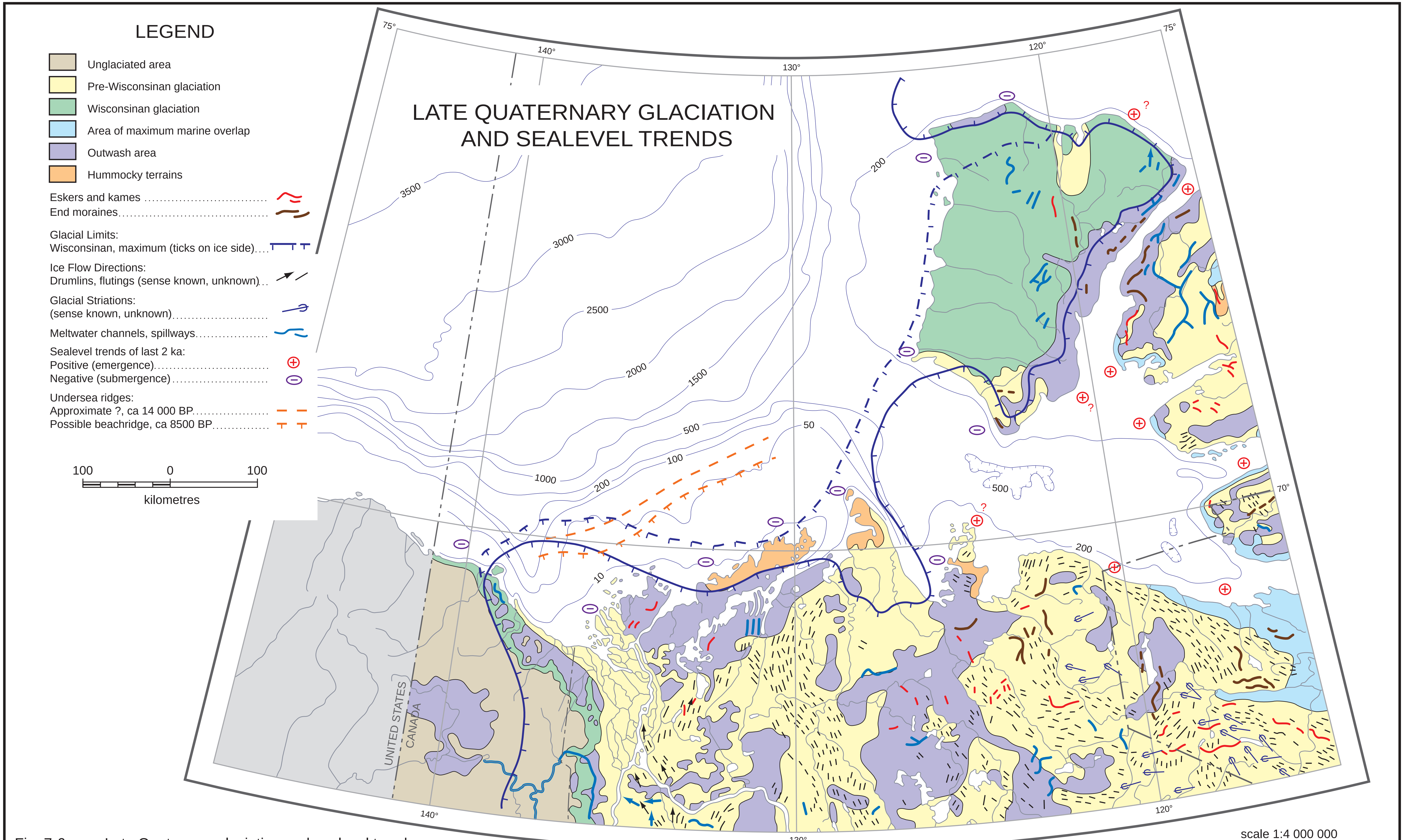


Fig. 7-6. Late Quaternary glaciation and sealevel trends.

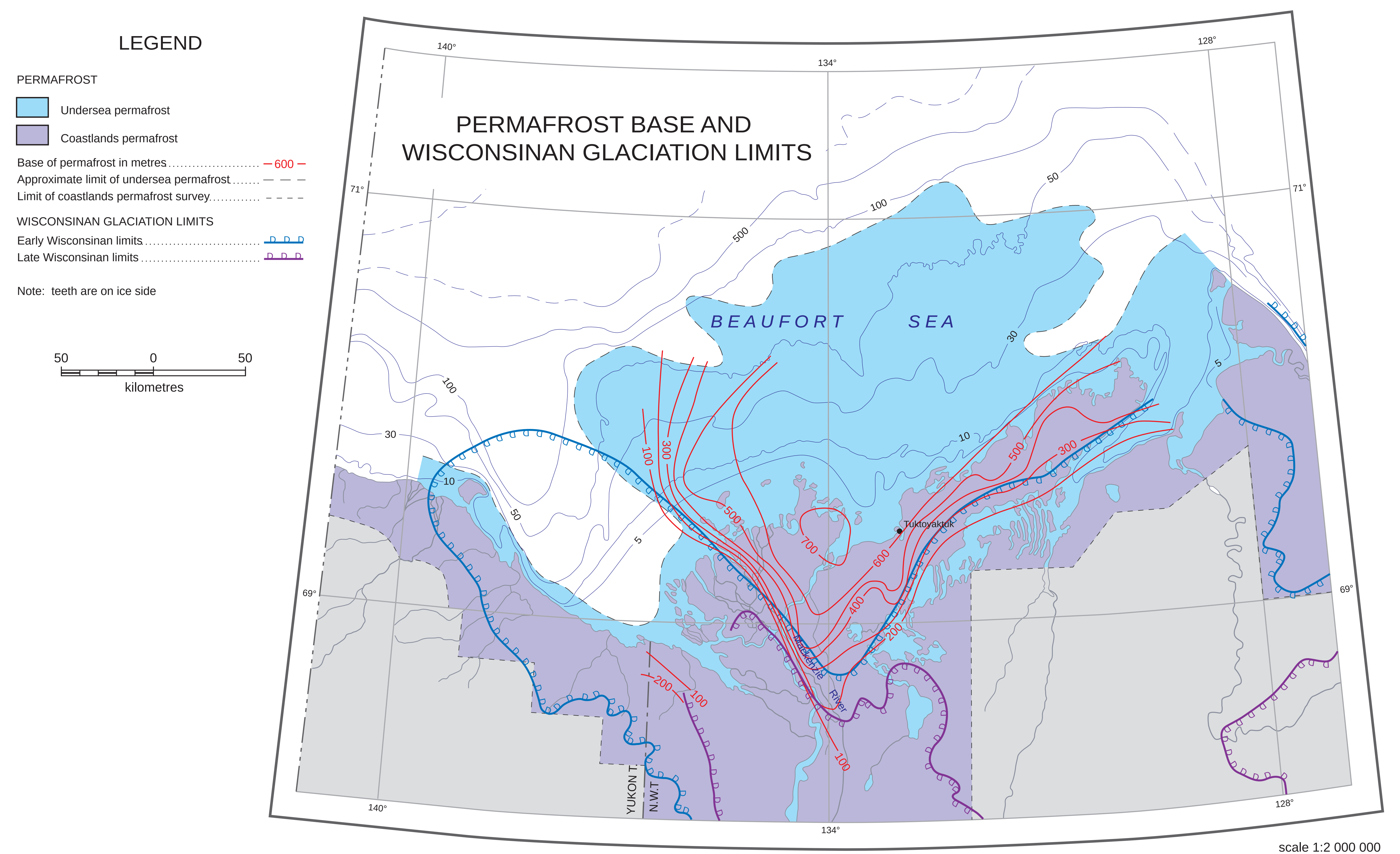


Fig. 7-7. Base of permafrost in the Mackenzie Delta region and the Wisconsinan Glaciation limits.

those rich in clays and silt, and organic soils may contain significantly more ground ice than coarser-grained sandy and gravelly soils. This may be observed directly in layered sediments in which ice lenses tend to develop near the base of fine-grained sediment beds and above the top of coarser beds. On the other hand, reticulate vein ice commonly forms a network of ice veins within the body of clayey soils that have an admixture of silt.

From the standpoint of hazards it is important to realize that the most ice-rich permafrost tends to occur in the uppermost part of the ground which is, coincidentally, the working zone for engineering and construction projects.

Extent of Permafrost

Permafrost conditions are described conveniently in terms of the spatial extent of permafrost, the amount of ground ice within the permafrost, the forms in which the ground ice occurs, and the temperature and thickness of the permafrost body itself. The details of permafrost and ground-ice conditions have been summarized largely from engineering geology field mapping by staff of the Geological Survey of Canada with others, including Survey field officers, carrying out surveys and reviews on Quaternary geology and ground ice. Deep ground temperatures and permafrost thicknesses are derived from boreholes drilled mainly by the petroleum industry during the 1970's and later, and shallow ground temperatures were compiled from a number of reports on engineering and scientific research sites, and from numerous data sets at the Geological Survey. Information on saline permafrost was included in some of these permafrost reports. The terminology used follows generally the recommendations of the former Permafrost Subcommittee of the National Research Council of Canada.

The geographic extent of permafrost in Canada includes almost half of the nation's landmass, primarily in the northern regions and at higher elevations in the western mountains. Certain undersea areas, such as the southeastern part of the Beaufort Sea and the channels of the Canadian Arctic Archipelago, are also underlain by permafrost. In Figure 7-8, almost the entire land area of the Beaufort Coastlands and the Beaufort sea continental shelf are underlain by permafrost. Exceptions are those areas of taliks or unfrozen ground beneath large lakes and rivers, and beneath the Mackenzie Trough. The distribution of permafrost is described in terms of four distinct classes, as follows:

- continuous permafrost (>90% of land areas underlain by permafrost)
- extensive discontinuous permafrost (65-90%)
- intermediate discontinuous permafrost (35-65%)
- sporadic discontinuous permafrost (10-35%)

A fifth class, isolated patches of permafrost (0-10%), is not present in the map area. Adjacent undersea occurrences of permafrost are also indicated, and are classified similarly on the accompanying map (see inset).

Ground-ice content is described in terms of the proportion, by volume, of structure-forming ice (segregation ice, intrusive ice, reticulate ice veins, ice crystals, and icy coatings on soil particles) in the uppermost 5 to 10m of the ground. Three classes are used, with the following approximate percentages by volume of ground-ice: high (>20%), medium (10-20%), and low (<10%). As mentioned previously, ground ice also includes relatively pure ice such as ice wedges, pingo ice and massive ice. These are accounted for separately.

The four main categories of permafrost occurring in the land areas Beaufort Coastlands, together with their thicknesses, ice contents and ground temperatures are as follows:

Continuous Permafrost

Continuous permafrost is ubiquitous within the map area, except for ground beneath the modern deltas of the Mackenzie and other rivers, river valley floors, and beneath shorelines and offshore spits and bars. Thus, permafrost occurs essentially everywhere beneath exposed land surfaces. Taliks (bodies of unfrozen ground within permafrost) occur beneath thermokarst depressions, river channels, thaw lakes and recently drained lake basins. Ground ice is widespread and extensive, occurring as structure-forming ice and, also, as larger bodies of more-or-less pure ice (ice wedges, pingo ice, and massive ice). Structure-forming ice commonly exceeds 10% by volume of the permafrost, and can be much higher. Permafrost thickness varies considerably across the region, from as little as 100m to more than 740m (see Fig. 7-7). The thickest permafrost is in the area of northeastern Richards Island and the adjacent offshore area. The basal part of the permafrost in these areas is, of course, relict. The permafrost becomes thinner both to the southwest beneath the Mackenzie Delta, and to the southeast beneath the Anderson Plain and adjacent uplands. The thinner permafrost is associated with those areas that were covered by the Laurentide Ice Sheet of the Late Wisconsinan substage. Thermal conductivity of the sediments also has a great effect on the thickness of permafrost. Ground temperatures within continuous permafrost are controlled strongly by site locations and conditions. At sites remote from large bodies of water and from modern deltas, these temperatures are between -7° and -9°C.

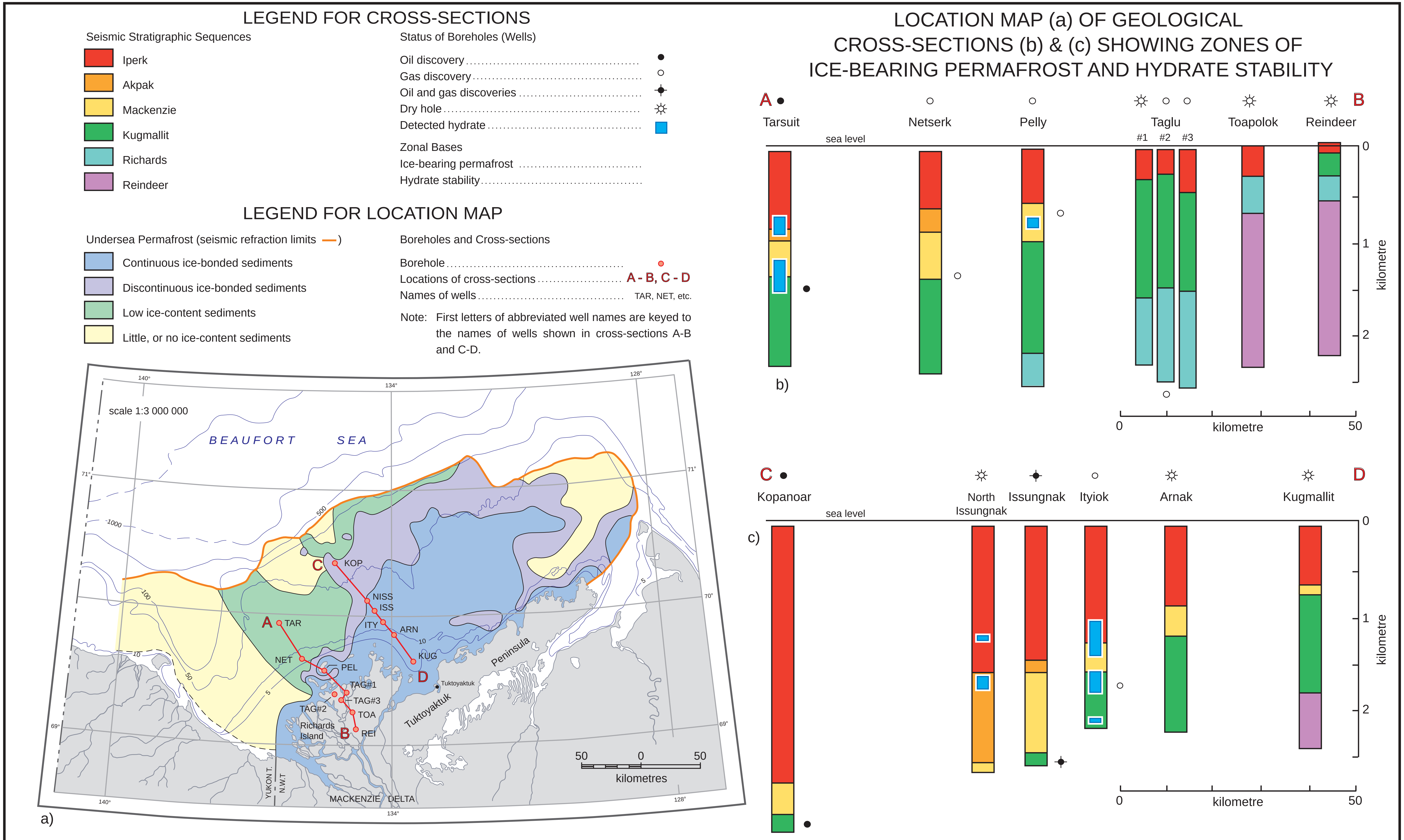
Extensive Discontinuous Permafrost

Small areas of extensive discontinuous permafrost exist in alluvial deposits beneath the flood plains of the lower reaches of the Horton and Mason rivers in the eastern part of the map area, and beneath the Babbage River and several creeks in the western part. In these sites, taliks exist beneath the rivers and flood plains, and the ground-ice content is low to moderate (<20% of the volume of permafrost), occurring mainly as structure-forming ice and ice wedges; massive ice may also occur at depth. No specific data on permafrost thickness or temperature are available for any of these river valleys.

Intermediate Discontinuous Permafrost

Beneath the modern deltas of the Mackenzie and other rivers, discontinuous permafrost is only intermediate in extent; that is, it is thought to underlie about half the exposed land area. The content of ground ice in these areas is also low to moderate (<20% by volume); the ground ice, itself, occurs as thin seams, lenses and reticulate veins. Ice wedges also occur, although they are not very widespread. Data on the thickness of this class of permafrost are available only for the modern delta of the Mackenzie River (next overleaf). The thickness rarely exceeds 100m and at several sites is considerably less. Permafrost temperature data are also available for several sites within the modern Mackenzie Delta where the mean ground temperature is between -2°C and -4°C (see second overleaf).

Sporadic Discontinuous Permafrost



Note: First letters of abbreviated well names are keyed to the names of wells shown in cross-sections A-B and C-D.

Fig. 7-8. a) Location map of boreholes (wells) and cross-sections, and boundaries of undersea permafrost; b) cross-section A-B; and c) cross-section C-D.

Permafrost is only sporadic in extent where it is found beneath the beach deposits, spits and bars of the Beaufort Sea shoreline. At depth, however, relict permafrost occurs, similar to that beneath the continental shelf, and this may be more or less continuous in extent. In the beach deposits, ground-ice contents are nil to low (<10% by volume). What little ground ice that exists occurs as thin seams, individual crystals and coatings on sand grains. Thickness of permafrost beneath these shoreline areas is highly dependant on their specific location. Beneath the spits lying east of Hooper and Pullen islands, to the of Richards Island, permafrost is more than 600m thick; however beneath the spits immediately to the west of Shallow Bay, the thickness of the permafrost is less than 100m. As with the case of continuous permafrost, the ground temperature is also controlled by regional factors.

Ice Wedges, Massive Ice and Pingos

As noted, ground ice occurs as large bodies of more-or-less pure ice, in addition to the structure-forming ice. The Tuktoyaktuk Peninsula and adjacent areas contain the world's largest concentration of pingos; more than 1450 occur in an area 120km long, by 50km wide. Massive ice and ice-cored terrain, also, are widespread in the Beaufort Coastlands. It is thought that much of the higher ground in the Pleistocene Mackenzie Delta, particularly Richards Island and the Tuktoyaktuk Peninsula, owes its elevation to the presence of thick, extensive, tabular sheets of ground ice. Ice wedges occur widely throughout the region, generally as intersecting networks of frost polygons or ice-wedge polygons. Any widespread melting of massive ground ice would lead to extensive ground surface subsidence, which would significantly alter the landscape and adversely affect engineering and transportation facilities.

Environmental Problems

On land, permafrost and, more particularly, ground ice present special problems regarding activities for engineering and economic development. In this area, ground ice is generally near its melting point, and is therefore susceptible to surface disturbance and slope failure. In fine-grained, high ice-content ground, any surface disturbance commonly leads to the development of thermokarst, extensive subsidence of the surface, and the subsequent growth of thaw lakes. On slopes, deeper thawing leads to slope failures that initially occur in the form of skin-flows or failure of the active layer. If such shallow slope failures expose massive ground ice, retrogressive thaw-slides or bimodal failures (i.e., two different failure mechanisms) can develop. Along the Beaufort Sea coast are sections of cliffed coastline that are formed in frozen, unconsolidated sediments. Along these coasts and river banks, such thermal niches can develop very rapidly under storm conditions in the late summer and fall.

Saline permafrost is known to exist at the settlements of Tuktoyaktuk and Inuvik, and also at sites on Richards Island. It has also been reported to occur at the settlements of Arctic Red River and Fort McPherson to the south of the map area, and at Paulatuk immediately to the east. It may be assumed that saline permafrost underlies other parts of the Beaufort Coastlands as well. The salinity of the ground is important because high salinities have negative effects on the mechanical properties (strength, creep, etc.) of the soil, and so may require modifications to engineering designs.

Implications of Global Warming

Continued global warming, with even a moderate rise of a few degrees of temperature, is highly likely to have far-reaching effects on permafrost throughout the world. A general warming will probably lead to the widespread disappearance of permafrost, particularly in those regions where ground temperatures are warmer than about -2°C. In the latitudes of subarctic areas, the marginal permafrost will be the first to disappear. As the mean annual ground temperature rises and its thawing isotherm progress in a northerly direction, increasingly greater areas of permafrost will vanish. Eventually, the disappearance of permafrost would be underway across the entire Beaufort Coastlands.

Such effects of global warming would create many alterations to the existing landscape, particularly in areas of abundant ground ice, which lie in the zone of discontinuous permafrost. The ground would undergo subsidence and dislocation, thus leading to failure of foundations and other engineering structures. Drainage would be altered such, that while some lakes emptied others would form. Thermokarst topography would develop in areas of ice-rich permafrost, because of the thawing process; also, landslide activity and erosion of river banks and coastal features would accompany the thaw, while the uppermost surfaces exposed to the harsh Arctic climate would undergo freezing so that new permafrost would form, at least temporarily. With increased global warming, however, the concomitant destruction of permafrost and subsequent alteration of the landscape would continue.

Another factor of permafrost disintegration to consider is the release of so-called greenhouse gases (methane, carbon dioxide, water vapour, etc.) to the atmosphere. Very large volumes of these gases are presently trapped beneath the permafrost or are stored within it (described later in: Gas Hydrates). They occur commonly in frozen peatlands and other wetlands; they may exist also as shallow accumulations of natural gas hydrates. In any case, they pose a hazard in the event of global warming because of their capacity to hold heat and to inhibit the latter from escaping the upper atmosphere. As global warming increases, so would the rate of release of these gases increase.

J. Alan. Heginbottom
Permafrost and ground ice data after GSC Map 1691A,
Permafrost and Ground Ice Conditions of Northwestern Canada,
Natural Resources Canada, 1992

Natural Gas Hydrates

Natural gas hydrates are ice-like solids that consist of gas molecules, such as methane which are enclosed within a cage-like structure of water molecules. Originally discovered in the laboratory of Sir Humphrey Davy in 1810, they exist in nature and are stable under certain conditions of temperature and pressure such as those found in the sediments within and beneath permafrost in the Beaufort-Mackenzie Basin. Very large amounts of gas may be stored as gas hydrate, because one unit volume of gas hydrate may store or release 160 volumes of methane during its formation or decomposition. Thus gas hydrates may contribute to future energy supplies, but they may also represent a significant source of greenhouse gas. This gas can be released to the atmosphere during hydrate decomposition in response to climate warming or to sea-level rise by contact with water of warmer than the mean annual air temperature. Gas hydrates also present a hazard during exploration drilling or hydrocarbon production because they can become unstable during the drilling or production process. Uncontrolled gas releases, blowouts, fires and instability of sediments at the well site may result without adequate safeguards. Knowledge of the distribution and behavioural characteristics of natural gas hydrates therefore is important.

Gas Hydrate Stability

Temperature data from deep bore-holes and precise temperature surveys in the upper few hundred metres of the ground have been used to map the region in which stable conditions exist for gas hydrates. The depth to the base of the hydrate stability zone is shown in Figure 7-9. In general, gas hydrate is stable to depths of up to 1500 m; the thickest zones occur beneath the Beaufort Shelf, northern Mackenzie Delta and Tuktoyaktuk Peninsula. A comparison of this map with that of the permafrost distribution offshore (Fig. 7-8) shows that the gas hydrate-prone zone is thicker in areas of ice-bonded undersea permafrost than in areas of little ice-bonded permafrost.

The Beaufort Shelf east of 136^{o}W remained ice-free during a 140 m lowering of sea level during the Wisconsinan glaciation and, due to the extremely cold climate, was exposed to lower temperatures than sediments that were either ice-covered or water-covered. Under these conditions a thick permafrost and gas hydrate-prone zone beneath the Beaufort Shelf developed. Over the past 27,000 years however, sea level has risen, and transgressed the Beaufort Shelf. This process probably led to warming and some decomposition of gas hydrate over an area 73,000 km^2 in extent and therefore, gas hydrate decomposition may be the partial cause of gassy sediments found at the sea floor in some areas. Evidence of warming of sea-floor sediments has been observed in the few temperature logs for offshore sites.

In onshore areas changes in surface conditions such as migration of river channels, formation or draining of large lakes change the temperature conditions of underlying sediments and thus the stability regime for gas hydrates and for permafrost. Deep regional ground water flow may have an influence on both the permafrost and gas hydrate distribution, particularly on the base. The aquifers are recharged in the British and Richardson mountains and ground water may flow to the northeast beneath the Yukon Coastal Plain and the modern Mackenzie Delta. Similar regional groundwater circulation, flowing from the Brooks Range and beneath the Alaskan Coastal Plain has been proposed for northern Alaska.

Gas hydrate is stable in sediments underlying approximately 97,600 km^2 of the Beaufort-Mackenzie region. The total volume of sediment contained within the stability zone is approximately 5.4 x 10^{13} m^3. Assuming a reservoir porosity of 10 to 20%, a maximum of 5.4 x 10^{12} to 1.08 x 10^{13} m^3 of hydrate could be stored in this area. Whether or not hydrate is present depends on the availability of a hydrate-forming gas within the stability zone.

Geophysical Evidence of Hydrates

Geophysical well-log data have been used to outline the occurrence of hydrate. Petrophysical characteristics of gas hydrate intervals may include high resistivity, very low sonic velocity with cycle skipping (due to thawing of ice or hydrate during drilling), low density, high neutron porosity and an enlarged borehole diameter on the calliper log, all of which are dependent to some extent on the drilling conditions. The presence of gas hydrate was confirmed further, using mud gas logs when available.

Gas hydrate has been detected with high reliability in 45% of offshore wells, and 14% of onshore wells (Fig. 7-10). Gas hydrate generally occurs at, and to greater depths in the offshore region than onshore. The mean base of the gas hydrate occurrence base in offshore areas is approximately 1300 m and about 800 m in onshore areas. Gas hydrate may be found in the upper 200 to 300 m in terrestrial sediments, but only at depths greater than 400 m at marine sites.

The gas hydrate distribution appears to be associated with the hydrocarbon reservoirs in the region. At the end of the Miocene, hydrocarbons that were generated during a period between the Middle Paleocene and Late Miocene migrated along faults into the younger rocks of the offshore area, and into the older rocks in the near shore and Mackenzie Delta area. In the offshore region hydrocarbons have been discovered in sediments of Oligocene and Miocene age, which consist of the Kugmallit and Mackenzie Bay sequences. These sedimentary formations are commonly in the gas hydrate stability zone within which gas hydrate has been detected (as shown in Fig. 7-8). These reservoirs may be found beneath the Iperk sediments, which are in excess of 1000 m in thickness. Gas hydrates, therefore, are often found in the lower part of the stability zone at offshore sites. At Mackenzie Delta sites, hydrocarbons have been discovered in the older Richards and Reindeer formations, which are of Eocene and Paleocene age. Hydrate only occurs at these sites where these formations are within the gas hydrate stability zone, which is not as thick as those sites in the offshore. Therefore, gas hydrate occurrence is less common at terrestrial sites.

Gas Hydrate Volume

In order to evaluate the potential of gas hydrate as an unconventional energy resource, it is important to estimate the gas hydrate volume and the amount of gas stored as hydrate and to determine the location in the geological sequences wherein the gas hydrate volume is concentrated. Although gas hydrate may be stable over a broad area and throughout a considerable thickness of sediment, the actual distribution of gas hydrate will depend on the geological history and stratigraphic environment; it is these factors that influence the availability of water and gas as well as and the locations of potential hydrate reservoirs. The geophysical evidence indicates that gas hydrate generally occurs in small layers less than 50 m in thickness within the gas hydrate-prone zone.

Preliminary estimates of gas hydrate volume have been made for the Beaufort-Mackenzie region from the analysis of geophysical data. The thickness of gas hydrate-bearing sediment has been determined at each well, but this point information must be extrapolated to the region as a whole. Because the distribution of wells is non-uniform this task is complicated. First, a weighted average of the thickness of gas hydrate-bearing sediment is determined using the proportion of the total regional area represented by each well.

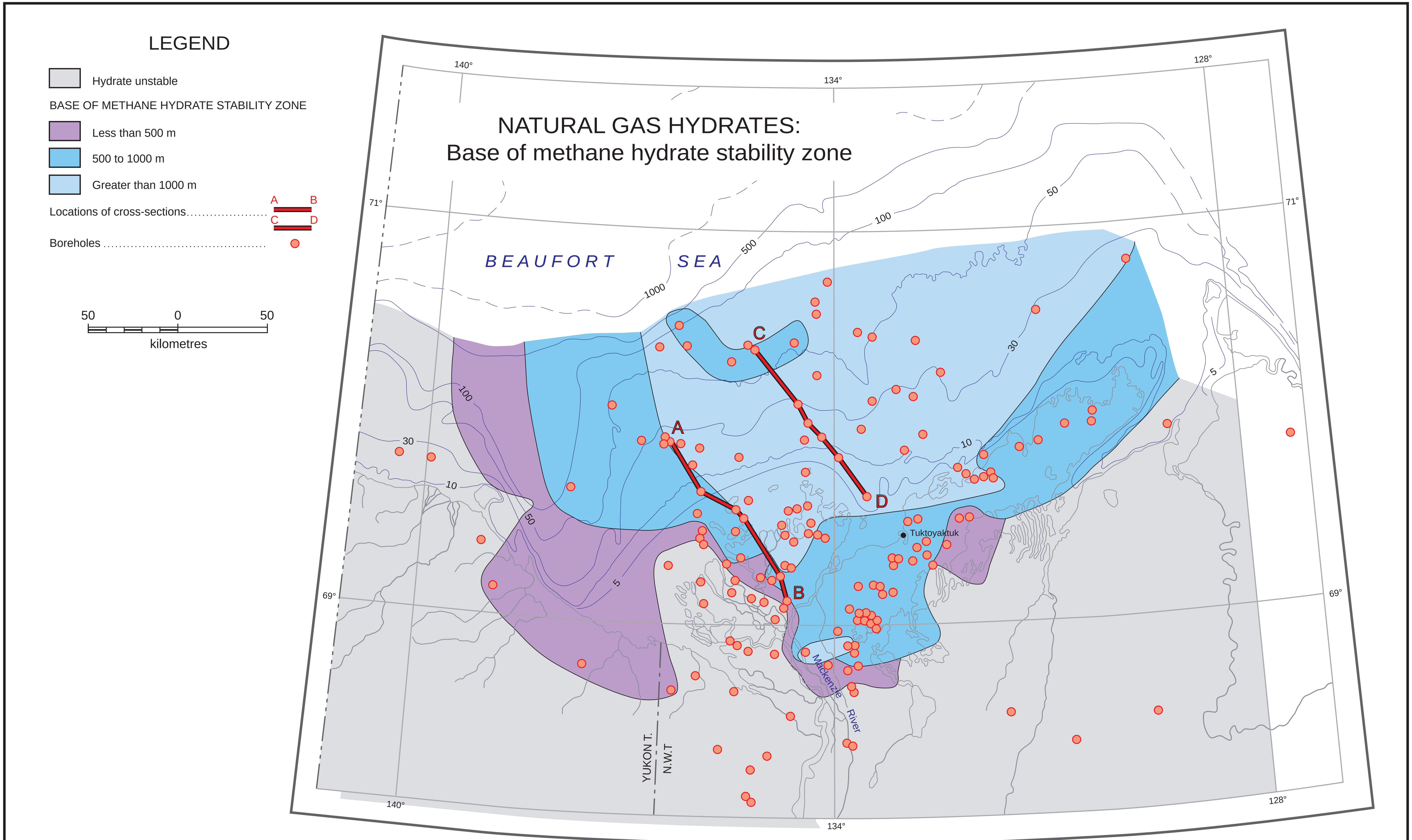


Fig. 7-9. Base of the methane hydrate stability zone.

scale 1:2 000 000

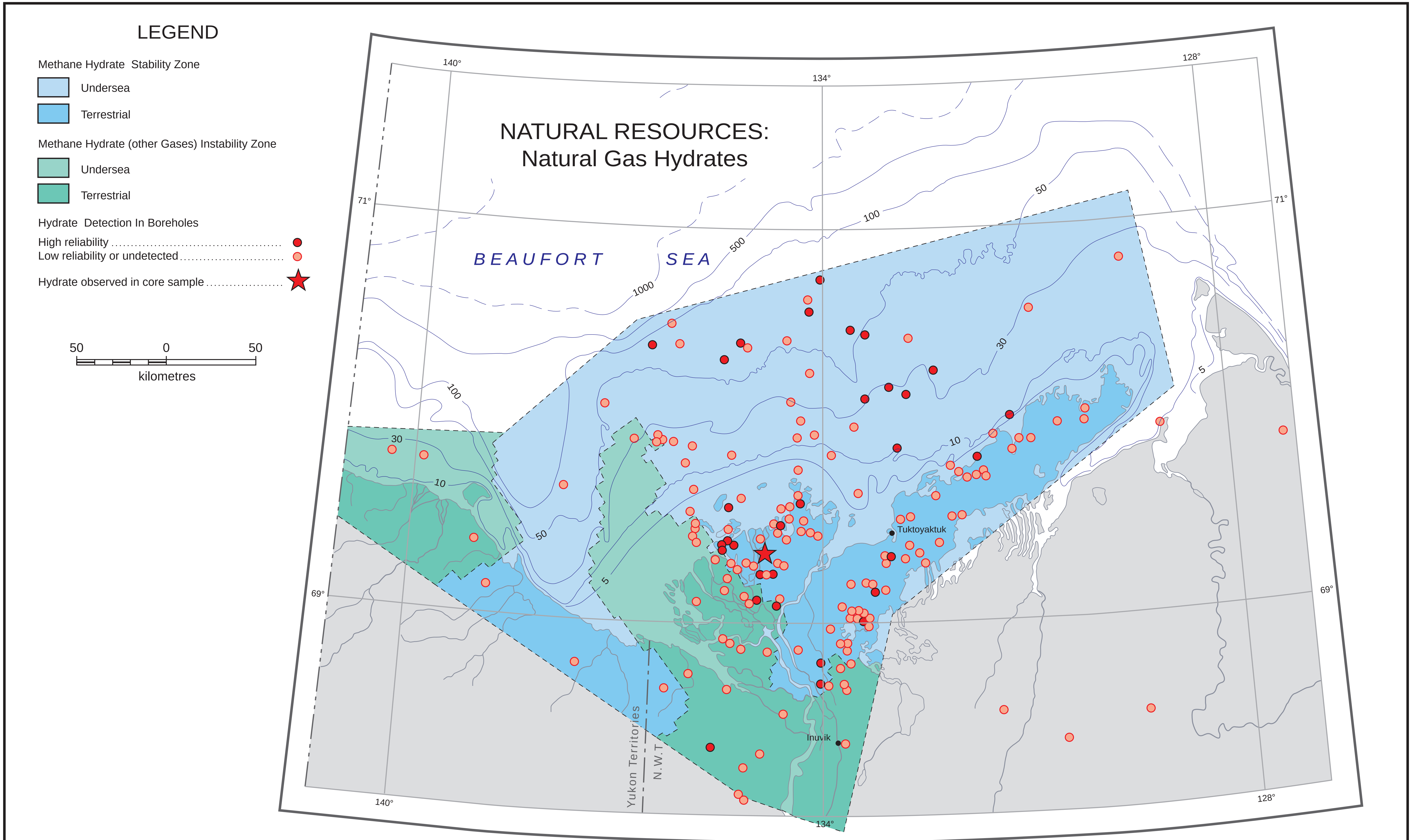


Fig. 7-10. The occurrence of natural gas hydrate in wells of the Mackenzie Delta.

scale 1:2 000 000

Information is then incorporated on the gas hydrate stability zone, the reliability of the well-log interpretation, and the reservoir porosity. Assumptions are made that gas hydrate saturated the pore spaces and that all hydrate cavities contain only methane. Therefore, the estimates probably represent upper limits.

The area over which gas hydrate presently occurs (see Fig. 7-11) is approximately 31,000 km^2, which is about one third of the gas hydrate-prone area. The present volume of gas hydrate-bearing sediment is estimated to be about 10^{13} m^3 and contains (assuming a porosity of 10 to 20%) between 1 x 10^{12} and 2 x 10^{12} m^3 of gas hydrate. Thus, the estimated amount of methane stored as hydrate is between 120 and 250 Gt. Most of this hydrate is concentrated in the offshore areas, where as much as 10^8 m^3 of hydrate per km^2 may be stored (Fig. 7-11).

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LEGEND

HYDRATE VOLUME/AREA (m^3 / km^2)

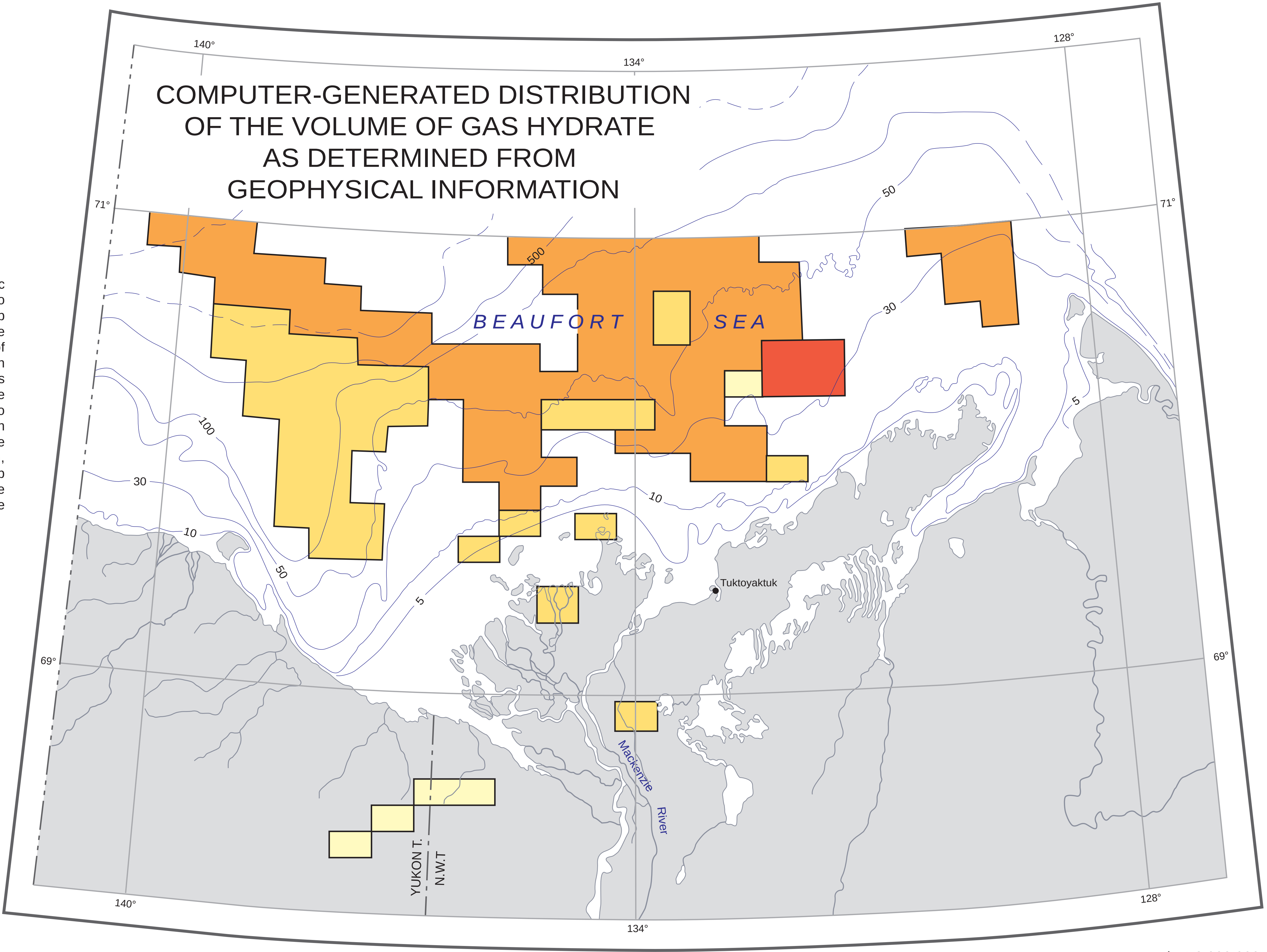
- 🟨 < 1 000 000
- 🟨 < 10 000 000
- 🟧 < 100 000 000
- 🟥 < 1 000 000 000

Drill hole sites are shown on the preceding map (opposite page). Reservior porosity of 10% is assumed.

Note: Statistical methods and GIS (Geographic Information System) have been used to apply information from well logs to map the spatial distribution of hydrate in the entire region. The thickness of hydrate-bearing sediment has been determined for each well site, and this information has been generalized to the region as a whole. This technique also incorporates factors such as information on the hydrate stability zone, the reliability of the well-log interpretation, and the reservior porosity. In the map so-produced, areas are outlined where hydrate accumlation is likely to be greatest.

50 0 50

kilometres



COMPUTER-GENERATED DISTRIBUTION OF THE VOLUME OF GAS HYDRATE AS DETERMINED FROM GEOPHYSICAL INFORMATION

Fig. 7-11. Computer generated distribution of the volume of gas hydrate, as determined from geophysical information.

scale 1:2 000 000

Massive Ground Ice

Massive ice is an occurrence of nearly pure ground ice that is at least 1m in thickness. Ice wedges, which are ubiquitous to many permafrost settings, are perhaps the best known form of massive ice (Fig. 7-12). However, a variety of forms can occur, with massive ice being observed frequently in shallow coastal sections, in boreholes and subsurface excavations. A rather striking characteristic of parts of the coastal areas of Richards Island and the Tuktoyaktuk Peninsula is that upland areas are often underlain by extensive bodies of massive ground ice that can be 10 or even 30 m thick. Two possible origins can be ascribed to these occurrences: (1) they may be buried remnants of glacial ice, or (2) segregated ice which has formed in place as part of the formation of the permafrost.

Buried Glacial Ice

Buried glacial ice is thought to be widespread in association with glaciofluvial sands and gravels which are found sporadically in the Beaufort Coastlands. These ancient deposits are the last northern remnants of the vast continental ice sheet that covered northern Canada up until about 13,000 years ago. In most settings glacial ice has been preserved and incorporated within the permafrost because this ice is mantled by a thick cover of glaciofluvial sand or gravel. The climate has remained relatively cold subsequent to deglaciation and this mantle has insulated the glacial ice from thawing. Scientists have reported buried glacial ice within the Ya Ya Lake esker system which tracks southwest to northeast across Richards Island. Similar deposits are found bordering Kittigazuit Bay and within the sand and gravel deposits used as granular sources near Tuktoyaktuk.

Segregated ice

The formation process of segregated ice can be complex and is related to freezing processes as permafrost aggrades downwards into underlying sediments which were previously thawed. Pingos or conical hills cored by massive ice are a striking form of segregated ice and perhaps the most unusual surficial features of the Beaufort Coastlands. These features, which can rise up to 50 m above the landscape and be several hundred metres across at the base, form when lakes naturally drain and permafrost aggrades into the water saturated lake bed sediments. When freezing takes place over the lake basin, pore water can be redistributed by the freezing processes and in some cases pressurized. As the basin continues to freeze the ground surface can be deformed upward by massive ice formation creating a natural mound on the landscape cored by massive ice. While the pingos of the Beaufort Coastlands are local tourist attractions because of their spectacular form and shape, they are not the most widespread occurrences of segregated ice. Extensive, continuous bodies of segregated massive ice occur beneath many of the flat topped hills inland of Tuktoyaktuk. Involuted Hill, located approximately 15 km east of Tutoyaktuk, is perhaps the best documented occurrence of segregated massive ground ice in the world (Fig. 7-13a). More than thirty boreholes (Fig. 7-13b) and extensive geophysical studies have revealed that a single continuous massive ice body is 20 m thick and cores the entire 0.75 km^2 hill (a staggering 15,000,000 m^3 of nearly pure ice).

Core samples from Involuted Hill (Fig. 7-13c and 7-13d) and examinations of a similar body of massive ground ice exposed by coastal erosion at Peninsula Point near Tuktoyaktuk have revealed that this type of massive ice most commonly forms between fine grained glacial till and a lower occurrence of clastic sands. It is envisaged that after glaciation permafrost aggrades into the thawed glacial till with the massive ice preferentially growing at the contact between the fine grained and coarse grained sediments. The upper contact of massive ice and the overlying till is generally parallel and conformable with the structure of the ice, as observed in the sedimentary banding. These contacts may be abrupt in certain cases, and gradual in others.

Periglacial processes associated with massive ground ice

While many bodies of massive ground ice are thousands of years old, periglacial processes associated with their formation and thawing are ongoing. Long term field investigations by the renown permafrost researcher J. Ross Mackay have addressed the geologic, hydrologic and climate controls on the formation of pingos and ice wedges in the Beaufort Coastlands. In more than a dozen scientific papers he has documented the full life cycle of pingos including the freezing processes triggered by lake drainage, the growth stages as the massive ice coring the pingos is formed, and their eventual demise as the thin sediment cover over the pingos is breached and they begin to thaw. His research has also resolved the processes controlling the formation of ice wedges which occur when surface water flows into vertical thermal contraction cracks.

The unique rheological properties of ground ice also mean that it can deform in unusual ways when it experiences differential loading. A 15 year study of hillslope deformation for instance has confirmed that the massive ice body at Involuted Hill is behaving as a glacier and is continuously deforming and creeping downhill at rates between 2 to 10 mm/yr. Indeed the name Involuted Hill was chosen because of the crenulated or ropey texture of the hill slopes resulting from gravity-induced creep of the massive ground ice. Similar processes can also happen when the weight of sediment covering a massive ice body changes. At Peninsula Point for instance, bands of sediment in the massive ice can be substantially deformed with distinct diapiric structures. These are thought to result from an upward deformation of the ice caused when the cover of till is removed by erosion or the formation of ice wedges (Fig. 7-12a).

Thawing or mass wasting of massive ground ice is an important consideration in some settings as it can cause unique landslide forms and greatly influence coastal and nearshore processes. Retrogressive thaw flow slides are often found on the Tuktoyaktuk Peninsula and Richards Island where lake and coastal erosion has exposed a massive ice body or icy sediments. These features generally have a near-vertical eroding faces that experience rapid thawing in the summer (Fig. 7-12). As the thawing continues, an apron of liberated water and saturated sediment accumulates at the base of the face and typically flows downslope as a liquefied mass. Because of sea level rise, the coastline of the southern Beaufort Sea is being transgressed causing ground ice bodies that were once beneath the land to be submerged beneath the sea. Sea floor settlement caused by thawing of buried ice bodies and the reduction of nearshore sediment volumes when ground ice erodes result in some areas of the coastline retreating much faster then would occur in a more temperate coastal setting.

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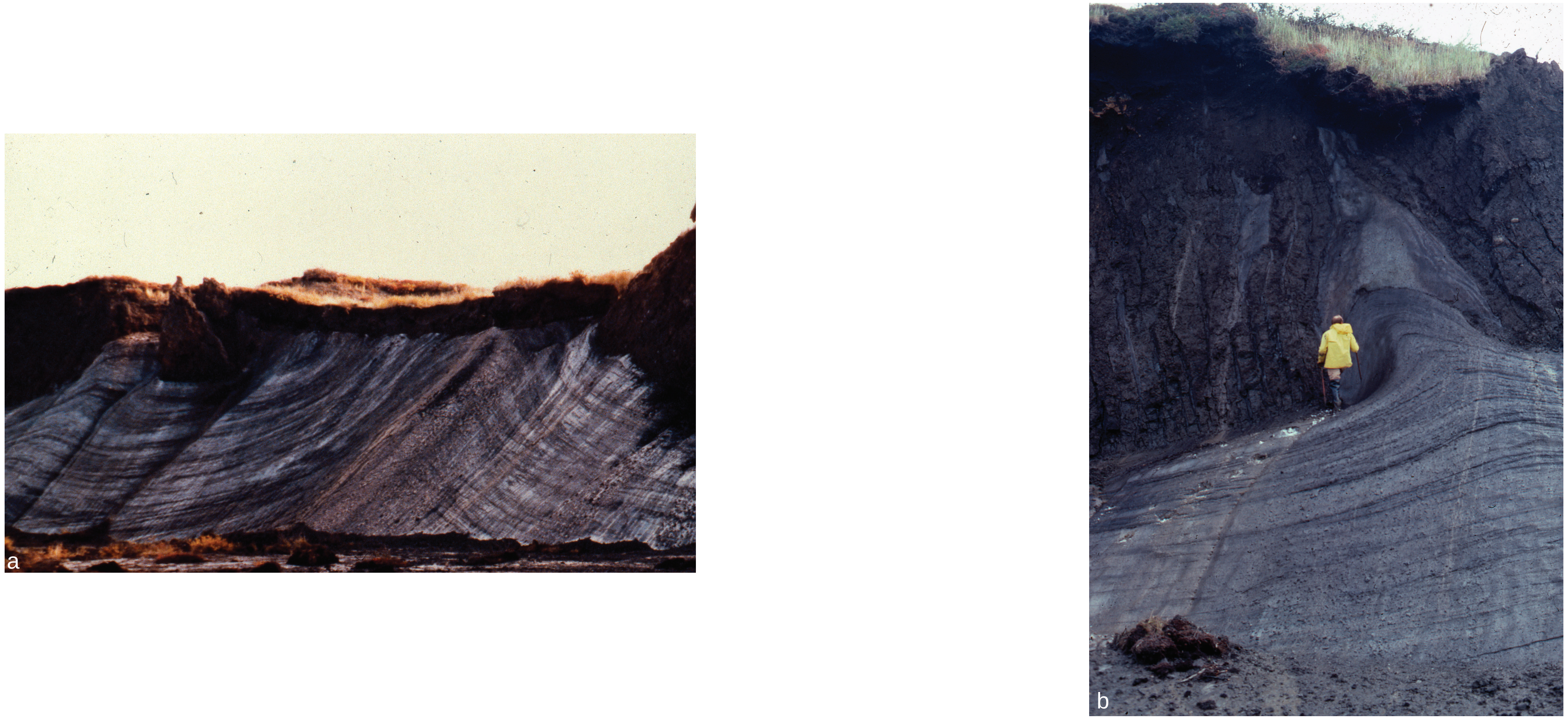

Figure 7-12. a) Exposure of massive intersedimental ground ice, Peninsula Point (height of exposure ~10 m) and b) massive intersedimental ground ice from same exposure showing involution caused by differential loading on the ice.

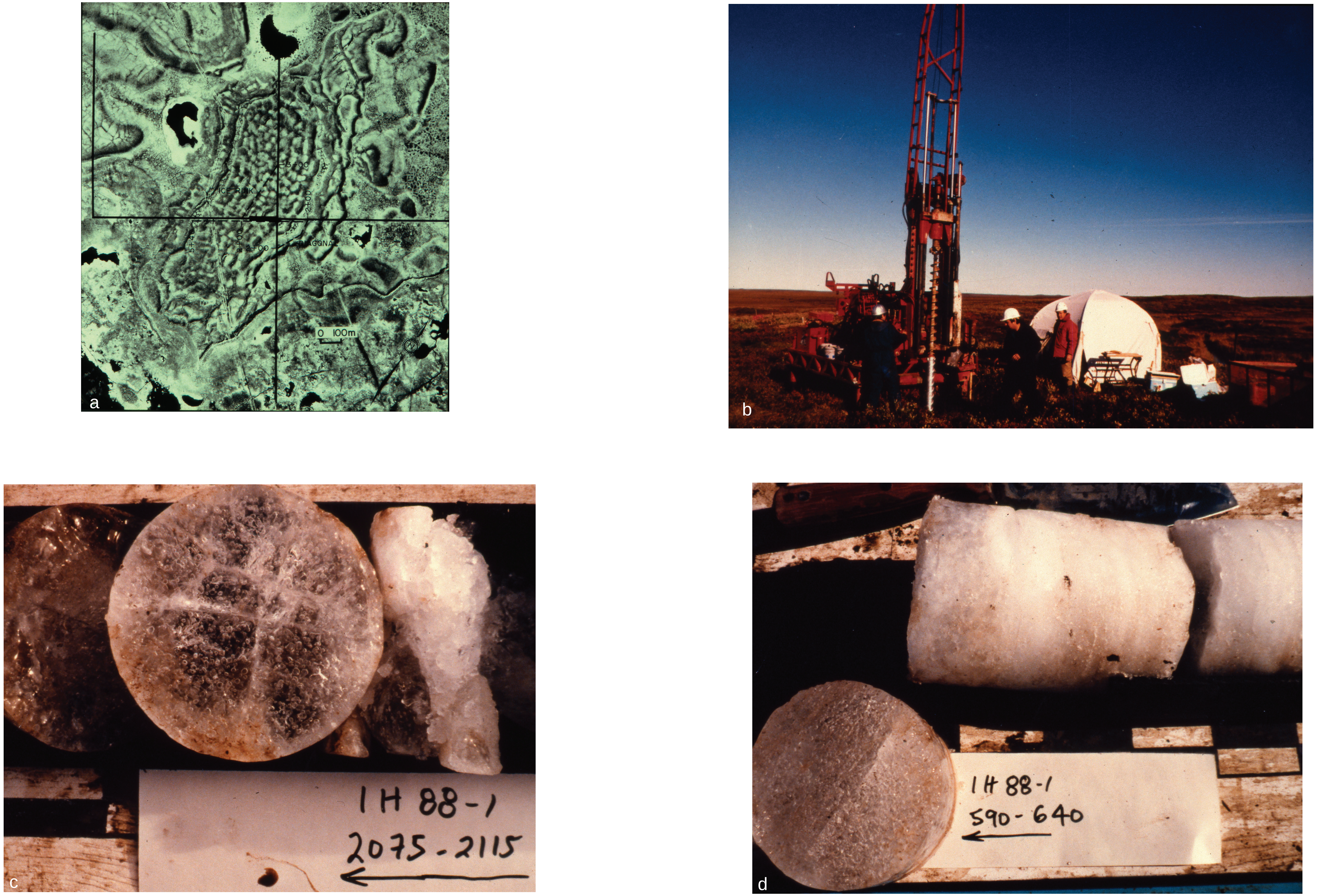

Figure 7-13. a) Vertical aerial photograph of Involuted Hill, Tuktoyaktuk Peninsula, showing unusual surficial character with concentric undulations parallel to slope. Subsequent instrumentation revealed this pattern is caused by downslope creep deformation of the massive ground ice; b) drill rig on Involuted Hill, collecting core samples; c) ore sample from 20.75 m showing clean, massive ground ice; and d) ore sample from 5.9 m showing clean, massive ground ice.

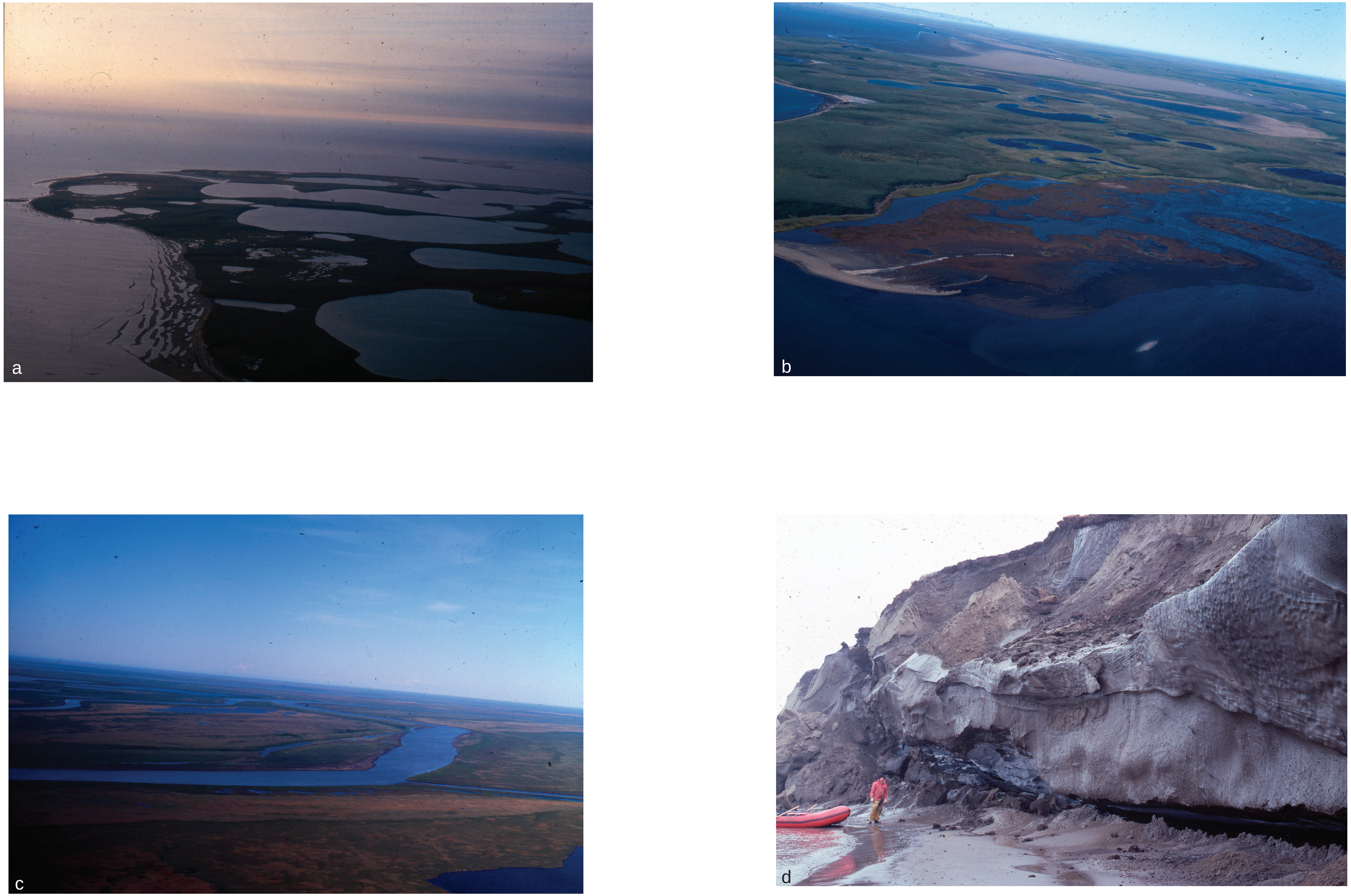

Figure 7-14. a) Oblique aerial photograph of northern Richards Island showing parallel coastal bar system and network of lakes breached by coastal erosion/sea level rise; b) oblique photos of depositional and erosional features in the outer Mackenzie River delta area; c) oblique photos of depositional and erosional features in the outer Mackenzie River delta area; and d) oblique photos of depositional and erosional features in the outer Mackenzie River delta area.

Pingos

Pingos are intrapermafrost features that are manifested on the landscape as conical, ice-cored hills that grow to 50 m in height and more than 300 m in diameter (Fig. 7-15 and 7-16). In the modern Mackenzie Delta, dimensions of the pingos are somewhat less. For example, they may be 8-20 m high, and perhaps 20-70 m wide. Some pingos occur in ridge-like forms, and may rise to 8 m and extend horizontally to 700 m; usually, they are half that length.

Generally pingos occur in areas formerly occupied by small, rapidly drained lakes or poorly drained channels. Depending upon topographic irregularities of the lake bed or channel, more than one pingo may grow in a single depression. This partly accounts for the growth of pingos in groups, or clusters; in some cases, pingo-like ridges may form. Shapes of pingos may be irregular, but are commonly oval or round. In cross-section they are asymmetrical with slopes ranging between 20 and 35 degrees and, exceptionally to 45 degrees. The conical profile of the pingo is rounded at top, except where the summit has been breached by the pressure of expanding ice. In such cases the ice cores are revealed, as well as the upturned strata that originally formed horizontal layers of soil and sediment associated with the beds of the previously drained basins (Fig. 7-17).

In terms of distribution, most pingos in the area occur along the Beaufort coastlands that are underlain by Pleistocene sands and silts lying east of the modern Mackenzie Delta. These pingos grow in clusters on Richards Island, along the Beaufort Sea coast to Cape Dalhousie, and on all sides of Eskimo Lakes. Professor J.R. Mackay estimated the occurrence of approximately 1400 pingos in this eastern and southern portions of the Beaufort coastlands (Fig.7-18). Holocene sediments comprising sands and silt occupy the modern Delta, the latter of which is the location of at least 80 pingos; several more occur just west of the Western Channel toward the Yukon border. Additionally, many pingos are found in partially eroded states in the distal islands of Mackenzie Delta on, and in the vicinity of Ellis Island.

Offshore more than 200 undersea pingos, also known as pingo-like features or PLF for short, have been mapped by the Canadian Hydrographic Service during the decades of 1970 and 1980. Locations of several of these undersea pingos, and their relationships to sea-floor morphology and coastal oceanography, are also depicted in Figures 7-19 and 7-20. The residual current direction along the coast indicates both the probable flow direction of warm water and the transport direction of sediment discharged from the Mackenzie River. A broad , 35-km wide zone of warm, less saline coastal water is created when southerly offshore winds blow this water (the so-called Mackenzie cell) seaward. This action partly inhibits the growth of pingos on the coastal sea floor. Thus, it is the combined factors of oceanography and meteorology which contribute to the absence of pingos in this offshore area.

The origin of pingos in the Beaufort coastlands is intimately associated with old lakes and channel beds. Lakes may drain because of shoaling as a consequence of river-bank erosion and the breaching of nearby lake borders, and the subsequent infilling with sediments. In the lakes along the coast, rapid drainage is effected by means of coastal retreat impinging upon, and breaching the lake borders lying contiguously with the sea coast. In any case, indigenous permafrost aggrades toward the centre of the lake bed and expels pore water ahead of it. At this stage, the basal perimeter of the pingo is frozen and established. The change in volume of the freezing pore water initiates doming of the lake bed and, with continued expulsion and freezing of this pore water, ice begins to grow peripherally within the dome. Because the pore water is under increasing hydrostatic pressure, it begins to rise vertically as it follows the path of least resistance. Upon freezing, an ice core is formed at, or near the centre of the dome. Ice accretion within the dome is upwards as well as sideways, thus enhancing the conical aspect of the growing pingo and establishing its mature form. In this final stage of growth, the overburden on the summit tends to rupture because of the increasing accretion and expansion of ice within the dome. This process forms tensional cracks in the overburden and, eventually, a breached summit.

Mature pingos may take up to 1000 years to grow, with an annual growth rate of 0.3 m per year in the early stages. They may last for a period of 5000-6000 years, particularly in permafrost with a protective covering of soil and vegetation. However breaching of the summit may expose the core, and thermal degradation of the ice may ensue. Continued thawing leads to eventual collapse, and an annular ridge forms about the fallen summit. This ridge may also be surrounded by water, or an old lake bed, and it is possible for a new pingo to form at this site.

Life expectancy of pingos along the sea coast may be reduced by processes exclusive of breaching and accompanying decay due to thermal factors. With further coastal retreat, because of erosion or rising sea level, mechanical disintegration commences from the hydrodynamic action of waves and currents in the shore zone. This destruction is accelerated by continued thawing as the ice is exposed to solar heat. Additionally, the warmer water (0-9°C) of Mackenzie River flows past these exposed cores at sea level, and decay by thermal action is enhanced. All pingos in these coastal waters disappear, and pingo growth is absent.

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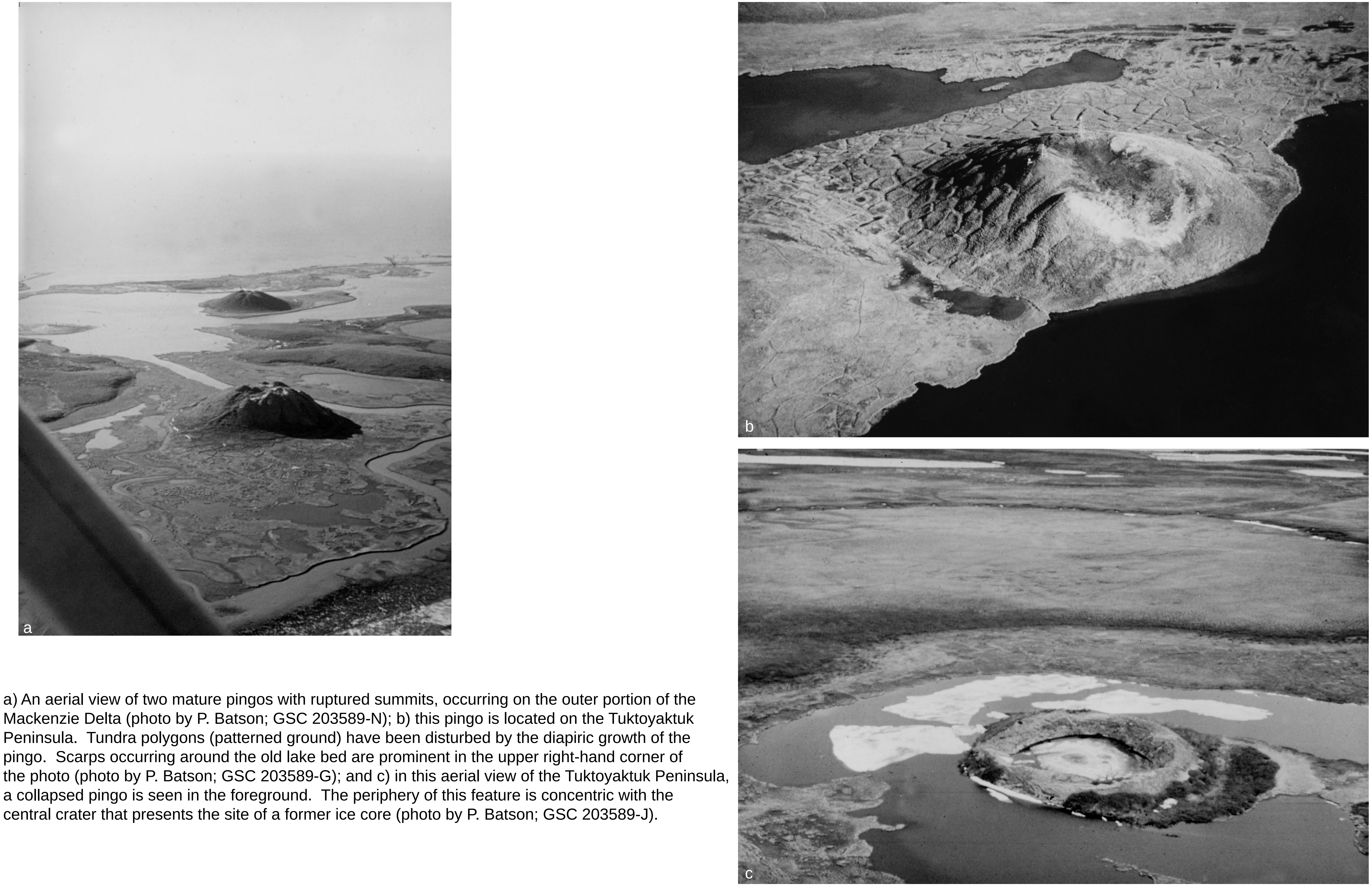


Fig. 7-15. a) An aerial view of two mature pingos with ruptured summits, occurring on the outer portion of the Mackenzie Delta (photo by P. Batson; GSC 203589-N); b) this pingo is located on the Tuktoyaktuk Peninsula. Tundra polygons (patterned ground) have been disturbed by the diapiric growth of the pingo. Scarps occurring around the old lake bed are prominent in the upper right-hand corner of the photo (photo by P. Batson; GSC 203589-G); and c) in this aerial view of the Tuktoyaktuk Peninsula, a collapsed pingo is seen in the foreground. The periphery of this feature is concentric with the central crater that presents the site of a former ice core (photo by P. Batson; GSC 203589-J).

Fig. 7-16. a) A mature pingo occurring in coastal waters lying off the northern part of the Tuktoyaktuk Peninsula. A fringe of driftwood lies around the basal perimeter of the pingo, and indicates earlier wave activity such as a possible storm surge (photo by G.D. Hobson); b) this view from the Beaufort Sea shows topographic profiles of two nearly symmetrical rising above the low, level coastal plain (photo by P. Batson); c) a partially submerged pingo is shown in the centre of the photo. It is undergoing erosion by wave action, including undercutting and block failure, and ice-melting from the thermal action of solar energy (photo by P. Batson); and d) This partially submerged pingo in the Beaufort Sea north of the Tuktoyaktuk Peninsula is completely surrounded by the sea. With time and a continuously rising sea, relative to the land, this pingo will be completely inundated (photo by P. Batson).

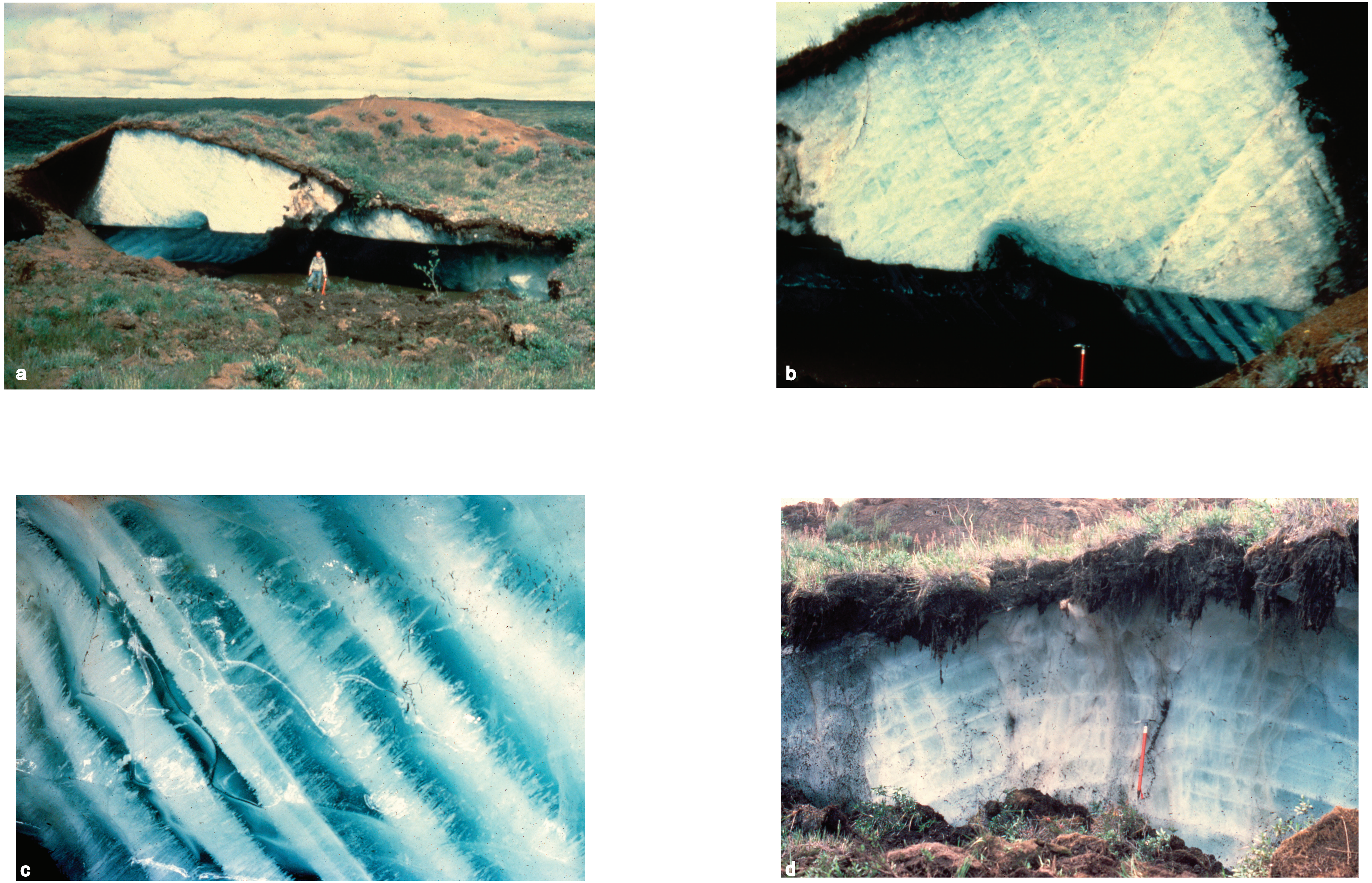


Figure 7-17. a) Oblique aerial photograph of Roger Pingo, Tuktoyaktuk Peninsula. The core of massive ground ice was exposed after catastrophic drainage of a small pond that had formed inside of the pingo (note under cut niche formed by a pond); b) Photograph of pingo ice from same site. Note sub-vertical banding in the ice caused by oriented bubbles in the ice. The banding is thought to indicate the annual growth pattern of the ice when the pingo was in its growth phase; c) detailed photograph of annual growth bands showing bubble trains formed transverse to the heat flow; and d) detailed photograph of annual growth bands at the apex of the pingo.

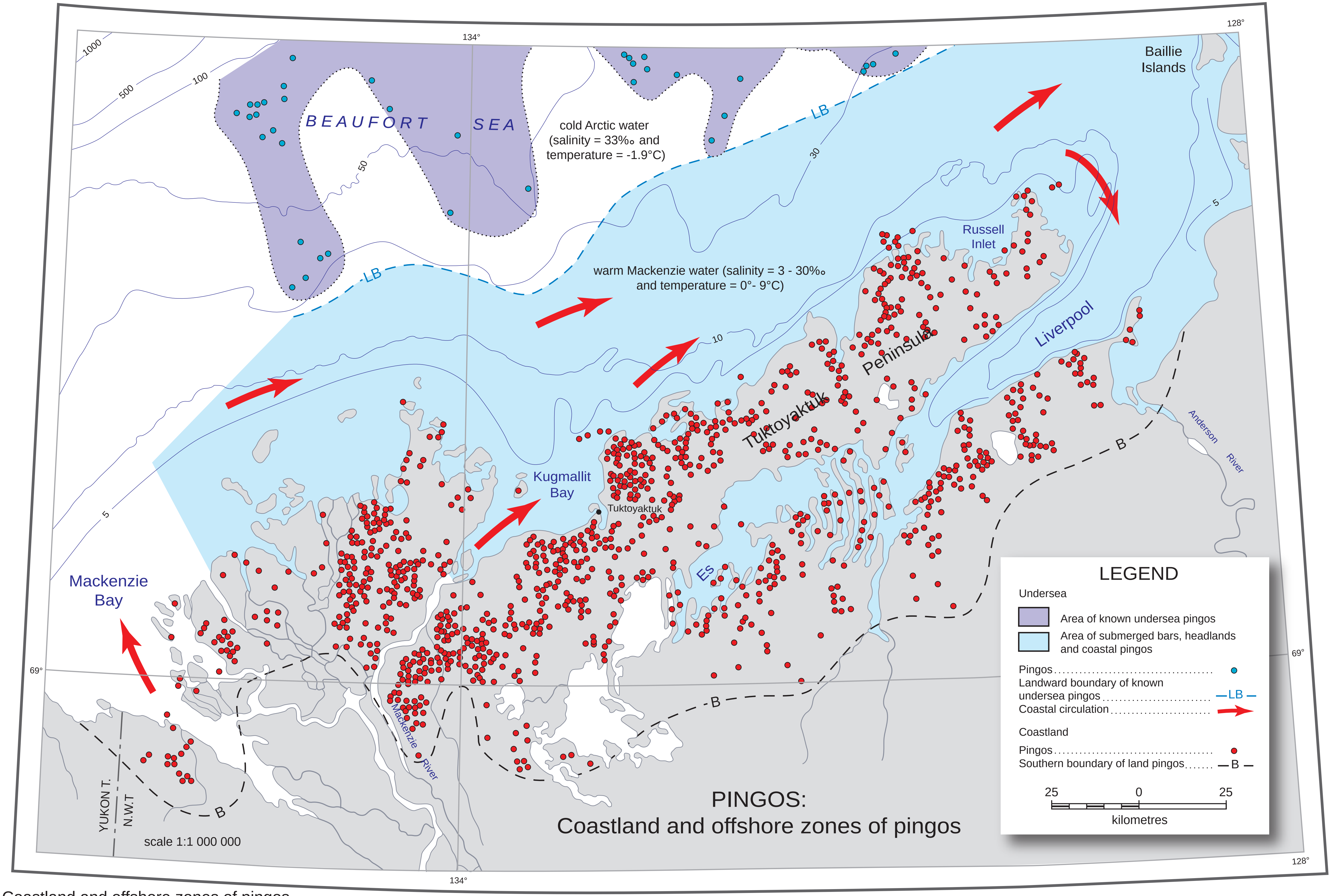


Figure 7-18. Coastland and offshore zones of pingos.

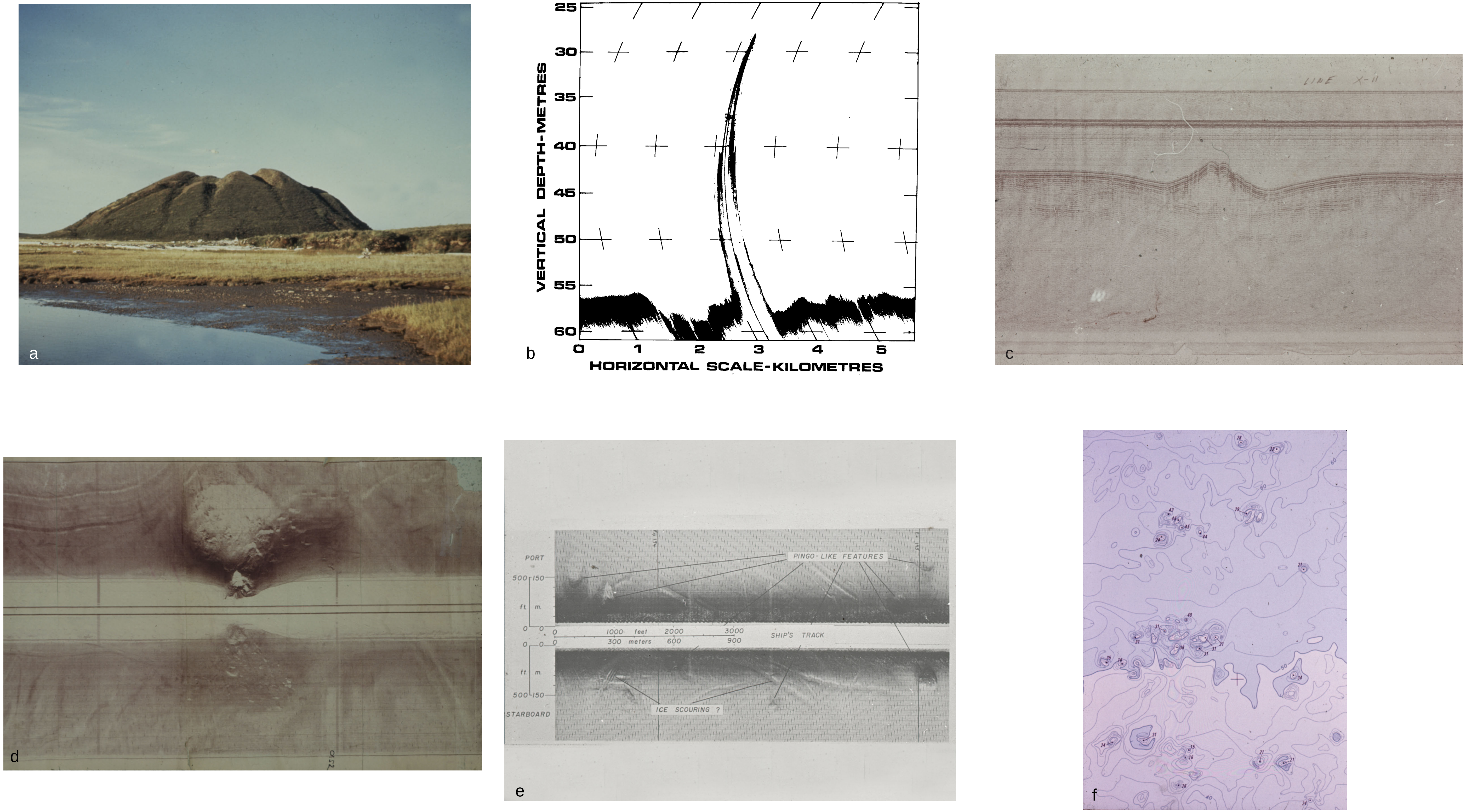


Fig. 7-19. a) Land pingo along the coast near Tuktoyaktuk (Photo by G.D. Hobson, PCSP in 1979); b) Echogram of a PLF (pingo-like feature) similar to the "Admiral's Finger" in the Beaufort Sea, recorded aboard MACDONALD in1969 while escorting MANHATTAN to Pt. Barrow, Alaska; c) First PLF recorded by seismic profiler in the Beaufort Sea was obtained while aboard HUDSON in 1970 (Courtesy of BIO); d) First side-scan sonogram of a PLF in the Beaufort Sea was recorded aboard HUDSON in 1970 (Courtesy of BIO); e) Cluster of PLFs revealed by side-scan sonar while recording aboard HUDSON in the Beaufort Sea in 1970 (Courtesy of BIO); and f) Portion of CHS chart showing clustering and the shallow depth of PLFs off the Beaufort coast (Courtesy of CHS, 1970s).

Distribution of Offshore Pingo-like features (PLFs)

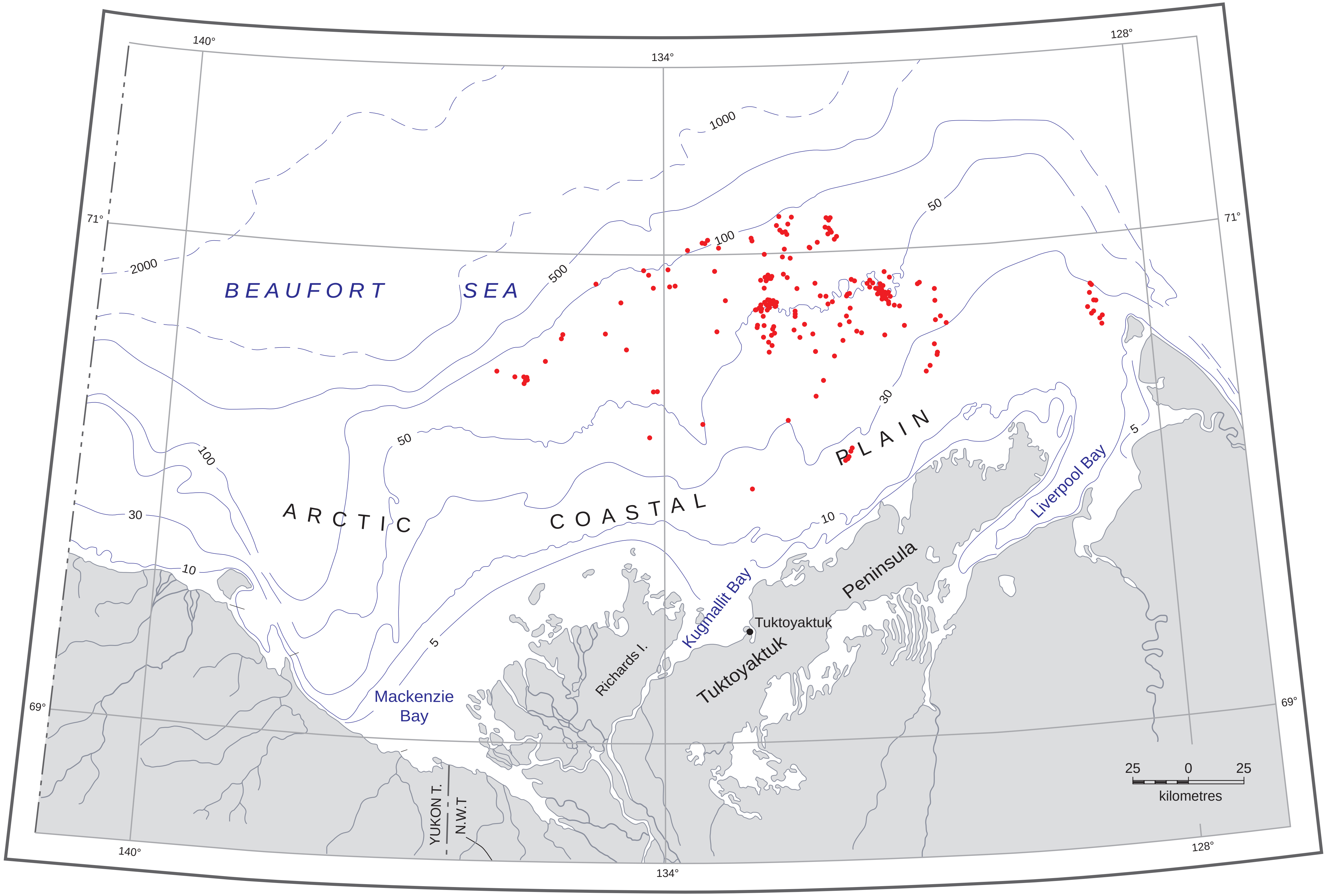


Figure 7-20. Distribution of offhshore pingo-like features (PLFs).

The Active Layer

Thaw-depth Monitoring

The active layer is the top layer of ground occurring above permafrost that thaws each summer and refreezes each fall (Fig. 7-21). It is the link between permafrost and the atmosphere and living things on the earth, including many human activities. Thickness, texture and moisture content of the active layer influence vegetation and soil conditions, potentially impacting hunting, gathering, forestry and agriculture. These same properties affect foundation conditions for purposes of transportation and construction. Changes in the active layer can reduce slope stability, with subsequent impact on transportation facilities and other structures. Slope failures near surface water can affect water quality (Kokelj et al, 2005). Changes in thickness and character of the active layer may also influence surface and subsurface hydrology through changes to porosity, permeability and storage capacity (Quinton et al, 2007). Therefore, knowledge of the manner in which the active layer varies locally and regionally, and of its response to environmental change is important. A program of thaw-depth monitoring contributes to an understanding of this sensitive feature of environments influenced by permafrost.

Thirty-five sites have been established to monitor the active layer in the lower Mackenzie Valley along a transportation corridor extending from Point Separation in the south, to the Arctic coast in the vicinity of northern Richards Island and Tuktoyaktuk in the north (Fig. 7-22). Because the development of the active layer is affected by climate, vegetation, topography, hydrology and soil properties, undisturbed sites were chosen in an attempt to reflect the diversity of these factors for the Mackenzie Delta region.

Several measurements and observations were made initially at each site, in order to characterize the nature of the local environment. These data include a description of landforms and surface morphology, estimations of slope and aspect, measurement of the elevation of the site, description of the vegetation, and sampling of the soil to, or below the frost table for laboratory determinations of moisture content and texture.

Selection of sites and instrumentation have been co-ordinated with other studies in the region that deal with air and ground temperature which provides a continuous thermal record at many monitoring sites. The relationship of air temperature to surface ground temperature depends on a complex combination of local factors such as topography, coastal exposure, vegetation and snow cover, presence and thickness of organic cover and characteristics of the soil such as drainage. Significant relationships between air and ground temperatures are shown in a series of graphs, in which high frequency, diurnal fluctuations, of air temperature are muted in the corresponding traces of the ground temperatures (Fig. 7-23a-j). Generally air temperatures are warmer than ground temperatures in summer, but are colder in winter. Freezing of the active layer in the fall may be delayed by as much as several weeks when a so-called zero curtain develops. This phenomenon, when the temperature of the active layer remains near 0°C for a period of time despite falling air temperature, is due to the release of heat from the soil moisture during freezing. When freezing is complete, the ground temperature in the active layer falls rapidly. The reverse process may occur in the spring, when melting of ice in the soil consumes heat and maintains a temperature near 0°C until thawing is complete. Precipitation and movement of soil moisture may cause perturbation of the zero curtain. Another feature of changing ground temperatures is the progressive attenuation of the amplitude and a delay of response to air temperature change with increasing depth within the active layer and underlying permafrost (Fig. 7-21c). The shallow ground temperature regime determines the development of the active layer.

The annual maximum thaw penetration and maximum heave and subsidence of the ground surface are measured by means of a modified version of a frost tube developed by J. Ross Mackay at the University of British Columbia, Vancouver, Canada (Mackay, 1973 and Tarnocai et al, 2004). With this technique maximum thaw penetration from a stable reference, unrelated to the shifting ground surface, is recorded without requiring occupation of the site at the critical time. Measurements of maximum thaw penetration and maximum subsidence from the previous year can be made during annual visits to the site, prior to time of maximum thaw. Through the use of light equipment and access to sites on foot, disturbance to the vegetation and soils during installation and observation is minimized; most sites recover completely from the initial installation after one or two seasons.

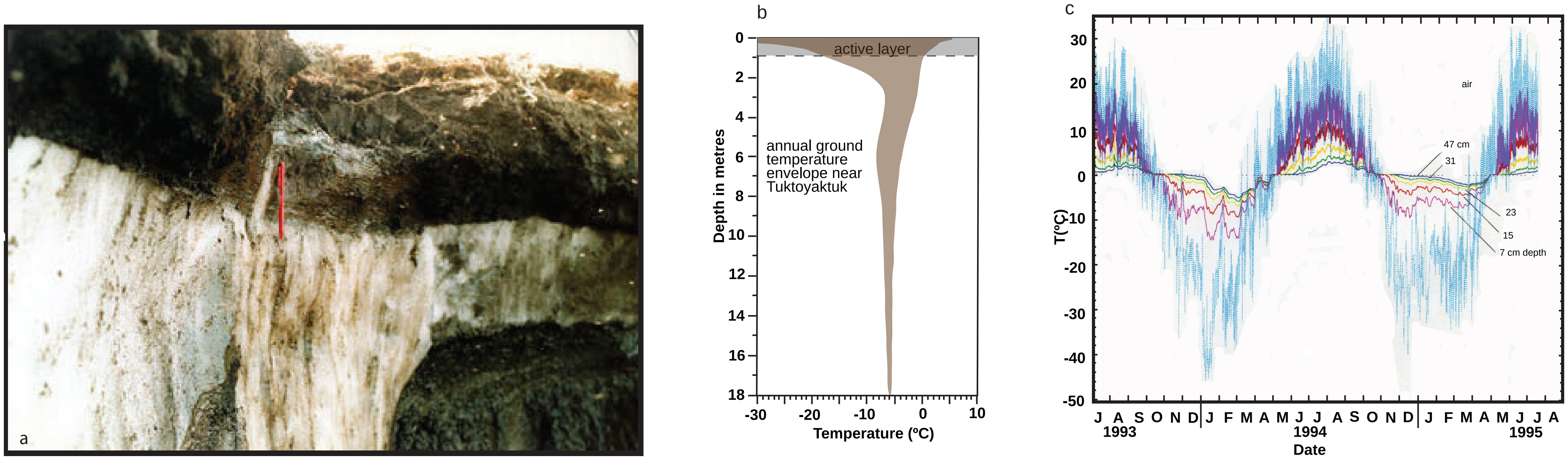
The thickness of the active layer is calculated using measurements of maximum thaw penetration and maximum subsidence of the ground surface from the reference (tube top). This assumes that the maximum penetration of thaw is concurrent with the maximum subsidence of the ground surface.

We now have at least ten years of record from sites in the Mackenzie Delta region. Thickness of the active layer ranges from 26 cm to 150 cm, between sites and over the period of observation. Variations occur from site-to-site, as a result of a complex interplay of site-specific and regional factors. Some of these factors include coastal exposure, topographic elevation, weather patterns, vegetation cover, moisture content of the soil, organic cover, and depth and duration of snow.

Examples of the effect of local factors can be seen when comparing active layers on the delta surface with nearby tundra values, for example 91TTC to 90TT8, 91TT13 to 91TT12 or hilltop tundra sites like 92TT1 to the drained lake basin situation at 92TT2 (Fig. 7-24). At other adjacent sites (e.g. 90TT5/90TT6, see Fig. 7-24), it is apparent that the presence and thickness of organic cover is the most effective local factor controlling the development of the active layer.

Many stations north of Inuvik were installed in 1990; thus over twenty years of observations are available (Fig. 7-24). The charts in Figure 7-24 show thaw penetration which includes both active-layer thickness and subsidence of the ground surface. These values are added on the charts to illustrate the annual thaw penetration, relative to the ground surface at maximum subsidence in the year of installation. The choice of this parameter for comparison of thaw from year-to-year simplifies the interpretation by eliminating the effect of variables such as melting of ground ice and compaction of the soil column. Most sites show a steady increase in thaw penetration until the end of the 1990s, a trend that is also reported for soil climate sites throughout Mackenzie Valley (Tarnocai et al, 2004). The decade of the 1990s was the warmest on record and 1998 was the warmest year (Atkinson et al, 2006). Since then, thaw penetration has generally decreased, reflecting the natural variation of thermal conditions within a long term trend.

Changes to thickness of the active layer will influence surface stability through thaw settlement, frost heave and bearing capacity. Slope stability will also be affected by these changes (Dyke, 2000). Besides these geotechnical characteristics, changes in the thickness of the active layer can affect hydrology and, in combination with enhanced disturbance due to mass movement, can induce changes in soil moisture and availability of nutrients. Stability, moisture and access to nutrients can impact the ecology of an area by modifying the pattern of vegetation (Edlund et al, 1989, Kokelj and Burn, 2005). Monitoring of the development of the active layer in a variety of settings, and analysis of the ways in which this development relates to widely available or easily measured parameters will provide field data to test models that include



Several features of the active layer are displayed in the accompanying illustrations. In a) an ice wedge is shown penetrating the active layer. The pen at the upper ice-soil contact indicates the upper portion of the active layer is 30 cm thick, and that another 30 cm, or more, lies beneath the lower-ice-soil contact. The schematic diagram (b), illustrates the thickness of the active layer (1 m) and its position above the permafrost. The temperature curve represents the minimum ground temperatures obtained from continuous monitoring for a period of one year; similarly the curve on the right represents maximum temperature. The graph (c) of continuous monitoring of air and ground temperatures at 4-5 hour intervals over a period of years, shows the following relationships:

(1) ground temperatures are warmer than air temperatures in winter but colder in summer; (e.g. the deeper active layer (47 cm) is about 8°C warmer than the shallower one (7 cm) in winter; in summer the deeper layer is 15-18°C cooler than the shallower one; (3) a zero curtain persists to some depth; and (4) fluctuations in air temperatures are smoothed in the deeper ground layers due to shielding and insulating effects of snow and vegetation cover. Thermal disturbance of the active layer shown in (d) produce dislocation of the soil cover and the vegetation it supports. A thickened active layer results from imperceplible and early movement in the soil due to thawing, which eventually results in a full-scale displacement of the active layer. When the slide occurs, debris is piled at the foot of the slope. This entire process could be a hazard situation, and could occur on gentle relief selected for construction and transportation.

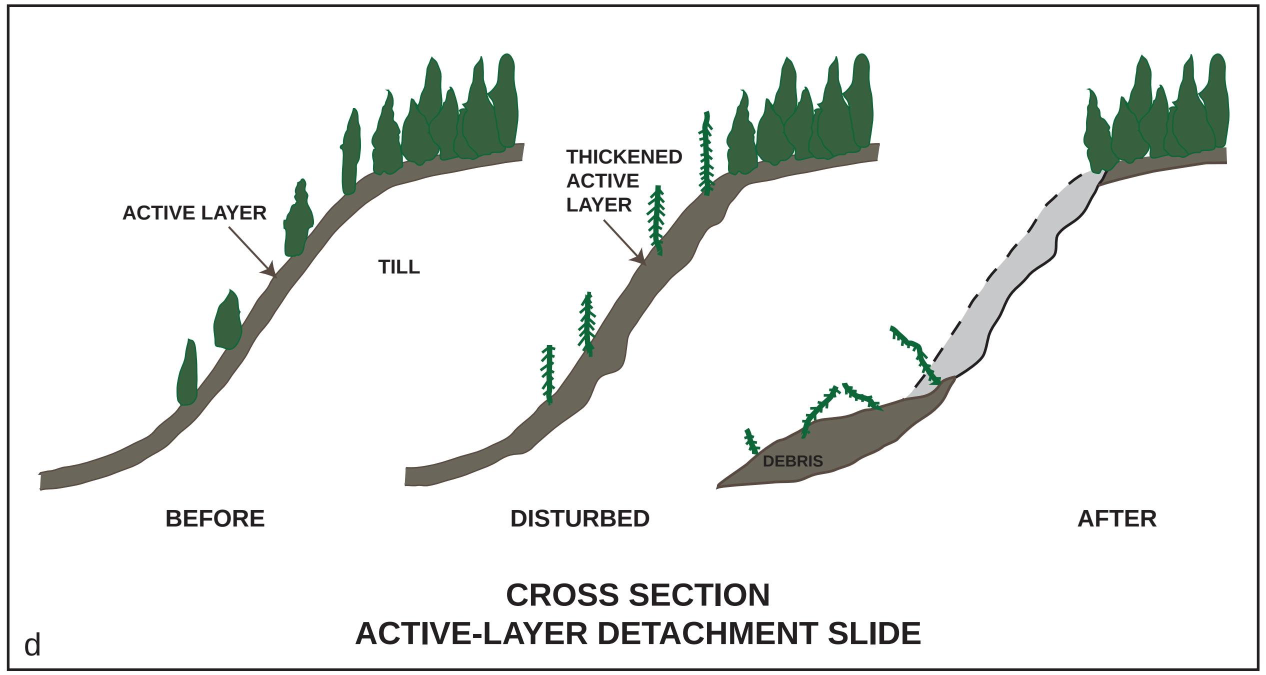


Fig. 7-21. a) Active wedge within lower part of active layer in thermokarst, Richards Island; b) Annual ground-temperature envelope in the active layer and permafrost, near Tuktoyaktuk, NWT.; c) active layer temperatures Mackenzie valley near Martin River, NWT.; and d) slope disturbance producing an active layer detachment slide (after N.W. Rutter).

ACTIVE LAYER :
thaw-depth monitoring

LEGEND

PERMAFROST (after Heginbottom et. al, this volume)
Units and content

Ch	Continuous unit with high ice content
Cm	Continuous unit with moderate ice content
Em	Extensive unit with moderate ice content

Units: continuous, extensive	C, E
Ice content: high, moderate	h, m

SITES (See table 1 for descriptions)

Thaw-depth monitoring sites	●
Site with air and ground temperature record	○

Note: sites 91TT14 and 91TT15 are shown on the index map depicted just south of the Mackenzie Delta.

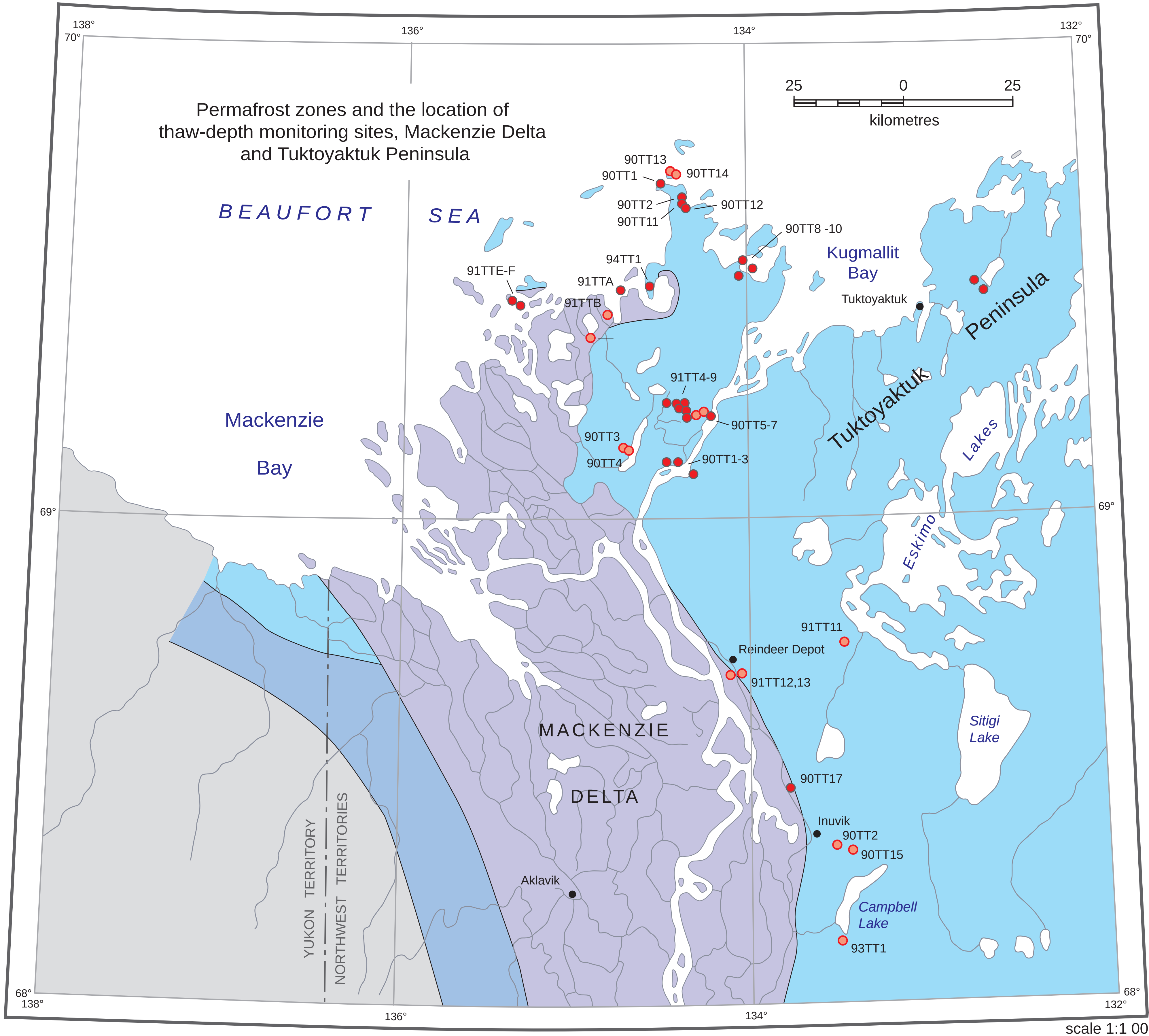
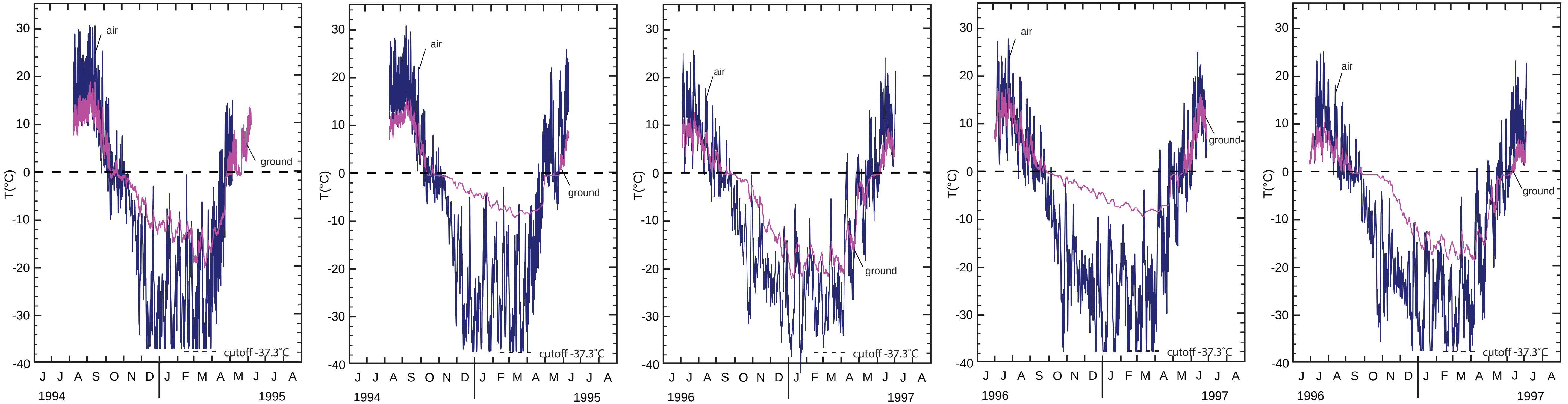


Figure 7-22. Thaw-depth monitoring sites.

scale 1:1 000 000



a) Rengleng Lake, site 91TT15;
67° 45.82’ / 134° 04.83’; Elevation 8 m

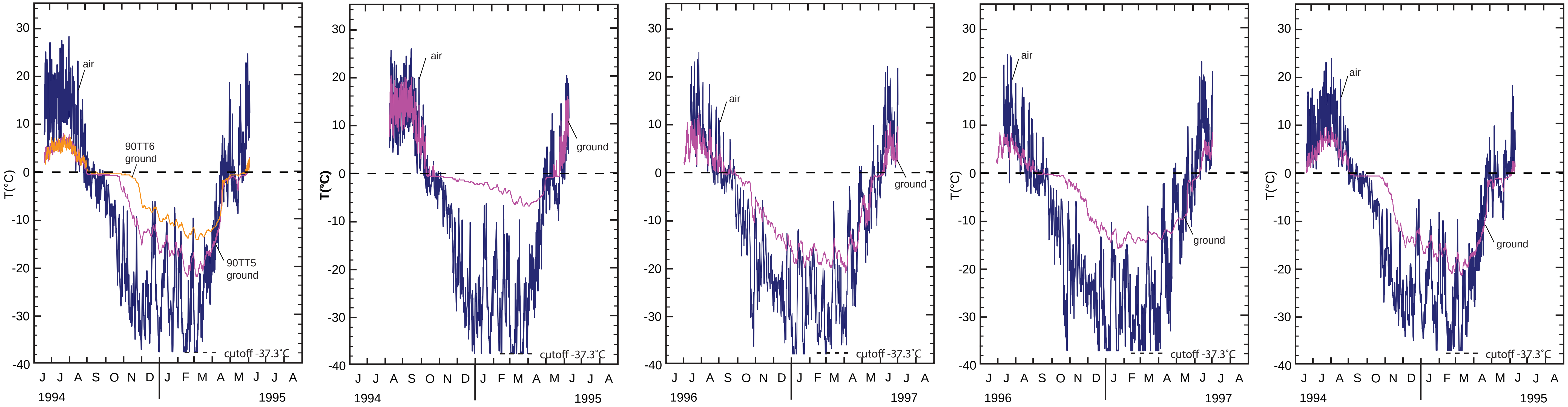
b) Rengleng River, site 91TT14; 67° 47.70’ /
134° 07.56’; Elevation 13 m

c) Reindeer Depot, site 91TT12;
68° 41.40’ / 134° 06.62’; Elevation 152 m

d) Williams Island, site 91TT13;
68° 41.08’ / 134° 08.75’; Elevation 5 m

e) YaYa, site 90TT4;
69° 08.58’ / 134° 42.25’; Elevation 10 m

Figure 7-23. The accompanying graphs illustrate the relationships of air and ground temperatures recorded continuously every few hours during for one year periods during the mid-1990s. The plots show that ground temperatures are not as extreme nor do they vary as frequently or as much, particularly during winter, as the corresponding air temperatures, because of the insulating effect of vegetation and snow cover. Most ground traces illustrate the zero curtain during freezing and thawing of free water in the active layer in spring and fall. Vegetation, topography and the resulting snow cover are major factors influencing ground temperature. Rengleng Lake and River are boreal sites, Reindeer Depot, Ya Ya, Lousy Point, Involuted Hill, and North Head are tundra and Taglu and Williams Island are delta surfaces. Air temperatures do not vary much in pattern from one setting to another except in the case of coastal North Head in summer. Ground surface temperatures are much more responsive to local conditions. Delta surface sites have a deep snow cover trapped by riparian vegetation resulting in warm winter ground temperatures. Similarly, Lousy Terrace, under moderate, low density snow cover near the river is warmer than the ridge crest, scoured by winds. This exposed situation also applies at other tundra sites where even summer ground temperatures are lower than protected boreal and delta sites. Winter ground temperatures at Involuted Hill lowland site are again ameliorated by deep soft snow. Rengleng River ground temperatures under moderate snow cover are warmer than Rengleng Lake, where the ground sensor is near a large spruce that shelters the ground from snowfall.
Note: Refer to Figure 7-29 for site locations and to Table 7-1 for site descriptions.



e) Lousy Point Terrace (purple line); site 90TT6; 69° 13.02’ / 134° 16.77’; Elevation 9 m; and Lousy Point Ridge (orange line), site 90TT5; 69° 13.13’ / 134° 17.47’; Elevation 39 m

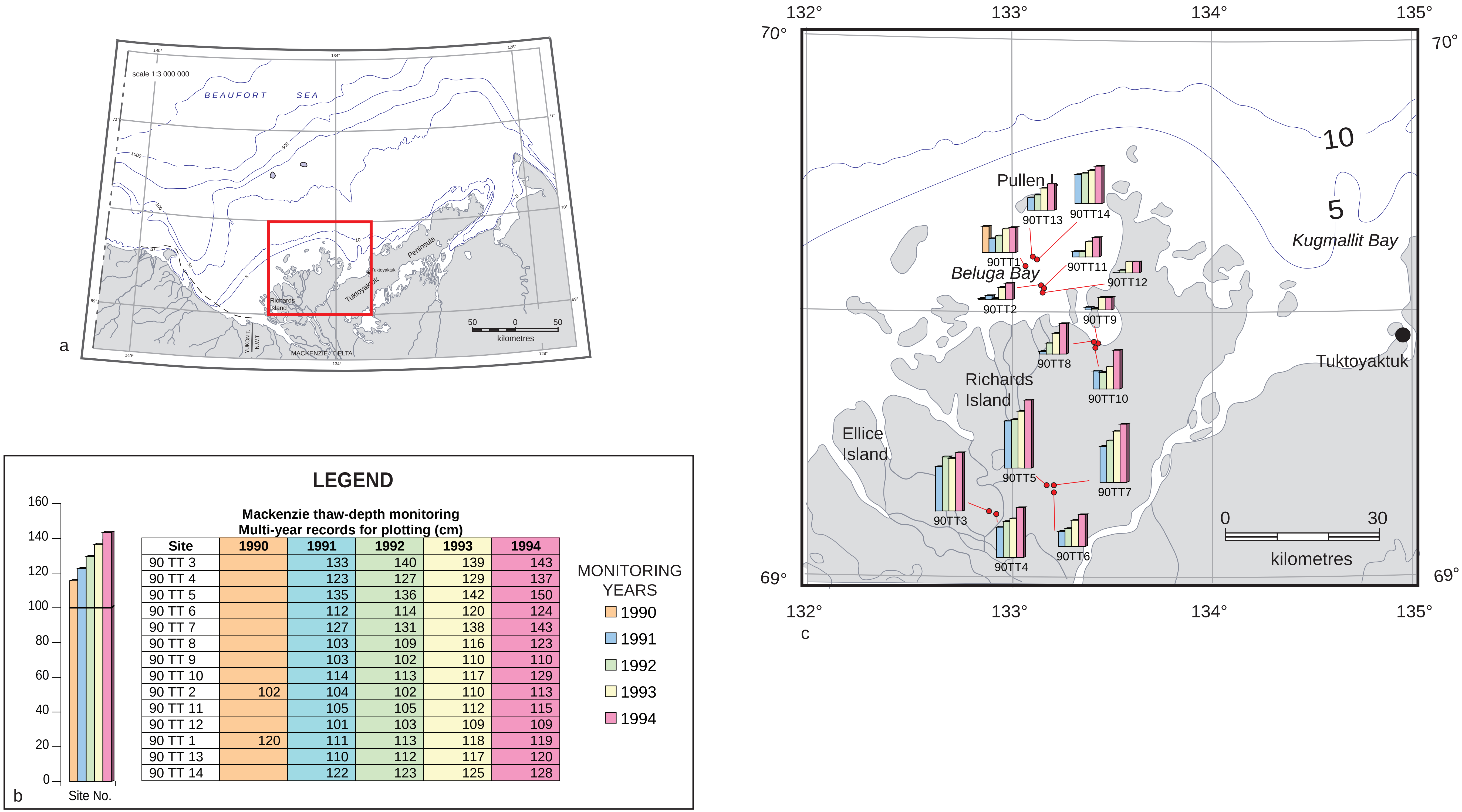
g) Taglu, Richards Island, site 91TTC; 69° 22.15’ / 134° 56.92’; Elevation <2 m

h) Involuted Hill, top, site 92TT1; 69° 28.37’ / 132° 38.03’; Elevation 25 m

i) Involuted Hill, lowland, site 92TT2; 69° 28.35’ / 132° 38.42’; Elevation 4 m

j) North Head, Richards Island, site 90TT13; 69° 43.25’ / 134° 27.68’; Elevation 3 m

Figure 7-23. Continued from previous page.



Mackenzie thaw-depth monitoring
Multi-year records for plotting (cm)

Site	1990	1991	1992	1993	1994
90 TT 3		133	140	139	143
90 TT 4		123	127	129	137
90 TT 5		135	136	142	150
90 TT 6		112	114	120	124
90 TT 7		127	131	138	143
90 TT 8		103	109	116	123
90 TT 9		103	102	110	110
90 TT 10		114	113	117	129
90 TT 2	102	104	102	110	113
90 TT 11		105	105	112	115
90 TT 12		101	103	109	109
90 TT 1	120	111	113	118	119
90 TT 13		110	112	117	120
90 TT 14		122	123	125	128

Figure 7-24. a) Index map of Richards Island sites; b) legend for each year of data collected; c) thaw-depth graphs for locations throughout the Mackenzie Delta.

response of the active layer to the effects of climate change.

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Geological Survey of Canada

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Landslides

Introduction:

Landslides are common in the region of the Beaufort Sea coast (Fig. 7-25). Retrogressive thaw flows, also known as retrogressive thaw slumps or ground ice slumps, are the main form of slope failure. They are found along the ice rich cliffs of the Tuktoyaktuk Peninsula, Richards Island, the islands north of the Mackenzie Delta, parts of the Yukon coast, and along the shores of thermokarst lakes in these areas. Large debris flows are restricted to the Caribou Hills bordering the East Channel of the Mackenzie River. They form large debris fans and supply a significant amount of sediment to the river and the coast. Other forms of mass movement significant to cliff and coastal retreat include block falls and topples. These are a common process of coastal erosion and retreat involving only the first few meters of the coast and the debris is usually quickly eroded by waves.

Landslide Inventory:

An inventory of landslides, based mainly on airphoto interpretation of 1982 photos, has been compiled. Landslides which post-date the 1982 aerial coverage but which are known from field work or publications or personal communications have been included. The inventory consists of a map showing the distribution of landslides (summarized in Fig. 7-25) and an accompanying database summarizing landslide type, location, aspect, size, and material association, etc. Within this area about 3450 landslides ranging from very small features to large coalescing failures have been identified. Of these, fully 99% are retrogressive thaw flows and the final 1% are debris flows in till on the Caribou Hills or small rotational slides. Active layer detachment failures and block falls and topples, although locally significant in coastal retreat and in development of retrogressive thaw flows, are too small to be detected on air photos and are not included in the inventory. In many areas, landslide density is so great that the scars actually coalesce, forming zones of intense landslide activity. For ease in depiction, closely spaced, similar landslides have been grouped into clusters and represented by one dot on Figure 7-25. The 3450 landslides form 457 clusters with a mean of 5 landslides and a range from 1 to 65 landslides in a cluster.

About 24% of the landslides occur along the Beaufort coast and 62% line the shores of the hundreds of small lakes found in the region. The remainder occur on hill slopes, river banks, ravines, and shores of drained lakes. Because so many are closely associated with the edges of water bodies, there is no strong trend in aspect (direction of movement); however northerly directions are most common, probably reflecting the presence of north facing cliffs along the Beaufort coast. Data on landslide size is summarized in Table 1.

Table 1: Summary of landslide size

	mean	median	range
length (m)	151	93	2-2286
width (m)	70	55	4-1496
area (m^2)	12584	8990	228-415956

Landslides are associated with ice-rich, fine grained sediments which include clayey till, lacustrine sediment, and fine grained glaciofluvial deposits (Fig. 7-25, inset map).

Retrogressive thaw flows:

Resembling giant bites into the slope, retrogressive thaw flows have a characteristic bowl shape with a steep headwall and low angle tongue. The headwall gradually erodes upslope as massive ground ice or icy sediment thaws in the scarp and the resulting water saturated sediment flows downslope away from the scarp, - hence the name, retrogressive thaw flows.

Retrogressive thaw flows may be initiated by any process or event which results in the exposure to melting of massive ice or icy sediment. For example, for active layer detachments, downslope movement of the active layer induced by thermal disturbances such as tundra fire or unusually deep annual thaw, may develop into a retrogressive thaw flow if ground ice is exposed. Alternatively, massive ice may become exposed in dilation cracks resulting from growth of ground ice or in tension cracks formed as icy sediment deforms and creeps under its own weight. Exposure of the ice rich scarp (Fig. 7-26a), which is essential to the development of thaw flows, may also be initiated at coastal sites by block falls or topples (Fig. 7-26b).

Once the massive ice or icy sediment is exposed in the headwall, a seasonal cycle becomes established, beginning in summer when snow melts away from the scarp face. Water derived from snow melt and melting of ground ice helps to clean the scarp face of debris that may have accumulated the previous season. As sediment is released from the melting ice it falls, slides or flows down the scarp face. Melting of the ice undercuts the active layer at the top of the scarp and the undercut peat and sediments detach and fall down to the base. These become incorporated into the water and debris at the base of the scarp face and flow downslope over the beach or older flow deposits (Fig. 7-26c).

Although the scarp face retreats through this process, it does not necessarily result in shoreline retreat. In fact it may result in a temporary transgression (McDonald and Lewis, 1973). However, if wave energy is effective in removing the debris, coastal retreat or enlargement of the lake basin occurs (Fig 7-26d, Fig. 7-27a). Rate of scarp retreat at sites with active retrogressive thaw flows range from about 1 m per year to 9 m per year (Forbes and Frobel, 1985). These rates of retreat are averaged over several years but erosion at a site can be extremely variable from year to year, depending largely on summer weather conditions. Eventually the slide stabilizes as the face becomes buried by debris, the ice content of the sediment at the scarp decreases, or the slope of the scarp decreases (Mackay, 1966).

Retrogressive thaw flows tend to be cyclic in nature. The scarp face may become buried if debris is not removed at a rate faster than it is supplied. If the flow is not reactivated immediately, it can become quickly revegetated (Fig. 7-27b) because any slump blocks that remain intact carry vegetation into the bowl of the slide (Mackay, 1966). If the flow does reactivate, a new scarp face may develop within the old scar (Fig. 7-27c) and the old flow deposits are recycled in the new failure. In this system the landslide will remain active if wave energy is sufficient to erode the flow debris and keep the scarp face exposed. Rising water levels and wave activity during a storm may reactivate a stagnated slide by eroding the toe of the slide and triggering more movement of debris away from the face (Carter et al., 1987). During major storm surges the debris may be overtopped or quickly eroded back to expose the ice face to direct wave attack. Other processes of mass movement such as block falls may begin to dominate coastal erosion.

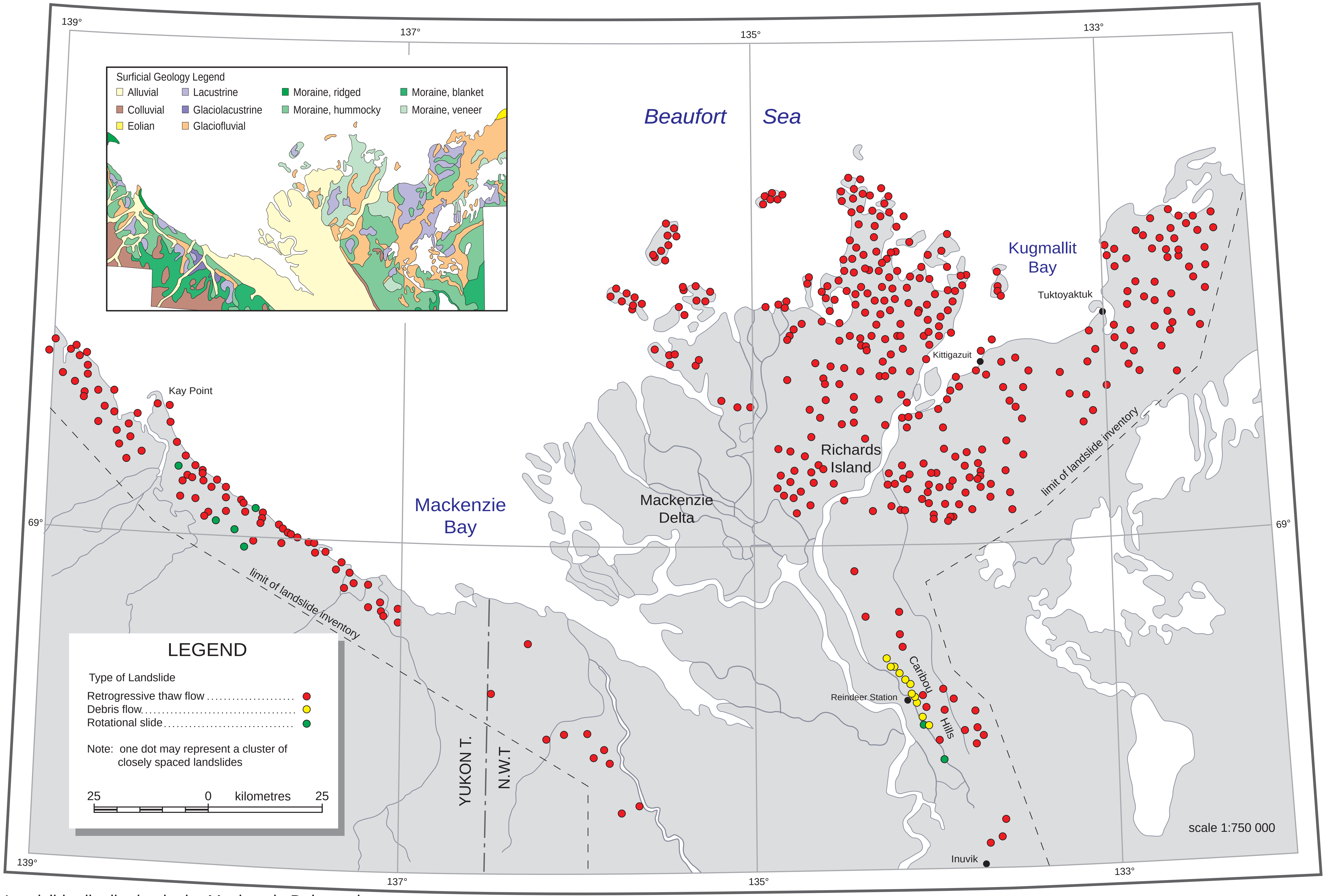

Fig. 7-25. Landslide distribution in the Mackenzie Delta region.

Fig. 7-26. a) Ground ice and icy sediment are exposed in the scarp of a retrogressive thaw flow slide along the Beaufort coast (Photo by P.A. Egginton); b) topples or blocks of sediment along the cliff expose ground ice and induce retrogressive thaw flow slides. The present activity occurs within the scour of an older failure (Photo by J.A. Heginbottom); c) a recent mud flow overlies older flow sediments of a large retrogressive thaw flow slide located at Peninsula Point near Tuktoyaktuk (Photo by J.M. Aylsworth); and d) this view of a large retrogressive thaw flow slide at Peninsula Point near Tuktoyaktuk shows the development of a failure over a period of 8 years (Photo by M.M. Burgess, 1984). Massive ground ice is exposed in the scarp. See Photo (a) on next page.

Fig. 7-27. a) This photo shows part of the long-term development of the scarp shown in (Fig. 7-26d), taken by M.M. Burgess in 1984. The above photo was taken in 1992 by J.M. Aylsworth; b) this retrogressive thaw flow slide along the north shore of Eskimo Lakes has become partially stabilized through re-vegetation of the scar (Photo by J.M. Aylsworth); c) the re-activation of an older landslide at Kay Point is shown in the foreground (Photo by S.R. Dallimore); and d) Falls and topples of blocks of sediment, or undercut cliffs shown here are contributors to coastal retreat. Wave action removes the fallen debris, thus setting the stage for another cycle of slope failure along the Beaufort coast (Photo by S.R. Dallimore).

Block falls and topples:

Falls and topples are virtually indistinguishable processes, producing similar results. Both involve a relatively intact block of sediment detaching and collapsing due to gravity. Falls collapse downward and topples rotate forward as they collapse. Both occur on very steep scarps or where cliffs have been undercut by physical or thermal erosion. Their role in the development of retrogressive thaw flows has been described above.

Block falls and topples (Fig. 7-27d) contribute to rapid rates of coastal retreat. In locations where there is little or no beach protecting the cliff this process is common. Storm surges may also cause waves to overtop the beach and erode directly into the ice rich cliff. The ice in the cliff may also be thermally eroded (melted) by proximity to or contact with water near the base of the cliff and a thermo-erosional niche undercuts the cliff face. Failure often occurs along the margins of ice wedges above the niche so that an entire polygon falls to the base of the slope (Carter et al., 1987). Wave action at the base of the cliff removes the debris leaving the cliff susceptible to continuation of the process. These conditions have resulted in some of the most rapid rates of retreat recorded from the Beaufort Sea coast (Mackay, 1979).

On lower coasts, the collapse of a portion of the shore undercut by a thermo-erosional niche may result in a peat layer dropping down over the exposed ground ice (Fig. 7-28a). This effectively armours the ice from further thermal erosion, at least until the peat can be eroded or floated away during a storm (Mackay, 1986).

Active layer detachment failures:

Shallow slope failures involving detachment and downslope movement of only the active layer and vegetation mat are known collectively as active layer detachment failures (Fig. 7-28b). Movement may involve either sliding of a relatively intact, thawed piece of ground on the underlying frozen sediment (sometimes known as an active layer glide) or flow of water saturated sediment (also known as a skin flow). They are generally triggered by unusually warm temperatures or some disturbance of the vegetation mat. Either instance will result in overdeepening of the annual active layer which may detach and move downslope. If failure exposes massive ice or icy sediments, it will probably develop into a retrogressive thaw flow.

Debris flows:

Debris flows, a rapid flow of water saturated sediment, occur in areas of higher relief. These flows are typically long narrow flows which widen into debris fans at their base.

Numerous debris flows can be found on the west slope of the Caribou Hills bordering East Channel north of Inuvik. The Caribou Hills are composed of poorly consolidated Tertiary sands, gravels and mudstone of the Reindeer Formation (Norris, 1975) and capped mostly by till. Debris flows have developed when till at the top of the slope becomes saturated, loses strength and flows rapidly downslope, generally incorporating some of the Tertiary sediments as well. One such debris flow near Reindeer Station was triggered by abnormally warm summer temperatures in 1992 which thawed ice-rich till, resulting in mobilization of the upper slopes (Aylsworth et al., 1992). In a matter of minutes, this flow ran 1.5 km downslope and extended 200 m into East Channel below water level. The speed was such that one third of the way down the slope, a sharp turn in the gully (Fig. 7-28c) caused the flow to run up three metres on the outside bend. At the base of the slope debris formed a large fan, 240 m wide at river level (Fig. 7-28d).

Geological Control:

The occurrence of landslides in this region is largely dependent on the presence of ground ice. Retrogressive thaw flows and block falls and topples occur in fine grained sediments where ground ice is most likely to form. Debris flows are also influenced by ground ice since water required to promote them may be provided by ground ice melt. In the region of the Beaufort coast ice rich sediments include clayey tills which generally overlie marine sediments, lacustrine silt and clay, and fine grained glaciofluvial deposits (Rampton, 1988).

There are few landslides in sandy areas such as occur along the coast southwest of Tuktoyaktuk to near Kittigazuit because of lower volumes of ice present in the sediment (Mackay, 1966). Coastal retreat or lake basin enlargement is not as effective in these coarser materials. At the coast, slumped sands and gravels are not as easily removed by wave action as clay and silt and often remain to form beaches, bars or spits that protect the cliff from further wave erosion (McDonald and Lewis, 1973).

Trigger Mechanisms and Conditions:

Landslides may be induced by a number of physical or thermal conditions, however in most cases, the result of the trigger action is the exposure and subsequent degradation of icy sediments or massive ice. The previous section showed how geological conditions in the form of ice rich, fine grain sediments control the distribution of slope failures. In some cases geological process may also be a trigger mechanism. Ice may become exposed in dilation cracks resulting from the growth of massive ice or in tension cracks formed as icy sediments deform and creep under its own weight. In both instances such areas are susceptible to the development of retrogressive thaw flows.

Icy sediment may also be exposed by gullying into ice-rich slopes or physical erosion of the base of ice rich slopes by fluvial or wave action, inducing falls and topples that in turn expose ground ice.

Trigger mechanisms may also be thermal. Thermal instability induced by proximity to warm waters is an important trigger mechanism. This effect is enhanced where wave action removes the debris, constantly exposing new frozen sediment to thermo-erosion. This effect is also enhanced by rising sea level which effects not only the coast itself but also causes water levels to rise in streams and lakes in low lying valleys. Thermal instability resulting from inundation of previously frozen ground results in permafrost degradation at the base of slopes, promoting loss of support at the base of the slope, and detachment and downslope movement of the higher active layer. Disruption of the vegetation cover and organic mat, often the result of tundra fire, but also following human activity, results in a deeper active layer, thaw of previously frozen icy sediments, and potential slope failure.

Seasonal variability in climate, including extreme climate events, play a significant role in inducement of landslides. Many failures, ranging from shallow active layer detachment failures to large debris flows, result from increased depth of annual thaw during an unusually warm summer. For example, the Reindeer Station debris flow of 1989 followed four summer months of temperatures 2° to 4°C above normal. Summer temperature not only controls ablation rates at exposed ice scarps and depth of active layer

Fig. 7-28. a) The collapse of a peat layer (centre) temporarily protects the underlying icy sediment from melting (photo by P.A. Egginton); b) proximity of this cliff face to warm water induced a shallow active layer detachment, initiated by thermal erosion at the base of the slope. This latter activity was caused by rising sea level (Photo by P.A. Egginton); c) a large debris flow shown above at Reindeer Station occurred in 1989, following an abnormally warm summer. The flow began near the top of the Caribou Hills, and made an abrupt turn about one third of the way down the gully. See adjacent photo (d) (photo by P.A. Egginton); and d) The debris flow is 240 m wide at the level of Mackenzie River, and the length extends another 200 m under water (photo by P.A. Egginton).

thaw, it also influences the temperature of water bodies and thus thermo-erosion potential. Dry weather may result in tundra fires which can change the ground thermal regime. Along the coast, climate factors also include timing of the ice pack recession from shore, amount of open water, wind direction, and the frequency and intensity of late summer storm surges.

Conclusions:

Geological and geographical conditions are largely responsible for the distribution of ground ice and thus the distribution of landslides. Climatic conditions, however, provide the fuel for the processes to operate, as ultimately it is the thawing of ice rich sediment that induces the landslide and continues to maintain the failure. The role of seasonal variability in weather is obvious. Longer term climatic changes, such as may occur from global warming, is likely to have an important role in the future as it influences ground and water temperatures, pack ice, wind direction, etc. A period of dynamic adjustment of the land to changing climate conditions will probably result in increased landslide activity for some time.

Acknowledgements

The authors gratefully acknowledge the able assistance of Johanna Guertin and Glen Kruszynski who provided most of the aerial photograph interpretation.

The Beaufort landslide database forms the northernmost portion of the Mackenzie Landslide Database, a compilation encompassing the entire Mackenzie Valley and adjacent mountains as well as the Beaufort Sea coastal area. Funding and support for this work came from a number of direct and indirect sources including Geological Survey of Canada, Polar Continent Shelf (Projects 32-87 and 76-90), Panel on Energy R and D (Project 612.20), Indian and Northern Affairs, and Canadian Climate Centre (Mackenzie Basin Impact Study).

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CHAPTER 8
COASTAL PROCESSES

COASTAL PROCESSES

Major Oceanographic Factors

Several oceanographic factors affect the shores of the Beaufort Coastlands: surface circulation involving the Beaufort Gyre, upwelling along the edge of the Beaufort Shelf, currents along shore, tides and storm surges, movement of the Mackenzie River cell, temperature and salinity of the water mass, and the direction and velocity of coastal waters along the shore. Although the presence of sea ice is a major consideration concerning costal processes in the area, it is excluded here because of its inclusion in other accounts: SUMMER WEATHER AND OPEN WATER, and ICE BREAK-UP, ZONATION, AND MOVEMENT IN THE BEAUFORT SEA. The present contribution is an account of open-water effects on the Beaufort Coastlands.

Coastal Circulation

The main feature of surface circulation in the Beaufort Sea is a huge, counter-clockwise motion of water known as the Beaufort Gyre (Fig. 8-1). It is formed in that sector of the Arctic Ocean lying between the northernmost latitudes (85°N, or so) of the Arctic Ocean and the northern mainland of North America, the latter comprising the western part of the Northwest Territories (District of Mackenzie), the northern Yukon, and northern Alaska. The longitudinal boundaries of the Beaufort Gyre extend from the outer continental shelf lying off the western portions of the Canadian Arctic Archipelago, to approximately Longitude 180°W. In plan the longitudinal diameter of this elliptically-shaped body is about 2 000 km, and its east-west diameter is at least 1100 km. Only the southern boundary of the gyre is shown in Fig. 8-2a, but its continuing direction of movement is southerly off the Canadian Arctic Archipelago, westerly across the Arctic Basin and edge of the Beaufort Shelf and, finally, northerly along the vicinity of Longitude 180°W to complete the gyre in the northern polar region. This gyral motion is a response to the Coriolus Force which deflects currents to their right in the northern hemisphere.

In coastal areas currents along shore respond to wind conditions partly, but their motion is complex. These currents are also affected by the Mackenzie River discharge as shown in Fig. 8-2a, but their residual drift along the coast of the Tuktoyaktuk Peninsula is toward the east; again, the direction of residual flow is under the influence of the Coriolus force. This can be observed on both sides of the Mackenzie Delta where spits and barrier bars are constructed under the influence of longshore currents. These currents control the erosion of headlands and islands, as well as the direction of sediment transport and leeward deposition. Entrained in this coastal flow is the sedimentary discharge from the Mackenzie River. Its turbidity creates a plume that is visible on satellite imagery and, from such observations, a dispersal pattern can be followed over a period of several days to a few weeks. Beyond the main area of the sediment plume, the direction of sediment transport is discerned where it evolves from a complex pattern of eddies and contrasting flow directions occurring off the Mackenzie Delta, to a more regular flow off the coast of the Tuktoyaktuk Peninsula. At times some of this easterly flow near Amundsen Gulf is northward where it is influenced by the southern part of the Beaufort Gyre, and then moves westerly toward the Alaskan offshore zone.

Tides and Storm Surges

Tidal currents and amplitudes are minor components of the physical processes affecting the coastal areas of the Beaufort Coastlands (Fig. 8-2b). Bottom tidal currents are negligible, and rarely exceed velocities of 2-3 cm/s. Generally, tidal heights along shore are 10-13 cm, but may reach 0.5 m under the influence of astronomical conditions such as those producing spring tides. Because of this small amplitude, a tidal zone is almost negligible; however, the vertical range of a storm surge is considerably greater (2-3 m), and has correspondingly more influence on shoreline erosion and alteration.

Storm surges require a fetch, i.e. a length of open water, in order for the wind to generate the energy that will drive the resulting waves forward. These conditions are demonstrated in the storm-surge models shown in Fig. 8-2b, which indicate the height of the waves as they travel across the sea and reach shore. In these models the fetch extends from the edge of the polar pack ice to the coastline, a distance of approximately 300 km; also, the wind is from the northwest in both cases. Specifically wind conditions are described as 70 km/h for a period of 30 hours in one model, and 65 km/h for a period of 24 hours in the other. The lesser condition shown in Fig. 8-2b yields wave heights of 1.0 m along shore which, when added to the tidal height, can create a strong erosional force. However the greater storm surge shown in the models produce wave heights up to 1.5 m along shore, and a height of water amounting to 4.0 m in the inland portion of the Mackenzie Delta at locations lying about 60 km from the sea. Such surges are exceptional and may occur only once in several decades, but minor surges are likely to occur every several years or more often. Shoreline retreat of up to about 10 m for one storm has been recorded.

Wind Direction and the Movement of the Mackenzie Cell

In Fig. 8-2c, two major wind directions are depicted: an onshore wind that drives the Mackenzie cell shoreward; and an offshore wind that moves this cell seaward. The Mackenzie cell is characterized by several properties as follows: it is comprised of low-salinity water mainly; it is turbid, in that it contains fine sediments; and it also contains driftwood and organic matter.

When the Mackenzie River enters the Beaufort Sea, its turbid discharge creates a discoloration of the sea water around the Delta. This phenomenon forms a plume that is easily observed in satellite imagery, but the actual turbidity comprising the plume can also be observed at ship-board elevations. Driftwood can be seen and, in times of post-flooding of the Mackenzie River drainage basin, this flotsam is considerable and must be avoided by small propeller-driven vessels. After the discharge reaches the sea and forms the Mackenzie cell, the sediment plume moves offshore as well as along the coast in different directions as it reacts to wind conditions and local currents. Some mixing of sea water occurs so that low salinities of 5-10parts per thousand and warm temperatures of 10-12°C prevail.

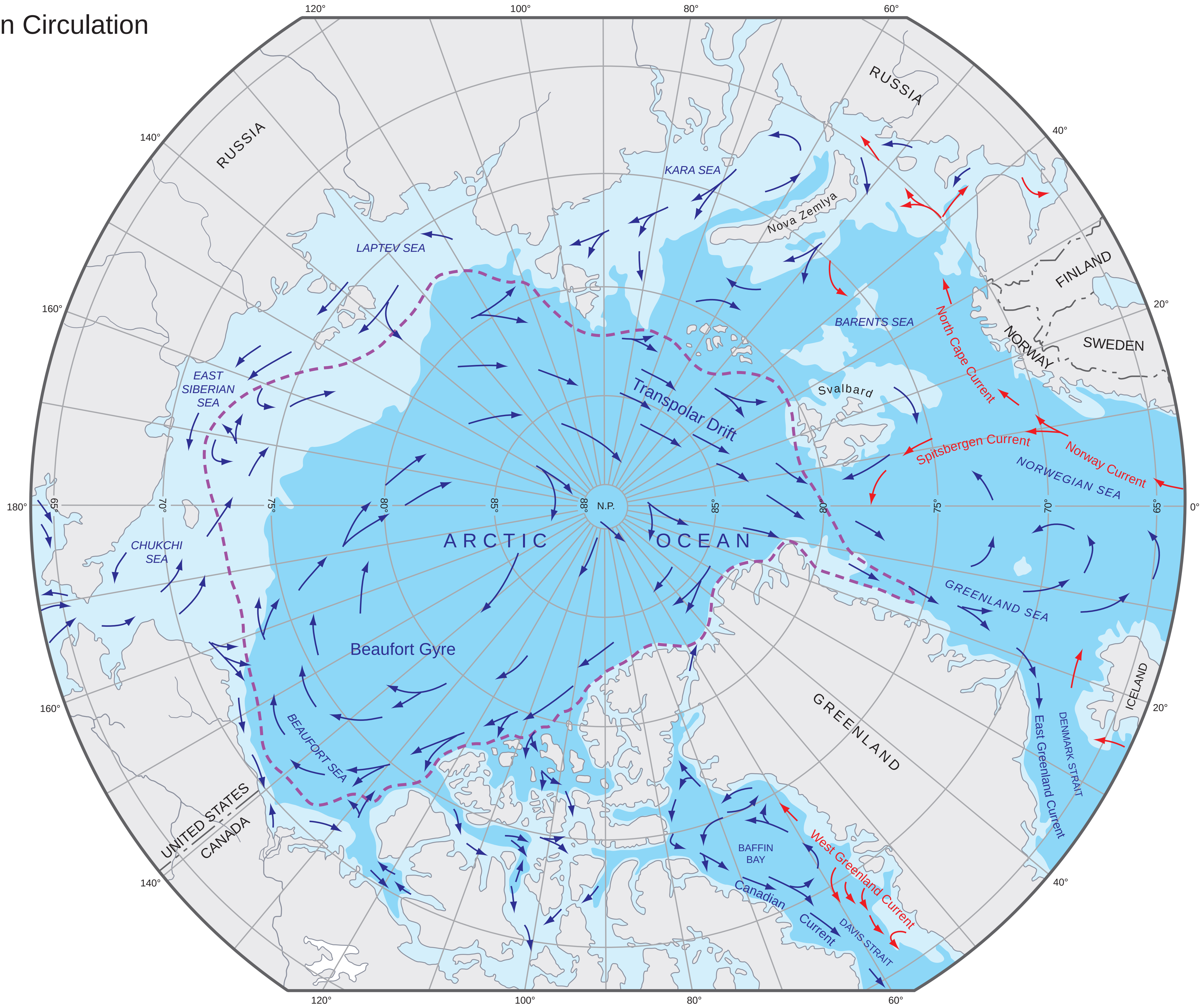
Offshore winds (Fig. 8-2c) direct the movement of the Mackenzie cell seaward into areas of open water. The sediment plume disperses with this offshore movement, and cold, saltier water continues to mix with Mackenzie River water. More of the cold, sea water with negative temperatures to -1.9°C and salinities of 33parts per thousand are drawn in beneath, and beyond the cell in a shoreward direction. Upwelling at the edge of the shelf is part of this process, and the resultant underflow continues to be drawn shoreward as the Mackenzie cell is displaced seaward. The advance of the cold water up the beach is inhibited by the oppositely blowing wind, thus producing a minor negative surge. In this case the shoreline advances seaward and finally occurs beneath the previous level of the sea. Erosion of the shore is reduced under these conditions, and the Mackenzie cell may extend 30-40 km offshore where mixing of water, dissipation of turbidity and dispersal of sediment continues.

ENVIRONMENT: Arctic Ocean Circulation

LEGEND

Cold surface currents .... →
Warm surface currents.............................. →
Approximate maximum limit of permanent polar ice cover .... - - -
Depths to 200m .... ▬
North Pole .... N.P.

Note:



500 0 500
kilometres

Fig. 8-1. Arctic Ocean circulation.

MAJOR OCEANOGRAPHIC FACTORS AFFECTING THE BEAUFORT SEA COASTLANDS:
a) Coastal circulation; b) Storm surges; c) Wind directions

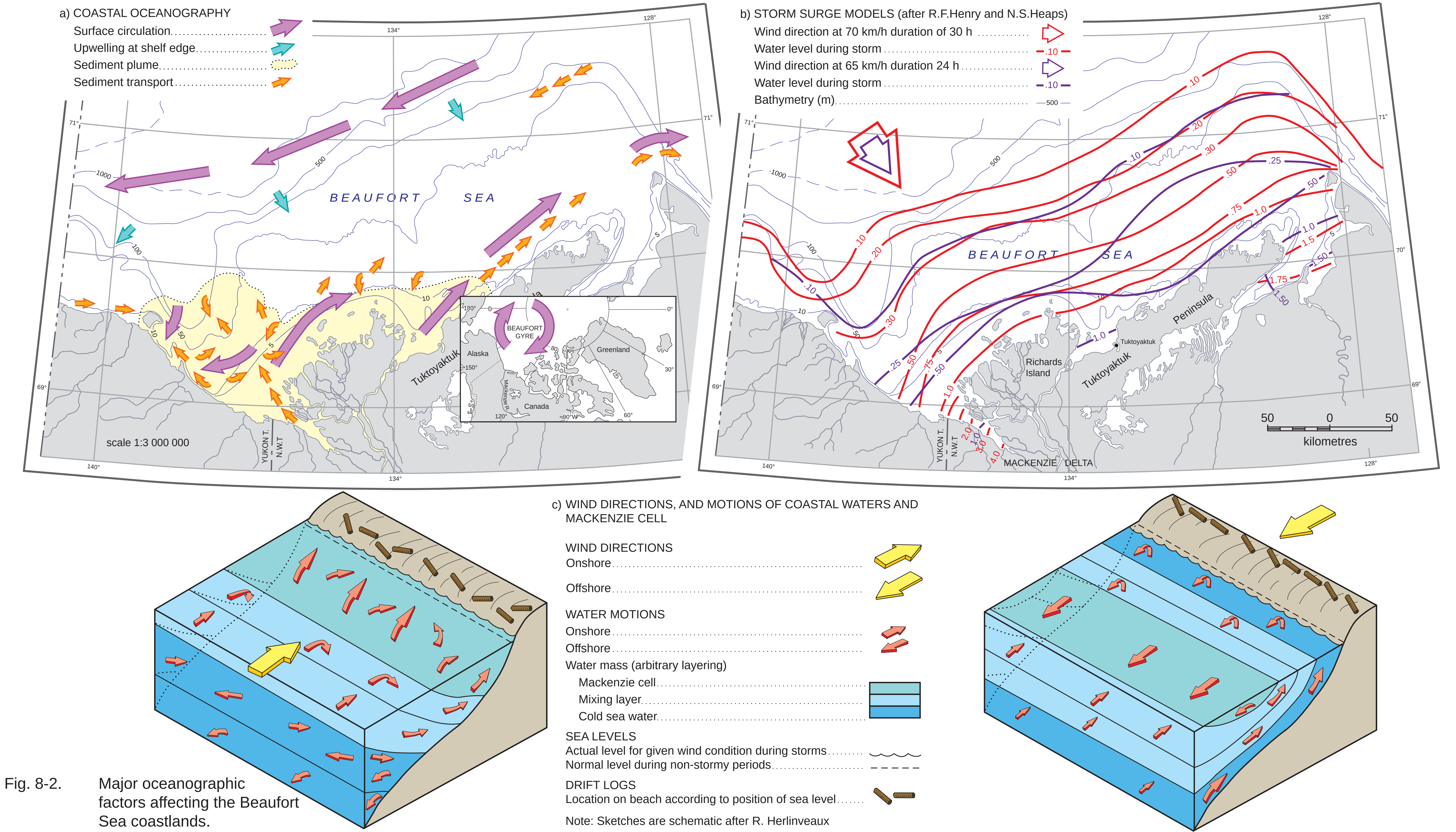


Fig. 8-2. Major oceanographic factors affecting the Beaufort Sea coastlands.

Onshore winds (Fig. 8-2c) force the Mackenzie cell against the shore along the entire Tuktoyaktuk Peninsula. The water is driven above normal sea level, and driftwood may be pushed higher up the beach. Erosion of cliffs and other shore features by waves and currents takes place under these conditions, which are those of a positive storm surge. Because the cell is adjacent to the shore and is bounded by the seabed beneath, the presence of warm water in the cell may inhibit the freezing of the seabed beneath it. This phenomenon may also prevent the growth of pingos, and partially explain their absence in this area of the seafloor.

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Coastal Morphology, Sediments and Processes

The coastline of the Canadian portion of the Beaufort Sea is composed of unconsolidated ice-bonded sediments that include mud, sand, gravel and a mixture of all these sediments (Fig. 8-3). This mixture is called a diamicton or diamict and, because of its glacial origin, is called a glacial diamicton. The ice content of these sediments can be considerable, with thick lenses of massive ice being common at the contacts between underlying porous sands and overlying impermeable diamicts.

Coastal landforms include low-angle tundra slopes that are being drowned gradually by the encroaching sea, deltas, tidal flats, supratidal marshes, beaches and barriers, lagoons, and complex embayments formed by the breaching of thermokarst lake basins. Cliffs are the dominant coastal landforms, representing 52 percent of the shoreline. Cliff morphology ranges from temporarily stable, vegetated slopes to nearly vertical wave-washed cliffs that rise to more than 50 m in some places, although cliff heights of less than 10 m are more common.

Processes of cliff erosion include gullying, development of basal wave-cut niches, shallow sloughing, block failures, and retrogressive thaw failures. These latter failures occur where massive ice is exposed to warmer temperatures in retreating headwalls. They develop amphitheatre-like basins with associated mud flows that transport sediment downslope from the source at the headwall, to the shore. These features are concentrated along the Yukon coast, on parts of Richards Island, and in the vicinity of Tuktoyaktuk. They show a tendency for cyclical development, with stabilization and re-activation on time scales of 10 years or so.

Retrogressive flows as a source of coastal sediment are shown in Figures 8-4 and 8-5. Longshore currents redistribute this material, along with sediment derived from wave-generated retreat, contributing to the formation of bars and sand flats. Figures 8-4 and 8-5 also show the major accumulations of alluvial sediment transported by rivers.

Shore-zone mapping has been used to categorize coastal morphology and the nature of the ground surface along the Beaufort Sea coast. Six unique coastal types have been identified which occur between the Baillie Islands on the east and the Yukon-Alaska border on the west (Fig. 8-7 and 8-8). Four types are characterized as erosional, and two as accretional. Descriptions of each coastal type are given in the summaries below, and their distributions are shown in the accompanying maps. Erosional landforms comprise 63 percent of the coast and even where accretional landforms occur, evidence exists that they are retreating. Typical coastal retreats vary from 1 m per year to as much as 20 m per year; in fact, more than 10 m of coastal retreat may occur in a single storm event. The most rapid rate of coastal change takes place along the very low Mackenzie Delta shoreline, and in areas of ice-rich cliffs.

Summary of Erosional Coastal Types

Ice-Poor Cliffs: coastal cliffs with low to moderate relief usually, and fronted by narrow beaches (<15 m) of sand/gravel materials (Fig. 8-7a); mass-wasting is dominated by debris slides and surface-wash erosion; cliff materials usually consist of sands or gravelly sands capped by peat; moderate to low retreat (<1 m/yr).

Ice-Rich-Cliffs: coastal cliffs with moderate to high relief (5-15 m) usually, fronted by narrow gravelly sand beaches (Fig. 8-7b); upper cliff sections typically show retrogressive thaw failures, indicating ice-rich material; mudflows from such failures commonly flow across beaches; retreat rates are moderate (0.5 to 1.0 m/yr).

Low Tundra Cliffs: low coastal cliffs (< 1 m relief) fronted by narrow sand, or sand and gravel beaches (Fig. 8-7c); cliffs commonly show a veneer of sediment on tundra; log lines are common landward of cliff edge; retreat is moderate to high (1 to 2 m/yr).

Inundated Tundra: consists of submerged tundra extending into nearshore and foreshore areas; comprises low-relief areas from highly crenelated coastlines (Fig. 8-7d); beaches are narrow to non-existent, although wide intertidal and sub-tidal flats are commonly found in association ; organic-rich areas are common; this type has a high rate of coastal retreat.

Summary of Accretional Land Forms

Barrier Beaches and Spits: consist of sand to gravelly sand barrier beaches of variable width depending on wave exposure (widths 20-200 m); wider spits are usually associated with exposure to high waves (Fig. 8-8b); multiple recurved spits cause local increases in width; relief is low (< 1.5 m); associated with lagoons and/or estuaries which commonly contain a wetland fringe; dunes are rare; spit stability is determined by retreat of anchoring headlands; barrier islands are comparatively stable.

Intertidal Flats, Wetland and Channel Complexes: are usually associated with deltas; flats are typically very wide (up to several kilometres), and are comprised of sands, muddy sands and/or organic material (Fig. 8-8c); commonly are erosional scarps cut into peat at, or near the high-water line; coastlines are complex and highly crenelated with flats on the outer coast, and channels and wetlands to landward.

Erosion in the Vicinity of Tuktoyaktuk Harbour: a Case Study

The Hamlet of Tuktoyaktuk Harbour was established in 1934 by the Hudson's Bay Company, as a transshipment point for barge freight from the Mackenzie River. The harbour is 20-30 m deep in places and is the best facility of its kind between Herschel Island to the west and Cape Bathurst to the East. It had a population of approximately 1000 people as of 1994, and is the only permanent settlement on the coast of the Canadian portion of the Beaufort Sea west of Banks Island. During the 1970-80s, it was the supply depot and the main staging location for Canadian oil exploration on the adjacent Beaufort Shelf; however, declining oil prices have led to the so-called moth-balling of the exploration facilities.

The hamlet is located on a small peninsula along the Tuktoyaktuk Peninsula on the eastern shore of Kugmallit Bay. Surficial sediments in the region consist of glacio-fluvial sand and gravel capped by thin diamicts. It is in the zone of continuous permafrost and massive ice, which is in the form of intra-stratal sills, wedges and pingos, is common. Sea level is rising at a rate of approximately 2.5 mm /yr; consequently, much of the coast is erosional with typical, long-term erosional (multi-decadal) retreat rates of unlithified coastal bluffs on the order of 1-2 m/yr. Locally, aggradational features (spits and bars) are formed by transport of eroded sand and gravel. Spits on both ends flank the peninsula on which the hamlet is located.

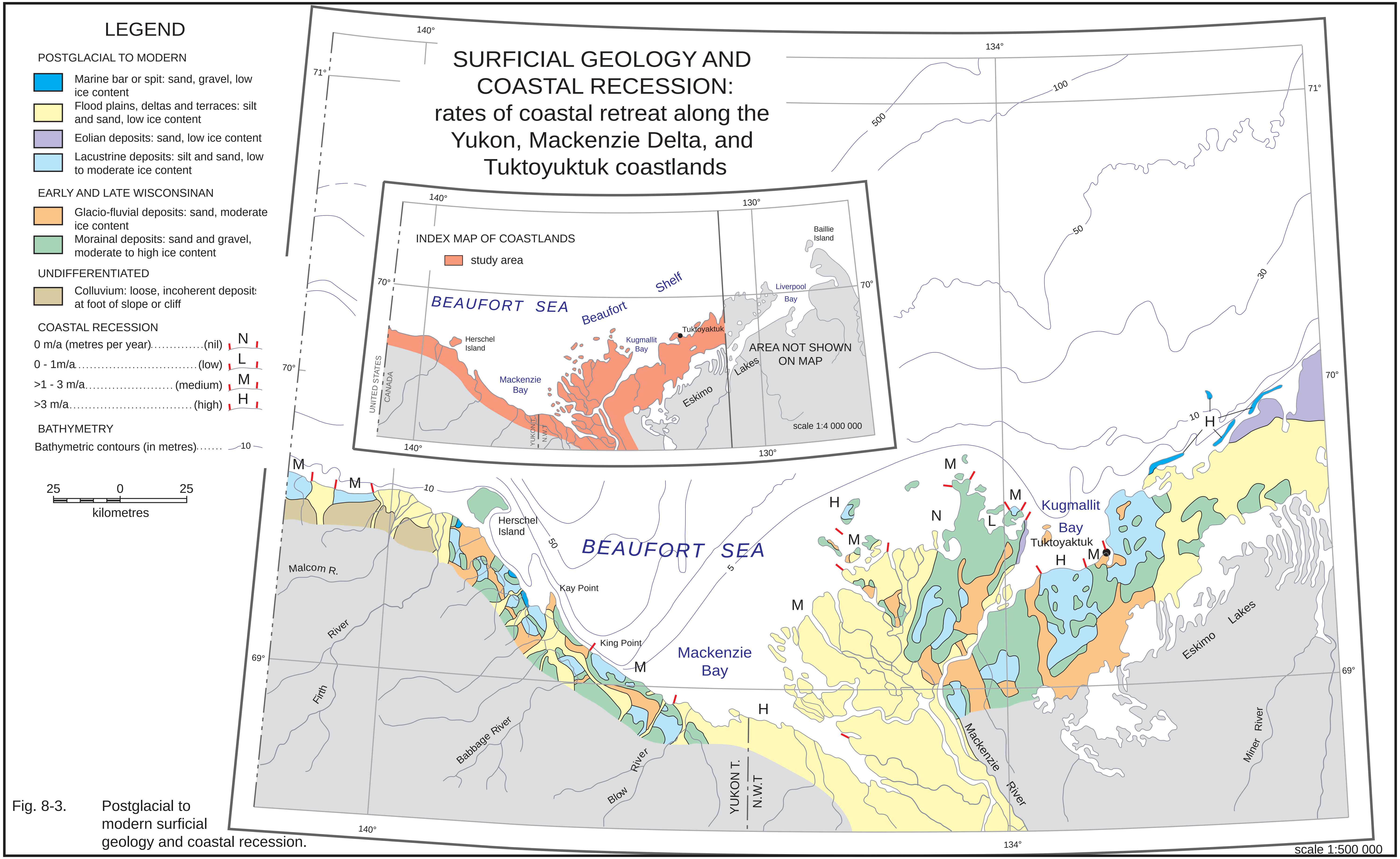


Fig. 8-3. Postglacial to modern surficial geology and coastal recession.

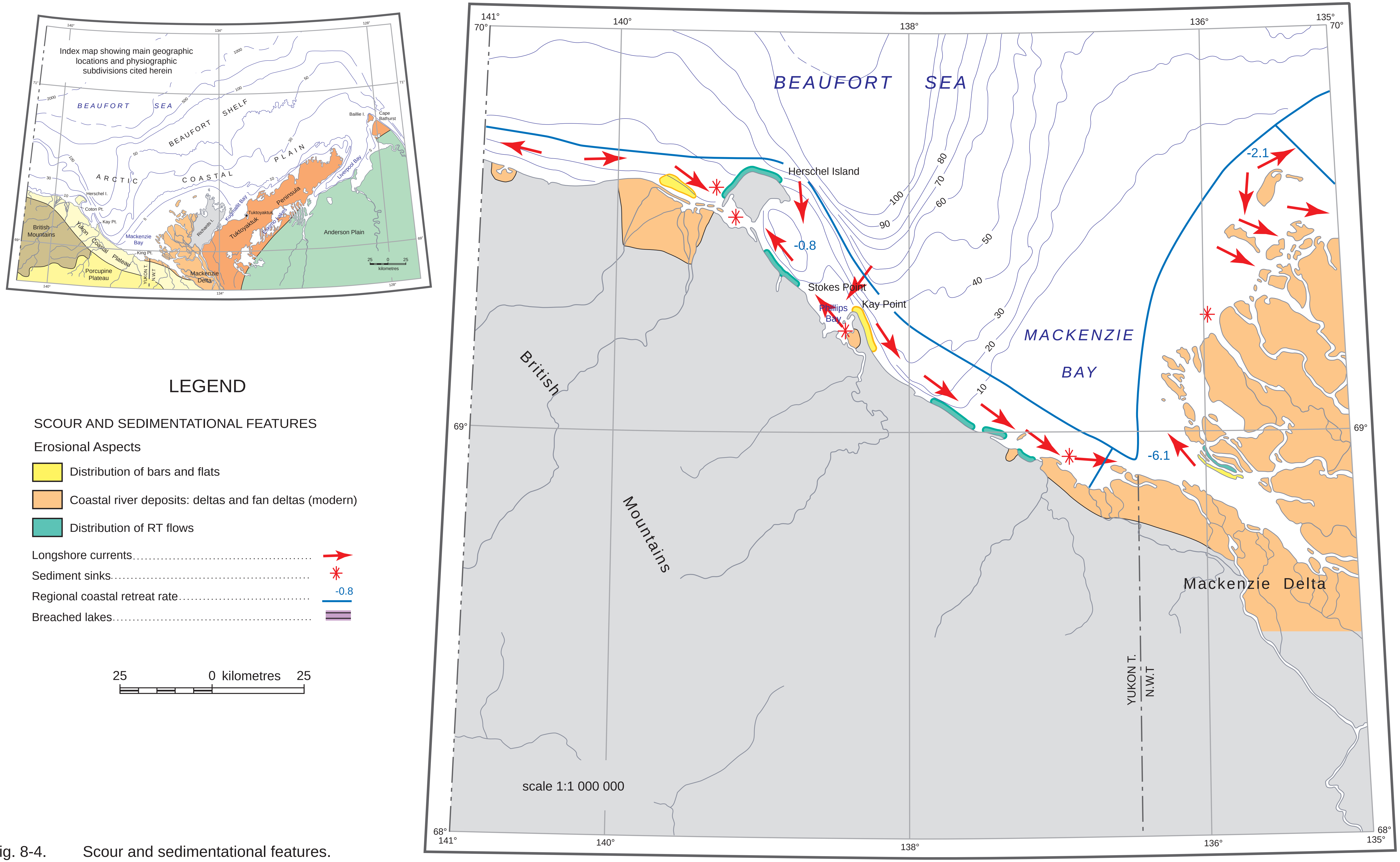
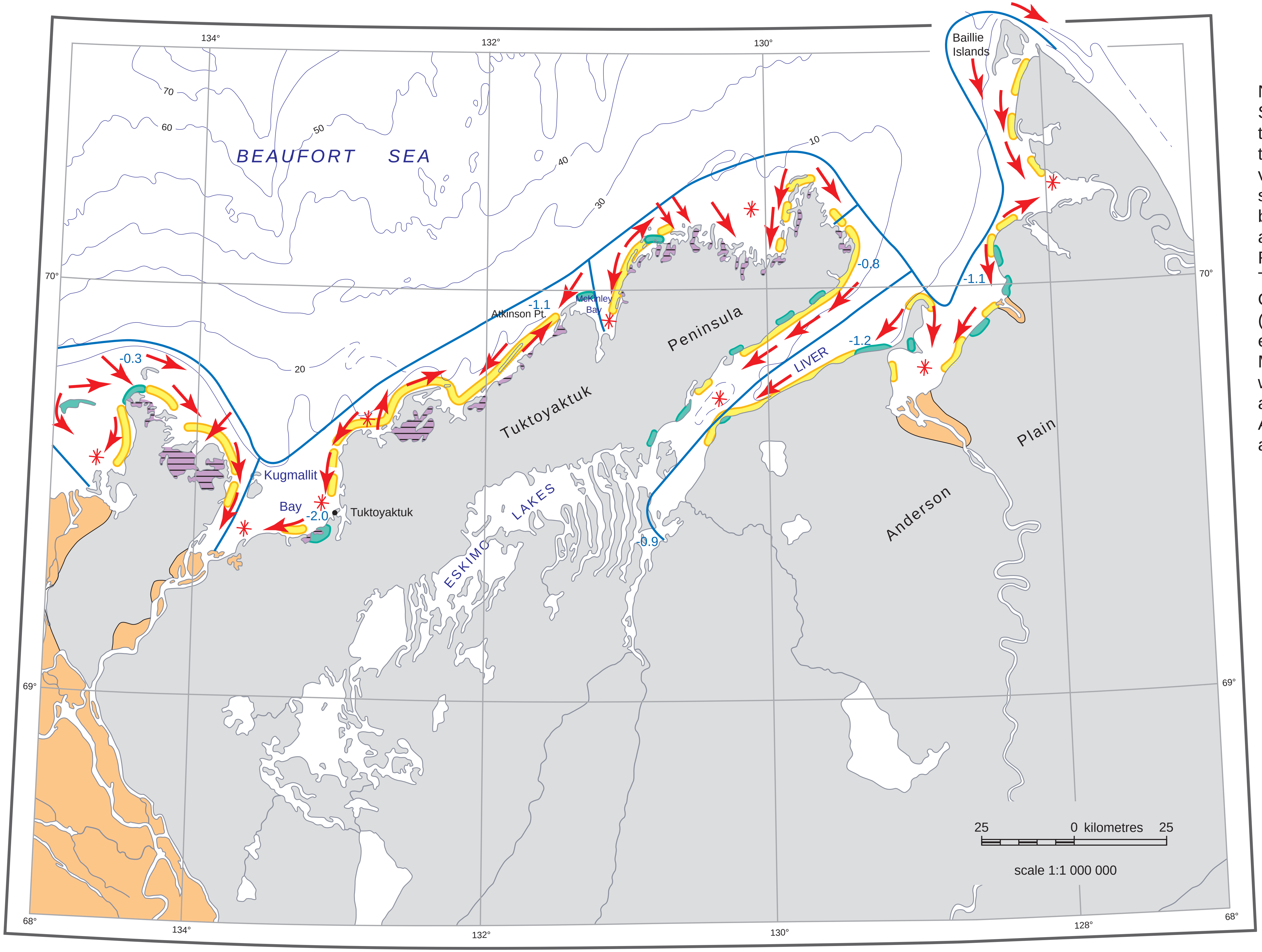
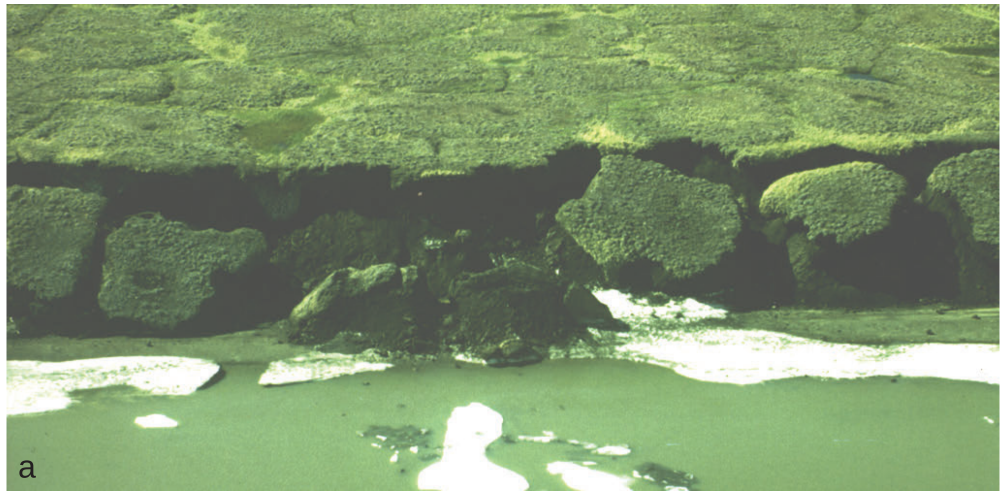


Fig. 8-4. Scour and sedimentational features.



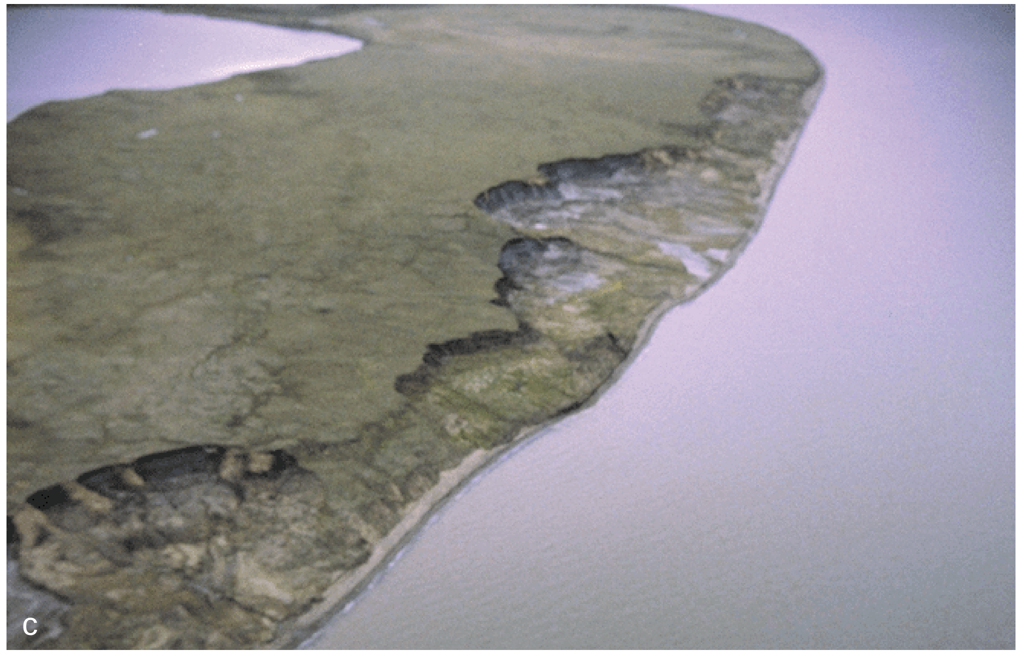
NOTES:
Sedimentational and erosional trends are the main features , together with the distribution of various landforms. Equally as significant is the distribution of breached lakes, which extends along the entire coast from northern Richards Island to eastern Tuktoyaktuk Peninsula. Occurrences of the RT flows (retrogressive thaw flowslides), except for a single RT feature in Mackenzie Delta, are fairly widespread along both the Yukon and Northwest Territories coastlines. Accretional landforms are common along the entire Beaufort Sea coast.

Fig. 8-5. Scour and sedimentational features.



a) Ice-rich cliffs experiencing block failure along ice-wedge polygons.

b) Inundated tundra and low tundra cliffs. The Arktos-Beta survey vessel and camp are in the background.



c) Retrogressive Thaw Failures

Fig. 8-6. Types of coastal cliffs along the Beaufort Sea coast.

COASTAL MORPHOLOGY, SEDIMENTS AND PROCESSES: Erosional Coastal Types

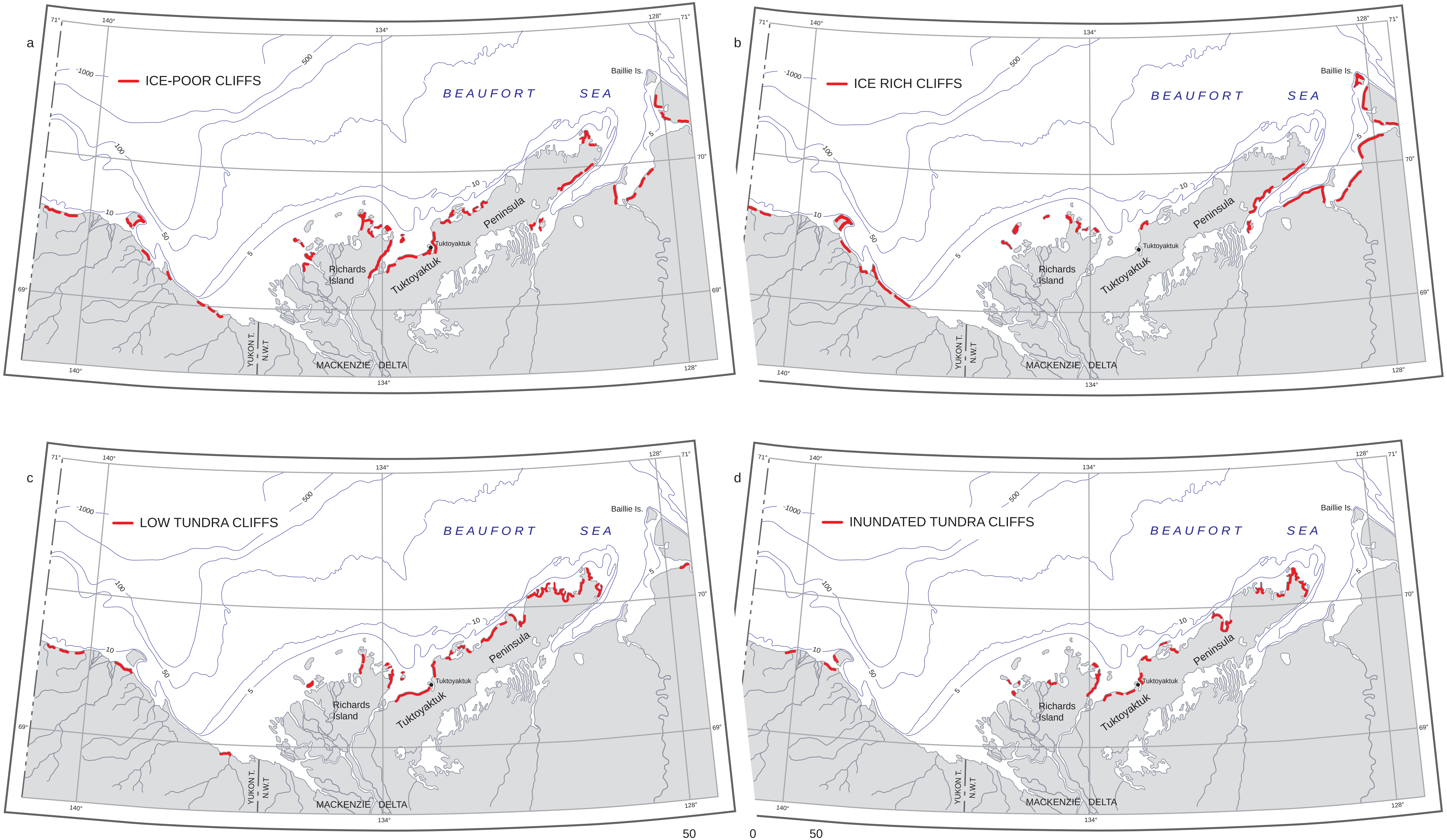


Fig. 8-7. Erosional coastal types.

50 0 50
kilometres

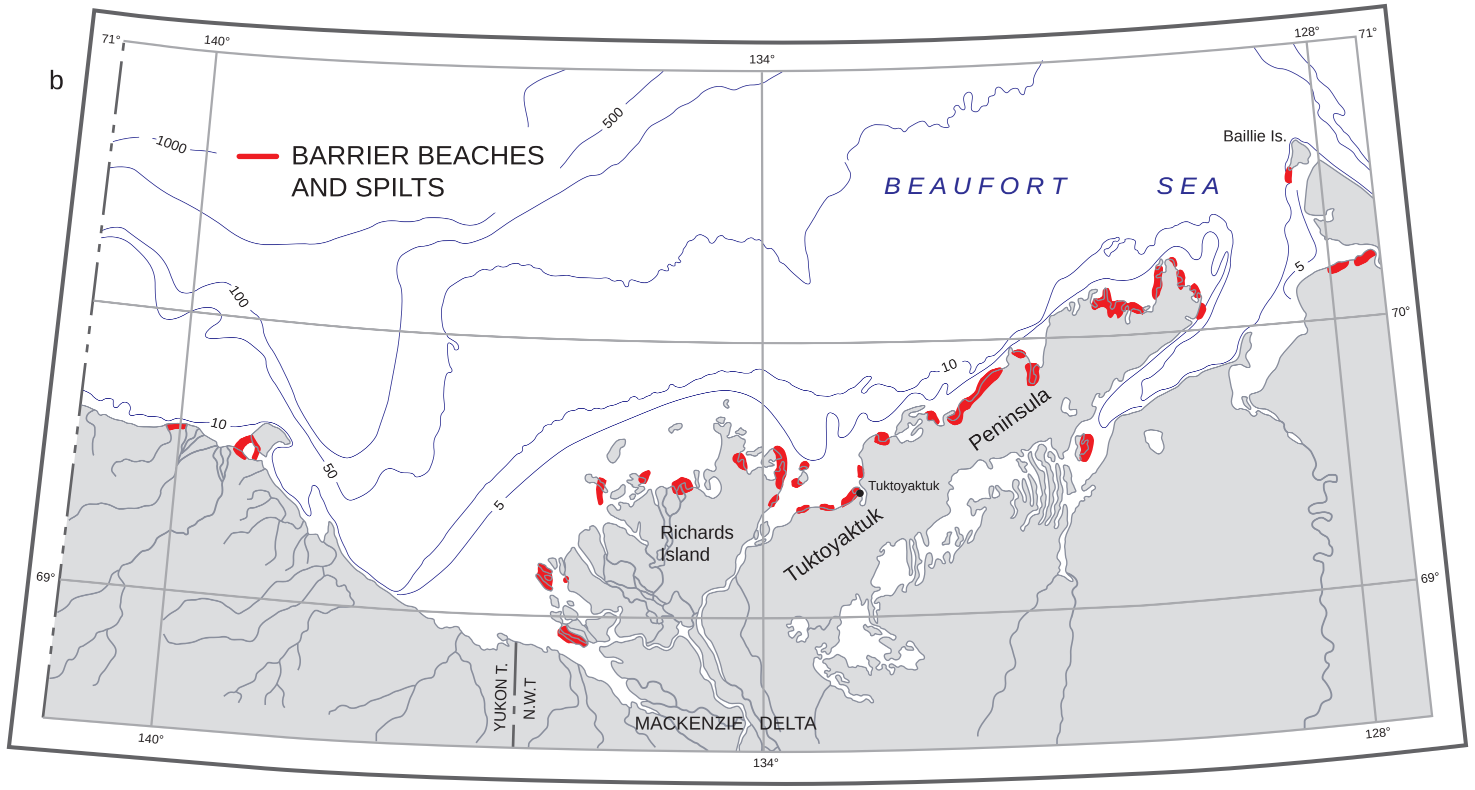
scale 1:3 000 000

COASTAL MORPHOLOGY, SEDIMENTS AND PROCESSES: Erosional Coastal Types

a) Barrier beaches and splits are aligned with the along shore current flow at King Point (photo above). The beach ridges at King Point indicate the gradual accretion or build-up of the barrier beach and spit complex across a former breached-lake basin.
Note the abundance of driftwood from the Mackenzie River.

Accretional Landforms

b) Barrier Beaches and Spits--sand to gravelly sand barrier beaches of variable width depending on wave exposure (widths 20-200 m); wider spits usually associated with high wave exposure; multiple recurved spits cause local width increases; relief low (<1.5m); with lagoons and/or estuaries which commonly contain a wetland fringe; dunes are rare; spit stability determined by retreat of anchoring headlands; barrier islands comparatively stable.



c) Intertidal Flats, Wetland and Channel Complexes--usually associated with deltas; flats are typically very wide (up to several kilometres) and comprised of sands, muddy sands, and/or organics; commonly low erosional sharp cut into peat at or near the high water line; coastlines are complex and highly crenelated with flats on the outer coast, and channel wetlands to landward.

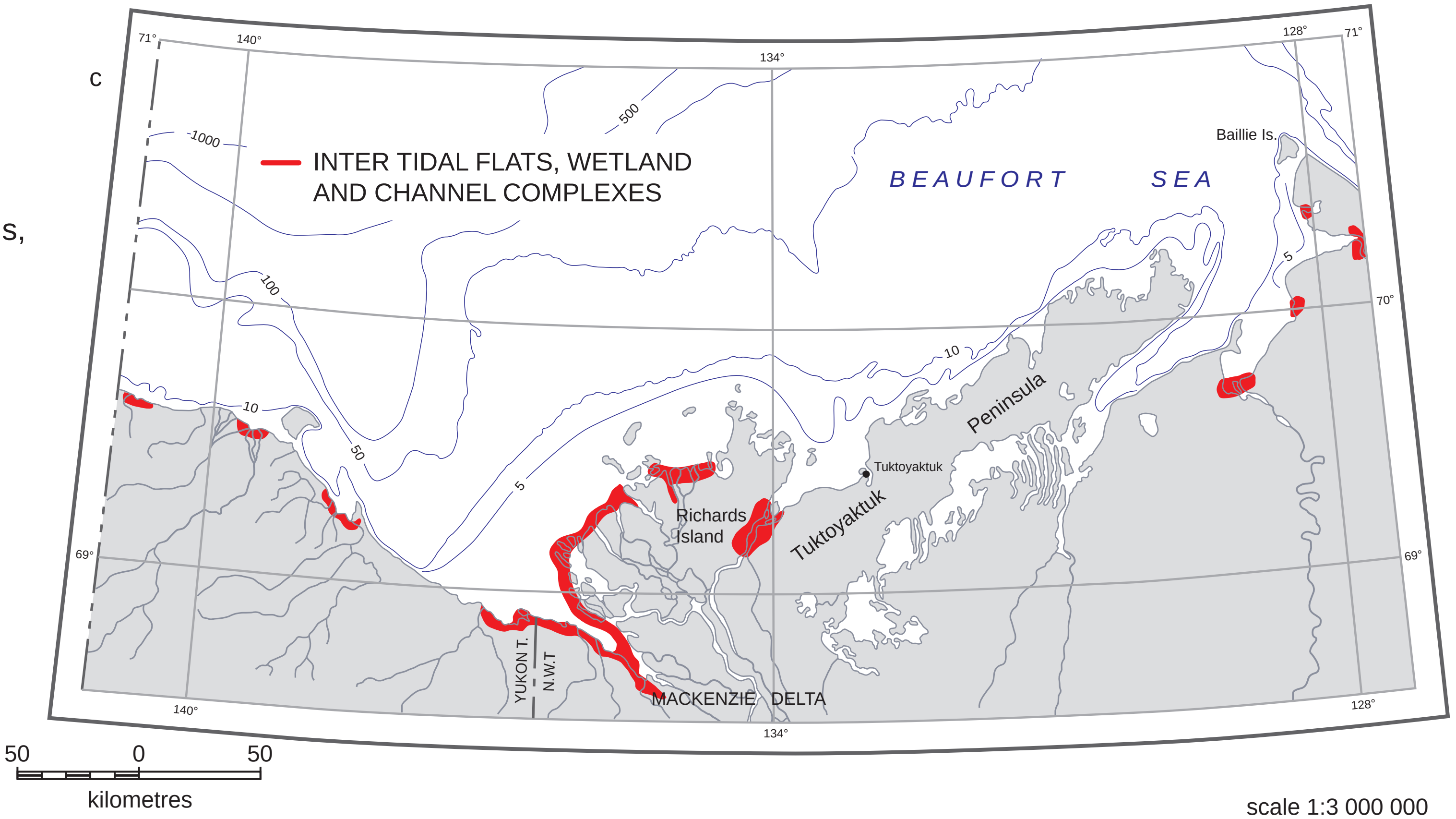
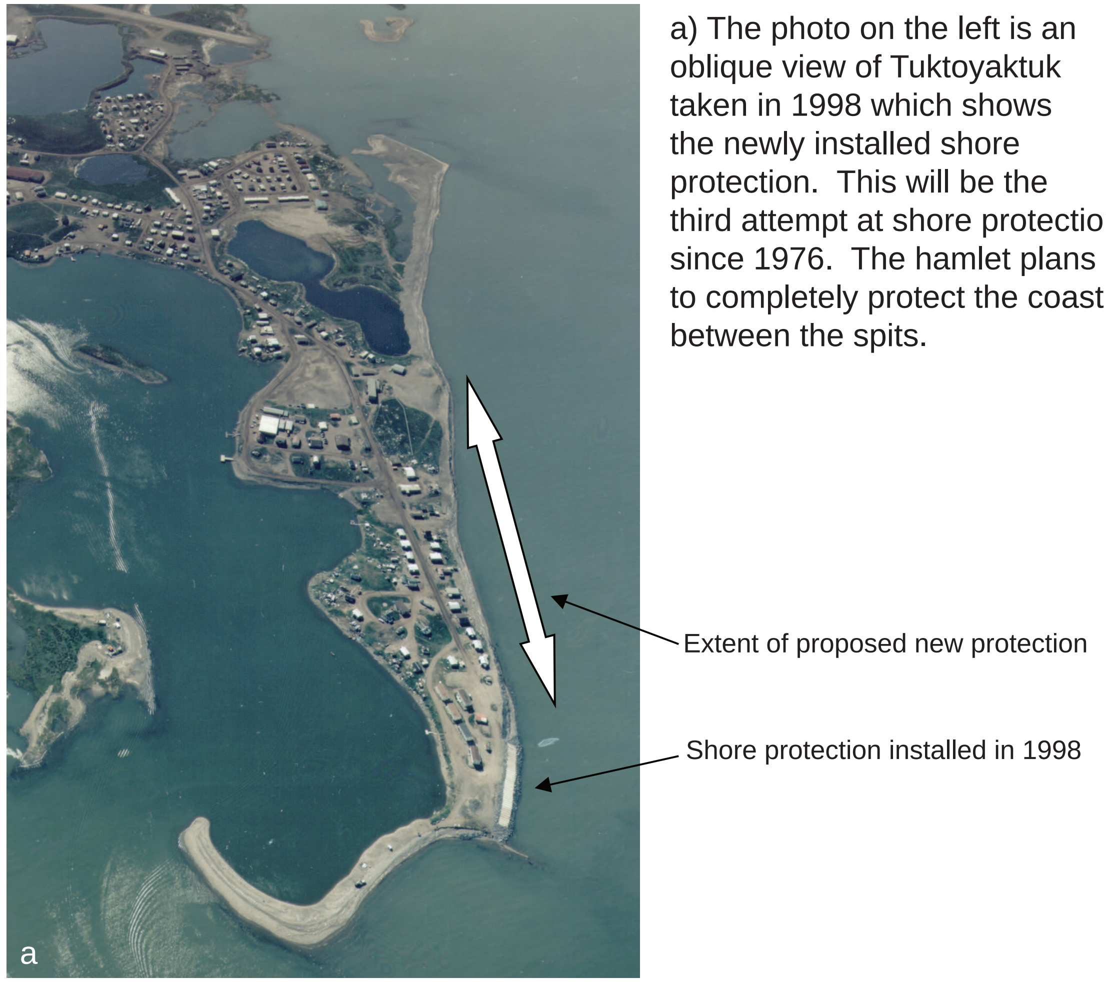


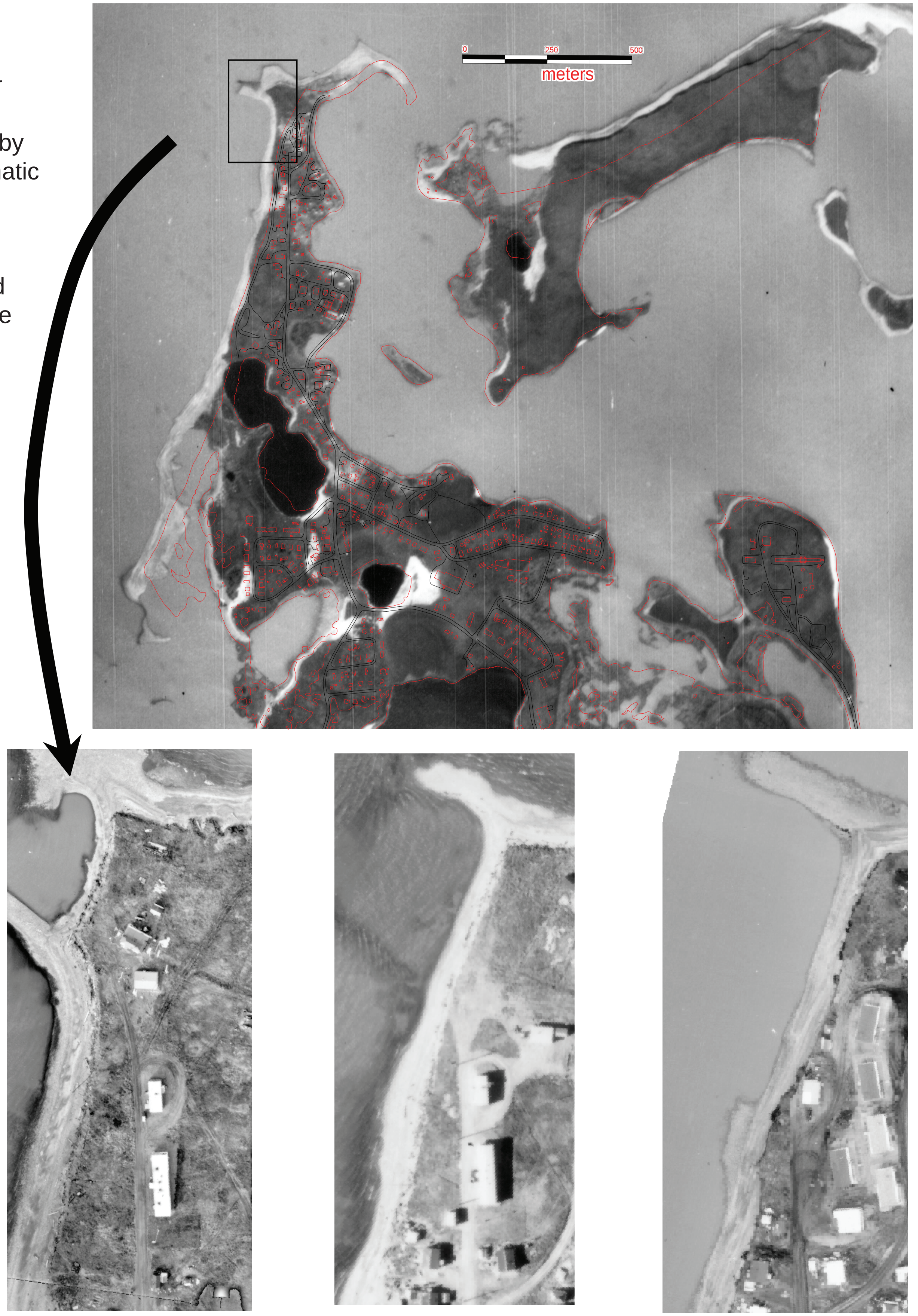
Fig. 8-8. Erosional coastal types.

scale 1:3 000 000

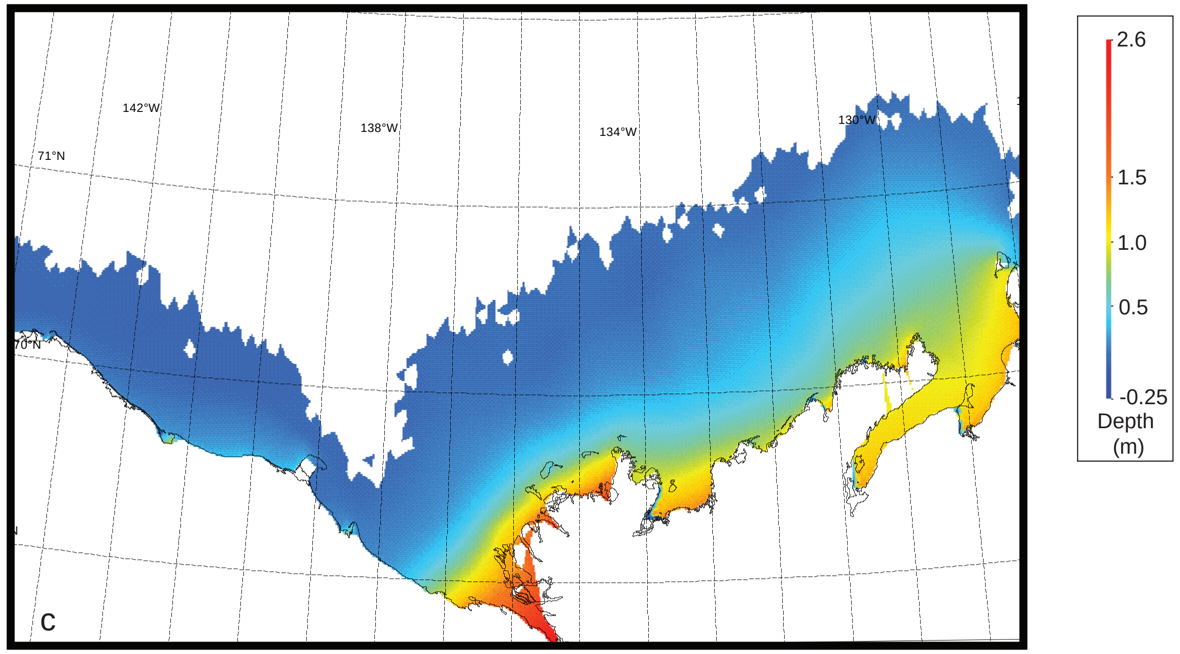
a) The photo on the left is an oblique view of Tuktoyaktuk taken in 1998 which shows the newly installed shore protection. This will be the third attempt at shore protection since 1976. The hamlet plans to completely protect the coast between the spits.



b) The photos on the right depict coastal changes in Tuktoyaktuk. The upper right shows a 1947 air photo with the 1993 shoreline, buildings and roads, as mapped by the GNWT (shown in red). Dramatic changes have taken place at the north and south ends of the peninsula where cliff erosion amounts to more than 100 m and spit movement of nearly the same amount. Shore protection installed in the late 1980s has slowed, but has not stopped cliff erosion, spit erosion continues and may increase even after new protection is installed. The insert at the lower right shows a closeup of changes at the northern tip of the peninsula.



1968 1978 1986



c) Storm surge August 1987

Fig. 8-9. Tuktoyaktuk coastal erosion case study.

Although erosion has certainly been a feature of the Tuktoyaktuk area prior to the founding of the hamlet, it is was first mentioned as a problem by V.N. Rampton and M. Bouchard in 1975. They reported that as much as 13 m of cliff retreat had occurred during a severe storm of 1970. Recent research has established the importance of fall storms, the position of the sea-ice edge, and the accompanying storm surges in the rapid retreat of permafrost-infested coasts.

Severe storms and very little ice in 1944, 1970 and 1993 resulted in major episodes of erosion. The curling rink was undermined and destroyed in 1980s, and the school was closed and razed in the 1990s. Climate change, due to warming trends, may increase the frequency of damaging storms because of decrease in the amount of ice in the area during the summer, and possible changes in storm intensity or frequency. Rising sea levels will have long-term impacts as well.

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CHAPTER 9
THE COASTLANDS

THE COASTLANDS

Introduction

Coastal mapping covers the adjacent coastal waters and land that extends from the Alaska-Yukon border eastward to, and including the northern part of Bathurst Peninsula on the western coast of Amundsen Gulf. This overall area includes the following: all islands lying in the Beaufort Sea from Herschel Island off the Yukon coast, to Baillie Islands north of Cape Bathurst; a broad swath of terrain paralleling the Beaufort Sea coast, and part of the coastlands lying along the northeastern part of Eskimo Lakes and adjacent Liverpool Bay; and a substantial portion of the northwestern sector of Mackenzie Delta (Fig.1).

In order to provide details of physical settings, surficial geology units and processes, as well as commentaries on natural resources and geological hazards, the region is subdivided into 27 mapping areas (Fig. 1) at a convenient scale of 1: 150 000. These maps are designated according to geographic location and a corresponding numeral, and are designed to cover the coastlands in the southeastern Beaufort Sea, and to serve as companion maps to those produced in two earlier works. One of these was authored by B.W. Worbets for the Arctic Petroleum Operators' Association (APOA Project No. 136) and deals with oil-spill protection and cleanup strategies in the southern Beaufort Sea; the other was produced by private consultants (DF Dickins Associates Ltd., and ESL Environmental Sciences Limited) and government staff for Environment Canada, and is devoted to oil-spill response and environmental sensitivity in the southern Beaufort Sea. Both works are concerned with oil-spill logistics in the coastal zone. However, the present atlas covers the physical aspects and the associated wildlife refuges in the coastland areas that could be affected by both natural and anthropogenic causes. All three series of coastal maps have the same scale, similar bases and the same geographic names and general boundaries, but their content and aims are somewhat different. Because of these qualities, the maps are complimentary to each other and present a well-rounded view of the environment of the Beaufort Coastlands.

Surficial Geology Units and Processes

A description of surficial geological units and processes is given in the following account, and is presented succinctly in the Legend on the facing page. The basis of the Legend has textural and engineering aspects that are utilized in other sections of the Atlas. Certain geotechnical features of the surficial units, such as texture, permafrost , stability and geological hazards are described, together with potential of the units as sources of aggregates for engineering purposes. The description in the Legend given here is expanded from that in Figure 1, and on the separate maps of the series. This practice provides a ready reference when proceeding through the series of Coastland Maps, and eliminates considerable repetition because some legend items may be utilized on only a few maps. This presentation provides an economy of space, even though the Legend is common to each map of the Coastlands series. Each legend item is described in the following account.

Unit 1. Beaches (see Coastland Maps 1-6,10,12-20,23-26).

This unit includes both marine and lacustrine deposits that occur along the beach, and comprises gravel and/or sand and gravel ridges about 0.5 -1.5 m in height. Some beaches may occur as flat areas along present, or former shorelines. Spits and bars that are composed of sand and gravel, and found adjacent to the present coastlines, are included in this unit. The ice content is low in active beaches, but is moderate in stabilized ones, on which an ice edge may develop adjacent to the sea. Ground surfaces of beaches and ridges are relatively dry, although depressions may be wet and occupied by marshes. Flooding occurs frequently in the lowest areas during periods of major storms when severe coastal erosion, alteration of beach ridges, and longshore transportation of sediments take place. The storm effects are the chief hazards associated with this unit. Although minor in total exposure, the barrier bars and spits are important to coastal activity. For example, they may close off inlets from the sea and establish refuges for wildlife. However operations involving excessive removal of aggregates from these units may accelerate erosion and destroy or displace these wildlife sanctuaries, as well as the physical features along the coast.

Unit 2. Thermokarst lake beds. (see Coastland Maps (2-6,10-27).

This unit consist of clay, silt, and peat, mainly, with local deposits of sand and gravel. The thermokarst is formed when heat from the water in local thaw pits melts the ground ice in the associated saturated peat and underlying mineral soil, and a sink or pond forms. The thaw basins so-produced may coalesce with others to form larger, steep-sided and flat-bottomed features. In this unit, the content of permafrost is moderate. About 40% of it occurs as segrated ice in the form of thin, 10 -15 mm seams in the finer sediments. Excess ice, or that ice in excess of the quantity that would be retained when water in the soil is lost upon thawing, is absent in the sands and gravels. Areas of occurrence of Unit 2 are wet and marshy, and contain numerous tundra ponds. Drainage is poor in these areas because of the absence of an integrated system on the surface. These areas are characterized by low-centred polygons. Hazards in this unit are associated with erosion occurring along ice-wedge cracks, and with slumping that is related to the forming of thermokarst around the steep slopes of lakes. Removal of thawed material can lead to subsidence amounting to 3 or 4 m in vertical extent. Unfrozen material in the organic beds can be compressed; therefore, the presence of thawed organic beds constitutes a unit of low strength. These beds could collapse under a load, thus leading to a construction hazard. This unit is a poor source of fill or granular material, except where it is developed in association with some of the tundra ponds in the sandy and gravelly features of Unit 6.

Unit 3. Fined-grained river deposits (see Coastland Maps 1-12, 14,20-25).

Sediments of this unit comprise silt, fine sand, and clay with peaty beds, all of which form floodplains and low, bordering terraces. Sands and organic silts are found in the alluvial fans and terraces of the numerous steams present in the areas covered by this unit. Other sandy deposits accumulate adjacent to islands lying down-current from the mouths of major deltaic distributaries, and around the shores of the outer islands of Mackenzie Delta. Stream channels are silt-laden, but other coarse deposits are found in the meander scars and anastomosing channels of the fluvial systems in these areas. On the coastal plain peat coverage is negligible, but can be 3 m or more in abandoned channels and on terraces. Ground ice is absent in unvegetated areas.

The topography of Unit 3 is flat, with overall relief ranging between 1-5 m. Thermokarst ponds may be common in some areas, particularly in Mackenzie Delta. Many lakes and ponds are actively expanding by means of thermokarst collapse of banks in some areas. The only integrated drainage in the unit is produced by the local river, and much of the area is wet and may contain small thaw pools and marshes. The main hazard is thermokarst subsidence, but other serious hazards include slumping of ground ice, gullying on the margins of lakes and channels, undercutting and collapse of banks along river channels during periods of high water, flooding during spring breakup and autumnal storms, and the shifting of river

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

some units may not appear on all maps

1 BEACHES (marine and lake): gravel and/or sandridges or flat areas along present or former shorelines

2 THERMOKARST LAKE BEDS: clay, silt, peat, and local sand on low flat areas formerly occupied by tundra ponds. These materials are generally less than 3m thick over till or sand. Pingos generally confined to this unit.

3 FINE GRAINED RIVER DEPOSITS: silt and silty sand in river channels, flood plains, low terraces adjoining rivers, and alluvial fans; includes organic silt, peat and minor gravel

4 COARSE GRAINED RIVER DEPOSITS: gravel and sand in river channels, floodplains, and terraces adjoining rivers and alluvial fans; includes some silt, peat, and organic silt

5 MARINE AND LAKE PLAINS (marine and lake deposits): clay and silt, commonly surfaced by sand or silt sand with discontinuous organic cover. Principally forming plains bordering rivers and coastal areas. Highly unstable in eroded slopes.

6 GRAVELLY AND SANDY HILLS, RIDGES AND TERRACES: gravel, sand and some silt. Includes eskers and other gláciofluvial deposits, river terraces, sanddunes, and moraines consisting of deformed, gravelly-sandy strata.

7 ICE-TRUST HILLS AND RIDGES: mainly silt and clay with minor sand and gravel in moraines; strata tilted and folded

8 TILL PLAIN: till, occuring as ground moraine with low rolling relief or parallel drumlin ridge. Large areas are clayey to silty till as a thin veneer on shale; locally forms a thin veneer on other kinds of bedrock. Includes undifferentiated areas of organic terrain.

9 HUMMOCKY TILL-CAPPED TERRAIN: clayey to gravelly-sand till, local gravel, forming rolling to hilly moraine composed of individual and coalescent hummocks. Local contrasts in material and ground ice between well drained hills and poorly drained depressions. Includes small undiffentiated areas of organic terrain

10 UPLAND AND PEDIMENT COMPLEXES: areas of moderated to low slope, in part hilly surfaced by till, disintergrated bedrock, and local clay, silt, sand, or gravel. Unconsolidated deposits generally form thin veneer over rock but in places they are more than 3m thick.

11 MOUNTAINOUS AND ROCKY AREAS: rock outcrop or rock thinly covered by rubble or driff. Moderate to steep slopes.

Geological boundaries of surficial units

Eroding river or shore cliffs (one or both walls)

Eroding river or shore cliff (one or both valley bedrock)

Pingos (major ones) ✳

Lowland swamps or weedy foreshore

Breached lakes on shoreline

Main sediment transport direction →

Coastal sediment sinks ✳

Barrier deposits, spits and bars

Bathymetric contours (m) 2

Hydrographic soundings (m) 94

Topographic contours (m) 30

Topographic elevations (m) 183 △

RESOURCES AND ACTIVITIES

Marine and wildlife:fish(F), mammals(M), birds(B) F,B, M

Camps for whaling(W), hunting(H), fishing(F) W,H, F

Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries) ●,●,●,✕

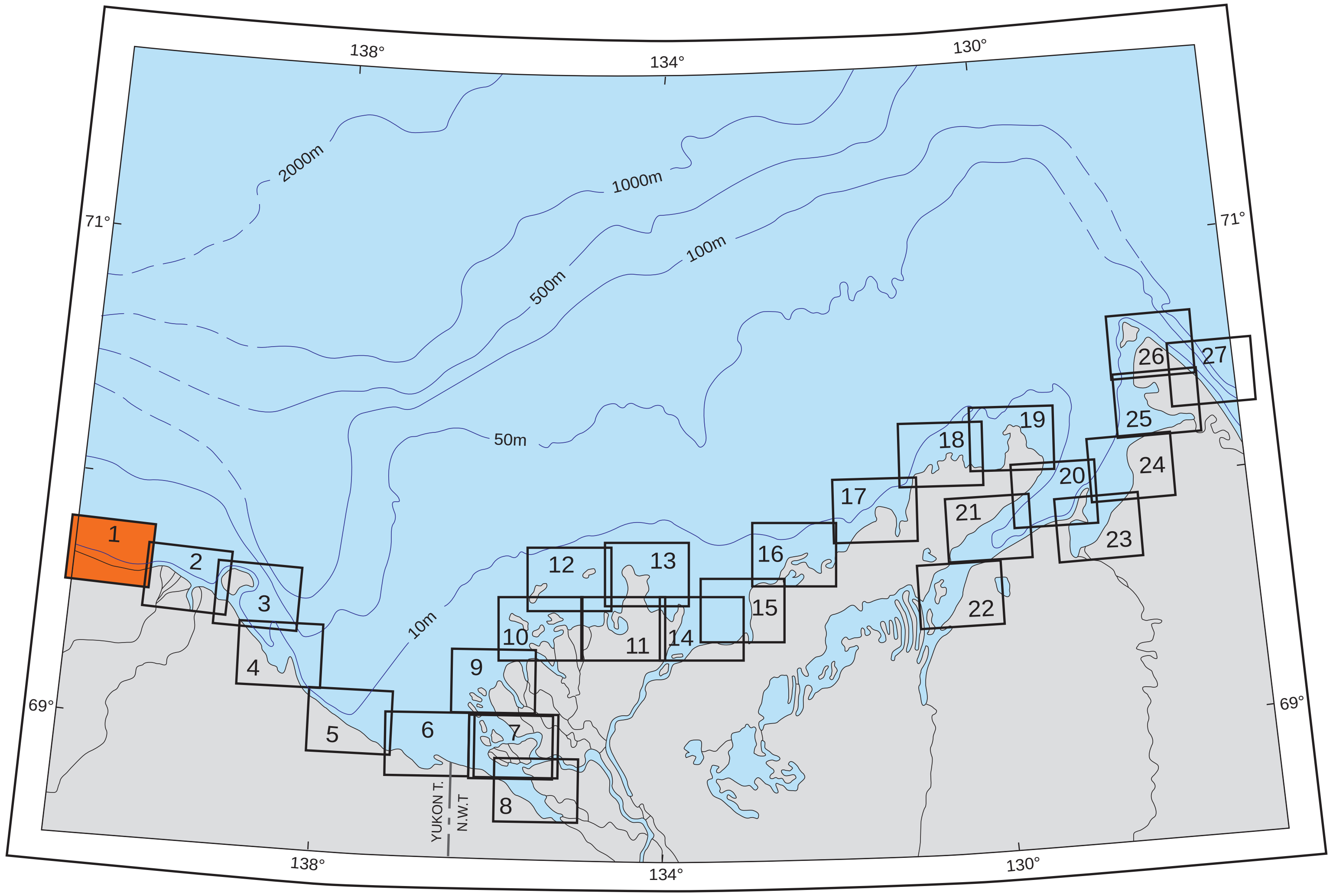


Fig. 1 Subdivisional maps of Beaufort Coastlands at a scale of 1: 150 000. Numerals indicate map number to correspond to map title in list given below. Tinted block represents the pertinent map of the series (e.g. Komakuk Beach 1). This index is shown on all maps.

LIST OF COASTLANDS MAPS

1. Komakuk Beach
2. Nunaluk Lagoon
3. Herschel Island
4. Phillips Bay
5. Shingle Point
6. Shoalwater Bay
7. Outer Shallow Bay
8. Inner Shallow Bay
9. Olivier Islands
10. Garry Island
11. Richards Island
12. Pelly Island
13. North Point
14. Kugmallit Bay
15. Tuktoyaktuk
16. Hutchinson Bay
17. McKinley Bay
18. Nuvorak Point
19. Cape Dalhousie
20. Nicholson Island
21. Liverpool Bay
22. Campbell Island
23. Wood Bay
24. Cape Woki
25. Harrowby Bay
26. Baillie Islands
27. Traill Point

channels. Due to its extremely low elevation, landslides are generally absent in the area of Mackenzie Delta. This unit is a poor source of burrow material because of its fine-textured sediments overall, high organic content, and only minor amounts of coarse sediments.

Unit 4. Coarse-grained river deposits (see Coastland Maps 1,2,4-6).

These sediments are mainly coarse gravel and sand, and may include silt, peat and organic silt. They occur in river channels of floodplains, in low terraces that lie adjacent to rivers, and in alluvial fans. On the floodplain terraces the coarser sediments are 1-7 m thick, and commonly with a veneer of silt about 0.5 - 2 m in thickness. The peat cover is 1-4 m thick and is restricted to former river channels, largely. With respect to permafrost, ice content is low in coarse-grained sediments, and rare ice lenses are present in the finer deposits. In the silt veneer, a moderately high ice content is present.

Shallow thermokarst ponds occur on low terraces that are present throughout Unit 4, but an integrated drainage system is absent. Ground surfaces of coarse-grained beds are generally dry, although swamps may be found in former river channels. The chief hazards are as follows: minor thermokarst subsidence, undercutting and collapse of banks during periods of high water, flooding during breakup and summer storms, and shifting of channels throughout the river system. Considerable sandy material is available for fill; however, excessive exploitation near river sites may lead to accelerated erosion and increased shifting of channels.

Unit 5. Marine and lake plains (see Coastland Maps 1,10-14,20-27).

Sediments in this unit consist of clay and silt ranging in thickness from 1-20 m, and comprise old lake beds that may have a discontinuous organic cover. Localized small areas may contain sand and gravel as well. The deposits of Unit 5 are associated with extremely shallow waters in the marine areas where depths are less than 2 m. Ground-ice conditions are moderate and, commonly, up to 40% of the ice may occur as thin, 25-mm seams in the upper 1-4 m of the beds.

In Unit 5, ground surfaces of the deposits are flat to gently sloping. These surfaces are wet and somewhat marshy in areas where low-centered polygons have developed. The beds tend to extend parallel with the coast, where they terminate as sea cliffs. Erosion occurring along the borders of ice wedges, together with the subsequent block-slumping of these beds, are part of the process leading to this cliff formation. Another hazard involves the removal of thawed material, which can lead to subsidence amounting to 2 m or more. Unfrozen material present has low strength, and this quality of the soil could cause foundering at construction sites. This unit is not a source of granular material or fill, except in localized areas.

Unit 6. Gravelly and sandy hills, ridges and terraces. (see Coastland Maps 3-6, 10,11,13-25,27).

The major components of these sediments comprise gravel and sand, with some silt. These sediments are found in eskers and other glaciofluvial deposits, as well as in undifferentiated river deposits. Sand and gravel beds are about 2-20 m thick, and a veneer of sand may be present on terraces in the vicinity of Eskimo Lakes. Typically, the ground ice present contains cement ice only; however, no segregated ice occurs in the well-drained sites. High amounts of segregated ice occur in silts locally, and at depths below the peat deposits found in channels or depressions. Massive ice is found at depths ranging between 6 and 20 m.

Ground surfaces of Unit 6 may form flat to gently sloping benches that are interrupted by shallow channels and low scarps, as well as by hummocky areas and esker ridges. Some ridges rise to elevations between 50 and 60 m, with adjacent occurrences of swamp in the intervening lower areas. In Unit 6, the drainage is mainly subsurface, but the ground surface is generally dry except on large flat areas and channel courses. Hazards in this unit relate to subsidence and slumping. For example, minor thermokarst subsidence occurs on large flat areas if a silt veneer or peat is present. If the mean annual temperature of the ground increases, ground-ice slumping and possible gullying will take place on slopes where ground ice is present above the base of the slope. Unit 6 is a major source of gravel, as well as mixtures of gravel and sand. Most of the gravels occur in the hummocks, rather than on the outwash terraces. The unit is also a suitable source of borrow material.

Unit 7. Ice-thrust hills and ridges. (see Coastland Maps 2-5,10,12,20,23)

Sediments in this unit consist of silt and clay in ridges, with a minor amount of sand and gravel occurring in moraines. These deposits are covered with a tundra-like vegetation, particularly on coastal islands in the Beaufort Sea. Permafrost, where present, comprises thick bodies of massive ice. Drainage is not a prominent feature of these surfaces which are generally dry. Although unlithified, these beds are tilted and folded, because of the action of former glacial, ice-pushing processes that were directed upon them from the south and east. The major hazards are found along the coast where the unit is susceptible to undercutting and block slumping due to thawing of the massive ground ice and subsequent erosion of the sediment by waves and longshore currents. Aggregates for industrial use are not common in this unit, except for coarser admixtures in the moraines.

Unit 8. Till plains (see Coastland Maps 10-13,15,24).

Sediments in this unit consist of clayey to silty till up to 7 m thick, although they may accumulate to 60 m locally. They are glaciogenic, and commonly form a thin veneer over shale and other bedrock, and may be characterized by the occurrence of a discontinuous peat coverage up to 5 m thick. This peat may be found in depressions or as isolated patches. Ice content in the till is moderate, and constitutes up to 10% in the form of segregated ice; the latter occurs as thin seams in the upper 2 - 4 m of the soil. Locally, thicker ice lenses are found at depths to 4 m, and little or no ice is present in the underlying bedrock.

Unit 8 occurs as ground moraine with a rolling relief of 30 m, or as parallel drumlin ridges. Mostly, the underlying bedrock tends to control the topography of these features. The ground surface is generally dry, but may be moist on the flatter surfaces. Except for local streams, which yield a dissected relief, no integrated drainage occurs in this unit; however, some drainage takes place as downslope seepage in sub-parallel rills. Hazards are due to gullying and a minor presence of permafrost, the latter of which induces the occurrence of permafrost subsidence. Superficial mudflows take place on the slopes. This unit is not a good source of gravel, and the usefulness of till for this purpose is restricted because of its content of ice.

Unit 9. Hummocky till-capped terrain (see Coastland Maps 2-6, 14-18,20-24).

Generally, the sediments in this unit consist of clayey to gravelly sandy till, with minor occurrences of gravel locally, and some organic terrain. Local contrasts in earth materials and ground ice are found between well-drained hills and poorly drained depressions. Up to 10% of ground ice occurs as thin and irregular discontinuous seams that are less than 25 mm wide in the upper 3 m of the unit. Locally these seams may comprise up to 40% of the ground ice present in Unit 9, but thicker ice lenses are present at depths of 4 - 50 m.

Generally, the deposits of Unit 9 form rolling to hilly moraine that is composed of individual and coalescent hummocks. The rolling relief, which rises to about 200 m in the uplands regions, is partly controlled by underlying occurrences of bedrock. Toward the coast, elevations decrease and the unit terminates as sea cliffs several metres in height. Inland, cliffs occur on the banks of numerous small streams that form an integrated drainage system in areas of moderate slope where this unit is commonly found. Drainage on hills is generally good, but is poor in the depressions; in the latter case, bogs or ponds may be present. Hazards are minor, because Unit 9 is only moderately susceptible to thermokarst subsidence and ground-ice slumping. However, ground-ice slumping and gullying may take place on slopes where ground ice is present above the base of the slope; also, a major thermokarst subsidence will take place if the mean annual temperature of the ground ice rises. Only minor sources of aggregates are present in this unit, and the usefulness of till as fill material is limited by the ice content.

Unit 10. Upland and pediment complexes (see Coastland Map 1,2,4-6, 23-27).

The features of Unit 10 are formed on ground surfaces, and are composed of till, disintegrated bedrock, boulders, and consist of clay, silt, sand, or gravel locally. These deposits form a thin veneer over bedrock but, in some places, they reach thicknesses of at least 30 m. Ground ice in this unit may be low in volume, and excess ice is generally absent altogether.

In some of the higher areas of the region at elevations of 100-300 m, these pediment complexes lie on hills with moderate to low slopes that may be unvegetated. Drainage is generally good on the moderately inclined slope, and consists of seepages in the downslope direction. However most slopes and hilltops are generally dry, with swampy terrain occurring in the depressions. From a standpoint of hazards, minor detachment slides are present. Also characteristic of this unit are the occurrences of gullying and mudflows, although of moderate intensity. This unit is a poor source of aggregates or fill but, where bedrock such as shale is close to the surface, it is a source of burrow material because of its low ice content and its strength under load.

Unit 11. Mountainous and rocky areas (see Coastland Maps 1,2).

These areas are flat and gently sloping, except for the occurrence of steep cliffs locally. In the higher elevations the beds are comprised of bedrock with a regolith of very coarse debris. Peat bogs may be present in local depressions in the topography. Ground ice is absent in the bedrock, and is negligible in the rubble, talus, or other types of overburden. However, the ice content is usually high in the peat bogs.

The slopes of Unit 11 rise to 200 m in the region and are well drained because they are transected by numerous streams. The chief hazards occur as isolated rock falls on the steeper slopes, gullying, ground-ice slumps, earth flows, landslides, and block collapse. These processes can be accelerated under unstable conditions such as those associated with newly thawed material. Flooding is a major hazard but is confined to the lower portion of stream valleys, where it varies from extreme conditions to common occurrences. This unit can serve as a good source of rubble, coarse granular material, and as a ready supply of rock.

Geological boundaries of surficial units.

These boundaries are those of individual, surficial geology units and are indicated by a heavy, solid line. The units that these boundaries enclose are coloured on the map, and are identified by a corresponding numeral given in the legend box.

Eroded and/or eroding river bank, coastal cliff and valley wall in unconsolidated material (one wall, both walls).

The common symbol for these features is a long single line, representing the cliff, with short perpendicular lines directed away from the cliff face. In the case of river banks and valley walls, the perpendicular lines are directed toward the river or valley floor; if both banks and both valley walls have cliffs, then a double track of such lines is used.

Eroded and/or eroding river bank, coastal cliff and valley wall in bedrock (one wall, two facing walls).

The common symbol for these features is a long single line, representing the cliff, with triangular-shaped teeth directed away from the cliff face. In the case of river banks and valley walls, the teeth are directed toward the river or valley floor; if both banks and both valley walls have cliffs, then a row of teeth is used on each side of the cliff line.

Pingos.

Only the major pingos (generally about 30 m in height, or greater) are shown, in order to indicate areas that are characterized by these features. The pingo is symbolized by a circle with 8 short lines radiating from the centre of the site.

Lowland swamps and reedy foreshores.

The characteristic, short horizontal line, together with shorter lines extending upward to represent a sedge-like feature, is used to indicate swampy terrain inland, and several reed-occupied areas alongshore.

Breached lakes on shoreline.

These features are shown as an undulating line that encloses partially open areas of water on the seaward side of the line. These areas are coloured, and are lined horizontally in order to distinguish them from the contiguous land. In certain cases, the colour extends to a presumed location that represents the former boundary of the breached lake.

Main sedimentary transport direction.

The red arrows plotted along the coast and at the distal part of the deltas, as well as around nearby islands and distributaries, depict the major direction of sediment transport. Although water currents may vary in direction locally, only the prevailing current direction is indicated.

Coastal sediment sinks.

These are miniature depositional centres that occur in marine areas that are characterized by decreasing sediment-carrying vigour of the sediment-bearing flow. Conflicting currents, coastal barrier deposits, shoaling waters and excessive sediment load are some of the causes of this phenomenon.

Barrier deposits, spits and bars.

These features are represented by stippled areas, shown in marine waters, which lie in the vicinity of land; some are adjacent to headlands, and some are in shallow water. They are coloured for the purpose of quick identification.

Bathymetric contours (m).

Medium-weight blue lines drawn in offshore areas represent equal depths of water and are so-indicated by the slanted numerals on those lines. Because these depths are synonymous with distance to the seafloor, the contours reveal the general topography of the undersea area.

Hydrographic soundings (m, and 0.1 m in subscript).

These are spot soundings shown in representative areas of the seafloor. The main numeral is the depth in metres, and the subscript numeral is the refined determination to tenths of a metre.

Topographic contours (m).

Relief on land is illustrated by means of topographic contours whose interval is 30 m, beginning with those shown nearest the coast. Some areas, such as the lower Mackenzie Delta, lie entirely below an elevation of 30 m; thus, no contours are shown in those areas.

Topographic elevations (m).

These are spot elevations that may be located at a topographic survey monument or marker.

Resources and Activities

Marine and wildlife are the principal biological resources in the region and lead to traditional aboriginal activities such as hunting, whaling and fishing. Other potential resources include petroleum and natural gas but presently, they are not being utilized. A number of oil and gas discoveries have been made during the past few decades, and these are plotted on the maps. Although the recent status on wells is one of abandonment, these potential producers are still shown. In the search for aggregates, many sand and gravel areas have been located; also, an inspection of the surficial geological units will reveal trends and locations of potential sources such as those indicating disintegrated or shattered bedrock and deposits of sand and gravel.
These materials are used as constructional aggregates. All legend items for natural resources and activities are indicated in the following account, and are shown in the legend of each map of the Coastland.

Marine and wildlife: fish (F), mammals (M), birds (B).

These are the main wildlife categories, and their habitats are indicated by a cross-hatch symbol. The capital letters beside the symbol are the abbreviations of the main marine resource. If a species is prominent, a subscript is used to identify it. For example, Mca represents the following: M for mammal and ca for caribou and so on.

Camps for whaling (W), hunting (H), fishing (F).

These activities are indicated by a tent frame or rack. The capital letters are an abbreviation for the activity that takes place at that site.

Oil and gas exploration (oil, gas, oil and gas wells).

Although abandoned, the geological status of these wells is indicated by the following symbols: a solid circle is for oil, an open circle is for gas, and the combined symbol represents a well containing both oil and gas.

Granular material (sand, gravel)

The crossed pick-and-shovel is the symbol used to indicate specific sites for sand and/or gravel. These deposits are related to pertinent surficial geology units.

Surficial geology data after W.N. Rampton and R.L. Monroe
Coastal landforms and processes after D. Forbes and P. Lewis
Bathymetric information from charts 7661-7662, and 7608:
Canadian Hydrographic Service, Fisheris and Oceans Canada
Wildlife information from Lands Directorate, Indian and
Northern Affairs, Canada
Date regarding oil and gas wells; National Energy Board of Canada
Information on granular deposits: R.J. Gowan, Indian and Northern Affairs Canada
Commentary: B.R. Pelletier

Note: all authorships cited above also apply to the entire series of Coastlands Maps (Map 1 – Map 27).

COASTLANDS MAP 1: KOMAKUK BEACH

The Physical Setting

This coastland area comprises a varied physiography, beginning with a low coastal plain that rises to an upland region within a few kilometres to the south. The upland then merges into mountainous relief about 10 km south of the map area. Most of the topography shown on the map comprises a piedmont that is dissected by many streams such as Clarence River, Craig Creek, Blackhouse River and Fish Creek. Some of these streams form major delta complexes, one of which lies in the western area and actually consists of coalescing fans in the vicinity of Clarence Lagoon. Another delta complex forms at the mouth of Fish Creek, in the vicinity of Komakuk Beach.

The moderate gradient (slope >3°) of the coastal plain terminates at the coast, and steepens within a few hundred metres offshore to the 10 m isobath. From this point seaward, a gentler slope prevails although an uneven undersea topography exists. The coastline is fairly regular, and is characterized by low (a few metres), steep organic cliffs that comprise ice-bonded sediments and earth. The cliffs have been produced by wave-undercutting, block slumping, and marine erosion of the fallen material. The resulting debris and sediment is removed by longshore currents, and is deposited elsewhere along the coast and offshore.

Surficial Geology and Hazards (Units 1,3,4,5,10, and 11)

The boundaries of most surficial units appear to correspond to the trends of the topographic contours, except for the river deposits that transect them. In Unit 11 the bedrock and its associated debris occur in the highest elevations of the area, where gullying is common. Ice may be present in joints, but is generally absent; however, it may be present in the overburden. In terms of landscape changes the main geological hazards here are rock falls, and superficial flows that occur on the steep, eroded slopes of the higher elevations. Other hazards include gullying, ground-ice slumps, earth flows, block collapse, and poor standing performance in unstable conditions such as those accompanying newly thawed materials. Flooding is a major hazard but is confined to the lower portions of stream valleys, and varies from extreme to common occurrences.

Unit 10 is the second major, surficial unit of this map area. Its upland and pediment complexes occur in areas of moderate and low slopes, which may be hilly with a surface of till, disintegrated bedrock, as well as some local clay, silt, sand or gravel. The unit is found in a belt that occupies most of the southern portion of the map sheet, and lies parallel to both Unit 11 and the coastal units. Most of the surface of Unit 10 is unvegetated, and may be covered by boulders. The content of ground ice is low, with little excess ice present. Hills are fairly dry, and drainage occurs as seepage in a downslope direction. The main hazard in this unit is the occurrence of detachment slides, and a somewhat moderate susceptibility to gullying and the production of mud flows. Very few troubles are associated with this unit.

Unit 4 and Unit 3 together comprise an important portion of the surficial deposits in this map area. These units follow river courses and form major coalescing fans. Because of the presence of thermokarst ponds in these units, an ongoing hazard would be thermokarst subsidence. Flooding is common, thus periods of rising high water during this event can lead to the collapse of river banks.

The lake and marine plains of Unit 5 lie in a broad band that is transected near the coast by the fan deposits of Units 3 and 4. Comprising fine-textured material mostly, with a partial organic cover, Unit 5 terminates at the coast in the form of sea cliffs. Ice wedges formed in the unit tend to cause block-slumping, which partly induces this type of erosion.. Removal of thaw material is a common hazard that may cause subsidence of a few metres in the soil. Because of the ice content that can amount to 40%, the unit has low strength. This property of the soil could lead to foundering at construction sites; therefore, it is considered an engineering hazard.

Narrow beaches of sand and gravel comprise the sediments of Unit 1, which are found at the shoreline junctions of the river deltas. Spits and bars are abundant in this unit, particularly in the vicinities of Clarence Lagoon and Fish Creek. Flooding is a major hazard, as it leads to intense coastal erosion, and alteration of landforms along the beach. Any operation involving removal of granular material in this area will lead to increased erosion.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units ....

Eroding river or shore cliffs (one or both walls)............

Eroding river or shore cliff (one or both valley bedrock)...

Pingos (major ones) .... ✳

Lowland swamps or weedy foreshore ....

Breached lakes on shoreline..................................

Main sediment transport direction .... →

Coastal sediment sinks .... ✳

Barrier deposits, spits and bars ....

Bathymetric contours (m) 2

Hydrographic soundings (m)................................... 94

Topographic contours (m) 30

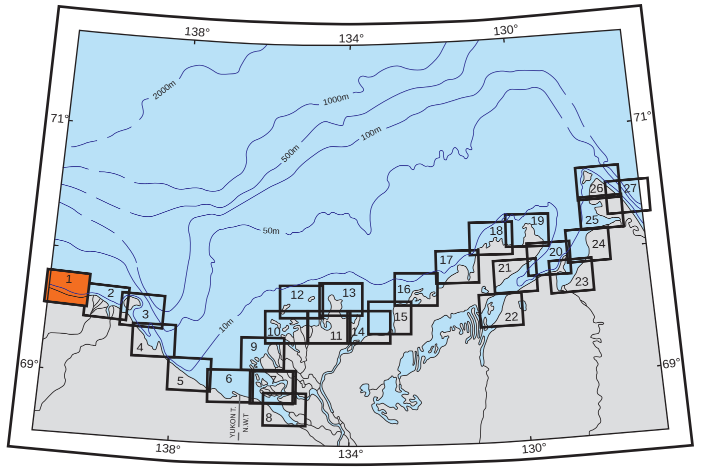
Topographic elevations (m) .... 183 △

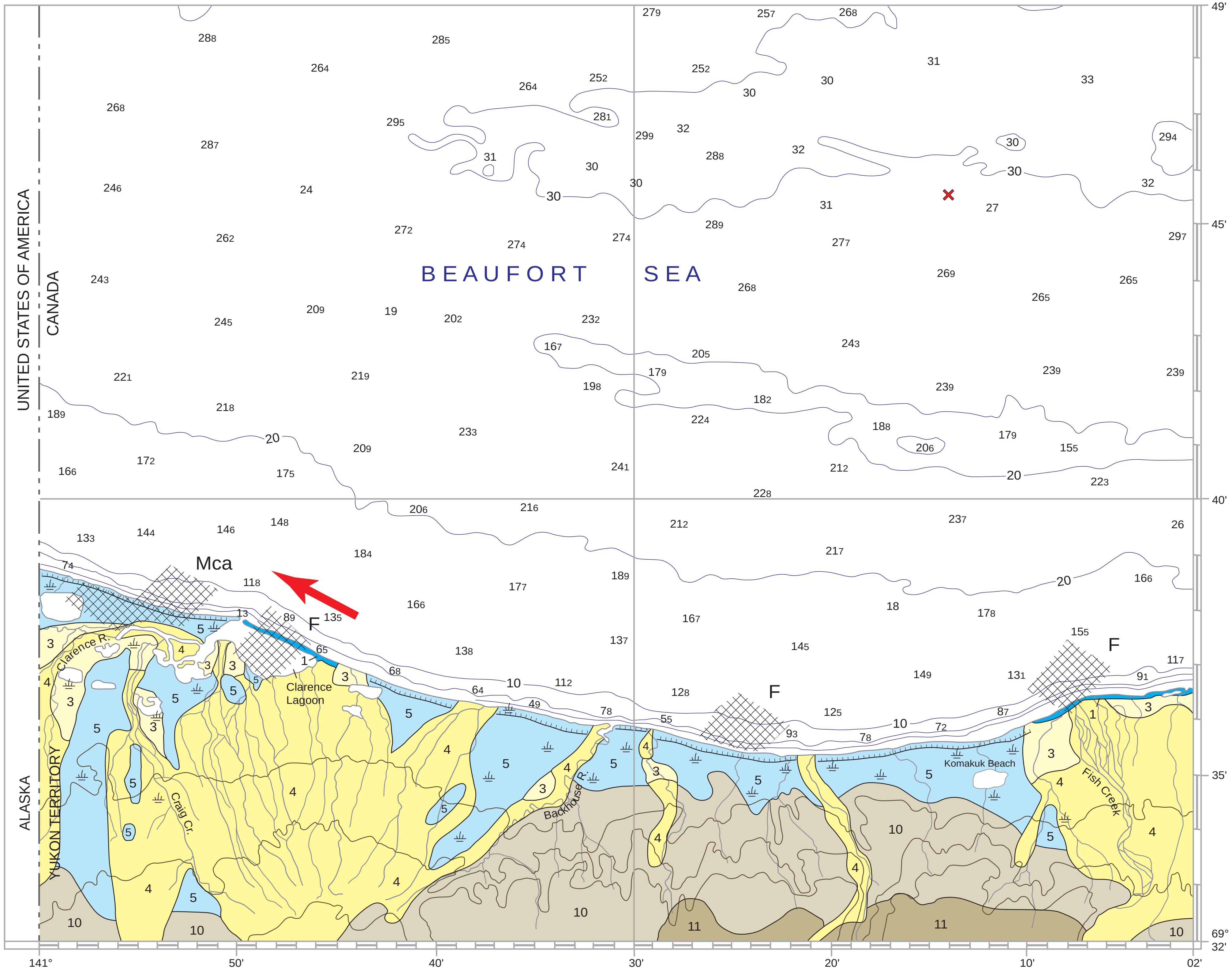
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M ▨

Camps for whaling(W), hunting(H), fishing(F)............... W,H, F

Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries).... ●,●,●,✕





Coastlands Map 1. Komakuk Beach

scale = 1:150 000

COASTLANDS MAP 2. NUNALUK LAGOON

The Physical Setting

The dominating aspect of this map area is the presence of a relatively large, subaerial delta complex that consists of many coalescing fluvial fans. These fans have been concentrated by sedimentary deposition from several major streams and their ancilliary tributaries which drain the uplands and mountainous regions to the south. Fish Creek in the west, Malcolm River in the central portion, and Firth River on the eastern side of the area are the main feeders to this delta complex. Numerous parallel streams, all of which originate in the hilly terrain to the south, and a coherent parallel to semi-parallel system of distributaries of the main rivers also carry sediments toward the coast and contribute to the build-up of this major delta.

Another important feature of this map is the plain that lies between the sea and the uplands to the south. It extends along the entire western portion of the lowland that is bordered by Workboat Passage on the east and Alaska on the west. Swampy terrain occupies most of this region, which lies a few metres above sea level and is part of the Coastal Plain.

Other physical aspects of the region are several barrier bars and spits that lie along the entire length of the sea coast. Nunaluk Spit is an example of one of these features, some of which may partially enclose lagoons, inlets, and somewhat broader marine bodies. Nunaluk Lagoon is a striking example of such water bodies. Sediment movement, commencing with the discharge from river mouths and the debris from eroding deltas and headlands along the mainland coast, contributes toward the construction of bars and spits in those areas influenced by fluvial and marine currents. These latter events are similar to those that produce the erosion and transport of sediments from the western part of Herschel Island. In some areas along the coast, particularly in Workboat Passage, a sediment sink has developed in response to the decreasing velocities of sediment-laden longshore currents.

Herschel Island is a separate and distinct feature of the coastlands in that it has striking local relief. Its elevation rises to nearly 190 m. The entire surface of this island is dissected by numerous stream that have left a network of gulleys in their passage to the sea. Bathymetry offshore begins with a moderately steep, but narrow inshore zone that interrupts the gentler gradient of the lower portion of the delta complex and the coastal plain. Within 1-2 km of shore, the seafloor gradient decreases and assumes a normal shelf aspect. However, in Workboat Passage, the depth of water is less than 3 m and is navigable to shallow-draft vessels only.

Surficial Geology and Hazards (Units 1,2,3,4,6,7,9,10 and 11)

The coarse-grained sands and gravels of Unit 4, the most prominent unit shown, comprise nearly two thirds of this map area. This unit has a gently sloping surface which provides the opportunity for numerous streams to shift their channels during periods of flooding. The main hazards, although minor in nature, involve thermokarst subsidence and undercutting of river banks that are experiencing flooding conditions. Interspersed with this unit are occurrences of Unit 3. These beds are finer-grained and susceptible to the same hazards as those in Unit 4; namely, flooding and the associated undercutting of river banks. Swampy terrain also occurs in this unit, and may induce some thermokarst subsidence.

In the higher elevations found in the southeastern part of the area, bedrock occurrences of Unit 11 and unconsolidated deposits of Unit 10 are present without organic cover. These deposits are characterized by moderate to steep slopes that engender hazards such as mud slides, gullying and rock falls.

Numerous occurrences of the hummocky till in Unit 9 are confined to the eastern part of the area; here, they are associated with the sandy deposits of Unit 3. Thermokarst subsidence in this area is common, together with ground-ice slumps and possible gullying on the slopes.

The barrier deposits of Unit 1 are exceptional in that they extend along the entire coastline of the mainland and parts of Herschel Island. Because of their low elevation and shallow inshore depth, flooding of these features together with the associated inundation of adjacent coastal areas can be widespread. This is particularly true in periods of strong storm surges, at which time alteration of beach ridges and erosion of coastal features is accelerated.

The unindurated, tilted and deformed beds of Unit 7 comprise nearly the whole of Herschel Inland. These beds are subject to gullying inland, and block-slumping along the coast.

A single, small area occupied by Unit 2, which lies adjacent to the low marshy ground in the eastern part of the map, is highly susceptible to thermokarst subsidence. The organic cover and presence of thawing ice wedges promotes this disintegration and collapse along the coast. A small occurrence of Unit 6 lies in the south-central part of the map area, where its gravels and sands form part of a ridge. The presence of ice would eventually lead to slumping with rises in air temperatures.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units ....

Eroding river or shore cliffs (one or both walls).............

Eroding river or shore cliff (one or both valley bedrock)... D D D

Pingos (major ones) ....

Lowland swamps or weedy foreshore ....

Breached lakes on shoreline..................................

Main sediment transport direction ....

Coastal sediment sinks ....

Barrier deposits, spits and bars ....

Bathymetric contours (m) 2

Hydrographic soundings (m)................................... 94

Topographic contours (m) 30

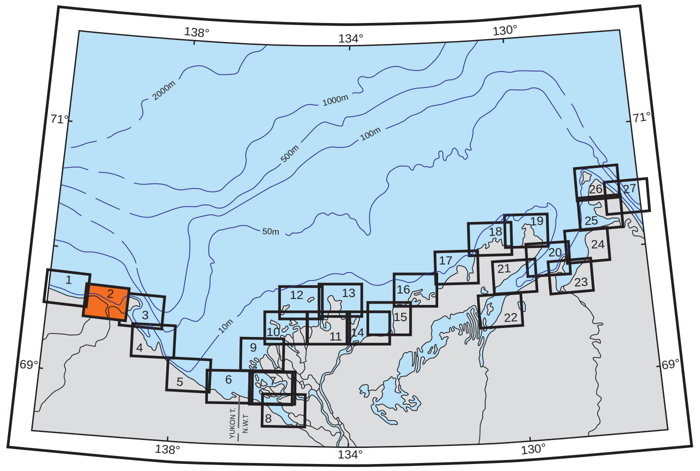
Topographic elevations (m) 183

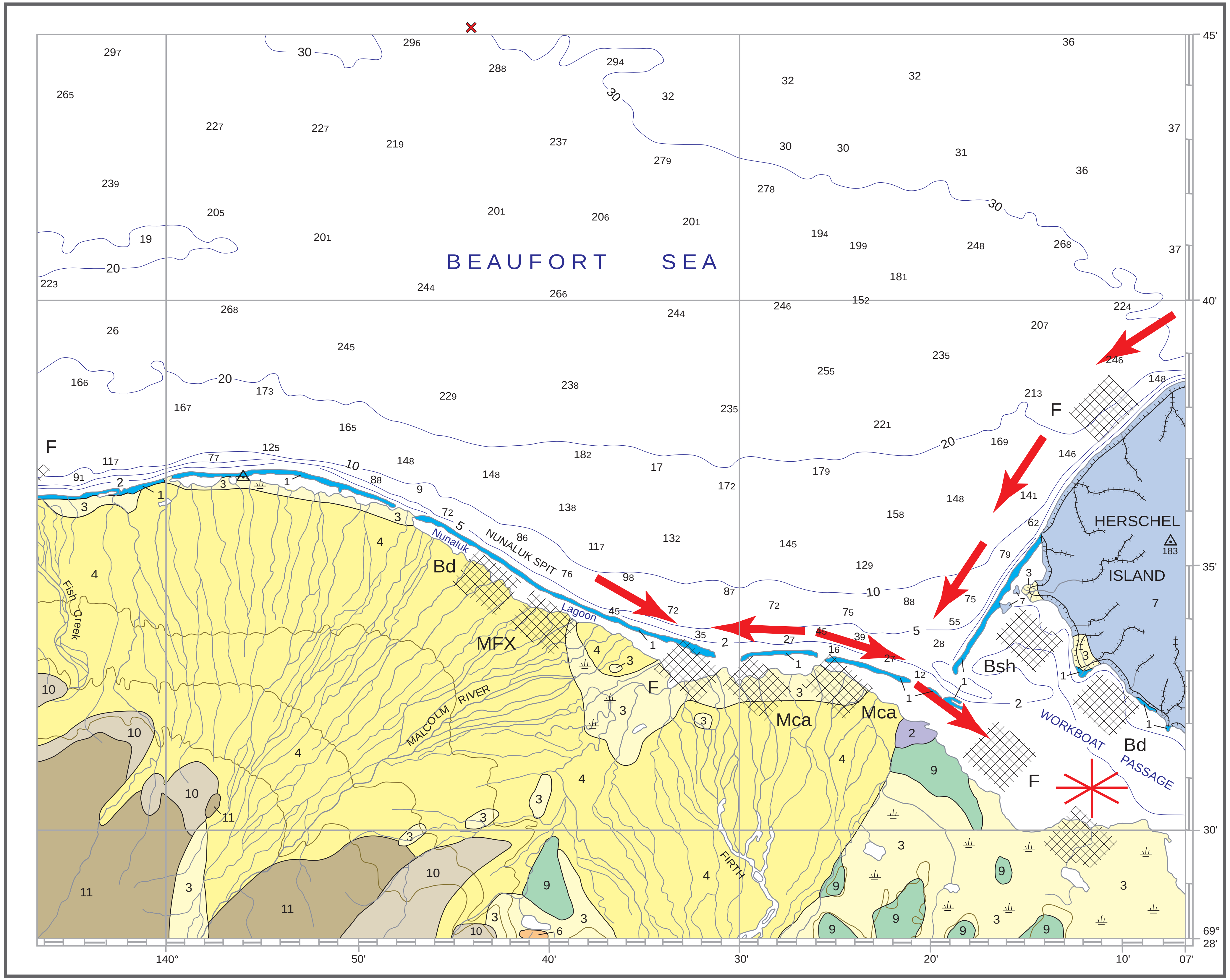
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M

Camps for whaling(W), hunting(H), fishing(F)............... W,H, F

Oil and gas exploration (oil, gas, oil & gas,
dry & abandoned wells) see (Oil and Gas Discoveries)... ●,●,●,✕





Coastlands Map 2. Nunaluk Lagoon

scale = 1:150 000

COASTLANDS MAP 3. HERSCHEL ISLAND

The Physical Setting

Herschel Island, with its irregular topography and hilly elevations rising to 183 m, is in marked contrast to the low-lying coastal terrain on the mainland to the south. Numerous cliffs are associated with rivers that originate in the higher, central part of the island, and continue as a tributary trunk system toward the coast. This drainage pattern is partly dendritic and partly trellis due to the underlying occurrences of folded and tilted unconsolidated strata. For example, where rivers flow over non-oriented features, the pattern is dendriditic; where rivers flow along structural axes, it is trellis in nature. These processes produce an intricate topography whose contoured elevations descend in involute patterns to the coast (not shown on the accompanying map). Along the coast, sea cliffs abound in the block-slumped terrain composed of the organic and mineral soil present over the Island.

On the mainland a low, swampy terrain is present, which lies adjacent to the coast and below the 30-m contour generally. An integrated drainage system is present throughout the area, and consists of numerous streams and small interconnected lakes. Barrier bars and spits are common along the coasts of both the mainland and Herschel Island. They are especially prevalent in areas of marine-eroded headlands, where they accumulate downward of the local, sediment-transporting currents.

Offshore adjacent to the coast, undersea gradients are relatively steep except in the area of Workboat Passage. In this location a shallow, flat bottom is maintained throughout. Herschel Basin, lying just southeast of the Island, is a unique steep-sided feature that exhibits a complex topography lying below the 20 m isobath. This basin may be the result of an ice-push event that took place during a glacial episode; indeed, a seismic profiling section extending across the Basin and Herschel Sill reveals beds that were bowed upwards, in a manner that resembles a so-called stress-release pattern. The resulting manifestation of this ice-push phenomenon is Herschel Island itself, and the tilted and folded unconsolidated strata beneath the basin are a part of the supporting evidence.

Northwest of Herschel Island the gradient of the Beaufort Shelf is considerably gentler than it is to the east, where it increases toward the steeper slope at the 90-m depth contour. This point is, more or less, the edge of the Mackenzie Trough. Because the deeper water around Herschel Island lies beneath Thetis Bay and over Herschel Basin, the southeast side of the Island is suitable for anchoring vessels of moderate draft.

Coastal currents have a variety of directions, some of which are affected by the presence of Herschel Island, the discharge from Mackenzie River, and the main oceanic circulation over the continental shelf. Adjacent to the coast, longshore currents erode prominent headlands and cliff bases, and deposit the debris in a down-current direction. This process leads to the construction of barrier bars and spits and, in one case, to the formation of a sediment sink in Workboat Passage.

Surficial Geology and Hazards (Units 1,2,3,6,7,9)

Two surficial units are most significant in this map area: one is Unit 7 on Herschel Island, and the other is Unit 3 on the mainland. Although the beds of Unit 7 are unlithified, the silt and clay and the minor components of sand and gravel are tilted and folded. Such deformation is a result of the ice-push phenomenon described above. This process appears to have originated from the southeast, at a time when glaciers moved northwesterly from the continental ice mass. Geological hazards relate to the extremely uneven topography, gullying by river erosion, and the marine erosion along the coastal strip with its accompanying cliff-forming and subsequent block-slumping actions.

The fine-grained river deposits of Unit 3 occur mainly on low-lying swampy land lying adjacent to the coast. Sands and organic silts are found in alluvial fans, floodplains and terraces adjoining the numerous streams present in the area. The main hazards are associated with thermokarst subsidence, ground-ice slumping, and gullying in the margins of lakes and river channels. Undercutting and the collapse of river banks is prevalent along all rivers during periods of high waters; in fact, this usually happens under stormy conditions when flooding is common and a considerable shifting of channels takes place.

Both Units 9 and 6 are interspersed with Unit 3, as well as with each other, and may be found at elevations of about 30 m in inland areas and less than a few metres of elevation along the coast. Unit 9 consists of hummocky tills lying on a rolling terrain, with some admixture of sand and gravel. This unit is moderately susceptible to thermokarst subsidence and ground-ice slump. Unit 6 is only slightly less common than Unit 9, and contains sand, gravel and silt in the form of eskers and other glaciofluvial deposits. Some undifferentiated fluvial deposits are present as well. Hazards such as thermokarst slumping are found on the larger flat surfaces of this unit. On the slopes where ground ice is present, slumping of this ice may occur. Gullying is an additional hazard of this unit.

Unit 1 comprises the beaches of sand and gravel occurring along the sea coast, where they take the form of barriers and spits. These features actually extend the length of the coast by as much as 20 % along the mainland, and perhaps by up to 5 or 6 % around Herschel Island. Flooding is the main hazard of this unit, together with the concomitant erosion of the coast and the subsequent alteration of its landforms.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units ....

Eroding river or shore cliffs (one or both walls)..............

Eroding river or shore cliff (one or both valley bedrock)... D DD

Pingos (major ones) ....

Lowland swamps or weedy foreshore ....

Breached lakes on shoreline ....

Main sediment transport direction ....

Coastal sediment sinks ....

Barrier deposits, spits and bars ....

Bathymetric contours (m) 2

Hydrographic soundings (m) 94

Topographic contours (m) 30

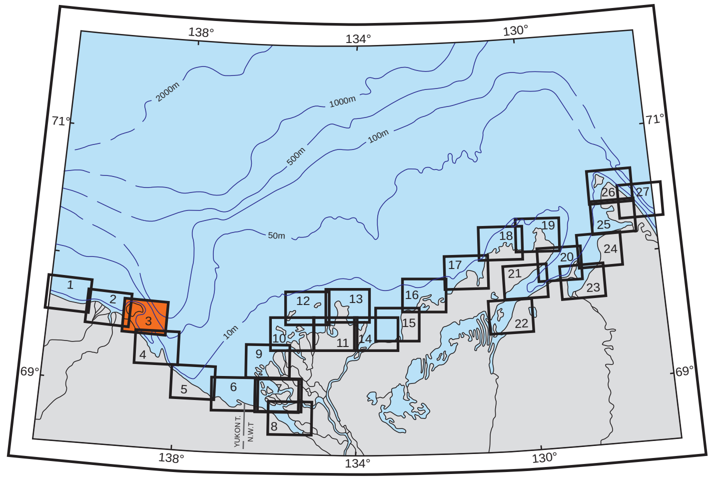
Topographic elevations (m) .... 183 △

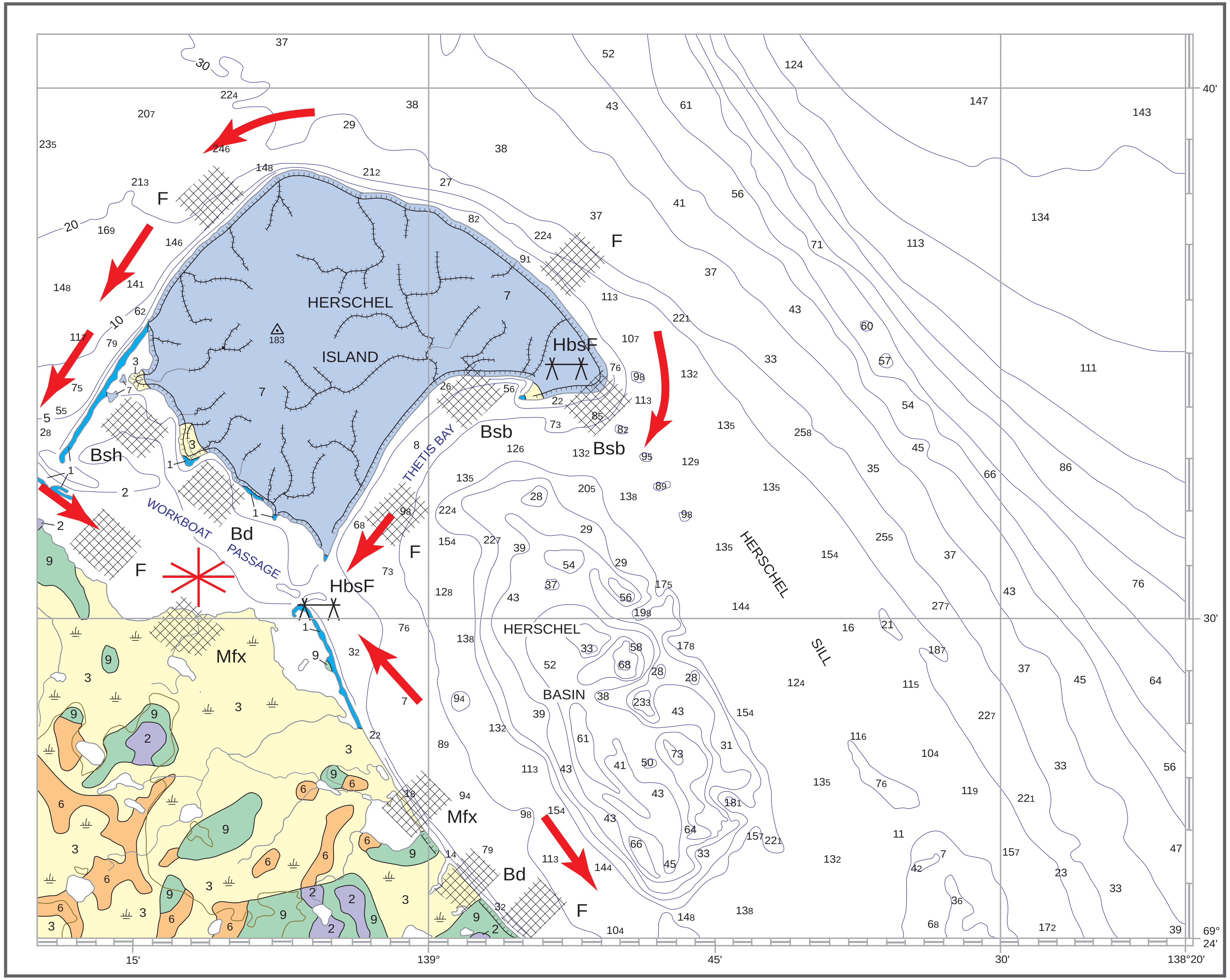
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M ▨

Camps for whaling(W), hunting(H), fishing(F)................ W,H, F

Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries)... ●,●,●,✕





Coastlands Map 3. Herschel Island

scale = 1:150 000

COASTLANDS MAP 4. Phillips Bay

The Physical Setting

The coastal plain is very narrow in this region where it lies adjacent to Babbage Bight; however, the plains are slightly wider in the northwestern sector of the area. Terrain, lying within a few kilometres of the Beaufort coast, rises 200-300 m to form upland topography in the western and southern parts of the map area. Large occurrences of Swampy ground is widespread in stream valleys and flats that are in the west-central portion of the map where they are located at intermediate and lower elevations. Numerous lakes are present in such areas, and may not have outlets; however, they are commonly interconnected by local streams.

An integrated drainage is a significant aspect of the region, and is characterized by the presence of meandering streams such as Spring and Babbage rivers, as well as lesser streams in the western and central part of the area. Numerous minor tributaries, which follow fairly straight courses, flow into the main trunk systems from the highlands to the south.

Along the coast, barrier beaches and spits are common, particularly in the vicinity of Stokes Point, Phillips Bay and Kay Point; however, long stretches of cliffed shorelines occupy most of the coast. Deltas are important also, as they form up to 30% of the coast around Phillips Bay. In this area, the headlands and barrier beaches form the most striking features, particularly Kay Point with its dominant hook extending to the southwest at the mouth of Phillips Bay. Both Kay Point and Phillips Bay appear to have undersea extensions to the northwest, probably representing a history of marine submergence in the region. This history may be associated with that of Roland Bay as well.

Offshore, the seafloor that lies immediately adjacent to the coast assumes a gentler gradient seaward. Progressing in a northerly direction, the bathymetric contours merge into those that define the topography of the Beaufort Shelf. Toward the east, these contours correspond to the more regular, flatter aspects of the seafloor lying beneath Mackenzie Bay and the headward portion of Mackenzie Trough (see Physiographic Regions).

Surficial Geology and Hazards (Units 1,2,3,6,9 and 10)

Several surficial geology units are interspersed throughout the area, with nearly equal representation. One of the more dominant is Unit 10, which comprises the upland and piedmont complex at the highest elevations in the area. These gravel-bearing uplands, with a thin veneer of sediments overlying bedrock, are found at elevations of 100-300 m. They are characterized by good drainage on moderately inclined slopes, with swampy terrain in the depressions. Geotechnical hazards in this unit comprise minor detachment slides, moderate gullying and mud flows. All these hazards are prominent in the southwestern part of the map area.

Unit 9 comprises hummocky terrain that consists of clayey to sandy till. Generally this unit is found at lower elevations than Unit 10, but commonly lies adjacent to it; however, it forms a considerable portion of the lower terrain in the area. Its surface is controlled by bedrock partly, a factor which also reflects on the integrated drainage in areas of moderate slope, as well as the central drainage in the swampy areas occupying local depressions. Hazards are expressed as thermokarst subsidence and ground-ice slumping, with minor gullying on slopes where ground ice is present.

Unit 6 forms gravelly sand hills, ridges and terraces, much of which is glacio-fluvial and fluvial in origin. The ground is relatively dry, with most of the drainage being sub-surficial in nature. Large, flat areas may be wet and swampy, particularly in channels or depressions where segregated ice may occur in silt beds and in zones lying below peat beds that may be present. Hazards are associated with minor thermokarst subsidence, and ground-ice slumping, or potential slumping, in areas where ground ice is present.

Unit 2 comprises thermokarst lake beds, and is found throughout the central part of the map where it lies parallel and adjacent to the coast. Most of this unit, which mainly comprises clay, silt and peat, occupies the general area lying below 60 m in elevation and forms part of the coastal plain. Areas of occurrence of this unit are wet and marshy, and contain numerous tundra ponds. One exposure of this unit forms the hooked cape in the vicinity of Kay Point which, in turn, forms a protective barrier for wildlife utilizing the adjacent lagoon to the east. Hazards accompany the development of erosion along the borders of ice-wedge cracks that are common in Unit 2. Thermokarst slumping may take place on steep slopes surrounding the lakes. Removal of thawed material anywhere can lead to 3-4 m of subsidence. This unit is also characterized by low strength, particularly if unfrozen compressible material (such as organic soil) is present.

The coarse-grained river deposits of Unit 4, together with the fine-grained ones of Unit 3, transect the entire map area from uplands to coast. Geotechnical hazards associated with Unit 4 include minor thermokarst subsidence, undercutting of river banks and their subsequent collapse during periods of high water. Considerable flooding occurs during break-up and summer storms. River channels in this unit are subjected to considerable shifting. In Unit 3, hazards also include thermokarst subsidence, ground-ice slumping and gullying on the margins of adjoining lakes and river channels. As in the case of Unit 4, undercutting and collapse of river banks occur along the river channels during periods of high water. Flooding is common during break-up and storms, and may be followed by occasions of shifting channels.

The beds of Unit 7 contain silt and clay, with minor admixtures of sand and gravel. This unit forms hills and ridges, partly because of the tilted and folded nature of the strata and partly because of erosion. The rough terrain is unsuitable for construction, but the main hazard lies in the presence of block-slumping that takes place along the coastal boundary of this unit.

Although minor in extent, the sand and gravel spits of Unit 1 are important to coastal wildlife activity. In places such as Stokes Point and the western side of Phillips Bay, barrier bars are gradually closing lagoons and establishing wildlife refuges. The main hazard here is the excessive exploitation of aggregate that will permit extensive erosion to ensue and subsequently affect these wildlife sanctuaries.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units ....

Eroding river or shore cliffs (one or both walls)............

Eroding river or shore cliff (one or both valley bedrock)...

Pingos (major ones) .... ⋇

Lowland swamps or weedy foreshore ....

Breached lakes on shoreline ....

Main sediment transport direction .... →

Coastal sediment sinks .... ✳

Barrier deposits, spits and bars ....

Bathymetric contours (m) 2

Hydrographic soundings (m) 94

Topographic contours (m) 30

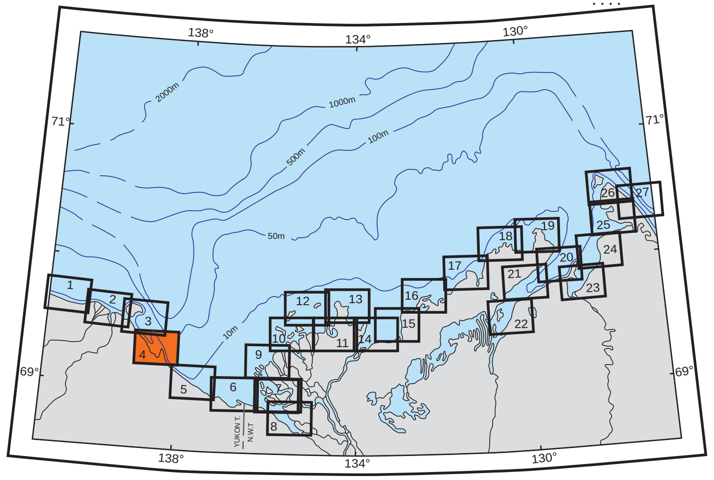
Topographic elevations (m) .... 183 △

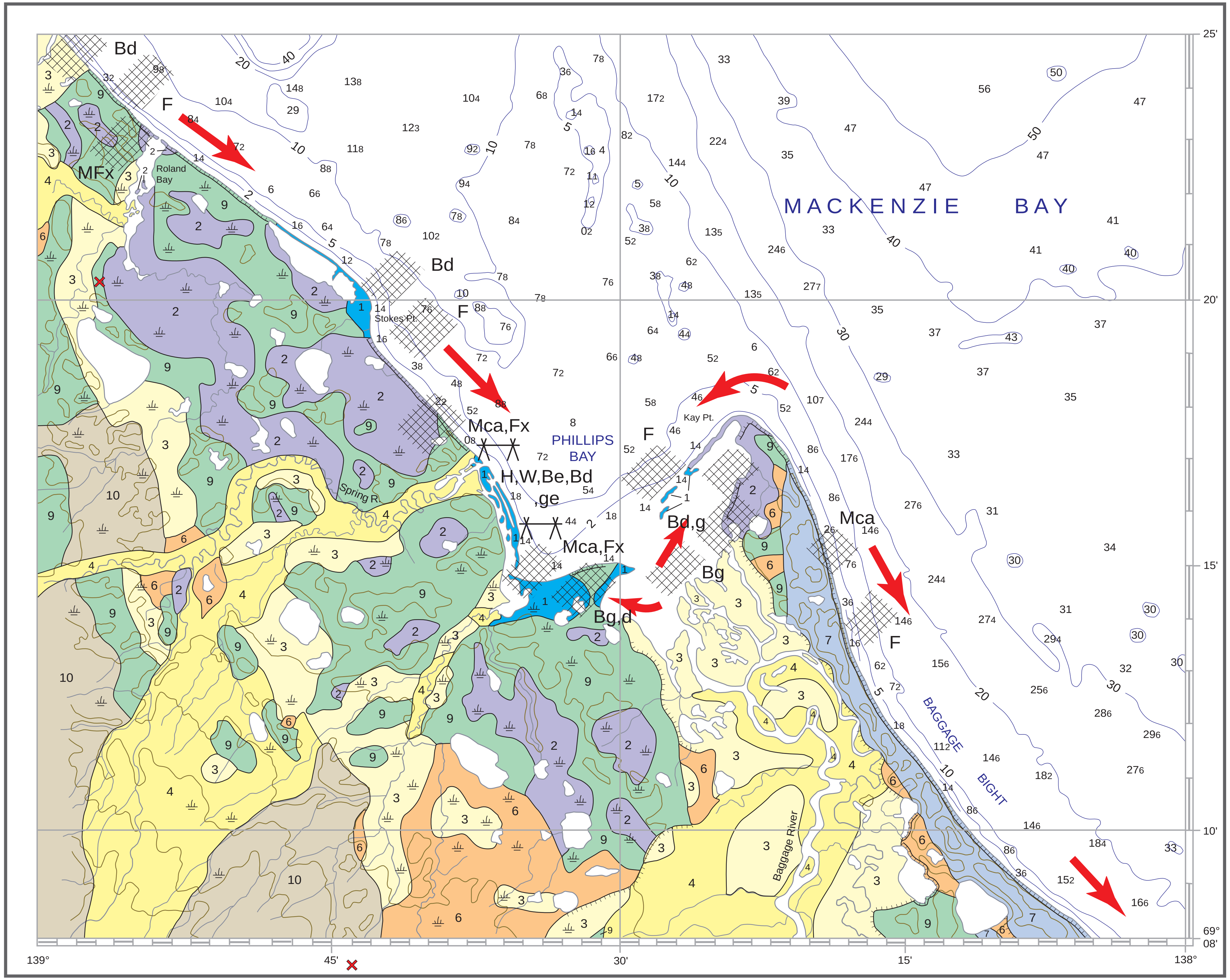
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M ▨

Camps for whaling(W), hunting(H), fishing(F)................ W,H, F

Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries)...





Coastlands Map 4. Phillips Bay

scale = 1:150 000

COASTLANDS MAP 5. Shingle Point

Physical Setting

The dominant aspect of the physical setting in this map area is the parallel to sub-parallel arrangement with the coastline, of the following elements: hilly expanses up to 60 m in elevation, lower valleys, steep cliffs several metres in height on river banks and sea coasts, streams, collective stretches of lakes, and the trends of surficial units. Deep Creek is a striking example of such parallel trends, many of which are interrupted in a minor capacity by transecting streams such as Ronning River and the upper part of Deep Creek in the eastern part of the map area.

The parallelism of barrier bars and spits with the coastline is expected because residual longshore currents transport sediments southeasterly in that portion of the coast. Mostly, though, sea cliffs are present along the entire coast. The seabed is relatively steep next to the cliffs, but the undersea topography becomes gentler seaward toward the edge of the continental shelf. Across the latter expanse, the orientation of the bathymetric contours follows that of the coastline and the distal portion of Mackenzie Delta; this orientation can be traced to the shelf-slope topographic break at the undersea edge of the continent.

Surficial Geology and Hazards (Units 1,2,3,4,6,7,9 and 10)

The river deposits of Unit 3 are, spatially, the most significant of the map area. The silts and sands that are deposited from Deep Creek may include organic material as well. Beginning in the upland area in the southwestern part of the area the stream meanders for its entire length and its tributaries connect small lakes occurring on the floodplains along their routes. A main geotechnical hazard in this unit involves thermokarst subsidence that takes place subsequent to ground-ice thawing. Around the margins of lakes and borders of channels, ground-ice slumping and gullying are common. Other hazards include the undercutting and collapse of river banks during periods of high water and flooding, which may be accompanied by the shifting of channels.

Occurrences of hummocky till in Unit 9 are transected by clayey and silty deposits of Units 3 and 4. Toward the coast, the northeastern segments of Unit 9 are considerably lower in elevation and terminate as sea cliffs about 7 m in height; however, to the southwest in the vicinity of the mountainous country, the hills of Unit 9 are in the uplands that are at least 200 m high. Hazards are confined to a moderate susceptibility of thermokarst subsidence, ground-ice slumps, and some gullying on the sloping terrain.

In Unit 6 the hills, ridges, and terraces, which are composed of sand, silt, and gravel with some silt, partially flank the deposits of Deep Creek. These wide ridges and terraces appear to alternate on either side of the Deep Creek floodplain, with cliffs present along many of the floodplain borders. The surface of this unit is dry, but drainage present is sub-surface in nature. Some thermokarst subsidence takes place on large flat surfaces, with gullying and ground-ice slumping occurring on the slopes.

Another important surficial body comprises the thermokarst lake beds of Unit 2. Clay, silt and peat are components of the low-lying swampy terrain that characterizes this unit. Low-centre polygons are present, and it is along the associated ice-wedge cracks that erosion takes place. Lakes are common in this unit, and their presence leads to thermokarst subsidence and slumping around steep slopes particularly. The inclusion of thawed, organic beds in this unit constitutes a hazard if considering infrastructure or other engineering activities because of its low strength under load. This could lead to subsidence as a major hazard, as well.

The coarse sand and gravels of Unit 4 are the major beds that transect Units 3, 6, and 9. The upland portion of Deep Creek and the lower reach of Ronning River contain the fluvial energy that activates the erosional and depositional aspects associated with the local transects of those units (i.e., 3,6, and 9). Surfaces of Unit 4 contain dry swamps and ponds, which are found in former stream-channel beds. Minor thermokarst subsidence is present, together with the processes of undercutting and collapse of river banks along their channels during periods of high water. Channel-shifting also takes place along these water courses.

Unit 7 is present in the extreme western portion of the map area, occurring solely along the coast. It is a continuation of its occurrence in the adjacent map area to the west, (i.e., the Phillips Bay map), and is characterized by similar ridges and hills, as well as tilted and folded strata of silt and clay, with sand and gravel admixtures in the moraine. Undercutting along the cliffed shores comprises the main hazard.

Unit 1, which consists of sand and gravel, comprises the natural constructional features seen along the coast. These landforms consist of the barrier bars at King Point and the mouth of Ronning River, and the large spits at Shingle Point. The main hazard in this unit is the over-exploitation of the deposits, a practice that could lead to widespread and deep erosion in the vicinity of these features. This erosion would be accelerated by wave-washover during stormy intervals, and could adversely affect wildlife habitats.

A single occurrence of Unit 10 is found in the uplands to the south at elevations of 100-200 m. It comprises bedrock rubble, till, and mixtures of clay, silt, sand and gravel, all occurring as a thin veneer overlying bedrock. Very little ice content is present, so that hazards are confined to detachment slides that occur on moderate slopes. Other geotechnical hazards are related to gullying and mud flows of low intensity. This unit is a poor source of aggregates, but may provide burrow material for constructional purposes because of its strength under load.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units ....

Eroding river or shore cliffs (one or both walls)............

Eroding river or shore cliff (one or both valley bedrock)... D D D

Pingos (major ones) .... ✳

Lowland swamps or weedy foreshore ....

Breached lakes on shoreline.................................

Main sediment transport direction .... →

Coastal sediment sinks ....

Barrier deposits, spits and bars ....

Bathymetric contours (m) 2

Hydrographic soundings (m) 94

Topographic contours (m) 30

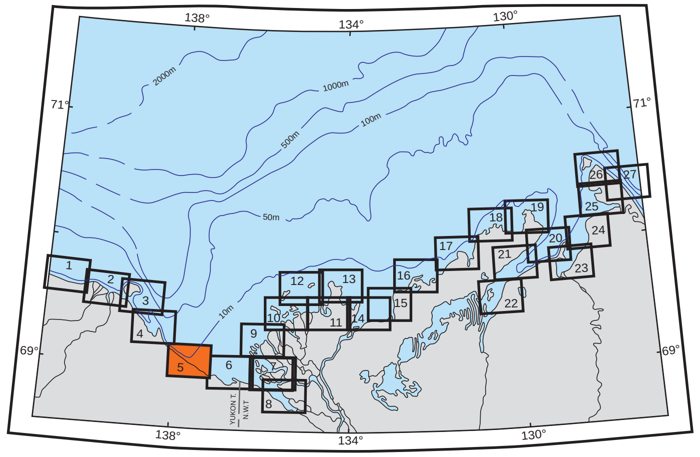
Topographic elevations (m) .... 183 △

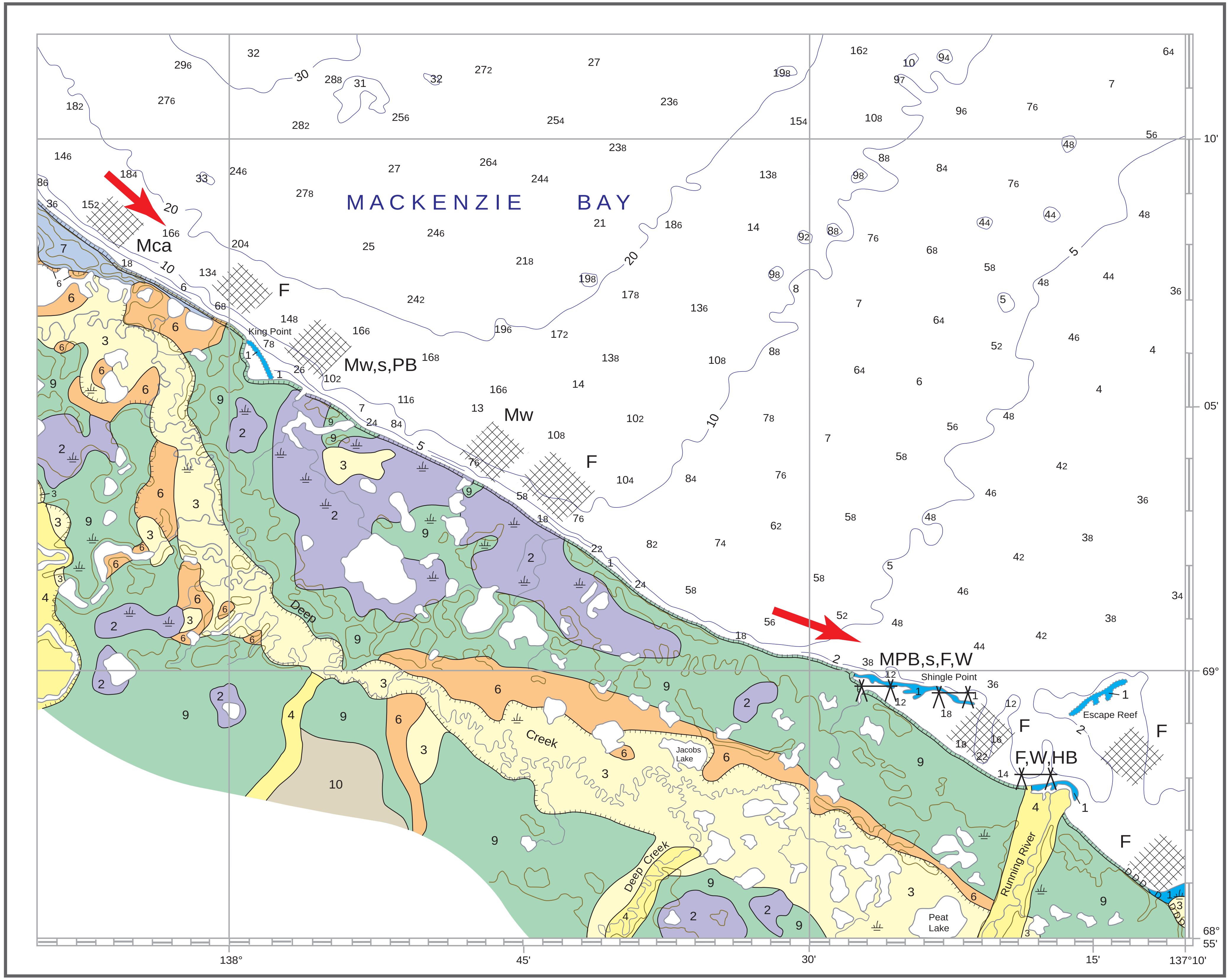
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M ▨

Camps for whaling(W), hunting(H), fishing(F)............... W,H, F

Oil and gas exploration (oil, gas, oil & gas,
dry & abandoned wells) see (Oil and Gas Discoveries)... ●,●,●,✕





Coastlands Map 5. Shingle Point

scale = 1:150 000

COASTLANDS MAP 6. Shoalwater Bay

Physical Setting

The physical setting of this area is deltaic-marine mainly, and is exemplified by the low elevations of the coastal features lying in the distal portion of Mackenzie Delta. These features include partly submerged barrier deposits, swampy ground occupied by numerous small lakes, clusters of small sandy and silty islands, and major fluvial channels and their distributaries with interconnecting water courses, all of which drain to the sea eventually. In contrast to this low-lying area is an upland rising more than 60 m and lying adjacent to the western boundary of the Mackenzie River floodplain. A cliff running parallel with the coast marks the boundary between the contrasting topographies of uplands and delta. This cliff is transected by a northerly trending floodplain which, itself, is flanked by cliffs that merge into those in the north and terminate at the Mackenzie River floodplain and western coastline. Another upland area lies to the south and is separated from the coast by expanses of marshy ground and hills of low relief.

Adjacent to the coast, water depths are extremely shallow (less than 2 m) and many silty sand bars, spits, and tombolos are present. A good example of this last feature is seen at Tent Island, and the islands on the westernmost part of the Delta. Much of the sedimentation is derived directly from the sediment plume that discharges from the Delta. The course of this plume is detailed by the arrows representing the direction of the longshore currents and sediment transport. A sediment sink occurs just a few kilometres from the northwestern corner of the Delta, where sediments entrained in the Delta plume conflict with the passage of sediment-bearing longshore currents from the west. Velocities of the currents are checked and deposition of their loads ensues. The gradient of the Delta and the adjacent offshore topography is sufficiently gentle that a vast shoal area occurs, extending several kilometres seaward beneath Mackenzie Bay.

Surficial Geology and Hazards (Units 1,2,3,4,6,9 and 10)

The most prominent deposits depicted on this map are the fine-grained fluvial sand and silts of Unit 3, occurring in the Mackenzie Delta; also, organic silts and peat are present in this unit in all channels and river flat in the area. A low swampy terrain is widespread over the entire Delta. Beds of Unit 3 occur in channels and terraces on the mainland as well, particularly in those that lie inland and parallel with the coast. With regard to geotechnical hazards, thermokarst subsidence is common together with ground-ice slumping and gullying on the margins of lakes and river channels; in the latter case, undercutting and collapse of banks take place during periods of flooding. On the outer parts of the Delta, flooding takes place during the spring freshet and periods of storm surges.

The tills in the upland and piedmont complex of Unit 10 occur in the hilly country adjacent to the Delta, and in the southern parts of the area. Cliffs are found on the numerous small streams that transect the unit, but also on its border that abuts the Delta. Drainage is downslope in Unit 10, although the hilly tops are dry. Minor detachment slides comprise the main hazard, with some susceptibility to gullying and mud flows.

Hummocky till deposits in Unit 9 contain silt, clayey sand, and some gravel locally. This unit is found near exposures along the coast in an interspersed association with Units 2 and 10 that lie adjacent to the Delta. Ice is present as thin discontinuous masses that occupy parts of the upper 3 m of the unit. Although the hills are well drained, the depressions have very little drainage. This latter aspect leads to the development of ponds and bogs in the area. The land in Unit 9 is moderately susceptible to thermokarst subsidence and ground-ice slumping.

A major deposit of coarse sand and gravel that comprises the beds of Unit 4 is found in the floodplain of a meandering river that transects several mainland surficial units, as well as those units on the extreme western edge of Mackenzie Delta. The major hazards in this unit are the occurrences of minor thermokarst subsidence, undercutting and collapse of river banks, and flooding during periods of high water.

Unit 2 is another significant surficial deposit, and consists of thermokarst lake beds. The swampy terrain inherent in this unit is underlain by fine sediments such as silt, clay, and organic matter. Peat deposits found in the old tundra ponds may be 4 m thick. In this unit an integrated drainage is absent, and low areas are wet and swampy. Segregated ice is found as thin seams and, where ice wedges are present, erosion takes place along the cracks of these wedges. This latter process creates a natural hazard of the landscape, but most geotechnical hazards are associated with thermokarst slumping around the edges of lakes where slopes are steep. If thawed material is present, it is characterized by low bearing strength and is susceptible to subsidence of 4 m or so.

Minor exposures of Unit 6, which comprise hills of gravel and sand, eskers and other glacio-fluvial deposits, are found in the western part of the area that borders the floodplains described for Unit 4 above. Moderate ice content in the form of lenses is present in Unit 6. This ice is segregated in the peat deposits occurring beneath the river channels, but is non-segregated in the well-drained sediments of this unit; as well, massive ice may be present at depths ranging from 7-50 m. With respect to drainage in Unit 6, the upper surface is dry but a flow exists beneath the surface. A minor amount of thermokarst subsidence constitutes the main hazard in this unit, but ground-ice slumping and gullying can occur on the slopes.

A single occurrence of Unit 1 comprises the sandy beach extending along the western shore, and the westernmost part of Mackenzie Delta. These sands have been transported by easterly directed longshore currents, and form part of the present and former shorelines; albeit a minor stretch in both cases. Ice content is low to moderate in the active part of the beaches, but may increase in amounts in more physically stable areas. The ground surface is dry on beach ridges, but is generally wet and marshy in the associated depressions. Flooding is the greatest hazard, and is common in the low-lying areas. When storms arise, active erosion of beach ridges takes place and results in alterations of the beach landforms, particularly the shape of the ridges. Excessive exploitation of the sands will have a deleterious effect on the beach forms as well, not to mention harm to an ecological niche such as wildlife sanctuaries and even hunting areas along the coast.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units ....

Eroding river or shore cliffs (one or both walls)............

Eroding river or shore cliff (one or both valley bedrock)...

Pingos (major ones) ....

Lowland swamps or weedy foreshore ....

Breached lakes on shoreline.......................................

Main sediment transport direction ....

Coastal sediment sinks ....

Barrier deposits, spits and bars ....

Bathymetric contours (m) 2

Hydrographic soundings (m)..................................... 94

Topographic contours (m) 30

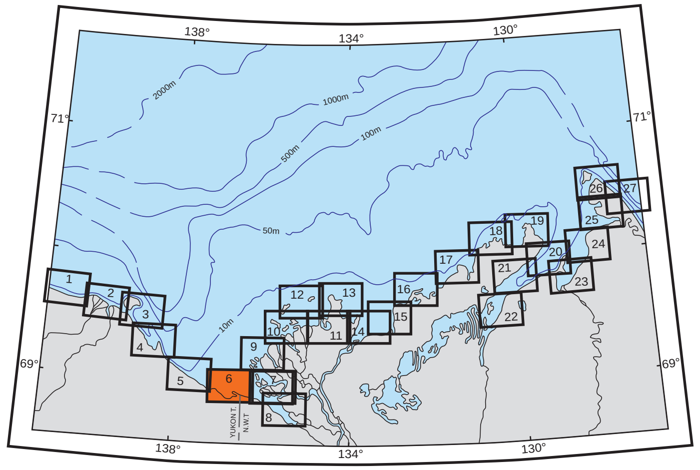
Topographic elevations (m) .... 183 △

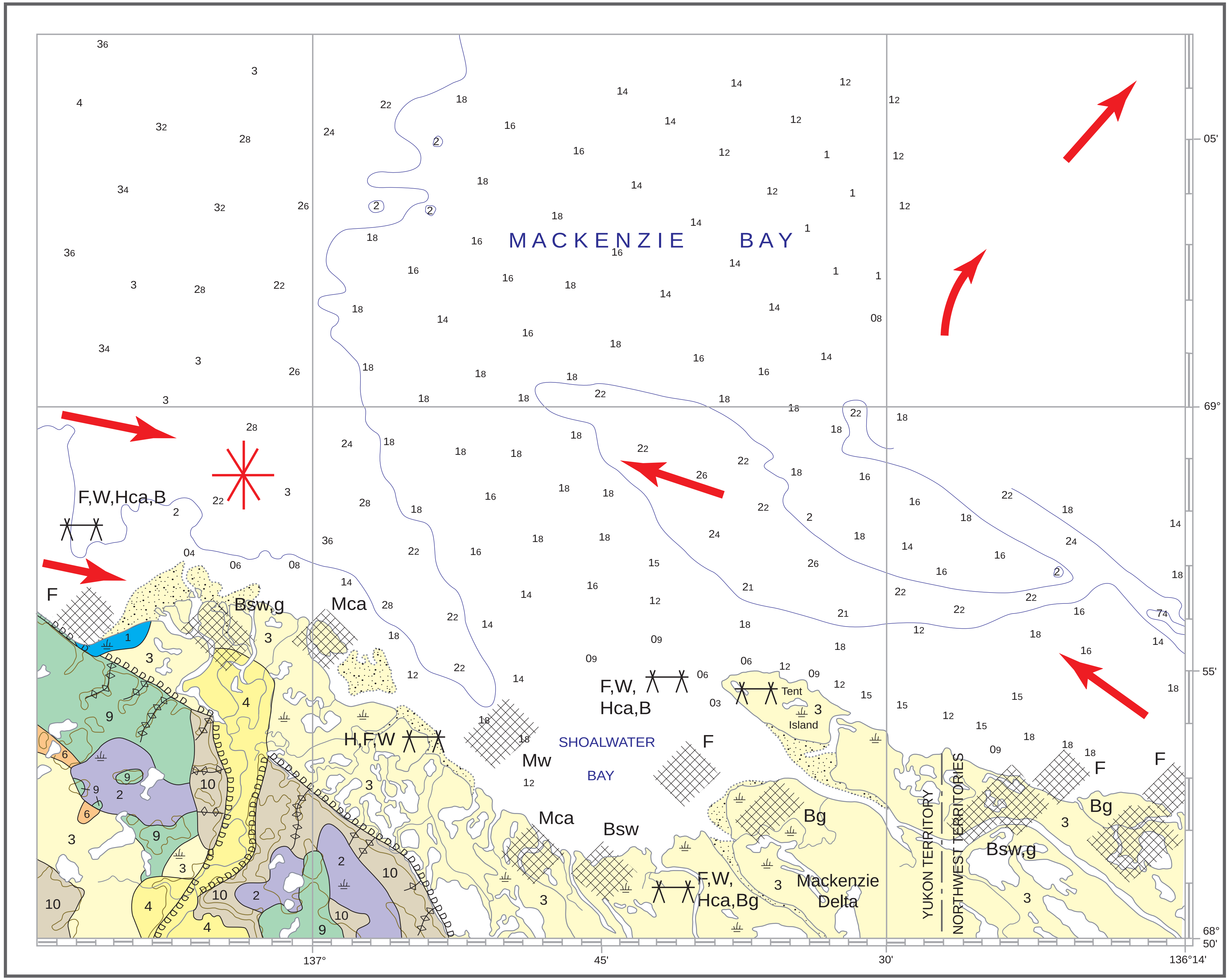
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M

Camps for whaling(W), hunting(H), fishing(F).................. W,H, F

Oil and gas exploration (oil, gas, oil & gas,
dry & abandoned wells) see (Oil and Gas Discoveries)... ●,●,●,✕





Coastlands Map 6. Shoalwater Bay

scale = 1:150 000

COASTLANDS MAP 7. Outer Shallow Bay

Physical Setting

Mackenzie Delta forms the entire physical setting of this map area. Overall the general elevation may be several metres above sea level, except for pingos which are generally less than 20 m in height. Swampy terrain, a profusion of isolated lakes, an extensive network of inter-connecting channels, and numerous small islands occurring on the Delta and immediately offshore are common physical features of Mackenzie Delta in its distal region. Relatively large meanders are present along the main channels, with shallow areas formed adjacent to the slip-off side of the river bend. Locally, terraces may border the river floodplains and may contain meander scars. The only integrated drainage occurs along the main channels (some of which may be almost 20 m deep) and their distributaries, as well as within the network of inter-connecting channels.

Currents emerging from the main waterways leading to the sea carry sandy, silty sediments to form barrier deposits in the low, underwater area along the channels and distal portions of the Delta. At certain times of the open-water period around the Delta, this sediment entrainment forms a plume that discharges directly into the sea from sources in the Mackenzie River and its distributary channels in the Delta. In Mackenzie Bay vortices are present in this initial discharge, which is manifested as currents with various northerly components. Some of the sediment plume is transported westerly towards Herschel Island, but most of it veers northeasterly over the outer part of Mackenzie Bay. These latter currents continue to move northeasterly around the outer islands of the Delta, under the influence of the Coriolus Force.

Surficial Geology Units and Hazards (Unit 3)

Only Unit 3, which comprises fine river sands and some gravel, is present over the entire Delta complex. This also includes numerous bars and spits that have been constructed on the lee side of the fluvial currents containing sediments in transport. Some of these barrier features remain attached to many deltaic islands, both along the river channels and offshore, and are found in floodplains and marine protected embayments respectively.

Low ice content is prevalent in Unit 3, and permafrost may be absent in willow-covered swales on the Delta. Many areas are wet, thus inducing the formation of numerous thaw pools and marshes. Hazards are universally associated with permafrost subsidence; however ground-ice slumping, gullying on the margins of lakes and channels, and undercutting of banks along the river are commonplace.

Many hazards develop during periods of storm, and in the aftermath of the associated flooding. Shifting of river channels usually takes place during these stormy periods inland. Because of the extremely low elevation of the Delta, landslides are generally absent; however the processes leading to the formation of pingos are present over much of this area. In the outer reaches of the Delta, marine flooding arising from storm surges at sea may produce considerable alteration to the landscape and damage to ecological niches. Because of its fine texture and presence of organic material, Unit 3 is a poor source of burrow material.

LEGEND

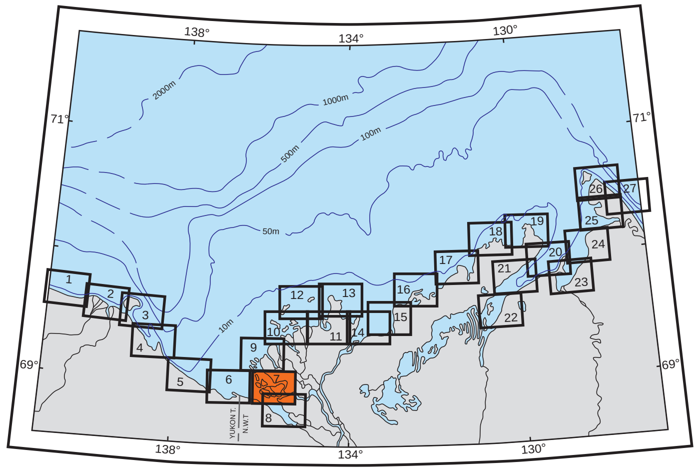
SURFICIAL GEOLOGY AND PROCESSES

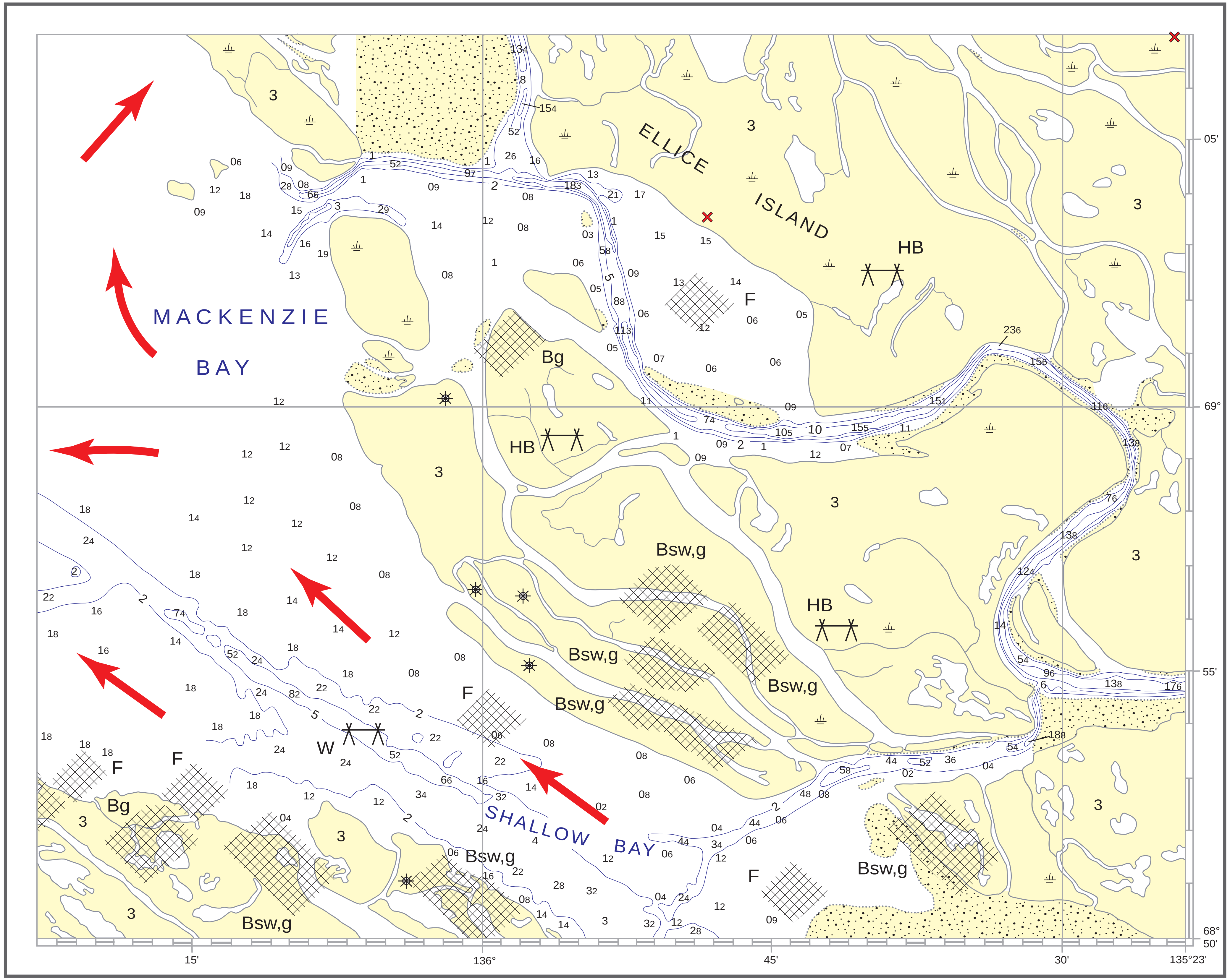
1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units	
Eroding river or shore cliffs (one or both walls)	
Eroding river or shore cliff (one or both valley bedrock)	
Pingos (major ones)	✳
Lowland swamps or weedy foreshore	
Breached lakes on shoreline	
Main sediment transport direction	→
Coastal sediment sinks	✳
Barrier deposits, spits and bars	
Bathymetric contours (m)	2
Hydrographic soundings (m)	94
Topographic contours (m)	30
Topographic elevations (m)	183 △

RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B)	F,B, M
Camps for whaling(W), hunting(H), fishing(F)	W,H, F
Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries)	●,●,●,✕





Coastlands Map 7. Outer Shallow Bay

scale = 1:150 000

COASTLANDS MAP 8: Inner Shallow Bay

Physical Setting

The terrain covered by this map area is entirely deltaic in nature. It has all the characteristics of an arctic lowland delta in that it contains the following features: a gentle gradient and a low elevation of less than several metres; numerous small lakes with irregular outline, many of which have a thermokarst origin and are totally undrained; a broad surface with a regular drainage in that several large distributaries of the Mackenzie River flow across the area in a general northwesterly direction and leave larger and smaller areas disconnected from other areas in the form of several, irregularly shaped islands; a secondary, irregular drainage in which short streams inter-connect the myriad of small lakes lying on the delta surface apart from, and between the main river channels; a large presence of lakes that remain totally undrained; many occurrences of barrier deposits and spits; and a vast extent of swampy ground occurring over the entire area.

Shallow Bay forms the inlet adjacent to Beaufort Sea (via Mackenzie Bay) and has depths of 3 m or less. Currents flowing northwesterly across the area from Mackenzie Delta are entirely fluvial in terms of source and content. Depths of the associated channels are generally less than one metre, although some main channels are 2-5 m deep. Where the fluvial currents exit at the northwestern part of inner Shallow Bay, a seabed channel of 3-m depth opens and deepens seaward.

Surficial Geology and Hazards (Unit 3)

The fine-grained river deposits of Unit 3 comprise the only surficial geology unit present in this map area. It occurs as silt and silty sands in the river channels and floodplains, and commonly on terraces adjoining the major streams. Beds of peat are also found in the floodplains and river terraces, particularly in older and abandoned meander scars. Sediments have accumulated to thicknesses of 5 m, and peats in beds up to 2 or 3 m. Other sandy deposits have accumulated adjacent to islands, in the down-current direction of major distributaries of the Mackenzie River. These deposits form barrier bars in the channels, and on spits lying off the points of neighboring islands.

Ice content in these sediments, although moderate in amounts, is the leading factor relating to hazards in this area because of thawing. This process occurs widely over the Delta, particularly in cases where river banks are present Most areas occupied by Unit 3 are wet, and their main hazard is associated with thermokarst subsidence, ground-ice slumping, and flooding during stormy periods. This unit is a poor source of burrow material because of its fine texture and organic content.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

- 1 Beaches
- 2 Thermokarst lake beds
- 3 Fine-grained river deposits
- 4 Coarse-grained river deposits
- 5 Marine and lake plains
- 6 Gravelly and sandy hills, ridges and terraces
- 7 Ice-thrust hills and ridges
- 8 Till plains
- 9 Hummocky till-capped terrain
- 10 Upland and pediment complexes
- 11 Mountainous and rocky areas

Geological boundaries of surficial units ....

Eroding river or shore cliffs (one or both walls).............

Eroding river or shore cliff (one or both valley bedrock)... D DD

Pingos (major ones) ....

Lowland swamps or weedy foreshore ....

Breached lakes on shoreline..................................

Main sediment transport direction ....

Coastal sediment sinks ....

Barrier deposits, spits and bars ....

Bathymetric contours (m) 2

Hydrographic soundings (m) 94

Topographic contours (m) 30

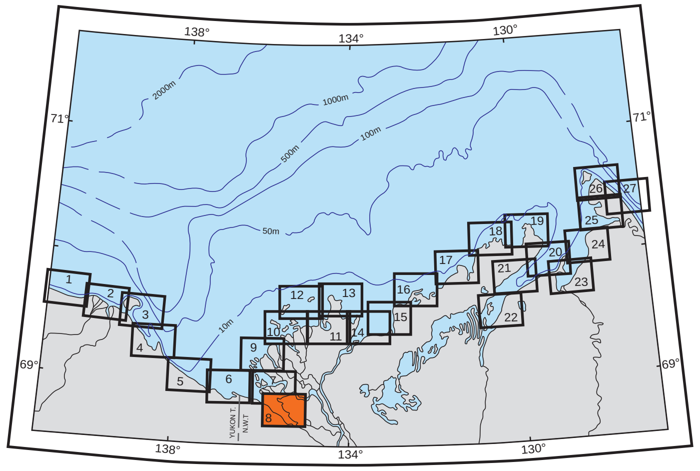
Topographic elevations (m) 183

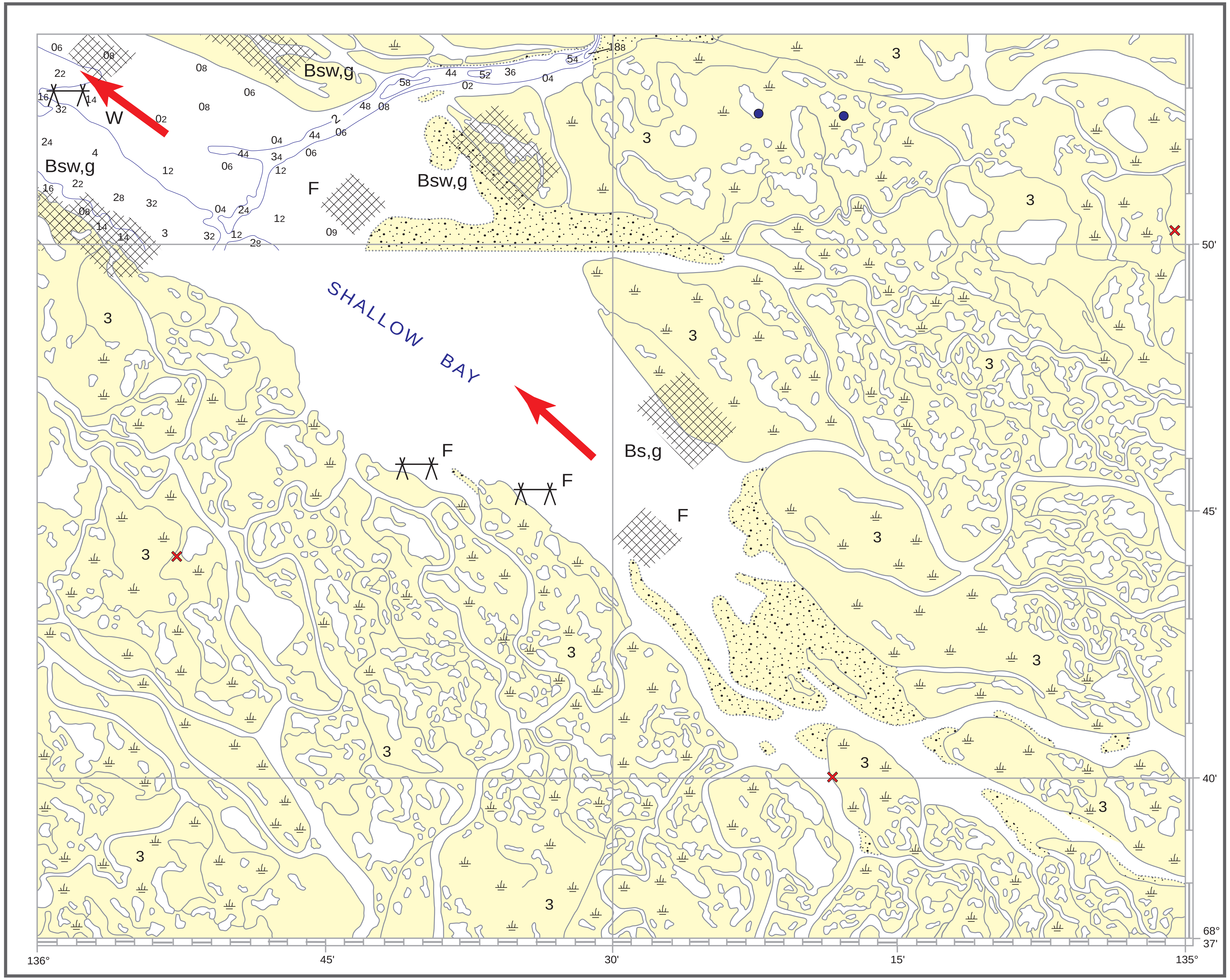
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M

Camps for whaling(W), hunting(H), fishing(F)................ W,H, F

Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries).... ●,●,●,✕





Coastlands Map 8. Inner Shallow Bay

scale = 1:150 000

COASTLANDS MAP 9: Olivier Islands

Physical Setting

This map area is an excellent representation of the distal portion of the Mackenzie Delta. Its elevation is extremely low, generally less than a few metres. As discussed in other Coastlands Maps (6-11) many features are identified as arctic-deltaic in origin and include the following: a profusion of small thermokarst lakes, the widespread occurrence of swampy ground, numerous pingos, and the network of inter-connecting channels with the consequent separation of land areas into islands. Only the main distributary streams of the Delta provide an integrated drainage system. On the wetland areas, small thaw pools, lakes and marshy ground are common. Some local drainage is provided by small streams that connect flooded meander scars and small lakes, while others connect to a main trunk a few kilometres distant. The sedimentational aspect of delta-building is revealed in the construction of bars and spits in the down-current direction. Most channels are shallow, with depths rarely exceeding 10 m; however the depths of some channels are not indicated, but could be scoured to somewhat greater depths than those shown.

Around the perimeter of the outer islands, river currents move northerly from the distal portion of the Delta until they reach the sea. At such points these currents are influenced by the Coriolus force, and begin to flow easterly around the islands as sediment-laden longshore currents. The fluvial sediments are entrained as part of the sediment plume emanating from the Delta and adjacent marine bodies. Conflicting routes of sediment transport in shallow water, such as those flows emerging from the Delta meeting those along shore, can produce obstructions to themselves. This process may lead to a diminished current velocity, together with local deposition of the contained sediment load; in consequence, a sediment sink is formed. One such sink has formed in the north-central part of the area at the junction of a major river channel and the sea. These marine areas lying adjacent to the Delta are extremely shallow, and form a broad 10-km zone shoreward of the 2 m isobath. This zone parallels the coastal portion of the Delta.

Surficial Geology Units and Hazards (Unit 3)

Unit 3 is the only surficial geology unit in the outer Mackenzie Delta, which is depicted in this map area. These sediments consist of silt and sandy silt, organic silt, peat and local gravel. The stream channels are silt-laden, but other slightly coarser and finer sediments may be found on the meander scars of old floodplains; these floodplain beds may include several metres of peat.

Ice content is minor in Unit 3, and permafrost may be absent altogether. A physical feature of this unit is the expansion of lakes and ponds by means of thermokarst collapse in some areas; in fact, the main geotechnical hazard is thermokarst subsidence. Ground-ice slumping and gullying on the margins of lakes, and the undercutting and collapse of channel banks during periods of high water are also prominent and hazardous events. Flooding is a major concern during stormy periods because of the low elevation of the terrain, and because of access of high waters to minor channels normally secure from rising marine waters. Channels may also shift during these flooding intervals, both at the edge of the Delta and inland. Unit 3 is a poor source of aggregates and burrow material because of its fine-texture, and organic content.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units

Eroding river or shore cliffs (one or both walls)

Eroding river or shore cliff (one or both valley bedrock)

Pingos (major ones)

Lowland swamps or weedy foreshore

Breached lakes on shoreline

Main sediment transport direction

Coastal sediment sinks

Barrier deposits, spits and bars

Bathymetric contours (m) 2

Hydrographic soundings (m) 94

Topographic contours (m) 30

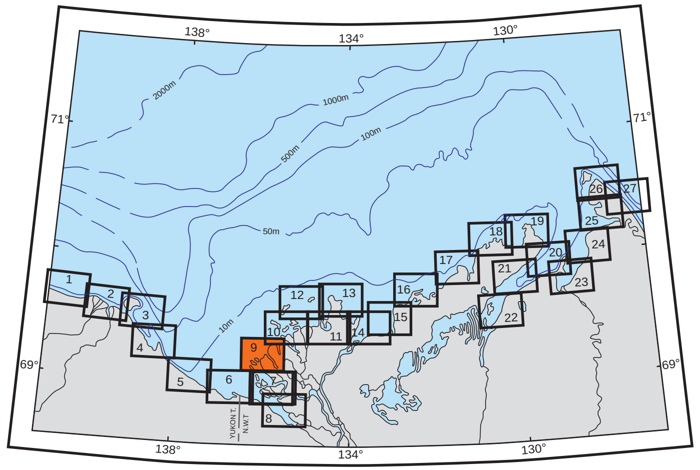
Topographic elevations (m) 183 △

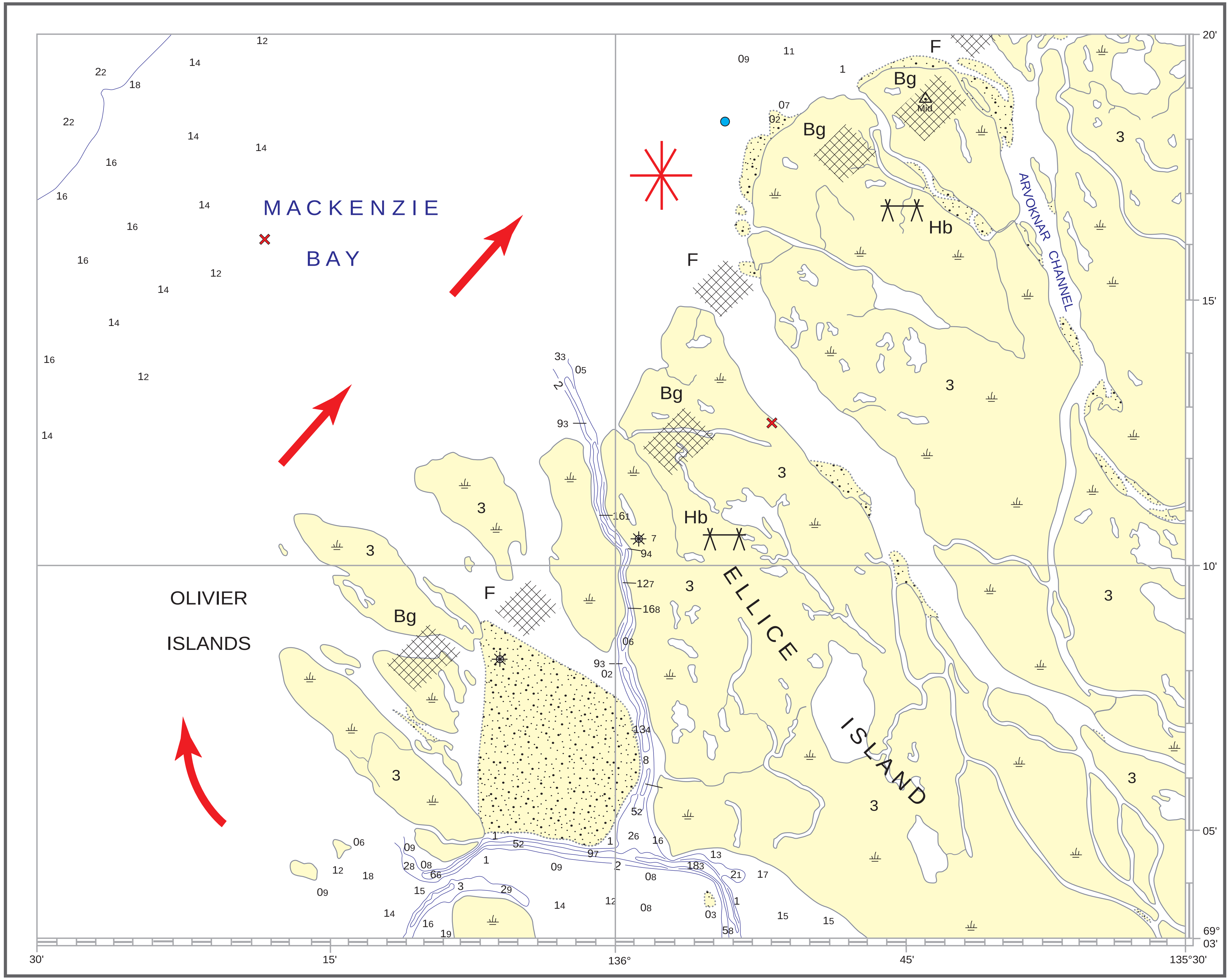
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) F,B, M

Camps for whaling(W), hunting(H), fishing(F) W,H, F

Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries) ●,●,●,✕





Coastlands Map 9. Olivier Islands

scale = 1:150 000

COASTLANDS MAP 10: Garry Island

Physical Setting

The main features of this map are the outer islands of Mackenzie Delta such as Taglu Island, and the numerous unnamed islands lying in close to each other. Several offshore islands including Rae, Kendall, Garry, and Pelly are characteristic features immediately offshore of the Delta edge. Within the Delta, Kimialuk and Big lakes are the most prominent fresh-water bodies, but numerous small lakes abound on almost all islands. Many areas of the Delta are wet, and an abundance of small thaw pools and lakes contributes to the occurrence of marshy ground.

Major distributaries such as Middle Channel in the northwestern portion, and other smaller channels that transect the Delta all flow in a northerly direction to the sea. Harry Channel, shown in the eastern portion of the map, forms the western boundary of Richards Island (see Coastlands Map 11). This channel is similar in aspect, size, orientation and flow direction to the other channels between it and Middle Channel.

On the surface of the Delta relief is extremely low, generally in the range of several metres only. Swampy terrain is prominent, although many small streams drain this area and the numerous lakes it contains. Some of the channel borders contain sand bodies that may be partly, and intermittently submerged. All running water empties into the Beaufort Sea eventually, particularly in the vicinity of Mackenzie Bay lying adjacent to the outer islands of the Delta.

The northerly flowing water courses join the currents flowing alongshore, and the combined water mass with its sediment load is directed easterly under the influence of the Coriolus force. This combined flow becomes part of the sediment plume emanating from the Delta. Where the velocities of these sediment-laden flows are checked by occurrences of shallow water and contrary currents, sediment deposition takes place and so-called sediment sinks are created. One such sink is present in the southeastern corner of the map area. In other areas, sedimentation may produce sand bars and spits locally.

Surficial Geology and Hazards (Units 1,2,3,5,6,7, and 8)

Unit 3 is the most widespread surficial unit in this portion of Mackenzie Delta. It consists of fine-grained fluvial sand, overlain by peat and organic deposits. Sands from this unit are found on channel borders and on the lee side of offshore islands, where they form spits and bars. They are also common in the proximal reaches of the Delta, where they are susceptible to submergence in the shallow waters that characterize the area.

Subsidence of localized areas due to the disappearance of permafrost constitutes a major geotechnical feature in Unit 3. Ground-ice slumping, and gullying on margins of lakes and channels also contribute to the presence of natural hazards. Other such hazards include collapse of river banks due to undercutting during periods of high water levels, and flooding in the spring because of break-up; also, flooding may take place in the fall when storms arrive. Another common occurrence affecting the land may be the alteration and re-location of river banks when water courses shift their channels. Deposits of this unit are unsuitable as a source of burrow material.

The hills and ridges of Unit 7 occupy a moderate portion of the outer part of the Delta and adjacent offshore islands, particularly Garry and Kendall islands. These beds consist of silt and clay, with minor amounts of sand and gravel in moraines. Tilting and folding of these beds due to moving-ice pressure are characteristic features of the unit; also, these beds are subject to subsidence due to occurrences of thermokarst. Gullying takes place on slopes where rills may be present. A geotechnical feature that may lead to hazardous conditions is the exposure of massive ground ice in the beds, which could produce slumping in the event of thawing. Along the coast, block-slumping is widespread and results in the formation of cliffs. Deposits in this unit are unsuitable as a source of aggregates, except in the moraines where coarser admixtures of gravel may be present.

In close proximity to the beds of Unit 7 are the hills, ridges and terraces comprising Unit 6. Exposures of this unit are found in the islands lying along a northwesterly axis in the central part of the map area. They are found in eskers, other glacial-fluvial deposits, and in undifferentiated fluvial sediments. Interstitial ice is present in well-drained areas and massive ice occurs at depths of 7-50 m. Generally the ground surface is dry because the drainage is mainly sub-surface in nature. On large flat surfaces, a veneer of silt or peat is present. On slopes where ground ice is present above the foot of the hill or ridge, ground-ice slumping, as well as gullying, will take place. The slumping process is most likely to happen with an increase in ground temperature. This unit is suitable as a major source of sand and gravel, and for burrow material as well.

The thermokarst beds of Unit 2 occur in association with Units 6 and 7 in the central part of the map area near Middle Channel, as well as on Kendall Island in occurrences of sand and gravel. They occupy low, flat areas that were former basins of tundra ponds, and their deposits vary between 2-8 m in thickness. Mostly they form surfaces that are flat, or gently sloping. Ice content in these beds varies from 10-40%, and can occur as thin seams. The drainage system leaves areas that consist of wet and marshy ground, particularly where patterned ground is visibile. Natural hazards may result from erosive action along the cracks induced by ice-wedging processes. Slumping, induced by the presence of thermokarst, may take place along the steep slopes that border the lakes in the area. The removal of thawed material can lead to subsidence amounting to 3 m. Generally the unfrozen material is incompressible if organic beds are present, and this material will be of low strength. Unit 2 is a poor source of granular material or fill, except where it has developed in close association with the tundra ponds of Unit 6.

Marine and lake deposits of Unit 5 are found in two places on southern Garry Island, and a single occurrence on a small island lying off the eastern coastline shown on the map. These deposits comprise clay and silt and are characterised by a discontinuous organic cover. Small areas of sand and gravel may be included in these beds, whose surfaces are gently sloping and contain extensive marsh coverage. A moderate amount of ice, ranging up to 10%, occurs in segregated seams about 25 cm in width in the upper 3 m of the soil. Where low-centred polygons have developed, the ground surface is wet. Erosion along the boundaries of ice wedges forms a hazard, as can the removal of thawed material due to subsidence that reaches 5 m. Unfrozen material present in this unit is low in strength; the unit, itself, is a poor source of granular material or fill, except in small areas.

An occurrence of Unit 1 lies directly off the northeastern hook of Garry Island, where it forms a barrier bar composed of sand and gravel. Such features are about 2 m above sea level, and are associated with present and former shorelines. They have a low ice content, but ice wedges may be present. Their ground surfaces may be dry except between ridges, in which case marshy ground may be found in the intervening depressions. Flooding is the main hazard, particularly in the lower areas where it is most common. Severe

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units ....

Eroding river or shore cliffs (one or both walls)............

Eroding river or shore cliff (one or both valley bedrock)... D D D

Pingos (major ones) ....

Lowland swamps or weedy foreshore ....

Breached lakes on shoreline.................................

Main sediment transport direction ....

Coastal sediment sinks ....

Barrier deposits, spits and bars ....

Bathymetric contours (m) 2

Hydrographic soundings (m) 94

Topographic contours (m) 30

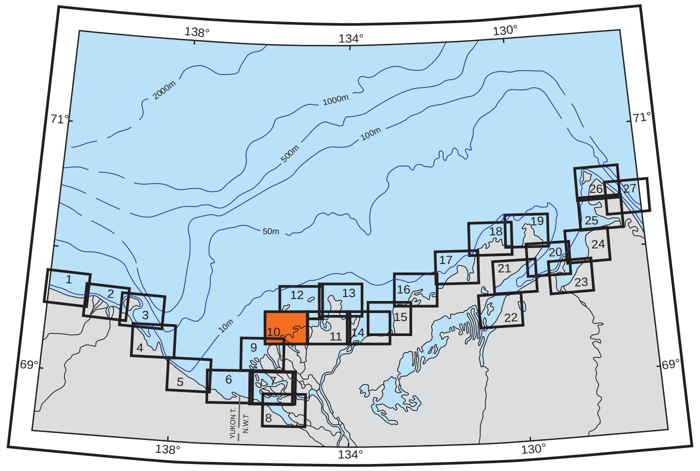
Topographic elevations (m) 183

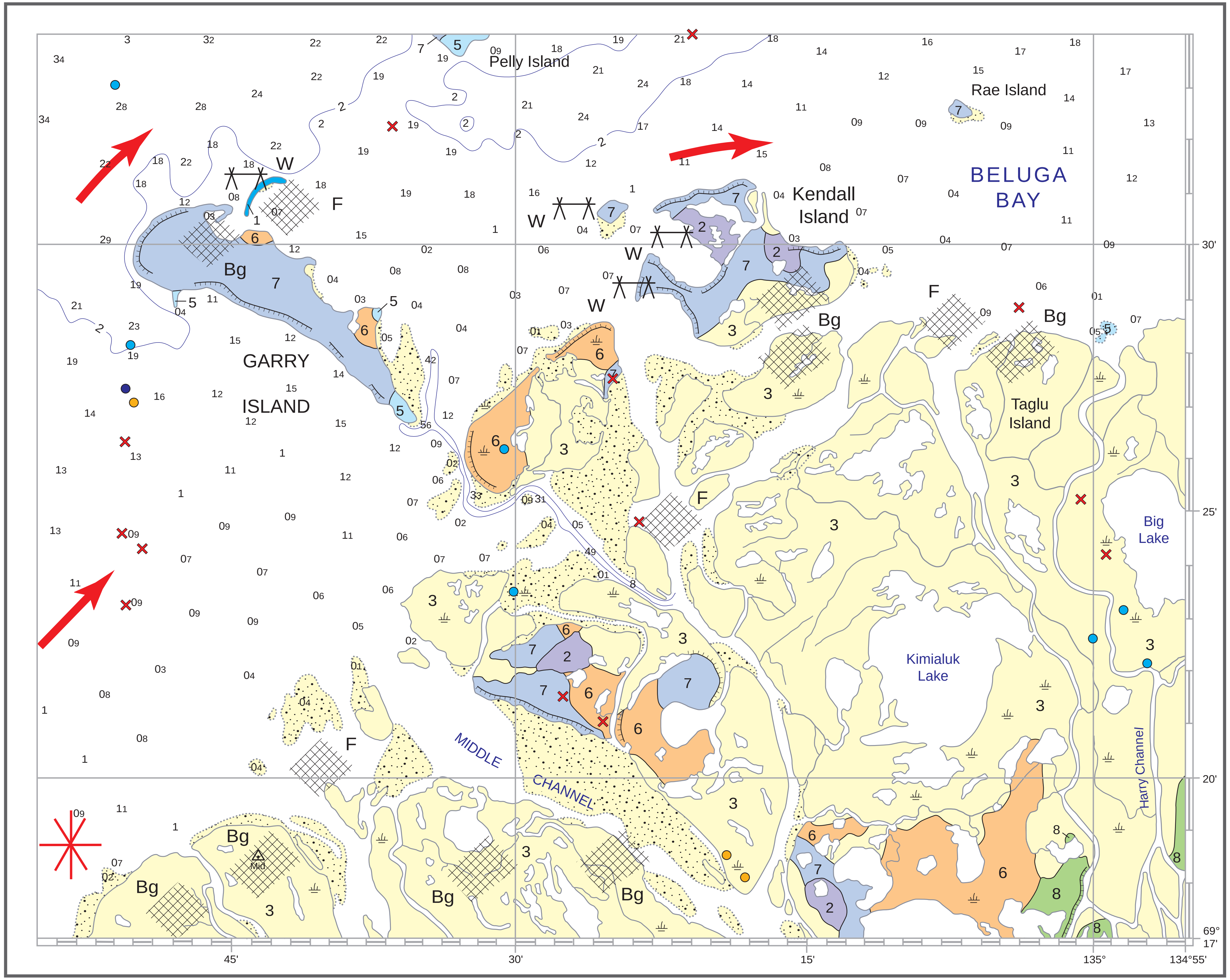
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M

Camps for whaling(W), hunting(H), fishing(F)................ W,H, F

Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries)... ●,●,●,✕





Coastlands Map 10. Garry Island

scale = 1:150 000

flooding of the upper part of the bars and ridges may alter their shape and orientation drastically, due to erosion and subsequent transportation of sediments. These features of Unit 1 comprise suitable sources of sand and gravel; however if severely exploited, the processes of erosion could be accelerated.

Unit 8 is found on three small deltaic islands in the southeastern corner of the map. These occurrences consist of till in the form of ground moraine with low, somewhat rolling relief and, in places, as parallel drumlin ridges. Large areas may include clayey to silty till in their soils. Ice content is moderate in the till, and may comprise 10% segregated ice in the form of thin seams in the upper 2-4 m of the deposit. The ground surface is usually dry, but may be moist on flat areas. An organized drainage system is absent, although down-slope seepage takes place in small sub-parallel rills. A moderate susceptibility towards gullying and the formation of thermokarst are the main hazards in these deposits, together with the prospect of superficial mud flows on sloping grounds. This unit is not a good source of gravel, and the usefulness as fill is restricted by its ice content.

COASTLANDS MAP 11. Richards Island

Physical Setting

Only the extreme easterly part of Mackenzie Delta is shown on this map. Its low marshy terrain is in moderate contrast to the higher elevations of Richards Island lying east of Harry Channel, and bordered on the Island's east side by Mackenzie River and Kittigazuit and Kugmallit bays (see COASTLAND MAP 14). The physiograhic contrast between the Delta and Richards Island is enhanced further by the apparent lack of orientation of physical features on the Delta, with the strong southwesterly-northeasterly trend of the lakes and intervening hills and ridges of Richards Island; also, the land is only a few metres above sea level on the Delta, but rises to more than 60 m on Richards Island. This entire map area comprises a profusion of small, to somewhat larger lakes, with very little inter-connecting flow. Small streams provide some drainage , although the latter is manifested in the much larger inter-connecting river channels present in the western third of the map and the southeastern corner adjacent to Mackenzie River. Pingos are present and some have summits exceeding 30 m in height; Denis Pingo in the southwestern part of the map is an example.

The configuration of the coastline is highly irregular and is characterized by the occurrences of comparatively large bays, numerous small inlets and channels around the distal islands of the Delta and Richards Island, and several very shallow, adjacent marine areas less than 2 m in depth. These latter areas may be inundated during the ice-free season, and serve as repositories of sand; in fact, a sediment sink occurs in the north-central part of the map area. This sink owes its origin to the deposition of sediments in these shoals and in the hydrodynamically less vigorous areas nearby. In regions of higher elevation along the coast sea cliffs are common, particularly in the eastern parts of Richards Island.

Surficial Geology Units and Hazards (Units 2,3,5,6 and 8)

Most of Richards Island is occupied by the gravel-sand hills and ridges of Unit 6. These latter features form eskers and other glacial-fluvial deposits; however silts are also present, particularly in the terraces that occur on the flat benches in the proximity of lakes. Low swamps are found near the coast, and some lie adjacent to Mackenzie River. In this unit, a distinct northeasterly orientation of the long axes of lakes, hummocks and ridges are present. Some ridges rise to elevations of 50 and 60 m, with adjacent occurrences of swamp in the intervening lower portions of the Island. Segregated ice is found in silts and beneath peat beds occurring in channels and depressions, and massive ice is found at depths ranging from 7 to 50 m. Ground surfaces of units are dry, with most drainage being sub-surface. The inter-connecting channels that are common to Mackenzie Delta are absent altogether.

Natural Hazards are related to thermokarst subsidence of large flat areas, particularly where silt and peat are present. On slopes where ground ice is present, gullying and ground-ice slumping may take place. This is particularly relevant to areas that lie above the base of the slope, and are susceptible to rises in the annual ground temperature. Unit 6 is a source of gravel as well as mixed gravel and sand; such sources are generally found in the hummocky areas. The flatter, outwash terraces are more suitable as burrow material.

The fine-grained river deposits of Unit 3 are second in order of major sedimentary deposits and, except for the southeastern corner of the area, are present exclusively in the western part of this map area. They consist of silt and silty sand in the river channels and the low floodplains and terraces of adjoining rivers. Organic silts, as well as peat and minor amounts of gravel may be present. In the floodplains, meander scars and thermokarst ponds are present. The peat beds are about 3 m thick in the terraces and abandoned channels along the floodplains. In active floodplains, the fine sediments and the peat are generally 3 to 5 m thick.

Ice content of Unit 3 is generally up to 10 % in volume in the form of thin seams about 2 or 3 cm wide in the upper 2 to 4 m of the beds. In some areas, lakes and ponds are expanding because of thermokarst collapse in the associated banks. Ground surfaces in this unit are wet in many areas and are characterized by numerous occurrences of thaw pools and lakes. An integrated drainage on the surface is absent, except for flows of minor creeks and wider and longer inter-connecting channels.

The chief geotechnical hazard is due to occurrences of minor thermokarst subsidence; additionally ground-ice slumping and gullying on the margins of lakes and channels takes place. Flooding is also a hazard along channels during periods of high water, and leads to undercutting of banks in those areas. Flooding most commonly takes place during break-up in the spring, and stormy periods in the fall. These events may be accompanied by shifts in the river channels. Because of its overall fine texture, organic content, and only minor amounts of coarse sediments, this unit is a poor source of burrow material.

Unit 8 occupies about one third of the western portion of the map area and is situated mainly between exposures of Units 3 and 6. Coincidentally, the long axes of these occurrences trend northeasterly in the same parallel arrangements as that of the hummocky terrain and major lake axes of Unit 6. All these features and the till plains of Unit 8 are glaciogenic. In Unit 8, the till occurs as ground moraine with low rolling of relief about 30 m and comprises parallel drumlins. A large pingo (Denis Pingo, >30 m in height) in the southern portion of the map indicates the height of some of the local features. Large areas comprise clayey to silty till generally up to 7 m thick, but may accumulate to 20 m locally. Peat cover is discontinuous and is found in depressions and isolated patches.

Ice content in Unit 8 is moderate, and up to 10 % may form as segregated ice in thin seams in the upper 2 to 3 m of the unit. Locally, thicker lenses may be found at shallow depths beneath the surface. Except in flat areas where the surface of the ground is commonly moist, the surface of this unit is generally dry. No organized drainage exists, except for the down-slope seepage occurring in shallow, sub-parallel runs. Hazards are restricted to gullying and the formation of thermokarst, with surficial mudflows taking place on the slopes. This unit is not a good source of gravel, due to the general absence of such deposits; even burrow material is limited because of the ice content in the finer sediments.

The exposures of Unit 2 are the next most abundant in the area, and lie somewhat in the central western part of the area. They are in close juxtaposition with the exposures of Units 6 and 8; in fact, the long axes of their exposures seem to be in parallel alignment with those of Units 6 and 8 in that they all trend northeasterly. Unit 2 comprises thermokarst lake beds which consist of clay, silt, and peat, with local occurrences of sand and gravel. The sediments of this unit are found in tundra ponds mainly, and may be 2 to 8 m thick and have flat to gently sloping surfaces.

In Unit 2, ice content is moderate in volume. About 40 % of the segregated ice occurs as thin 1-cm wide seams, and generally in the finer sediments. Sands and gravels found in this unit are free of excess ice, as a rule. The areas of occurrence of this unit are wet and marshy, particularly where low-centered polygons are present. Erosion along ice wedge-cracks constitutes a major hazard; another hazard is the process of thermokarst slumping, which may occur along the steep slopes around the lakes in the area. Removal of thawed material can also lead to subsidence amounting to 3 m at least. Another hazard lies in the nature of the unfrozen material; if organic beds are present, they are generally compressible and low in loading strength. Gravel and sand are associated with occurrence of Unit 6, otherwise the beds of Unit 2 are a poor source of granular material or fill.

Almost as abundant as Unit 2, are the coastal occurrence of Unit 5. Most are found in the northeastern part of the area near Mackenzie Bay and its adjoining inlets directly to the south. Other occurrences are located around Mason Bay in the northeastern part of the area. The exposures of Unit 5 comprise silt-clay plains consisting of marine and lake beds, and may be characterized by an organic cover. Small areas of sand and gravel may be included in this unit, whose surface is flat to gently sloping with extensive occurrences of marshy areas. In other parts of the unit, a discontinuous organic cover may be present. All these deposits are associated with extremely shallow water in the marine area, whose depths are less than 2 m.

Ice content in this unit is moderate, and up to 10 % may occur as thin 3-cm wide seams in the upper 3 m. Ground surfaces are generally wet and, as in the case in Unit 2, low-centered polygons may develop. Hazards may be localized along ice wedges, if erosion takes place at these sites. Thawing of material in this unit can lead directly to subsidence amounting to more than 2 m and, because of the low strength of such beds together with that of the unfrozen beds, this unit is unsuitable for foundations. Except in very small local areas, Unit 5 is a poor source of granular material.

LEGEND

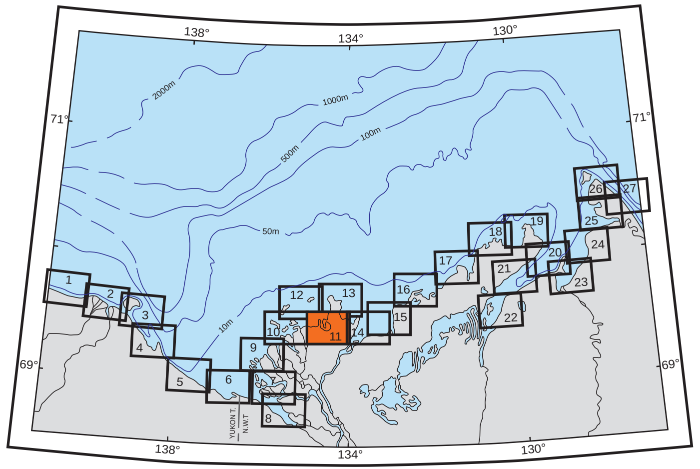
SURFICIAL GEOLOGY AND PROCESSES

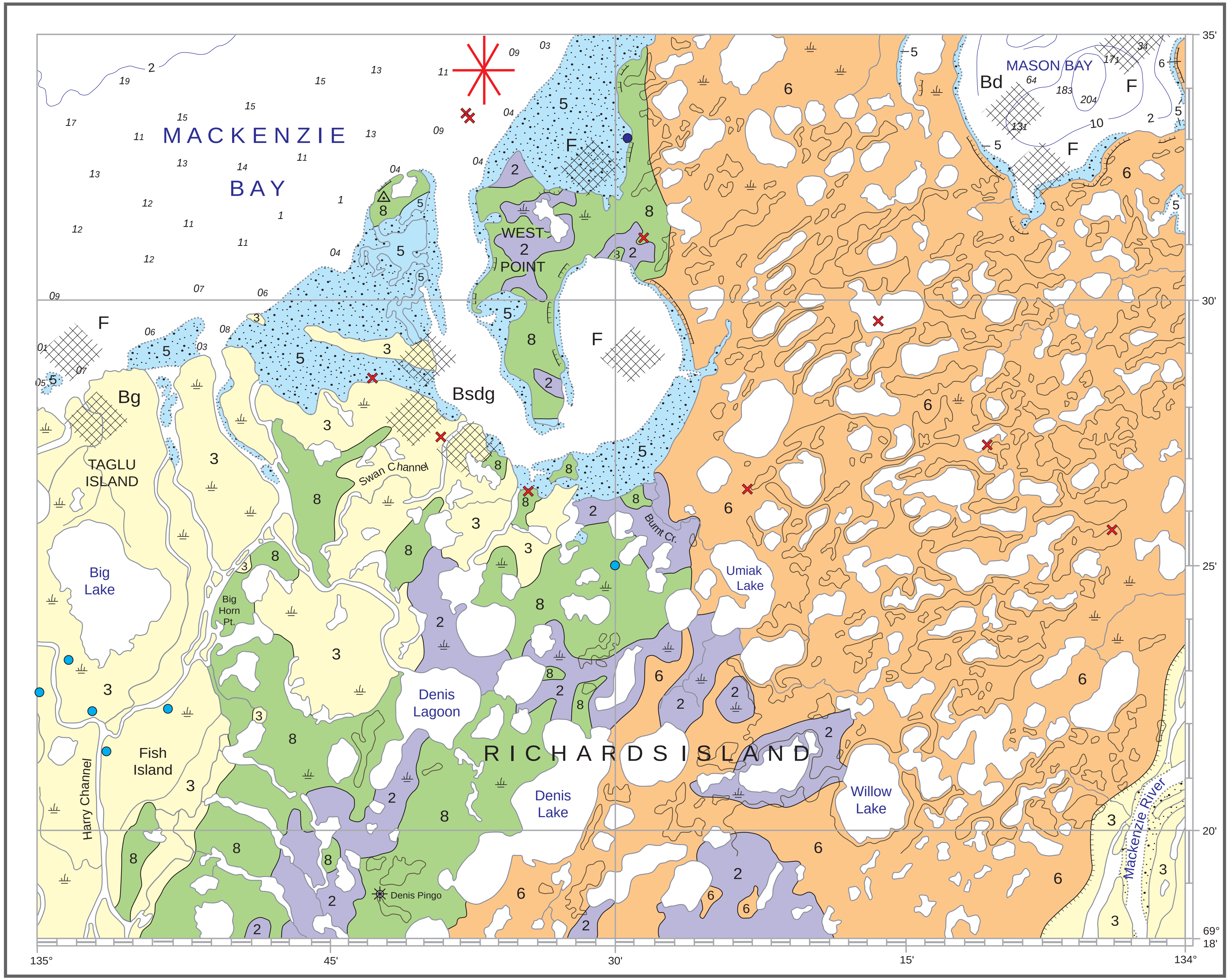
- 1 Beaches
- 2 Thermokarst lake beds
- 3 Fine-grained river deposits
- 4 Coarse-grained river deposits
- 5 Marine and lake plains
- 6 Gravelly and sandy hills, ridges and terraces
- 7 Ice-thrust hills and ridges
- 8 Till plains
- 9 Hummocky till-capped terrain
- 10 Upland and pediment complexes
- 11 Mountainous and rocky areas

Geological boundaries of surficial units
Eroding river or shore cliffs (one or both walls)
Eroding river or shore cliff (one or both valley bedrock)
Pingos (major ones)
Lowland swamps or weedy foreshore
Breached lakes on shoreline
Main sediment transport direction
Coastal sediment sinks
Barrier deposits, spits and bars
Bathymetric contours (m) 2
Hydrographic soundings (m) 94
Topographic contours (m) 30
Topographic elevations (m) 183 △

RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) F,B, M
Camps for whaling(W), hunting(H), fishing(F) W,H, F
Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries) ●, ●, ●, ✕





Coastlands Map 11. Richards Island

scale = 1:150 000

COASTALAND MAP 12. Pelly Island

Physical Setting

This map area comprises several islands lying offshore from the Mackenzie Delta, as well as a few in the distal portion of the Delta itself. All the islands are in water depths of less than 5 m and, in some cases, the water depth less than one kilometre offshore may only be a fraction of a metre. On the islands the topography rises to elevations of 30 m, although many parts are low with elevations close to sea level. A few small lakes, and many stretches of sea cliffs 3 to 5 km in length and 5 to 7 m in height occur in the main offshore islands such as Kendall, Pelly and Hooper. Ridges are common, and low swampy terrain lies in the intervening areas. Because of their proximity to the Beaufort Sea, all the islands in this region are subject to the action of longshore currents that move easterly under the influence of the Coriolus force.

These longshore currents are the agents of erosion and sediment transport, as exemplified in the construction of sand spits and barrier bars in the down-current direction. In these areas, current directions are variable and deflections off the islands are common; also, variations in current directions and movement may be caused by decreasing hydrodynamic vigour, shoaling sites, and opposing influence of variable winds and weak tidal currents. In such cases, current velocities are checked and deposition may take place. Commonly local sediment sinks form, such as the one occurring a few kilometres southeast of Hooper Island. Along the coast, small inlets appear to be closing to the sea as sand drifts across their mouths; in other cases it appears as though marine breaching of the shoreline is imminent, or under way. Eventually with a rising sea, breaching will continue and local barrier bars and spits will disappear because of inundation.

Surficial Geology and Hazards (Units 1,2,3,5,7, and 8)

The silt-clay ridges of Unit 7, which is the most abundant unit of this area, are present on nearly all the islands. These beds also comprise minor amounts of sand and gravel which, together with the finer sediments, form moraines everywhere. Much of this strata is tilted and folded, because it was subjected to compression by the force of moving ice and has elevations that may exceed 30 m. Sea cliffs are characteristic of this unit and at lower elevations, a few small lakes are present.

Segregated ice in amounts up to 50% occur in the upper 3 m, and may form thin seams and reticulate networks. At depth, thick tabular bodies of massive ice are prominent. Geotechnical hazards include the following: gullying on slopes, soil failure on scarps, active-layer detachment slides, retrogressive thaw-flow slides, and thermokarst subsidence. The presence of fine-grained material leads to poor load-bearing capacity of the ground.

The thermokarst lake beds of Unit 2 are the next in abundance of the surficial units in the map area. They consist of clay, silt, and peat, and sand and gravel locally. These beds, which are 2 to 8 m thick and may be peat-covered, lie in low flat areas that were formerly occupied by tundra ponds. Generally their elevation is low, with small lakes and some swampy terrain present. Surfaces of the deposits are usually flat, or gently sloping.

Ice content in this unit is moderate, ranging between 10 to 40% and occurring as seams about 1 to 2 cm wide. Drainage is poor, resulting in areas that are wet and marshy, particularly where low-centred polygons are present at the surface. Hazards are induced by erosion along ice-wedge cracks, and by thermokarst slumping along the slopes around lakes. Removal of thawed material can lead to erosion of 3 m or more. The presence of compressible frozen material will produce ground of low strength, particularly if organic beds are present. Gravel and sand may occur locally, but Unit 2 qualifies as a poor source of granular material or fill.

Almost equal to Unit 2 in terms of areal coverage in this map area is Unit 5. These beds consist of clay and silt with a discontinuous organic cover, and with small occurrences of sand and gravel included. The unit comprises old marine and lake beds and presently form low-lying, flat to gently sloping silt-clay plains in the coastal regions of the islands. The latter occurrences form spits and bars, which may be inundated periodically.

A moderate ice content of up to 10% occurs as seams about 3 cm wide in the upper 1 to 4 m of the unit. The ground surface is wet in areas where low-centred polygons have developed. Materials eroding along the boundaries of ice wedges can lead to hazardous soil conditions, as can the removal of thawed material; the latter effect will produce subsidence of 2 m or more. Unfrozen material present will have low strength, and this situation will present a constructional hazard. This unit provides no sources of granular fill, except in localized areas.

Unit 1 occurs in two main exposures in the vicinity of Pelly Island only where it is found as beaches and bars on flat areas in the marine region along former or present shorelines. It consists of sand and gravel which may form ridges about one metre in height, or form as regular stabilized beach deposits.

Ice content is low in the active beaches, but is in moderate amounts in the stabilized shore zone. Ground surfaces are relatively dry on the beach ridges, but are wet and marshy between the stabilized ridges. The greatest hazard is the occurrence of frequent flooding of the lowest areas; however, the higher portions of actively forming ridges will also be flooded during periods of major storms so that minor coastal erosion and re-shaping of beach ridges will take place. This unit is a suitable source of gravel, as well as mixed sand and gravel; however excessive exploitation of these materials can accelerate the processes of coastal erosion.

Unit 3 comprises fine-grained river deposits, and is found mainly on the outer islands of the Delta in this area. These deposits consist of fine silt, sand and clay with peaty beds, all of which form floodplains and low, bordering, riverine terraces. The unit is generally flat, with overall relief of less than 5 m. Ice content is moderate, with seams of ice occurring in the upper few metres. Because of the paucity of lakes and associated permafrost, the main hazard in this unit is flooding during spring break-up and autumnal storms. This unit is a poor source of borrow material.

Only one occurrence of Unit 8 is present in this map area, and it lies in the southeastern part of the map on a tip of Richards Island. It comprises till plains occurring as ground moraine, with low-lying rolling relief of approximately 30 m. Sediments of this unit consist of clay and silt, with some cover of peat. Ice content is moderate in till exposures, with up to 10% segregated ice in the form of thin seams in the upper 2 to 4 m of the unit. Locally, lenses of ice up to 3 m thick are found at depth. The ground surface is dry, but may be moist on flat areas. Organized drainage is absent, but down-slope seepage takes place in small rills. The main hazards are thermokarst formation, gullying, and superficial mudflows. This unit is not a good source of gravel materials, nor is it suitable for fill because of the ice content.

LEGEND

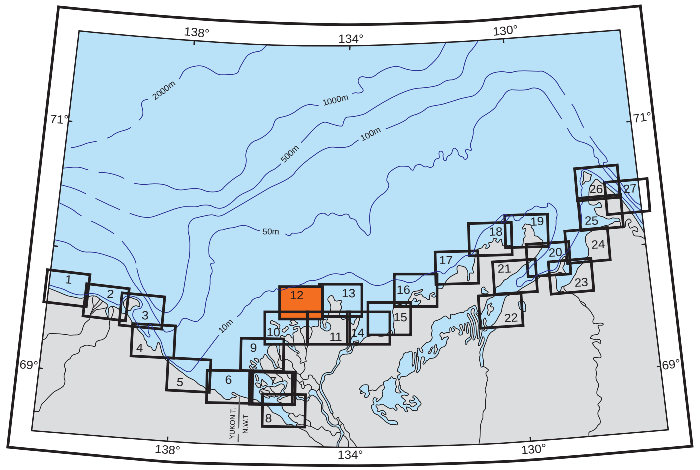
SURFICIAL GEOLOGY AND PROCESSES

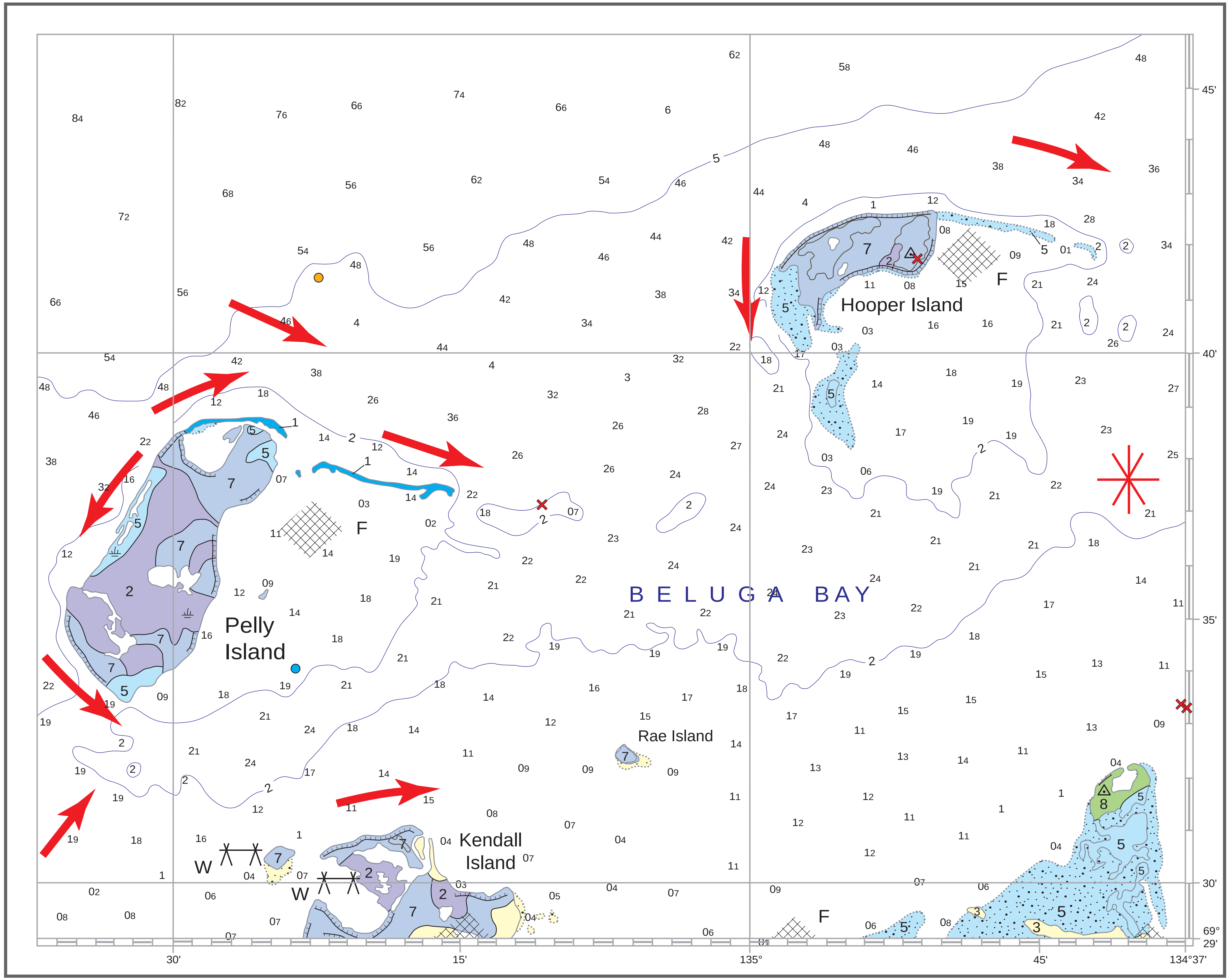
- 1 Beaches
- 2 Thermokarst lake beds
- 3 Fine-grained river deposits
- 4 Coarse-grained river deposits
- 5 Marine and lake plains
- 6 Gravelly and sandy hills, ridges and terraces
- 7 Ice-thrust hills and ridges
- 8 Till plains
- 9 Hummocky till-capped terrain
- 10 Upland and pediment complexes
- 11 Mountainous and rocky areas

Geological boundaries of surficial units ....
Eroding river or shore cliffs (one or both walls)............
Eroding river or shore cliff (one or both valley bedrock)... D D D
Pingos (major ones) ....
Lowland swamps or weedy foreshore ....
Breached lakes on shoreline...................................
Main sediment transport direction ....
Coastal sediment sinks ....
Barrier deposits, spits and bars ....
Bathymetric contours (m) 2
Hydrographic soundings (m) 94
Topographic contours (m) 30
Topographic elevations (m) .... 183 △

RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M
Camps for whaling(W), hunting(H), fishing(F)................ W,H, F
Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries)... ●,●,●,✕





Coastlands Map 12. Pelly Island

scale = 1:150 000

COASTLANDS MAP 13. North Point

Physical Setting

The peninsula of North Point is the most dominating geographical feature of this map and is followed in prominence by the occurrences of several major, offshore islands such as Pullen, Hawden, Summer as well as Reindeer Islands. Most of the land lies at elevations less than 30 m above sea level, but ridges, hills and eskers with elevations exceeding 30 m abound in the southern part of North Point. Hilly elevations are also present on the western coast and northern interior, as well as on the eastern islands. Sea cliffs several metres in height are present on all coasts, including those of most islands; but other cliffs occur on the shores of rivers and lakes. However, another important aspect of North Point and its neighbouring islands is the presence of numerous small lakes. Commonly these features are associated with swampy terrain in the lower elevations.

In the coastal zone, barrier bars and spits are being constructed everywhere as sediments are transported through and around the islands and deposited by waning longshore currents. In one case these processes have produced a sediment sink on the west side of North Point. In other places such as those around Pullen, Hawden, and Summer islands, where the general trend of the coastal currents is easterly, numerous bars and spits are actively aggrading. In this map area, the undersea platform adjacent to the mainland and island features is extremely shallow. This situation permits the passage of very shallow-draft vessels only, along coastal routes.

Surficial Geology and Hazards (Units 1,2,5,6 and 8)

Unit 6 is widespread, occurring on most of North Point peninsula and all adjacent islands. Its sand and gravel bodies comprise ridges and eskers, with the intervening areas occupied by swampy terrain and several pingos. The latter are not shown here, as their elevations and that of the swamps are less than 30 m. However one large pingo, which exceeds 30 m in height, is located on the western side of Summer Island. Unit 6 forms cliffs on most of the sea coasts and some lake shores.

Next in importance as a surficial body is Unit 5. It is found exclusively in coastal areas, comprises sand and gravel, and lies at the lowest elevations shown on the map. Because of their location, exposures of this unit constantly receive sediments from longshore drift and are susceptible to flooding.

Unit 8 comprises till bodies, and is exposured along with Units 5 and 6. Ridges and swampy terrain are present and are found only in the southwestern corner of the map area. Cliffs are prominent in this area as well, particularly where they are in contact with the low-lying beds of Unit 5.

The thermokarst beds of Unit 2 also occur in the southwestern part of the area. They are swampy in nature, are associated with low elevations of only a few metres, and have small lakes occupying some of their expanse.

Only one occurrence of Unit 1 lies in this map area and it forms a spit extending from the northeastern end of Pullen Island in the northernmost part of the area. The map clearly shows the trend of the longshore, sediment-laden currents that have constructed this feature from its anchored position on Pullen Island to its extended position in Kugmallit Bay.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units ....

Eroding river or shore cliffs (one or both walls)............

Eroding river or shore cliff (one or both valley bedrock)... D D D

Pingos (major ones) .... ⁕

Lowland swamps or weedy foreshore ....

Breached lakes on shoreline.................................

Main sediment transport direction .... →

Coastal sediment sinks .... ✳

Barrier deposits, spits and bars ....

Bathymetric contours (m) 2

Hydrographic soundings (m) 94

Topographic contours (m) 30

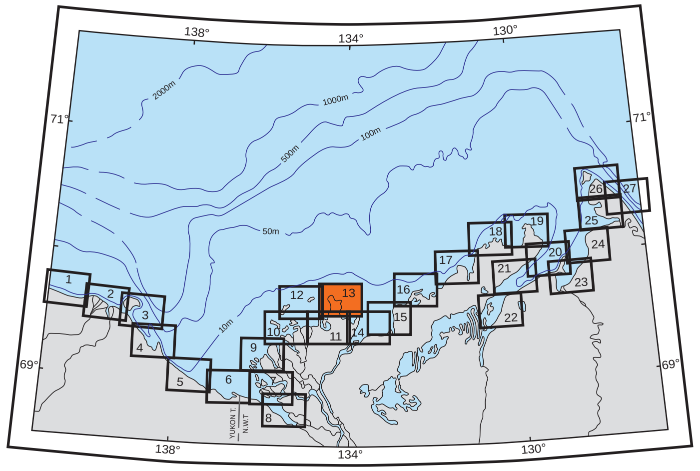
Topographic elevations (m) .... 183 △

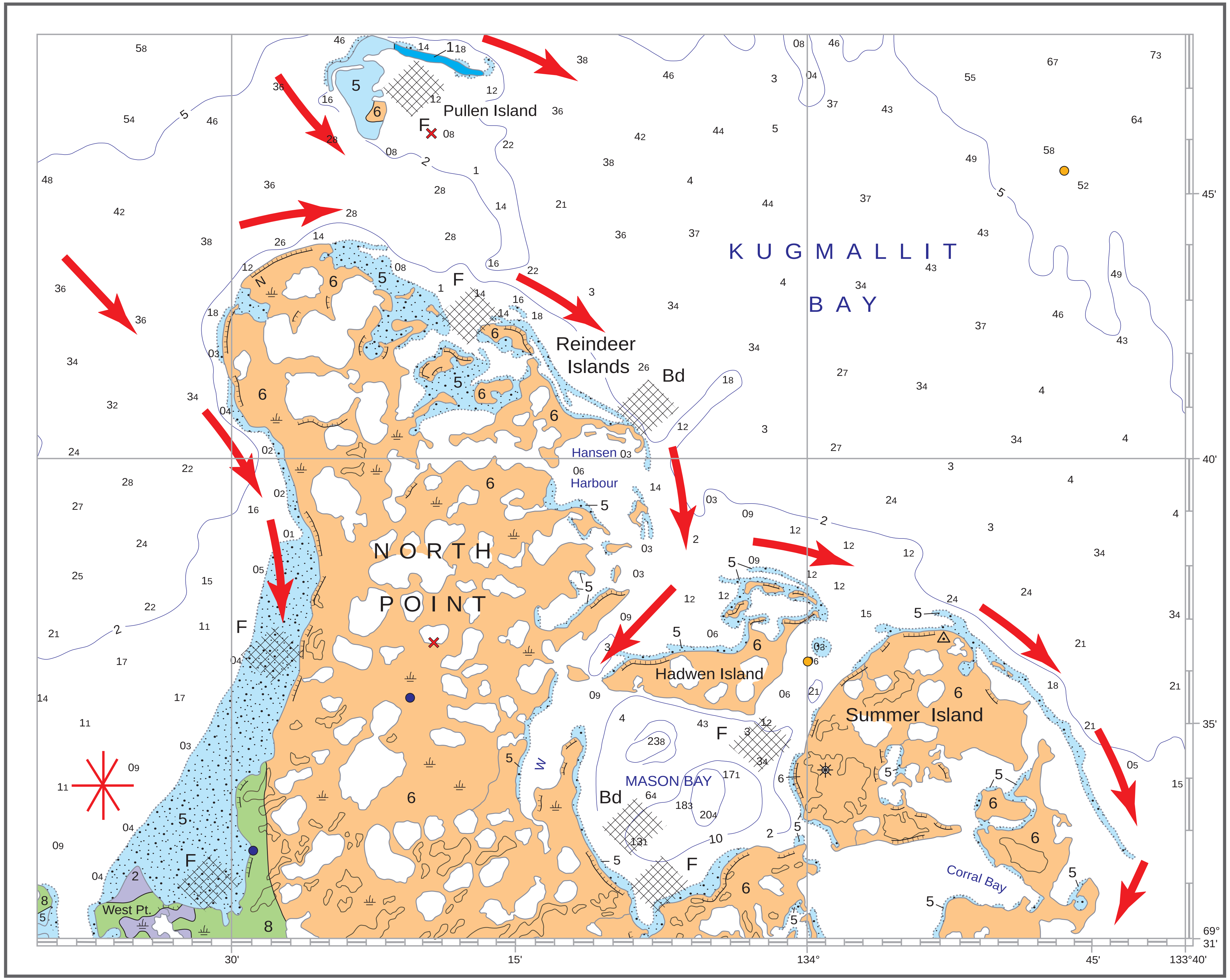
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M ▨

Camps for whaling(W), hunting(H), fishing(F)................ W,H, F

Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries)... ●,●,●,✕





Coastlands Map 13. North Point

scale = 1:150 000

COASTLANDS MAP 14. Kugmallit Bay

Physical Setting

The extensive water body of Kugmallit Bay occupies the central and northeastern portion of this map area and serves to separate Richards Island and adjacent offshore islands in the west, from the Tuktoyaktuk Peninsula which comprises a part of the mainland to the east. These western islands are low-lying in the coastal regions, but exhibit relief greater than 30 m in the form of hills and ridges. Swampy terrain and numerous small lakes occupy the depressions in the land on all sides of Kittigazuit Bay. Cliffs, several metres high and formed by under-cutting processes, are common features along the modern and earlier coasts in the western part of the area. On the eastern side of the map, small lakes, rivers and swamps are profuse. Hills and ridges are also present and these rise to at least 30 m in elevation. Pingos abound in this region, particularly near the coast where some are more than 30 m in height. Along the eastern shore of Tuktoyaktuk Peninsula, the borders of small lakes and ponds have been breached by a rising and invading sea. After the water drains seaward from these breached features, pingos are likely to develop singly or in clusters along the coastal land only a few metres above sea level.

This map is unique in that it displays a total portion of a small but modern delta at the mouth of Mackenzie River. Such features as channels, low-lying islands consisting of silt and sand deposits, considerable occurrences of swampy ground lying only 2 m or so above sea level, and underwater troughs and depressions aligned with the current direction of the discharging streams, are all characteristic of this deltaic complex. Where longshore currents and river flow meet, current velocities are checked and sediments are deposited to form a sediment sink. Another such sink is formed in the southeastern corner of Kugmallit Bay, where the flows of sediment-laden currents have been resisted and deposition has taken place. Proceeding seaward from the mouth of Mackenzie River, the coastal seabed is extremely shallow with depths of less than one metre; however, it becomes gradually deeper toward the northeastern corner of the map where the water is 4 - 5 m deep. Generally, the trend of the bathymetric contours conforms to that of the embayment and surrounding shoreline

Surficial Geology and Hazards (Units 1,2,3,5,6, and 9)

Two surficial units (2 and 6) occupy the land almost equally. Unit 6 consists of gravelly and sandy hills composed of eskers and other glacio-fluvial deposits, which commonly rise 50-60 m in height. Beds in these features are found in the western part of the map area on both sides of Kittigazuit Bay, and in the northern part lying west of Kugmallit Bay. These beds occupy most of Richards, Hendrickson and Summer islands. Unit 2 occurs predominantly on Tuktoyaktuk Peninsula, with a single exposure on Hendrickson Island. The area of breached lakes in the northern part of the Peninsula is a highly significant feature of this unit, because it is a harbinger of additional breaching of lakeshore boundaries and the potential creation of small inlets along the coast. Both Units 6 and 2 are characterized by lakes, swamps and pingos in their lowland areas. Although most pingos are small, some of them exceed 30 m in height; Ibyuk, Split and Whitefish pingos are the most notable examples.

Unit 3 is the only surficial unit comprising the deltaic complex situated at the mouth of the easternmost channel of Mackenzie River. Silts and sands of this unit lie very close to sea level (< 2 m), and comprise the numerous swamp-ridden islands of the narrow delta. Much of Unit 2 is bounded by cliffs that are several metres high and are found at the adjacent borders of Unit 6. Almost uniformly within the map area of Unit 2 are the several occurrences of the hummocky till-capped terrain of Unit 9. These beds are found exclusively in association with those of Unit 2, and comprise the highest ground within that portion of Tuktoyaktuk Peninsula.

The marine and lake beds of Unit 5 are exposed only around northern Richards Island and adjacent Summer Island. These beds consist of very fine-grained deposits, some of which form barrier bars along the coast. Unit 1, the least abundant surficial unit in the area, also contains barrier deposits of sand and gravel; however, these deposits form significant spits along the easternmost coast of the Peninsula.

LEGEND

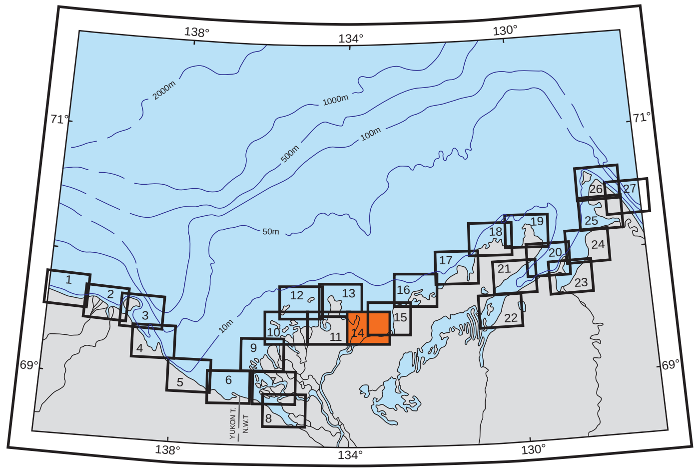
SURFICIAL GEOLOGY AND PROCESSES

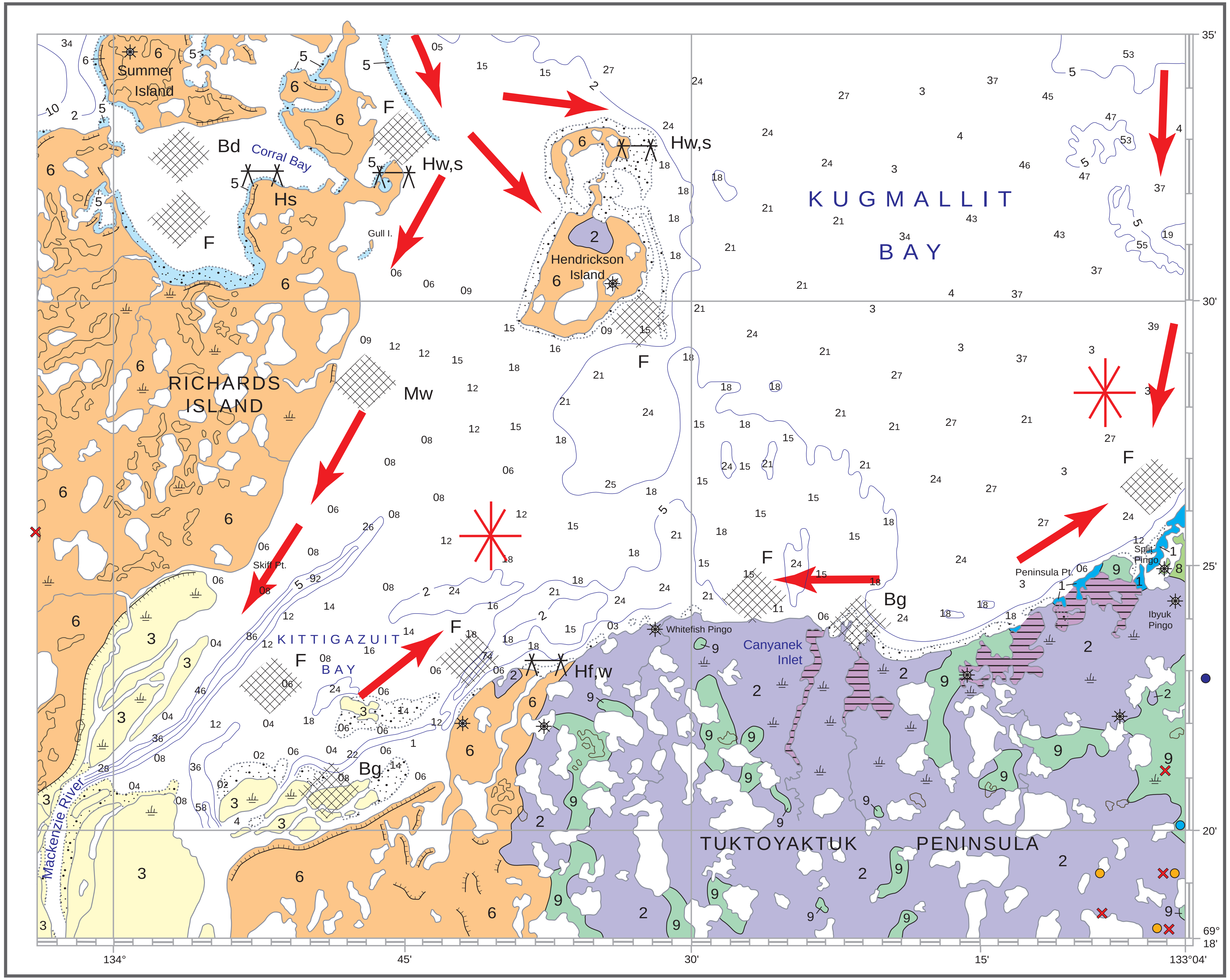
1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units	
Eroding river or shore cliffs (one or both walls)	
Eroding river or shore cliff (one or both valley bedrock)	
Pingos (major ones)	✳
Lowland swamps or weedy foreshore	
Breached lakes on shoreline	▤
Main sediment transport direction	→
Coastal sediment sinks	✳
Barrier deposits, spits and bars	
Bathymetric contours (m)	2
Hydrographic soundings (m)	94
Topographic contours (m)	30
Topographic elevations (m)	183 △

RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B)	F,B, M ▦
Camps for whaling(W), hunting(H), fishing(F)	W,H, F
Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries)	●, ●, ●, ✕





Coastlands Map 14. Kugmallit Bay

scale = 1:150 000

COASTLANDS MAP 15. Tuktoyaktuk

Physical Setting

The landscape in this area is subdued, featureless, and characterized by swampy terrain and an abundance of thermokarst lakes. However, the physiographic monotony is broken by the striking occurrences of large pingos, many of which are greater than 30 m in height and 100 m in diameter. In the vicinity of the hamlet of Tuktoyaktuk, after which this map area is named, such pingos may occur singly or in clusters and are generally accompanied by numerous smaller ones. Thus, this area of the coastlands is one of the most densely populated in terms of these ice-cored hills.

An integrated drainage is absent, except for a few minor, inter-connecting streams. Inlets along the coast are common features, together with the irregular occurrences of breached lakes in the southwestern and northern parts of the area. Low-centred polygons are also present in this area, and some can be found in the vicinity and on the flanks of pingos.

Several barrier bars and spits are found around Tuktoyaktuk and the coastline to the north. Longshore currents are variable in direction but, in the vicinity of Tuktoyaktuk, a checking of their velocities has lead to the deposition of their load and the formation of a sediment sink. Elsewhere, these longshore currents, which bear a load derived from local coastal erosion and fluvial discharge, have created spits in the lee of small headlands and nearby islands. Shallow water is present adjacent to shore and for several kilometres seaward in the western part of the area; however, around Tuktoyaktuk Harbour the water is somewhat deeper. In the latter vicinity, the water depth is slightly deeper and a channel more than 5 m deep opens to the north, and thus permits the passage of shallow-draft coastal vessels.

Surficial Geology and Hazards (Units 1,2,5,6,8 and 9)

Most of this map area is occupied by elements of Unit 2, which contains beds of fine sediments with peat enclosed. The area of peat coverage is wet and marshy, particularly near the coast, and is dotted with numerous ponds of thermokarst origin. Other units such as 6, 8, and 9, occur in moderate amounts throughout the map area. Unit 9 comprising hummocky till-capped terrain, consists of clay and gravelly-sandy till. The hummocks rise at least 30 m above the low, swampy terrain surrounding its exposures. Along the coast Unit 9 forms sea cliffs several metres in height, which consist of till predominately. Unit 8 consists of clayey deposits and till, and forms moraines with low rolling relief up to 30 m; it may be characterized by occurrences of drumlins lying in parallel arrangement with adjacent or nearby ridges. This unit is found almost exclusively around the southern and western margin of Tuktoyaktuk Harbour and vicinity, where it may exhibit some dissected relief from the action of small streams. The sands and gravels of Unit 6 occupy most of the remaining area surrounding Tuktoyaktuk Harbour. These deposits form ridges and terraces up to 60 m or so in height, and may contain minor amounts of ice. This ice may show evidence of compressional stress in the manner in which it is deformed; it may be folded, and sheared. The remaining surficial geology units in this area consist of Units 1 and 2, and are predominant along the coast. Unit 5 comprises coastal plain, clay deposits and lie adjacent to the beaches, barrier deposits and spits making up Unit 1. However, the deposits of Unit 5 may form cliffs and be disturbed by frost-wedging action and subsequent slumping.

LEGEND

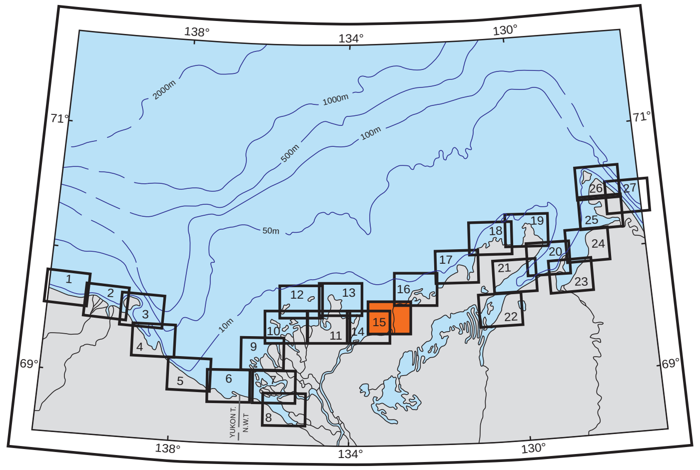
SURFICIAL GEOLOGY AND PROCESSES

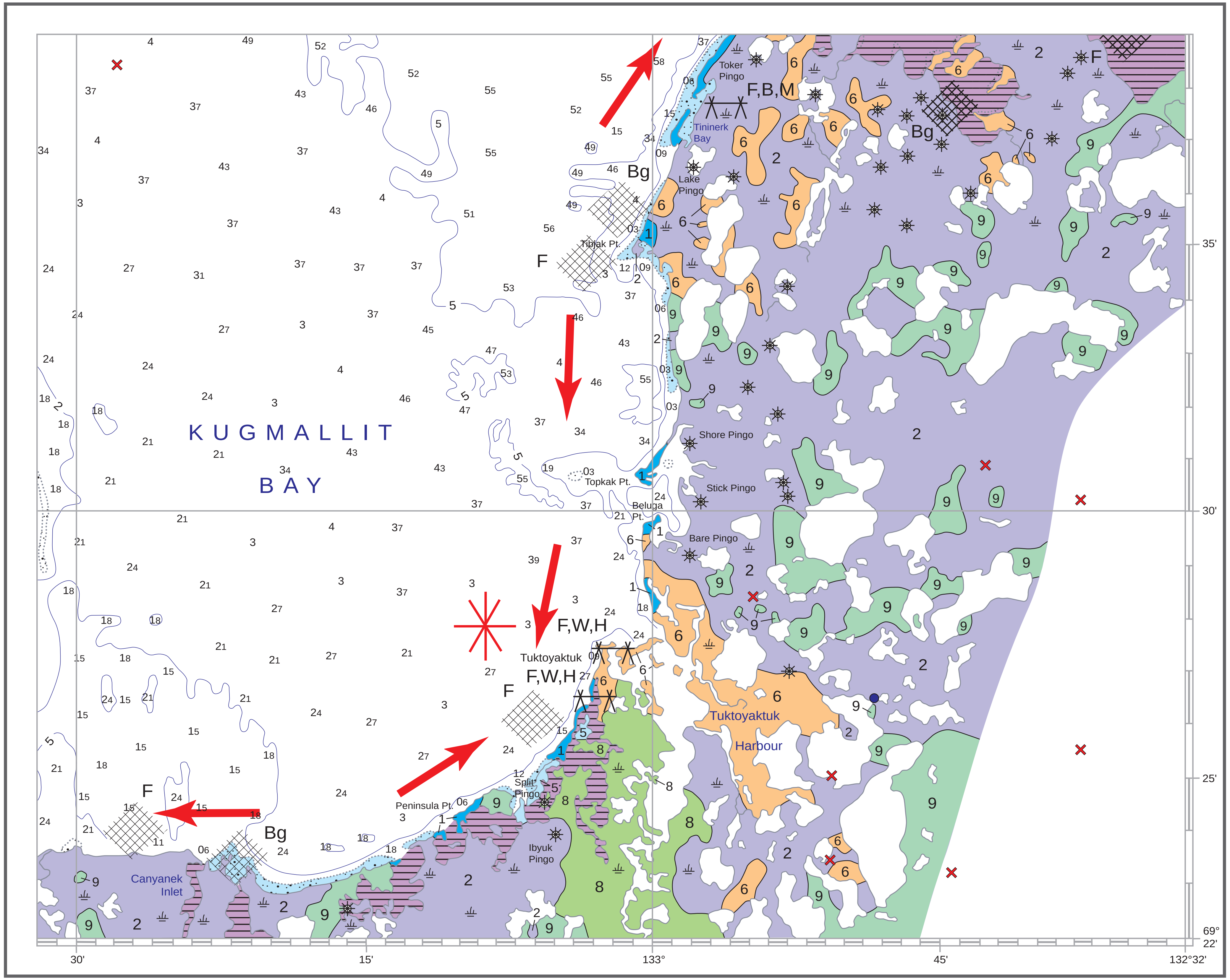
1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units	⁀
Eroding river or shore cliffs (one or both walls)............	┴┴┴┴
Eroding river or shore cliff (one or both valley bedrock)...	ᑭᑭᑭ
Pingos (major ones)	⋇
Lowland swamps or weedy foreshore	⫫
Breached lakes on shoreline....................................	▤
Main sediment transport direction	→
Coastal sediment sinks	✳
Barrier deposits, spits and bars	⁘
Bathymetric contours (m)	2 ∼
Hydrographic soundings (m)	94
Topographic contours (m)	30 ∼
Topographic elevations (m)	183 △

RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B)	F,B, M ▩
Camps for whaling(W), hunting(H), fishing(F)	W,H, F ⩚⩚
Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries)...	●,●,●,✕





Coastlands Map 15. Tuktoyaktuk

scale = 1:150 000

COASTLANDS MAP 16. Hutchinson Bay

Physical Setting

Many small lakes along this portion of the coastlands comprise the dominant aspect of the landscape. Particularly striking are those former lakes whose borders have been breached by the sea, and now form larger inlets and bays with a direct connection to the sea. Along the shore, these inlets are bordered by low-lying swampy terrain that is characterized by many large pingos. At higher elevations up to 60 m or so, most of the lakes are part of an integrated drainage system. However, this drainage system is unlike that of a regular trunk system in that its streams and tributaries are really inter-connecting water courses and lakes which lack tributary branches of any consequences.

Along the coast, barrier deposits and spits that extend from small headlands have formed as a response to the direction of sediment-laden longshore currents on the lee side of these headlands in shoal marine areas. In the nearshore areas where currents have slackened, sediment sinks have formed as observed in the westernmost part of the coast west of Tuft Point. Barrier deposits are forming in the shoals east of Bois Point on the easternmost coast.

Surficial Geology and Hazards (Units 1,2,6 and 9)

Almost all of the land in this map area is occupied by the sand and gravelly ridges of Unit 6. This includes the central coastal section, as well as the entire eastern portion except for small occurrences of other surficial units. Although most elevations are below 30 m, several higher ridges may exceed 60 m in height. Intervening low areas are covered by swamps, and some coastal stretches terminate as sea cliffs. Hummocks, eskers and ridges are commonplace in this unit, and the ground surface of these features is generally dry.

Nearly one third of this map area comprises the clays, silts and peat that constitute the thermokarst lake beds of Unit 2. The presence of these beds along the coast and the southwestern portion of the map is common, and is characterized by the occurrence of pingos. These pingos, together with those in Unit 6, are greater than 30 m in height, although many smaller pingos exist throughout both units. The poor drainage of Unit 2 has led to the development of thermokarst, and its subsequent subsidence upon thawing.

A few exposures of two other surficial units are present: some hummocky till-capped features that rise to 50 m are present in the region, and are prominent in Unit 9; and the barrier deposits of Unit 1 are fairly important, and occur off the headlands in the vicinity of Hutchison Bay, as well as in the western embayments.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units

Eroding river or shore cliffs (one or both walls)

Eroding river or shore cliff (one or both valley bedrock)

Pingos (major ones)

Lowland swamps or weedy foreshore

Breached lakes on shoreline

Main sediment transport direction

Coastal sediment sinks

Barrier deposits, spits and bars

Bathymetric contours (m) 2

Hydrographic soundings (m) 94

Topographic contours (m) 30

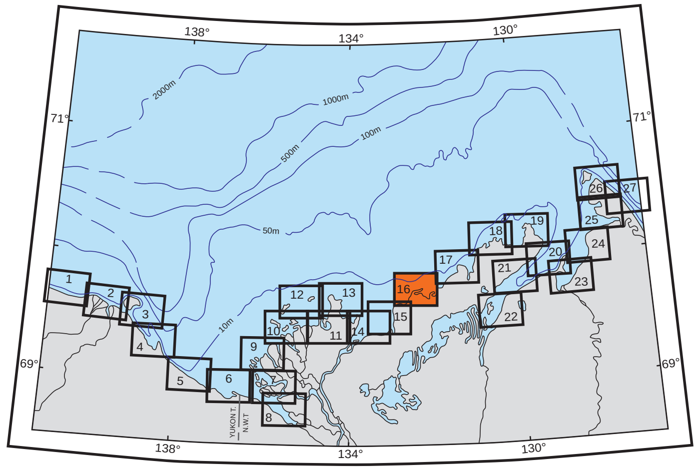
Topographic elevations (m) 183 △

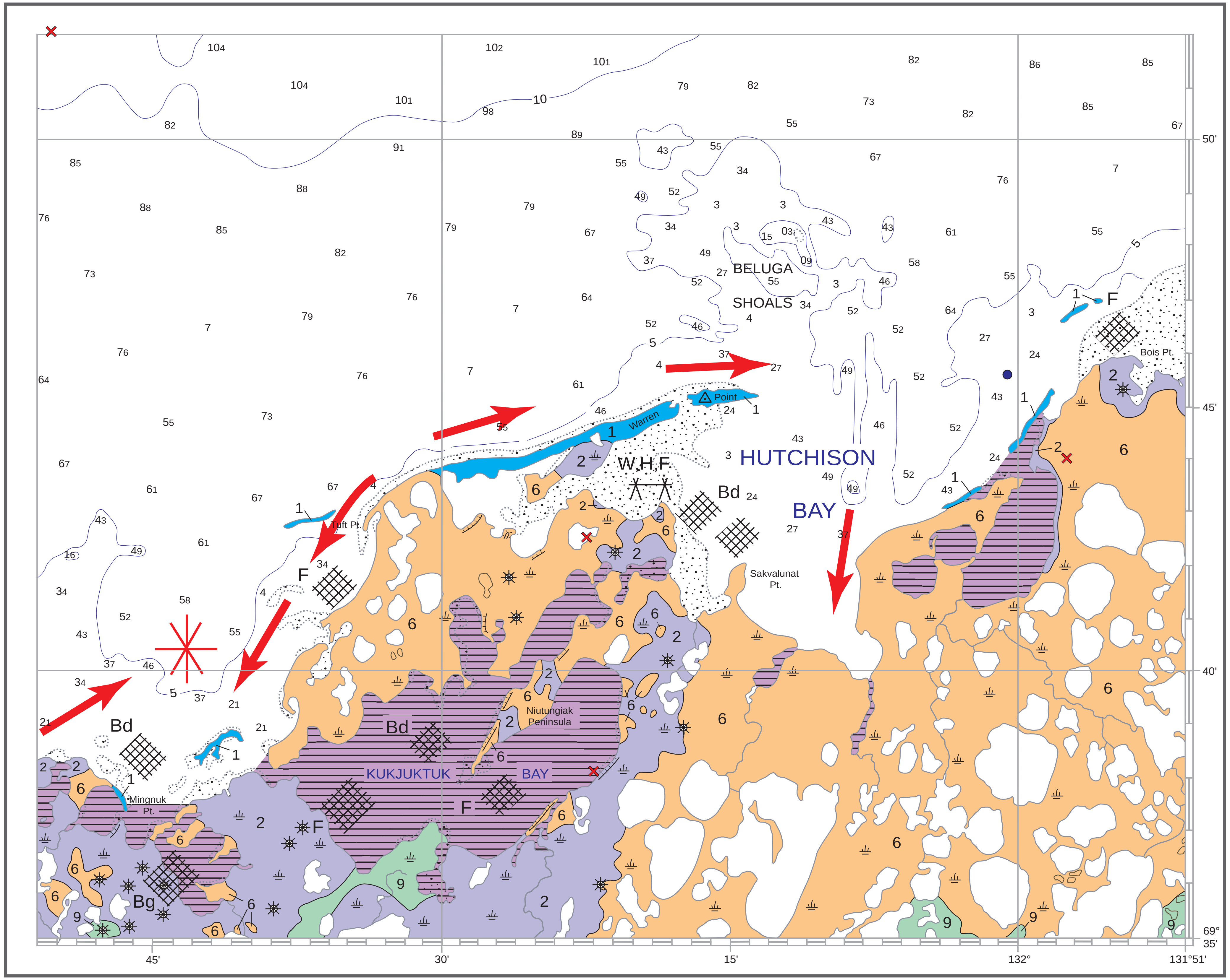
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) F,B, M

Camps for whaling(W), hunting(H), fishing(F) W,H, F

Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries) ●,●,●,✕





Coastlands Map 16. Hutchison Bay

scale = 1:150 000

COASTLANDS MAP 17. McKinley Bay

Physical Setting

This map area is similar to adjacent areas in that it comprises a lakeland setting. Because of the dominating effect of thawing permafrost, small lakes inter-connected by short, irregular water courses abound throughout the region. Numerous small pingos (not shown) occur singly and in clusters of two or more, and are generally less than 30 m in elevation. Several incidents of breached lakes are in evidence along the coast and, in some cases, the lake portion has disappeared due to submergence by the slowly rising sea. Numerous inlets and bays have been created by this process, which has also acted over different parts of the coastline of Tuktoyaktuk Peninsula. McKinley Bay, though, has a different origin in that it is actually the headward portion of an undersea valley that deepens seaward across the Beaufort Shelf (see PHYSIOGRAPHIC REGIONS). It is the largest marine feature shown on the map, and has been used as an over-wintering harbour for resources exploratory vessels including offshore drilling rigs.

Along the coast, longshore currents are active in eroding and transporting sediments. Variable longshore current directions flowing with decreasing velocities have produced depositional features in the lee of headlands and some of these features are built in different settings paralleling the coast. In McKinley Bay, a sediment sink has formed because of the vagaries of the sediment-laden currents and their waning velocities. Lessening current action on the northwestern coast of this map area has produced sandy shoals adjacent to the land. In the central coastal areas, longshore currents have developed major barrier deposits and sand spits.

Surficial Geology and Hazards (Units 1,2 and 6)

In this map area, Unit 6 is the major component of the surficial geology deposits. Its sands and gravels occupy virtually all of the Tuktoyaktuk Peninsula in the region where its component hills, ridges and terraces rise to 60 m in elevation in the southeastern part of the map area. In areas of thermokarst, where peat is present, slumping and subsidence are common. However, most of Unit 6 is dry even though it is occupied by numerous small lakes that are drained, in part, by short inter-connecting streams. The thermokarst lake beds of Unit 2 occur in minor amounts around a few lakes, both inland and along the coast. They are also associated with areas of marine-breached lakes whose borders lay close to the coast in the recent past. Unit 1 contains sand and gravel which comprise the barrier deposit and spits in the vicinity of Atkinson Point, and extend for several kiolmetres on both sides of the point.

LEGEND

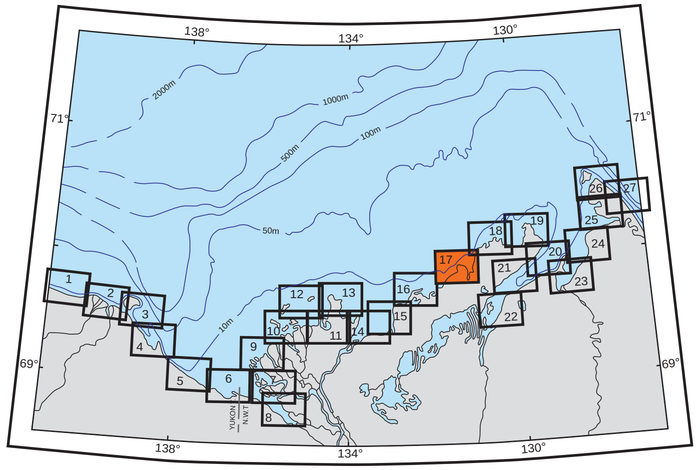
SURFICIAL GEOLOGY AND PROCESSES

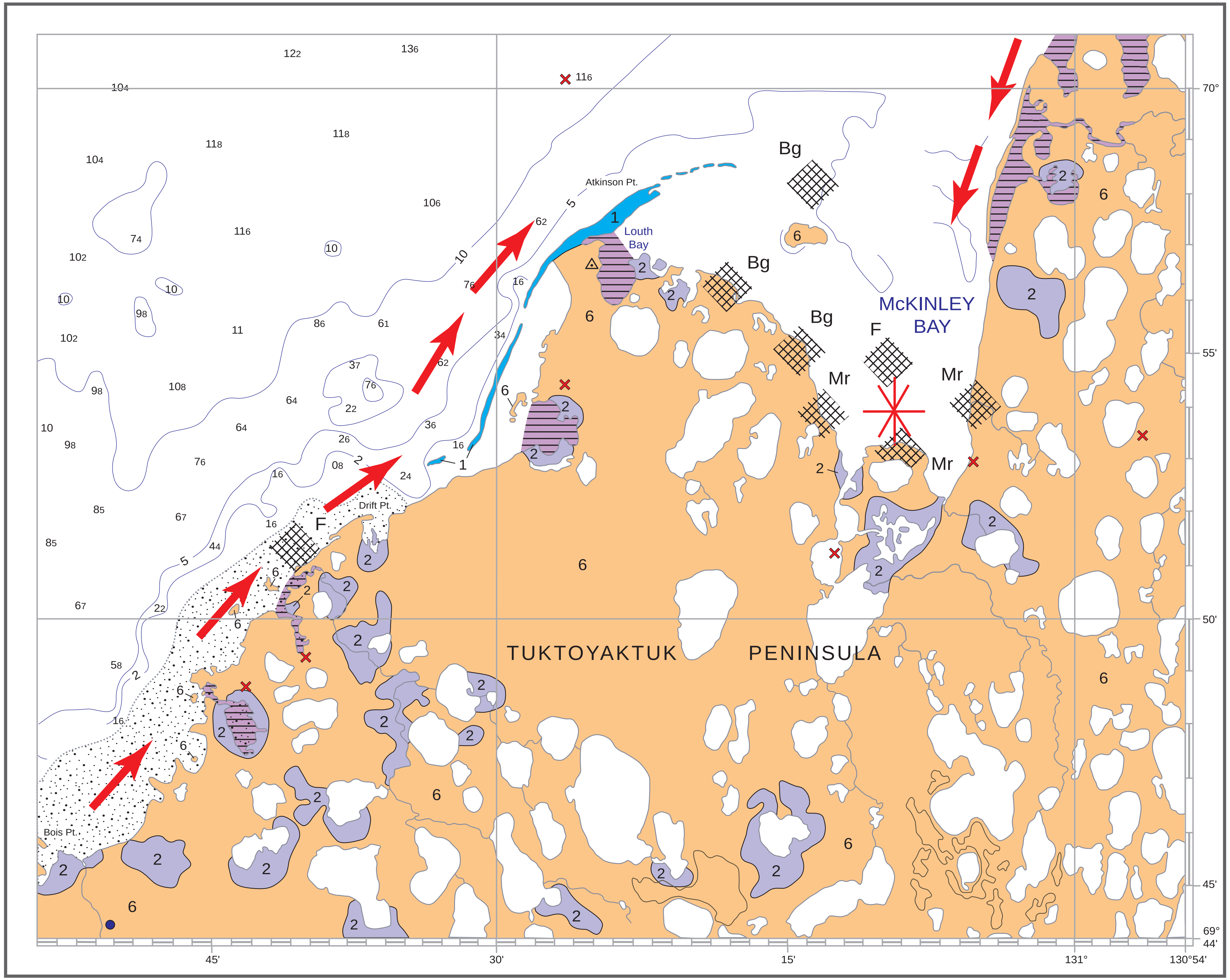
1 Beaches
2 Thermokarst lake beds
3 Fine-grained river deposits
4 Coarse-grained river deposits
5 Marine and lake plains
6 Gravelly and sandy hills, ridges and terraces
7 Ice-thrust hills and ridges
8 Till plains
9 Hummocky till-capped terrain
10 Upland and pediment complexes
11 Mountainous and rocky areas

Geological boundaries of surficial units
Eroding river or shore cliffs (one or both walls)
Eroding river or shore cliff (one or both valley bedrock)
Pingos (major ones)
Lowland swamps or weedy foreshore
Breached lakes on shoreline
Main sediment transport direction
Coastal sediment sinks
Barrier deposits, spits and bars
Bathymetric contours (m) 2
Hydrographic soundings (m) 94
Topographic contours (m) 30
Topographic elevations (m) 183 △

RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) F,B,M
Camps for whaling(W), hunting(H), fishing(F) W,H,F
Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries) ●,●,●,✕





Coastlands Map 17. McKinley Bay

scale = 1:150 000

COASTLANDS MAP 18. Nuvorak Point

Physical Setting

The lakeland setting of the previous map, as well as that of most of the Tuktoyaktuk Peninsula, is a dominant aspect of the landscape. This setting is further enhanced by the occurrence of an area of breached lakes, which lies along the entire coast and serves as an outer bordering fringe of this unique small-lake country. On the mainland, large pingos exceed 30 m in height and occur throughout the map area. Some of these features are found in the low terrain around the drainage routes, including the lakes, while others abound in the nearshore regions. Along the coast, some pingos are undergoing both thermal and mechanical erosion from the combined influence of solar and wave-induced energy. Many of these pingos exhibit an exposed ice core, and are presently being submerged by the action of a slowly rising sea. Cliffs are prominent along the shores of many lakes and their inter-connecting waterways and may border the sea coast as well. This is particularly the case in the region of the breached lakes.

In the coastal zone, many ancient headlands have been separated from the mainland because of the erosive and flooding action of a rising sea; coincidentally, this action has produced the submerged areas formerly occupied by lakes that were breached. The islands, also produced by erosion and rising seas, extend as a fringing band paralleling the coast. In the nearshore zone, current action is variable and ceaseless, and is both the cause and the transporting mechanism of eroded sediments along the coast. Spits and barrier bars, up to several kilometres in length, have formed from this marine action. About 3 - 8 km offshore, water depths are greater than 10 m so that coastal traffic by means of shallow-draft vessels is feasible.

Surficial Geology and Hazards (Units 1,2 and 6)

In this map area, only Units 1, 2 and 6 are present, but Unit 6 occupies the area almost entirely. Its sediments consist of sand and gravel, with minor amounts of silt. Low hills and ridges occur in the south mostly and rarely rise to more than 60 m in elevation. This unit may contain dunes, and is characterized by a dry surface. However some ground is wet so that slumping and subsidence is still common, as shown by the numerous small scarps throughout the area. Slumping of the soil presents the main hazard in this unit.

Only a few small areas on this map represent the thermokarst beds of Unit 2, and these occur near the southern and eastern parts of the coastline. Generally they are close to areas of marine-breached lake borders that lie around the seaward fringes of Unit 6. Thawing of permafrost is the main hazard in this unit, which also possesses poor loading strength that could lead to unstable bases for construction of any kind.

The sands and gravels of Unit 1 are the main constituents, and are found in the spits and barrier bars along the western shore and the adjacent shallow water. Phillips Island is the location of a small spit, with a larger one occurring just to the south. Other barrier deposits of sand occur along most of the mainland inlets, and around the islands that lie in association with the breached lakes. The shoals just offshore are also occupied by these barrier deposits. Flooding and excessive exploitation of these granular deposits are the main hazards of this unit.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units ....

Eroding river or shore cliffs (one or both walls)............

Eroding river or shore cliff (one or both valley bedrock)...

Pingos (major ones) ....

Lowland swamps or weedy foreshore ....

Breached lakes on shoreline...................................

Main sediment transport direction ....

Coastal sediment sinks ....

Barrier deposits, spits and bars ....

Bathymetric contours (m) 2

Hydrographic soundings (m)................................... 94

Topographic contours (m) 30

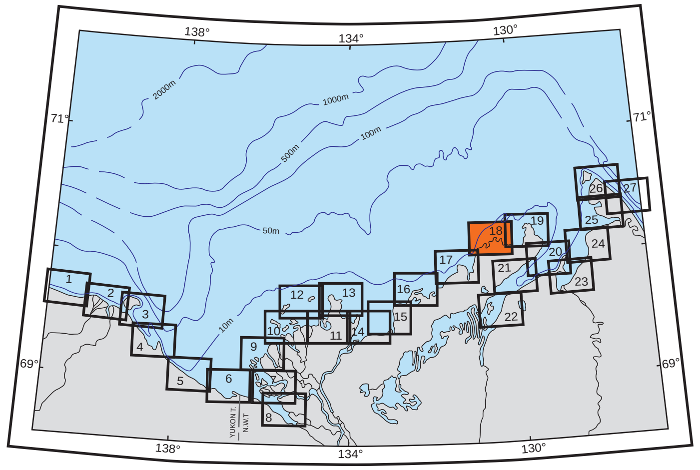
Topographic elevations (m) .... 183 △

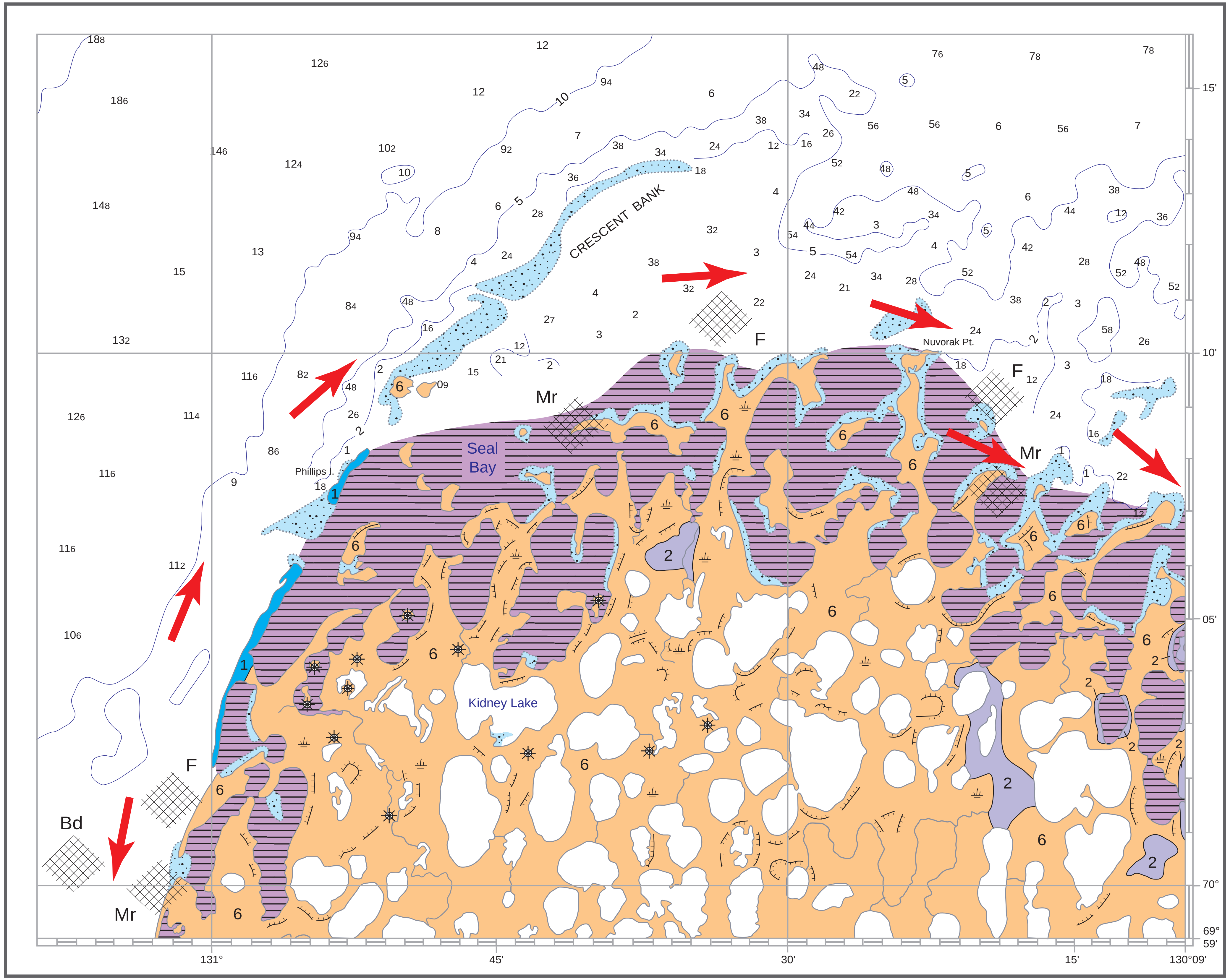
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M

Camps for whaling(W), hunting(H), fishing(F)............... W,H, F

Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries)... ●,●,●,✕





Coastlands Map 18. Nuvorak Point

scale = 1:150 000

COASTLANDS MAP 19. Cape Dalhousie

Physical Setting

Cape Dalhousie, situated on the eastern end of the Tuktoyaktuk Peninsula, is the dominant geographical feature in this area. Numerous small, thermokarst lakes with sporadic inter-connecting water courses characterize the drainage and the land surface. In association with the lakes are the occurrence of small scarps, and a few large pingos. Many smaller pingos are present around the coast and some lie just off the northeastern coast of Cape Dalhousie (see PINGOS). Low swampy areas are prevalent near the eastern coast, but are present in some inland areas as well. Another notable feature of this map is the large fringing band of sea-breached lakes occupying nearly all of the coastal area; some of these inlets penetrate several kilometres inland.

Barrier deposits such as spits and bars occur along the coast, surrounding many of the small islands that are separated from the mainland in the breached-lakes area. In the nearshore marine areas waters are shallow, a situation that is partly conducive to the building of barrier landforms. The residual longshore currents that transport sediments around the promontory near Cape Dalhousie are also factors in forming these constructive features. In Russell Inlet currents are weak and probably variable, as enhanced in a sediment sink that has formed a few kilometres offshore in only slightly deeper water from that inshore. However deeper water occurs in all directions offshore, particularly toward the northern part of the map area. The somewhat, parallel orientation of the bathymetric contours around the coastal promontory indicates a site of the former presence of the Tuktoyaktuk Peninsula in these areas prior to the recent submergence brought about by rising sea levels.

Surficial Geology and Hazards (Units 1,2 and 6)

As in the case for the entire northern portion of the Tuktoyaktuk Peninsula from Hutchinson Bay eastward to Cape Dalhousie, the sands and gravels of Unit 6 are the most abundant surficial deposits in the area. They occur almost exclusively around virtually all lakes and coastal shores, and may be associated with low-lying wet areas, as well as with low ridges, terraces and hills. The major geotechnical hazard is the prevalence of slumping and subsidence, as observed in the production of numerous scarps several metres in height. This process is exacerbated in units containing ice and undergoing an episode of thawing.

Of lesser significance in abundance are the silts, clays and peat of Unit 2. Most of these beds occur around several small lakes, as well as around those breached by the sea. Most of the area so-occupied is low, wet and poorly drained, thus leading to the formation of thermokarst lake beds. The greatest hazard in this unit is the lack of soil strength, particularly during periods of thaw, in which case these beds could collapse and become a construction problem.

The beaches of Unit 1 are the least common of all surficial deposits. They are restricted in occurrence to the coast, and may be associated with island headlands and small promontories of the mainland. Marine flooding of these deposits is common during periods of storm, but extensive exploitation will destroy them and thus leave portions of the coast susceptible to increased erosion.

LEGEND

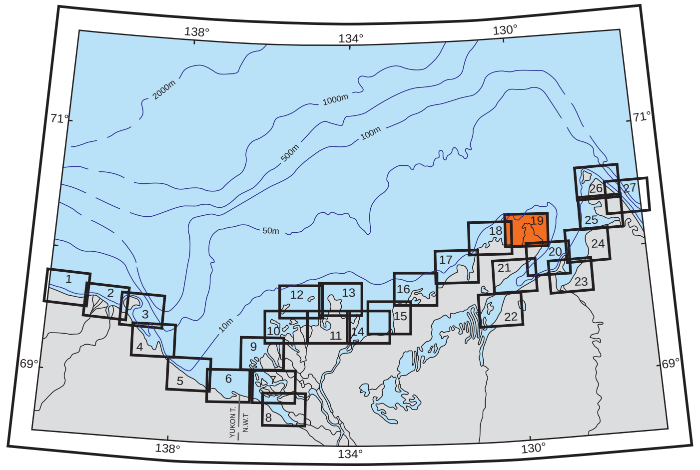
SURFICIAL GEOLOGY AND PROCESSES

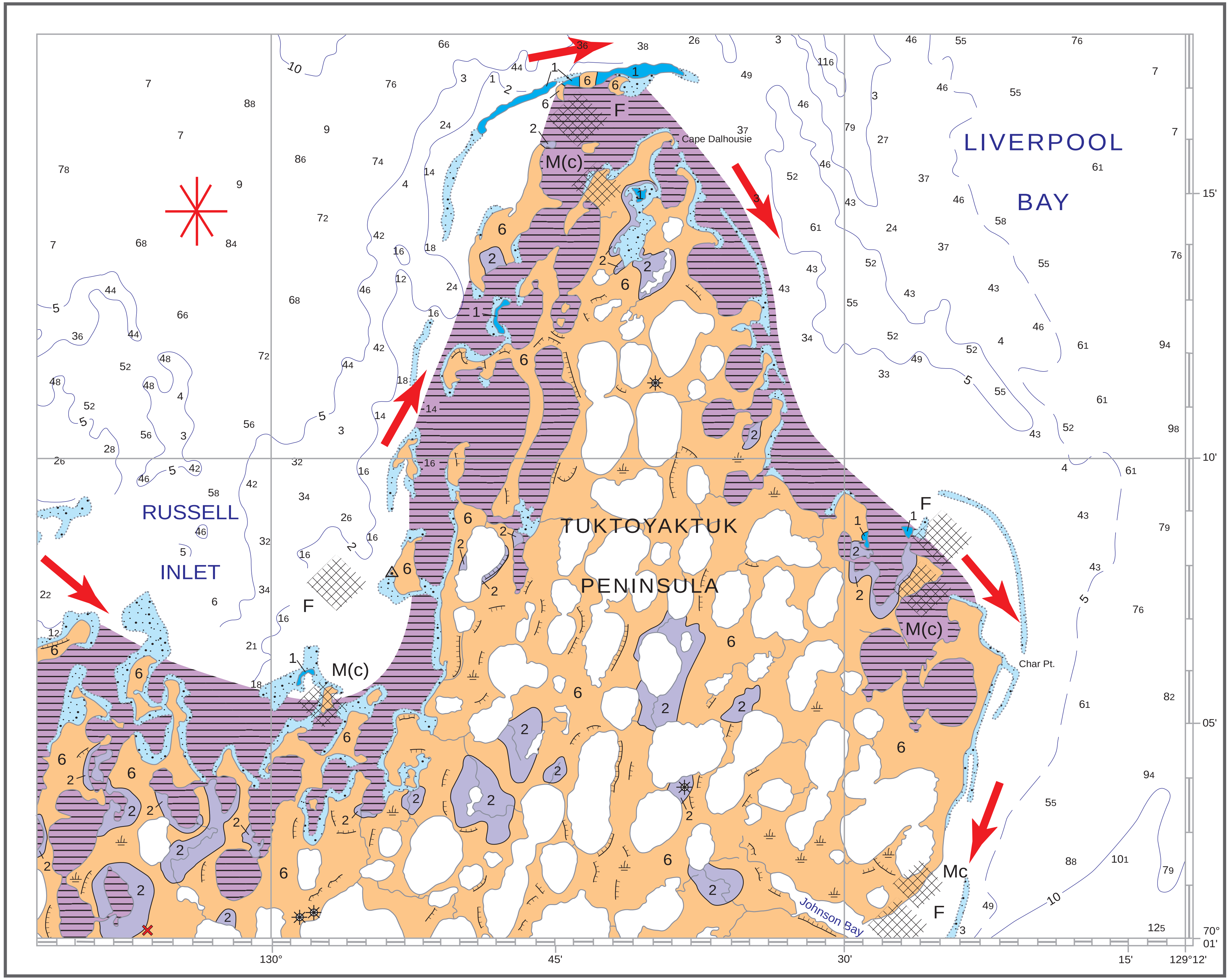
1 Beaches
2 Thermokarst lake beds
3 Fine-grained river deposits
4 Coarse-grained river deposits
5 Marine and lake plains
6 Gravelly and sandy hills, ridges and terraces
7 Ice-thrust hills and ridges
8 Till plains
9 Hummocky till-capped terrain
10 Upland and pediment complexes
11 Mountainous and rocky areas

Geological boundaries of surficial units ....
Eroding river or shore cliffs (one or both walls)............
Eroding river or shore cliff (one or both valley bedrock)...
Pingos (major ones) ....
Lowland swamps or weedy foreshore ....
Breached lakes on shoreline.....................................
Main sediment transport direction ....
Coastal sediment sinks ....
Barrier deposits, spits and bars ....
Bathymetric contours (m) 2
Hydrographic soundings (m)................................... 94
Topographic contours (m) 30
Topographic elevations (m) .... 183 △

RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M
Camps for whaling(W), hunting(H), fishing(F)................W,H, F
Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries)....●,●,●,✕





Coastlands Map 19. Cape Dalhousie

scale = 1:150 000

COASTLANDS MAP 20: Nicholson Island

Physical Setting

In this map area, the landmass of Tuktoyaktuk Peninsula in the north is separated from Nicholson Island and the mainland in the south by the occurrence of Liverpool Bay. The lake-strewn country of the eastern portion of Tuktoyaktuk Peninsula is exemplified in this map, and is similar to that in adjoining areas to the west. However one distinction in this map is the absence of a sea-breached coast, although Johnson Bay may be such a feature. Other physical characteristics of the Tuktoyaktuk Peninsula include the absence of an integrated drainage, the presence of low swampy ground in the east, and the occurrences of widespread escarpments around several of the thermokarst lakes in the area. However, an absence of cliffs around the southern coast of the Peninsula is apparent.

The terrain of Nicholson Island and the mainland is characterized by higher elevations than the Peninsula, some of which exceed 60 m. This variation in topography between areas is manifested as hummocks and ridges, which restrict the small lakes and drainage courses to lower elevations. Major pingos are present, as well as cliffs, along the coasts of the mainland and Nicholson Island. On the mainland in the southwest, where elevations exceed 30 m above sea level, coastal cliffs extend from the vicinity of Cliff Point to the lower elevations at Nicholson Point; also, a few small scarps occur inland near the lakes.

Barrier deposits are present in shoal waters adjacent to the coasts of Liverpool Bay along the southern portion of Tuktoyaktuk Peninsula, and the northern part of the mainland and Nicholson Island. In these areas, longshore currents flow southwesterly on the north side , and northeasterly along the south side of Liverpool Bay. In this flow, currents deposit sediments that form the barrier deposits lying adjacent to all coasts. As a result of the variability and lessening of current velocities south of Nicholson Island, a sediment sink has been produced. The deeper parts of Liverpool Bay lie in the northeastern part of the area, but they become shallower along the bay axis toward the southwest. Both the 5- and 10-m bathymetric contours tend to conform to all coastal configurations, and exhibit a more gradual decrease in water depth off the coast of the Peninsula, than off that of the mainland. Because of the overall shallow depths, Liverpool Bay is only suitable for navigation with shallow-draft vessels.

Surficial Geology and Hazards (Units 1,2,3,6,7 and 9)

The sands and gravels of Unit 6, occurring in ridges, are the most abundant surficial deposits in the section of the Tuktoyaktuk Peninsula shown on the map. In this unit the physical features are fairly dry, except in the low areas. Here slumping and subsidence are common, as well as in areas containing ice in the sediments; in the latter case, thawing will also lead to subsidence. Scarps occurring throughout the area are evidence of these processes.

Unit 9 comprises clayey to gravelly till, and occupies the hummocky till-capped terrain on Nicholson Island and the coastal mainland adjacent to Liverpool Bay. It is the most abundant surficial unit in the southern and eastern portion of the area, and generally terminates as cliffs occurring along the coast. Because of the dry nature of the soil, this unit possesses minor geological hazards; however, low-lying areas are susceptible because of wetness, and may prove to be unsuitable for construction purposes. In other parts of this unit, slumping and gullying are common because of thawing ground ice.

Thermokarst lake beds of Unit 2, which occur in all land areas of the map, are associated with low elevations and poor drainage. In some areas of Nicholson Island, the land is occupied by several large pingos. Various hazards are associated with these beds of clay, silt, and peat and include the following: formation of ice wedges that melt and produce slumps due to removal of thawed material; and the formation of beds with low loading strength, thereby leading to construction problems. This unit is a poor source of aggregates.

Ice-thrust hills and ridges of Unit 7 are found in the northern portion of Nicholson Island. Elevations of these features exceed 60 m but, along the coast, their component silts and clays are intermingled with minor sands and gravels that terminate as sea cliffs several metres in height. Sand beaches of Unit 1 are found only in the northeastern portion of Nicholson Island at Hepburn Spit. This area contains a considerable quantity of aggregates, but a threat to the existence of the deposit would be the practice of over-exploitation. Another single occurrence of a surficial unit is the fine-grained river deposit of Unit 3 found south of Nicholson Point at the easternmost end of the mainland. Thermokarst subsidence and slumping along the river banks, together with flooding, constitute the main natural hazards in this locality.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units ....

Eroding river or shore cliffs (one or both walls)............

Eroding river or shore cliff (one or both valley bedrock)...

Pingos (major ones) .... ✳

Lowland swamps or weedy foreshore ....

Breached lakes on shoreline.....................................

Main sediment transport direction .... →

Coastal sediment sinks .... ✳

Barrier deposits, spits and bars ....

Bathymetric contours (m) 2

Hydrographic soundings (m) 94

Topographic contours (m) 30

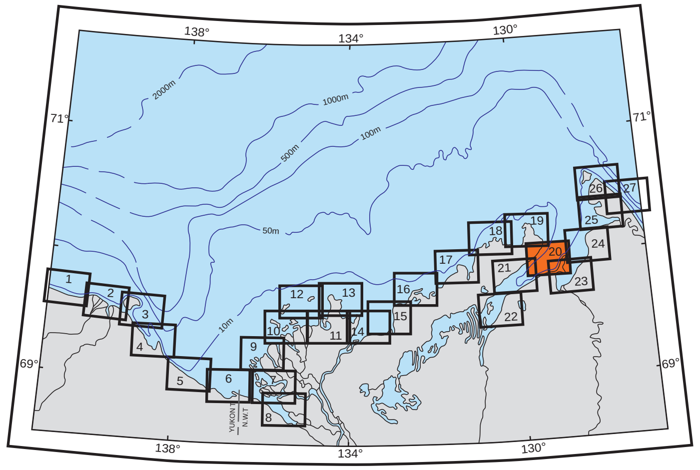
Topographic elevations (m) .... 183 △

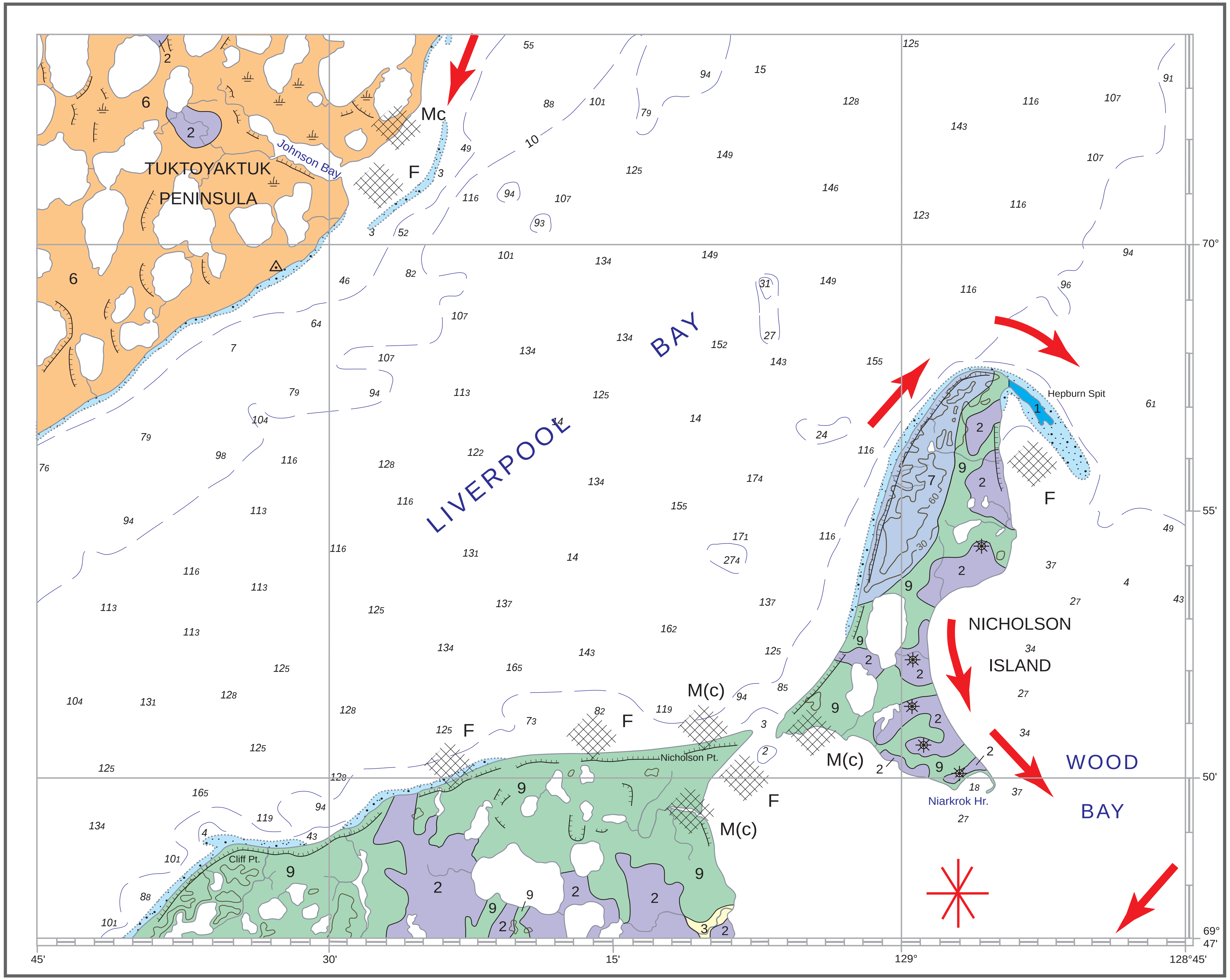
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M ▨

Camps for whaling(W), hunting(H), fishing(F) .... W,H, F

Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries)... ●,●,●,✕





Coastlands Map 20. Nicholson Island

scale = 1:150 000

COASTLANDS MAP 21. Liverpool Bay

Physical Setting

Liverpool Bay, extending northeasterly from its head in the southwest, effectively separates Tuktoyaktuk Peninsula from the Arctic mainland of Canada in the south. Mostly the Peninsula is covered with numerous thermokarst lakes, some of which are interconnected by short, irregular water courses. A central drainage is absent altogether, but low-lying areas along the coast may be the sites of underground drainage. Two large pingos are present along the coast in the eastern end of the Peninsula, although several more with heights of less than 30 m abound in the area occupied by thermokarst lakes. A few small cliffs are present inland, but a more extensive development of these features is present along the south coast of Tuktoyaktuk Peninsula. In the latter area these features are longer and, in some cases, almost continuous.

Generally the low-relief features such as terraces, ridges and small hills, commonly found on Tuktoyaktuk Peninsula, are present in the northern part of the map area. Toward the southwest such features rise to about 60 m and, notably, are contrasted to the lower adjacent elevations in the northern regions. The higher topographic features are present in the mainland portion of the map area; in fact, their presence appears to mirror those in the landmass directly to the west. The abundance of hills and ridges on the mainland have restricted the extent of small lakes and controlled the direction of short water courses that lead directly to Liverpool Bay.

Residual currents are prominent along the north shore of Liverpool Bay, where sediments are directed southwesterly as shown by the build-up of barrier bars and spits in that direction. A lessening, and perhaps a reversal of current flow, occurs in the extreme southwestern part of the Bay. In this vicinity west of Turnabout Point, a sediment sink has developed. Because tidal forces (although weak) affect these waters, a weak return current, somewhat augmented by the flow from Eskimo Lakes, moves seaward to the northeast.

Occupying about 40 percent of this map area, Liverpool Bay is characterized by a slightly deeper axial region than that shown by the surrounding shallower water. The north side of the Bay has a wider, shallower region than the south side, the latter of which has deeper water lying closer to shore as indicated by the location of the 10-m isobath. Overall though, Liverpool Bay tends to shoal in its southwestern portion. Shallow-draft vessels are able to navigate through the Bay.

Surficial Deposits and Hazards (Units 2,6 and 9)

The continuation of Unit 6 as the main surficial deposit in the Tuktoyaktuk Peninsula is predominate in this map area. Another major occurrence of this unit is found on the mainland coast that lies adjacent to the southern portion of Liverpool Bay. The gravels and sands of Unit 6 are the sources of beach material along all coasts of the Bay, except for those of a few inlets. Hazards are related to slumping and subsidence , particularly when ice content in the soil melts and the covering slopes provide an impetus to the movement of the thawed soil. The occurrences of aggregates are significant throughout this unit.

Hummocky till-capped terrain is a component of Unit 9, which is the next surficial unit in order of importance. Hazards are minor because drainage in the hilly areas is generally good, and only minor amounts of permafrost are present; also, only moderate ground-ice slumping and subsidence takes place. Aggregates are present in small amounts, so borrow material is limited.

Unit 2 is present only along, and near the north coast of Liverpool Bay. Thermokarst lake beds are the chief components of this unit, and are also most prevalent in a hazardous sense. Wet and marshy ground is common, and is usually the site of unstable ground. As thawed material is removed, subsidence generally follows. Unit 2 is not a promising source of constructional aggregates in this region.

LEGEND

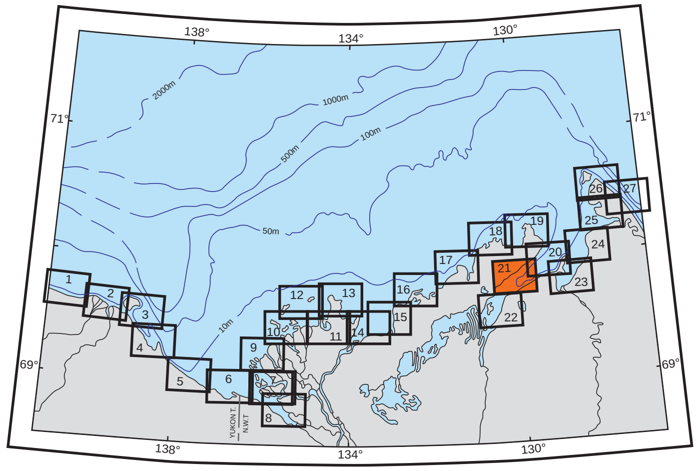
SURFICIAL GEOLOGY AND PROCESSES

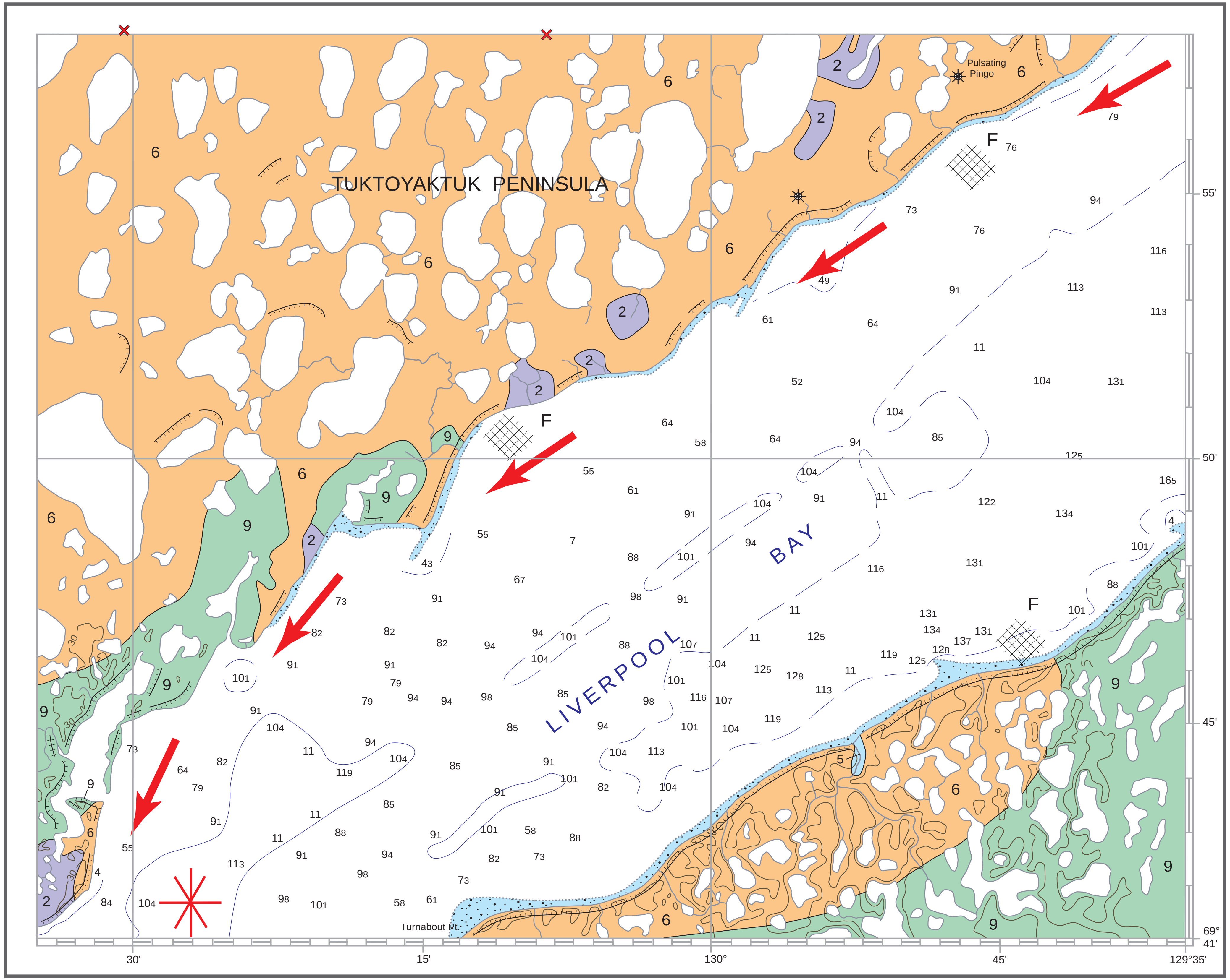
1 Beaches
2 Thermokarst lake beds
3 Fine-grained river deposits
4 Coarse-grained river deposits
5 Marine and lake plains
6 Gravelly and sandy hills, ridges and terraces
7 Ice-thrust hills and ridges
8 Till plains
9 Hummocky till-capped terrain
10 Upland and pediment complexes
11 Mountainous and rocky areas

Geological boundaries of surficial units
Eroding river or shore cliffs (one or both walls)
Eroding river or shore cliff (one or both valley bedrock)
Pingos (major ones) ✳
Lowland swamps or weedy foreshore
Breached lakes on shoreline
Main sediment transport direction →
Coastal sediment sinks ✳
Barrier deposits, spits and bars
Bathymetric contours (m) 2
Hydrographic soundings (m) 94
Topographic contours (m) 30
Topographic elevations (m) 183 △

RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) F,B, M
Camps for whaling(W), hunting(H), fishing(F) W,H, F
Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries) ●,●,●,✗





Coastlands Map 21. Liverpool Bay

scale = 1:150 000

COASTLANDS MAP 22. Campbell Island

Physical Setting

Hummocky topography characterizes all areas of the map as follows: Tuktoyaktuk Peninsula in the northwestern part of the area; the mainland along the eastern side of Liverpool Bay; Thumb Island in the southern part of the Bay; and the promontory of the mainland part of the so-called Fingers, lying immediately west of Thumb Island. Cliffs are also prominent features and occur along all sea coasts exclusive of those on Campbell Island, the southwestern mainland, and the eastern portion of Thumb Island and the adjacent small islands immediately to the east. In the southeastern part of the area, the terrain (not shown) rises to form uplands at least 200 m in elevation. This comprises the northern part of the Anderson Plain, but the adjacent land to the north lies in the Arctic Coastal Plain. The only prominent areas of low relief occur around Smoke River, the adjacent coastal area to the southwest, Campbell Island, and a few small islands between the mainland and Thumb Island - the same regions unoccupied by sea cliffs.

Overall, strong currents are absent in this portion of Liverpool Bay because of the physical impediment of islands, shallow water, the lack of a through-going channel from the Beaufort Sea, and the occurrence of a conflicting flow from Eskimo Lakes. Such quiescent hydrodynamic conditions have produced a sediment sink in Liverpool Bay, in the northern part of the map area. These conditions are partly responsible for the reduced growth of spits along the coast, except for a few occurrences in the southwestern portion of the area. Liverpool Bay is very shallow in this area, but deepens toward its mouth. The 2 m isobath, which surrounds the islands and parallels the mainland and peninsular coasts, indicates the presence of a former land area recently submerged by a rising sea. The Fingers, in association with Eskimo Lakes (not shown), have an origin related to the action of a regional ice sheet.

Surficial Geology and Hazards (Units 2,3,6 and 9)

Unit 9 consists of clayey to gravelly till, and is the most widespread surficial unit in the map area. It occurs as hummocky till-capped terrain on the mainland, Tuktoyaktuk Peninsula, Thumb Island and the easternmost part of The Fingers; also, it is cliffed everywhere along the coasts and river banks. This unit forms the uplands in the south, where it is described as rolling and hilly moraine. Because the hills have good drainage, many hazards associated with slumping due to permafrost thaw are absent; even thermokarst development is minimal. However, beneath the slope where ground ice is present, some disturbance of the land will occur when this ice melts. Unit 9 is a poor source of aggregates.

The sands and gravels of Unit 6 are the next abundant surficial unit. They form hills, ridges and terraces surrounding Liverpool Bay, and are widespread on Tuktoyaktuk Peninsula. Because of good surface drainage, most of the unit is dry. Cementing ice is common throughout these beds, and massive ice may be found at depths to 20 m below the surface. Slumping and subsidence are the major hazards, and are related to the thermokarst formations when they are exposed to rising air and ground temperatures. This unit is a good source of sand and gravel.

The thermokarst lake beds of Unit 2 are moderate in extent, where they occur on the mainland, and Campbell and Thumb islands. They are comprised of fine-grained, and commonly organic deposits that are confined to the low-lying areas containing numerous small lakes. Such areas may be the sites of pingos but, in this map area, only those less than 30 m in height (not shown) are present. Thaw basins that have developed from melting permafrost form the thermokarst; it is this process that induces the slumping and subsidence, particularly around the margins of lakes. Erosion occurring along the cracks in the soil related to ice-wedging is another hazard of this terrain. These beds have low strength and comprise a foundation that is unsuitable for the construction of buildings and attendant infrastructures such as roads and transmission corridors, particularly those for pipelines. Unit 2 is a poor source of granular material or fill, except where gravels occur locally.

Fine-grained river deposits of Unit 3 are found only in the southwestern part of the map area, and are confined to river beds and deltas on the mainland, and on Thumb Island. Because of their geographical association with thermokarst deposits, the main hazard of this unit is subsidence; however, undercutting of any river banks may produce another hazard. The general lack of coarse sediments inhibits the use of Unit 3 as a source of aggregates.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units ....

Eroding river or shore cliffs (one or both walls).............

Eroding river or shore cliff (one or both valley bedrock)...

Pingos (major ones) .... ✳

Lowland swamps or weedy foreshore ....

Breached lakes on shoreline.................................

Main sediment transport direction .... →

Coastal sediment sinks ....

Barrier deposits, spits and bars ....

Bathymetric contours (m) 2

Hydrographic soundings (m) 94

Topographic contours (m) 30

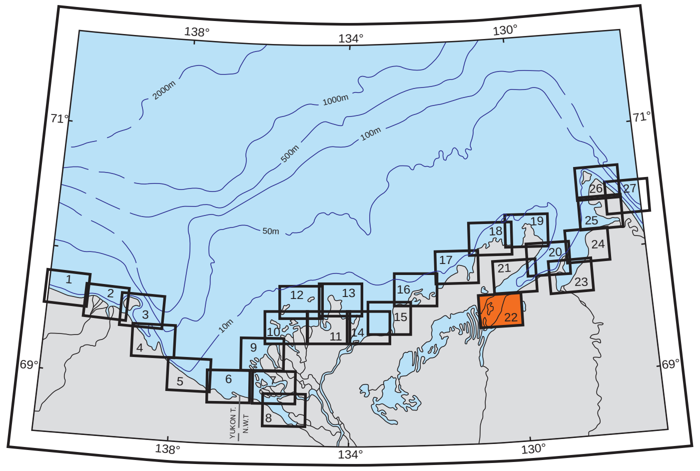
Topographic elevations (m) .... 183 △

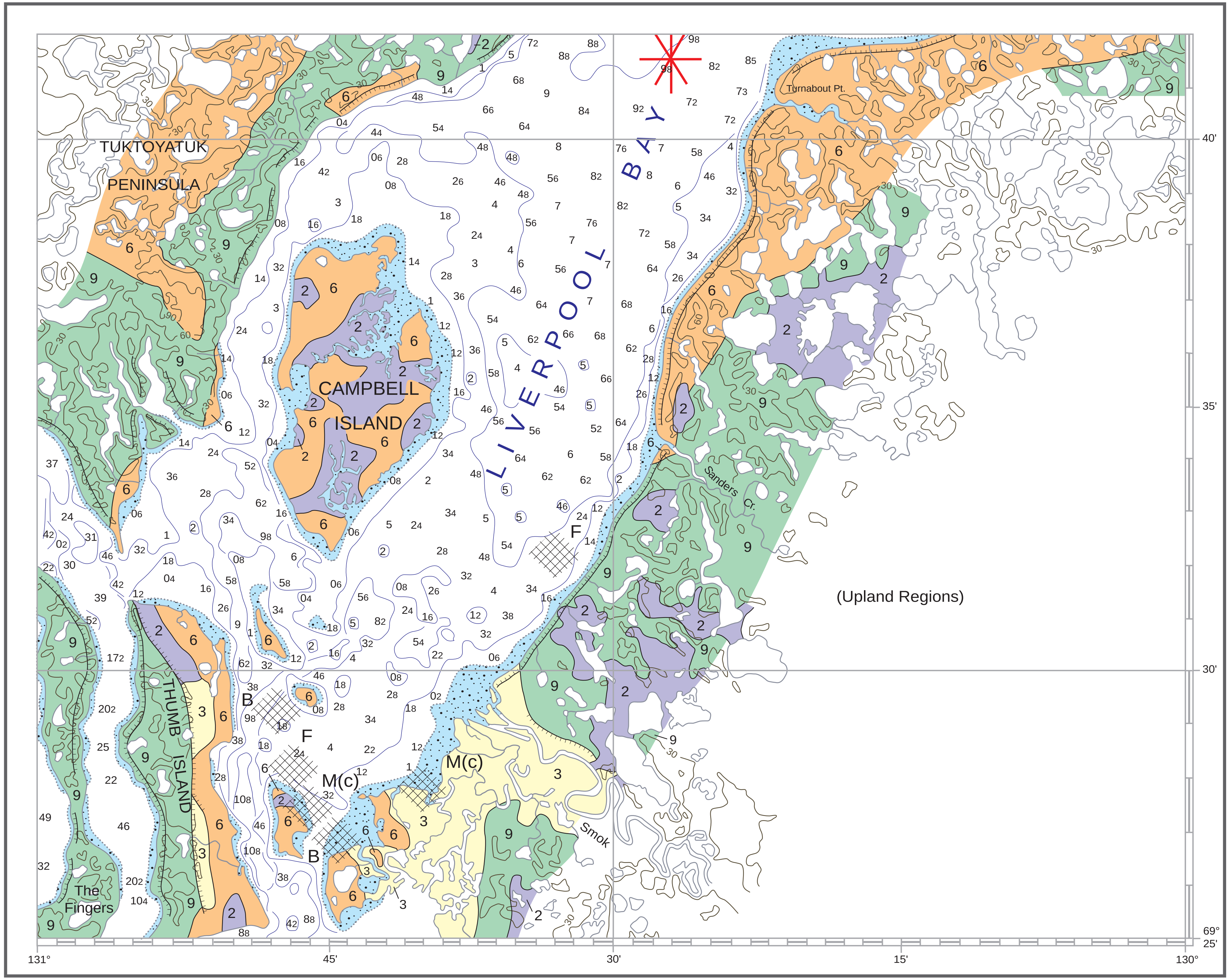
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M ▨

Camps for whaling(W), hunting(H), fishing(F)................. W,H, F

Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries)... ●,●,●,✕





Coastlands Map 22. Campbell Island

scale = 1:150 000

COASTLINES MAP 23. Wood Bay

Physical Setting

This entire map area, as well as the remainder of the Coastlands Maps, lies east of Tuktoyaktuk Peninsula and within the region of the Coastal Plain. The highest topographic elevations occur on Nicholson Island, where glacial deposits rise to heights exceeding 60 m. Most of this island, the only non-detrital one in the region, is below elevations of 30 m except for the ridges in the northwestern portion, and the pingos along its eastern coast; small lakes are common in these low areas. Hepburn Spit is a unique feature that has formed from currents sweeping more-or-less easterly around the northern tip of the Island. These longshore currents have deposited sediments in a southeasterly direction, and have produced barrier bars that extend from the spit in that direction. Sea cliffs several metres in height are prominent along the western and northeastern coasts of the Island.

On the mainland, low areas are occupied by numerous small lakes, but hills and ridges are also present. These latter features exceed elevations of 30 m, and may rise somewhat higher than 60 m in the eastern area. Cliffs are present along most of the coast, as well as inland along a few river courses. Two deltaic areas are present: one is in the western portion at the southern boundary of the map, and the other lies in the northeastern part.

Land and sea occupy this map area about equally; Liverpool Bay and Wood Bay surround Nicholson Island, and both water bodies extend from the mainland to the northern part of the area. Currents along shore affect all coasts, and entrain sediments eroded from cliff faces. These sediments are deposited in the leeward and less hydrodynamically vigorous locations such as in Wood Bay. Here a sediment sink is produced, as currents lessen and are unable to move their load seaward. A bathymetric contrast exists, in that very shallow water (<3 m) is present in the southern part of Wood Bay but, along the western mainland and to the north, water depths are greater than 10 m and may exceed 25 m.

Surficial Geology and Hazards (Units 1,2,3,6,7 and 9)

The clay-to-gravelly tills of Unit 9 form widespread hummocky moraines, and are the most prominent surficial deposits in the area. They occupy most of the coastal and inland regions of the mainland, as well as a considerable portion of Nicholson Island. The ice content in these beds presents hazardous conditions when air and ground temperatures rise, and thawing ensues. This action can be followed by slumping on the slopes, and subsidence in the lower elevations. Because of the lack of extensive sand and gravel deposits, this unit is unfavorable as a source of aggregates in the area.

Unit 2 occurs in close association with the beds of Unit 9, particularly in the lower elevations where it is found lying amongst the hills and ridges of Unit 9. The dominant position in the low-lying and lake-ridden areas, together with the content of permafrost, contributes to the thermokarst character of Unit 2. Its lack of drainage and the occurrences of small ponds, lead to the development of organic deposits such as peat, and the accumulation of fine-grained clayey and silty sediments. Ice-wedging and the formation of large pingos on Nicholson Island, and smaller ones there and elsewhere, are common features that may embody a geotechnical hazard; however, the formation of thermokarst around steep lake shores and the attendant subsidence is of more significant concern. In this area , the lack of suitable coarse sediments renders this unit a poor source of aggregates for construction purposes.

Comprising fine-grained river sands, the beds of Unit 3 are found in only a few places in this map area. One site lies in the delta in the southern portion at the head of Wood Bay and another such deposit occurs in the delta on the extreme northeastern coast. A few small deposits of Unit 3 are located in rivers in the extreme eastern and western parts of the map area. Where thermokarst has developed, the ground may undergo slumping and subsidence. Because of the lack of coarser sands and gravels, this unit is a poor source of building aggregates.

The gravelly, sandy hills of Unit 6 occur only along the southwestern shore of Wood Bay where it is heavily cliffed, and may contain ground ice in excess of several metres. The main hazards are related to subsidence and slumping of the soil, but they may relate to slumping of ground ice as well, particularly if ground temperatures increase markedly. This unit is an excellent source of aggregates.

Only one occurrence of Unit 5, which comprises silt, clay and silt, is found in the area. Characteristically, it is found along the coast, where it constitutes marine-plain deposits. Because of their coastal positions, these deposits commonly terminate as sea cliffs; these locations also lead to block-slumping and toppling due to erosion and removal of thawed material by means of thermal and mechanical action in the coastal zone. The material in Unit 5 has low strength, and its exposures are unsuitable sites upon which to build, or to extract aggregates for constructional purposes.

Only one occurrence of Unit 1 is present in this area, and that occurs off the northeastern point of Nicholson Island where it forms Hepburn Spit. This current-deposited feature is a potential source of sand and gravel, but undue exploitation could lead to excessive shore erosion during periods of storm and over-flooding.

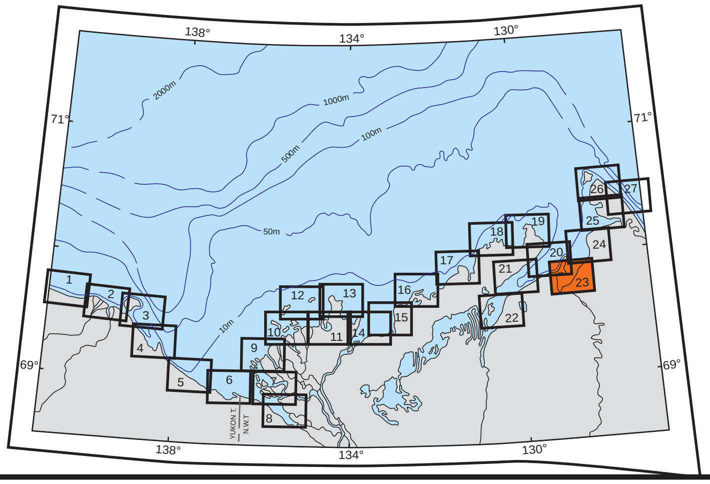
LEGEND
SURFICIAL GEOLOGY AND PROCESSES

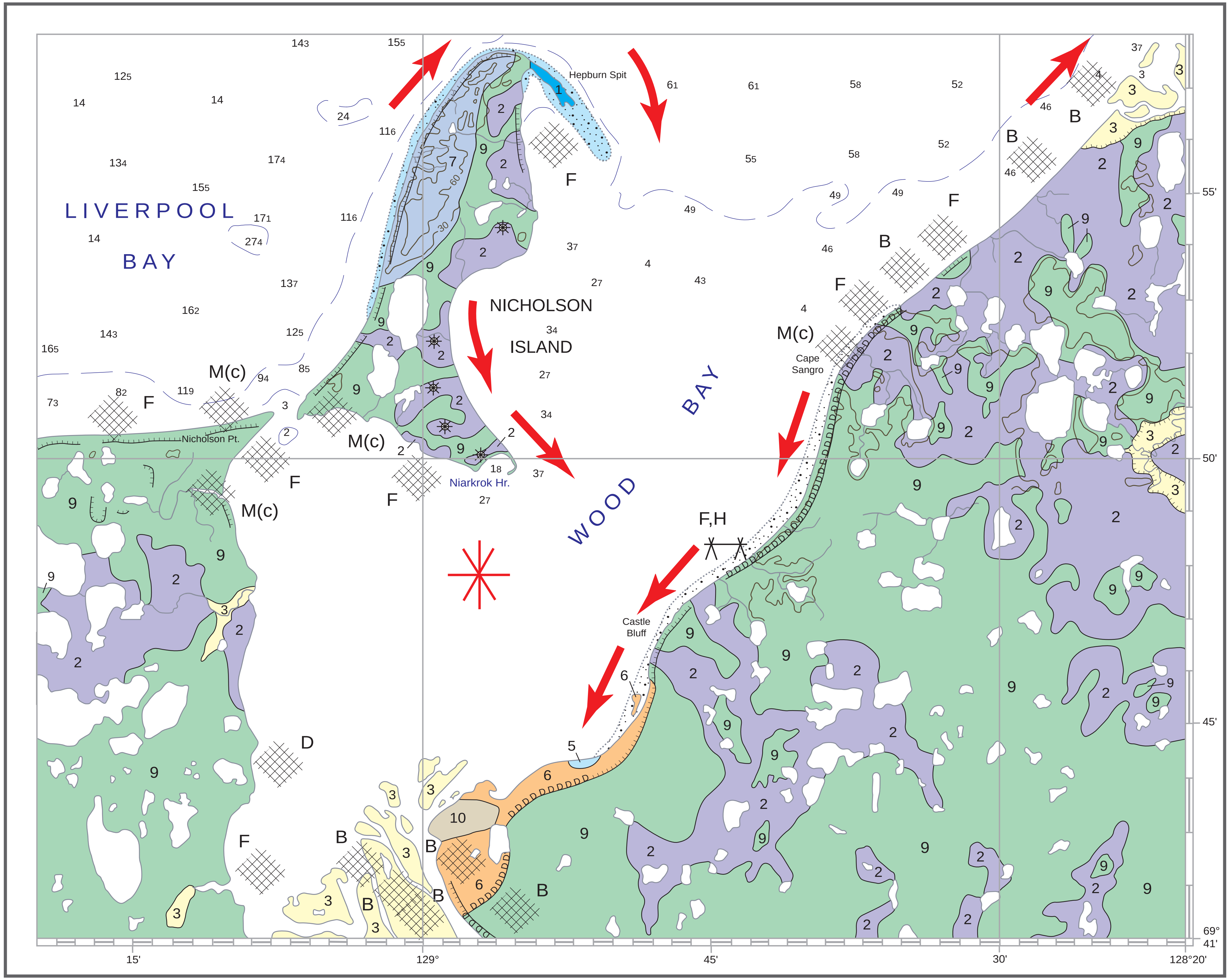
- 1 Beaches
- 2 Thermokarst lake beds
- 3 Fine-grained river deposits
- 4 Coarse-grained river deposits
- 5 Marine and lake plains
- 6 Gravelly and sandy hills, ridges and terraces
- 7 Ice-thrust hills and ridges
- 8 Till plains
- 9 Hummocky till-capped terrain
- 10 Upland and pediment complexes
- 11 Mountainous and rocky areas

Geological boundaries of surficial units ....
Eroding river or shore cliffs (one or both walls)............
Eroding river or shore cliff (one or both valley bedrock)...
Pingos (major ones) ....
Lowland swamps or weedy foreshore ....
Breached lakes on shoreline..
Main sediment transport direction ....
Coastal sediment sinks ....
Barrier deposits, spits and bars ....
Bathymetric contours (m) 2
Hydrographic soundings (m) 94
Topographic contours (m) 30
Topographic elevations (m) 183

RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M
Camps for whaling(W), hunting(H), fishing(F)................ W,H, F
Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries)... ●,●,●,✕





Coastlands Map 23. Wood Bay

scale = 1:150 000

COASTLANDS MAP 24: Cape Wolki

Physical Setting

This entire map area comprises a portion of the northern part of Anderson Plain, and contains many upland features such as hills, ridges, high morainal terraces and steep cliffs. Several areas near all coastlines have elevations rising to 30 m, and many isolated hills are between 30 and 60 m in height. Inland, however, numerous ridges are greater than 60 m high; in fact, in the southern part of the area, they are at least 100 m high.

Drainage is developed more regularly in the highlands than in the lowland-lake country. Mason River in the south, and smaller water courses in the west debouch sediments to form deltaic and estuarine deposits. Elsewhere along floodplains, old drainage routes and coastal reaches, cliffs are abundant in either soil or bedrock occurrences.

Generally the coastline is unbroken, except for the delta of the Mason River, and an unnamed inlet in the north. This latter feature is surrounded by land, some of which appears to be formed by longshore currents carrying sediments that are blocking the mouth of the inlet; otherwise, this inlet appears to be a drowned valley that is being created by a rising sea. Currents derived from adjacent Wood Bay are present, as indicated by the direction of growth of the spits at the eastern end of the inlet, but more so at its mouth. This process is apparent at both Maitland and lkpisugyuk points. Elsewhere along the outer western coast such as at Cape Wolki, variable longshore currents are eroding headlands and forming spits near inlets or very small bays. Further to the south just off the map (see Coastlands Map 23), these current-transported sediments are deposited in the sediment sink formed in Wood Bay. Most of Wood Bay is fairly shallow with the 10 m isobath occurring several kilometres offshore; thus, coastal navigation in shallow-draft vessels is feasible.

Surficial Geology and Hazards (Units 1,2,3,5,6,8,9 and 10)

This map sheet not only demonstrates the topography of the northern part of the Anderson Plain, but it reveals the lithology that is absent in the lowlands of the Coastal Plain. Most prominent of these rock units is the upland and pediment complexes of Unit 10. These deposits of disintegrated rock, together with glacier deposits forming landforms and thin veneers up to 30 m in thickness and overlying bedrock, occur in large northwesterly-trending belts in the central and eastern part of the map area. Unit 10 also comprises features with the greatest elevation in the area. Bedrock cliffs are common, particularly along old water courses. Ground ice may not be thick, or even present, so that geotechnical hazards may be restricted to the occurrence of detachment slides due to the presence of substantial slopes in the region. This unit is a poor source of aggregates, but the occurrence of near-surface bedrock and the absence of ice content lends itself to being a good source of burrow material capable of possessing strength under load.

Unit 8, consisting of glaciogenic materials, comprises till plains mainly. In this area it lies adjacent to the western exposure of Unit 10, and tends to cover bedrock as a veneer. It is found as a ground moraine that is expressed topographically in the form of rolling hills. Hazards are associated with gullying, and superficial mud flows on the steeper slopes. Permafrost is a minor constituent but, where it occurs, induces subsidence during periods of thaw. Because of ice content, this unit is an unsuitable source of aggregates and burrow material.

The next major surficial unit after Unit 8 is the hummocky till-capped terrain of Unit 9. A single, large exposure lies adjacent to Unit 8 in the western part of the map area, and the western boundary of this exposure is the coast of Wood Bay and the floodplain of Mason River. Where this unit lies near the latter, elevations decrease and the deposits may terminate as cliffs a few metres in height. Gravels are present in the well-drained hills and hummocks, but in the lower poorly drained depressions, deposits usually consist of fine material such as clay and silt with some organic soil present. Ice lenses and seams are prevalent, which could lead to hazardous conditions in the event of thaw; however, hazards are minimal in this unit. Only small amounts of gravels are present, thus rendering this unit unsuitable as a source of aggregates.

Unit 5, comprising sediments that formed in marine and lake plains, consists of clay and silt with minor surfaces of sand and organic cover. Occurring in the northeastern region of this map, these deposits terminate in low areas along the sea coast and river banks. Cliff-forming is a common process in all these locations. A major portion of Unit 5, lies adjacent to the lower elevations of Unit 10, where their surfaces are flat to gently sloping. The western exposures of Unit 5 practically surround the large inlet in the north, where they are cliffed extensively. Because of the considerable content of ice throughout this unit, any thawing would lead to hazardous removal of sediment and cause subsidence of the containing land. Aggregates and fill material are not common in this unit.

Other surficial beds occurring in the low-lying pockets of Units 5 and 10 in the northern part of the map area and in between the hummocks of Unit 9 in the south, comprise the deposits of Unit 2. These beds of clay, silt and peat are associated with thermokarst lake beds with a moderate content of permafrost. Much of the permafrost occurs as segregated ice, which may lead to slumping when thawed. Generally, the soil is of low strength and could collapse under a load. This unit is a poor source of aggregate and fill.

The fine-grained deposits of Unit 3 are found along a few river courses, particularly Mason River in the south and the extended region of the inlet in the north including the river feeding it from the east. The associated floodplains of these rivers contain silt, sand and minor amounts of peat, and their surfaces are generally flat. Usually ice content is minimal, especially in the unvegetated areas; however, where ground ice is present, subsidence can be a potential hazard. Materials in this unit are too fine-grained to serve as suitable aggregates.

Three occurrences of Unit 6 are represented on this map: one lies in the north, another is in the upland areas in the south, and the third is adjacent to Wood Bay in the west. In all cases they are in juxtaposition with Unit 10, and are cliffed for the most part. These gravelly and sandy ridges, hills and terraces may include eskers rising to 60 m; other glacio-fluvial deposits may be included in this unit. Moraines present may consist of deformed, gravelly and sandy beds. Massive ice is found at depths between 6 and 20 m; when thawed, these beds would create hazards such as subsidence and slumping. This unit is a good source of gravel, admixtures of sand and gravel, and substantial burrow material.

Unit 1 occurs in two places only, and both lie along the sea coast: one is at the northern part of the map; the other is south of Cape Wolki, just north of the Mason River delta. These deposits are marine in origin, and consist of sand and gravel ridges. The deposit in the north is associated with a flat terrain lying adjacent to the mainland, and terminating in a spit that extends northwesterly into Harrowby Bay (see Coastlands Map 25). The occurrence of Unit 1 in the south has taken the form of a spit as well. Growth of this spit is in response to longshore currents depositing sediment in the down-current direction of the flow. The main hazard involving these spits concerns over-flooding during periods of storm, and excessive exploitation that can deprive these forms of stability.

LEGEND

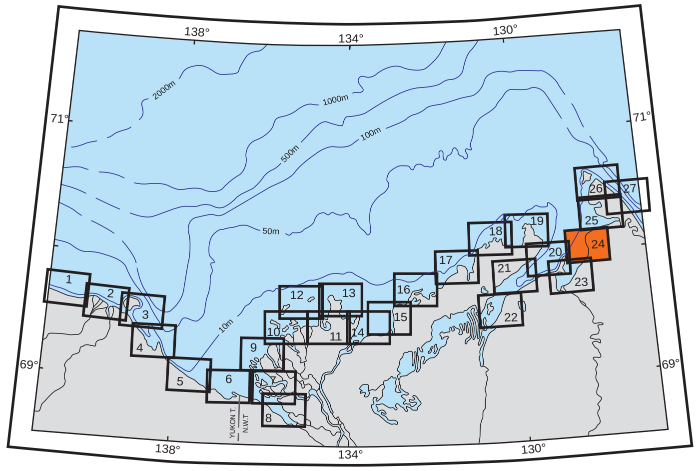
SURFICIAL GEOLOGY AND PROCESSES

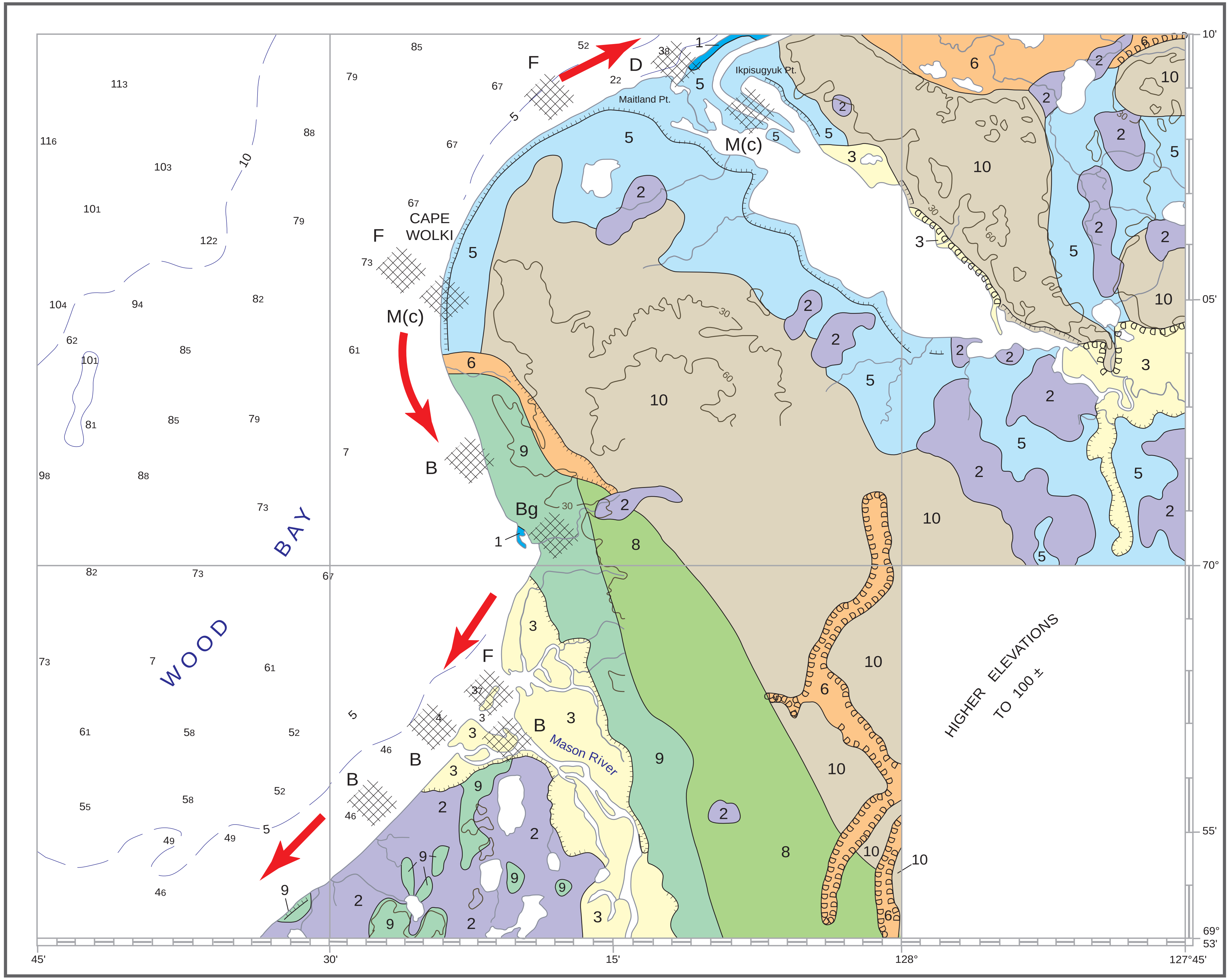
1 Beaches
2 Thermokarst lake beds
3 Fine-grained river deposits
4 Coarse-grained river deposits
5 Marine and lake plains
6 Gravelly and sandy hills, ridges and terraces
7 Ice-thrust hills and ridges
8 Till plains
9 Hummocky till-capped terrain
10 Upland and pediment complexes
11 Mountainous and rocky areas

Geological boundaries of surficial units ....
Eroding river or shore cliffs (one or both walls)............
Eroding river or shore cliff (one or both valley bedrock)... D D D
Pingos (major ones) ....
Lowland swamps or weedy foreshore ....
Breached lakes on shoreline..................................
Main sediment transport direction ....
Coastal sediment sinks ....
Barrier deposits, spits and bars ....
Bathymetric contours (m) 2
Hydrographic soundings (m) 94
Topographic contours (m) 30
Topographic elevations (m) .... 183 △

RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M
Camps for whaling(W), hunting(H), fishing(F)................ W,H, F
Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries)... ●,●,●,✕





Coastlands Map 24. Cape Wolki

scale = 1:150 000

COASTLANDS MAP 25. Harrowby Bay

The Physical Setting

This map sheet is notable in that it displays features of the Anderson Plain in the southern part, and characteristics of the Coastal Plain in the northern portion. The unspecified demarcation between these physiographic provinces would be a line extending northeasterly from the mainland on the southeastern shore of Liverpool Bay (see Coastlands Maps 20 to 24), to a point lying midway between Cy Peak Inlet and Harrowby Bay. From this point on the coast of Wood Bay, the demarcation line extends orthogonally across the peninsular neck of the mainland to a point north of White Bluff lying on the western coast of Amundsen Gulf. Actually, elements of both physiographic provinces lie on either side of this line that separates them from each other. North of this boundary, elevations in the low coastal lands are less than 30 m with some higher elevations around Cy Peak Inlet and the uplands to the east. In the south, elevations are less than 30 m above sea level but, mostly, the land is one of uplands with elevations exceeding 60 m. The latter elevations comprise the northernmost portion of Anderson Plain.

The low country is marked by the presence of numerous small lakes with little, or no drainage systems in most areas. In contrast, the drainage system in the uplands has developed into a trunk system with major outlets on all sides of the northeastern mainland. Old Horton Channel and the inlets around Ikpsiugyuk Point, as well as those streams leading into Cy Peak Inlet, are examples of these outlets. Cliffs occur along the banks of old water courses and on many steep surfaces inland, some of which may be associated with bedrock.

Along the coast, residual longshore currents sweep around the headlands from the north, and flow southerly into Harrowby Bay. At the mouth of the Bay, a sediment sink has developed as a result of deposition from waning and conflicting current movements in this water body. The erosive action by longshore currents has resulted in the entrainment of sediments, and this load is transported and deposited along the coast in a down-current direction. Subsequently these processes have produced spits and bars at various locations along the mainland coasts. This phenomenon is prominent in the northern part of the map area, where the spits have extended their growth southerly and then easterly into Harrowby Bay; in the southern part of the area, spits have grown in a northeasterly direction into the Bay. Some of this accretionary action is due to the presence of shallow water in the Bay, where current velocities are checked and the entire water mass becomes one of low hydrodynamic vigour. Directly offshore, shallow water occurs for a distance of several kilometres to the 10 m isobath; this bathymetric line roughly parallels the configuration of the coastline, as does the 5 m isobath. The bathymetric data and the submerging, ancient river mouths indicate the action of a rising sea. At present, only shallow-draft vessels can navigate these waters.

Surficial Geology and Hazards (Units 1,2,3,5,6 and 10)

The uplands and pediment complexes of Unit 10, comprising the most prominent surficial unit in the area, lie entirely within the northern part of the Anderson Plain. This is depicted on the accompanying map that shows the major occurrences of the unit in the northern part, and the lesser ones in the south. Cliffs are common at the base of the hills and ridges in the unit, and comprise outcrop and rubble, as well as local deposits of a wide range of sediments such as silt, sand and gravel. Ice is rare and the main geotechnical hazards are occurrences of detachment slides. Generally this unit is well drained and dry, except for the presence of swampy terrain in the lowest elevations. This unit is a poor source of aggregates, but has considerable worth as burrow material.

Gravel and sand are the major components of Unit 6, which lies along the coastal plains and hills surrounding Harrowby Bay. Because of its juxtaposition to Unit 10, it properly belongs to the Anderson Plain region, and less so to the Coastal Plain. The ridges and terraces comprising this unit are formed from glacio-fluvial processes. Peat formations are present in the lower elevations, and may contain massive ice beneath the surface. Hazards such as subsidence and slumping are related to thermokarst thaw and these processes are exacerbated when annual ground temperatures increase. This unit is a good source of sand and gravel, particularly in the hummocky areas; it may also serve as a good sauce of burrow material.

Unit 5 comprises marine- and lake-plain sediments that consist of clay and silt. These beds occur in much of the low-lying land around, and adjacent to Wood Bay and the major coastal inlets in both northern and southern parts of the map area. The removal of thawed material in zones of permafrost, especially where ground ice is prominent, may lead to minor subsidence; however, the soils of Unit 5 have low strength under load and any construction in the areas of occurrence would be hazardous. This unit is a poor source of granular material and fill.

Unit 2 contains fine sediments such as silt and clay, as well as extensive deposits of peat. Because thermokarst is prevalent, many small ponds, lakes and pits occupy the area. Such features may coalesce upon slumping, and form larger lakes as a consequence of this process. This unit is weak under load, a factor which presents an engineering hazard; it is also a poor source of constructional material, such as aggregates and burrow fill.

One of the lesser surficial deposits in the area is Unit 3, which consist of fine-grained river sediments with some peaty beds. It is confined to the floodplain of the Old Horton Channel, and is characterized by swamps in some areas. Meandering channels and sandy islands are associated with the unit.

Unit 1 forms numerous spits and sandy platforms along the coast of Harrowby Bay. It may also contain barrier deposits adjacent to shore, but generally its spits are directed in response to waning currents depositing sediments in the down-flow direction. Some of the ground surfaces of these deposits may be wet depressions occupied by marshes. In this region, Unit 1 is important to wild-life refuges, as it is a naturally protected habitat. Mostly these features undergo flooding and alteration of their beaches, and will be subject to permanent damage if exploited excessively.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

1	Beaches
2	Thermokarst lake beds
3	Fine-grained river deposits
4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units ....

Eroding river or shore cliffs (one or both walls).............

Eroding river or shore cliff (one or both valley bedrock)...

Pingos (major ones) .... ✷

Lowland swamps or weedy foreshore ....

Breached lakes on shoreline ....

Main sediment transport direction .... →

Coastal sediment sinks .... ✳

Barrier deposits, spits and bars ....

Bathymetric contours (m) 2

Hydrographic soundings (m) 94

Topographic contours (m) 30

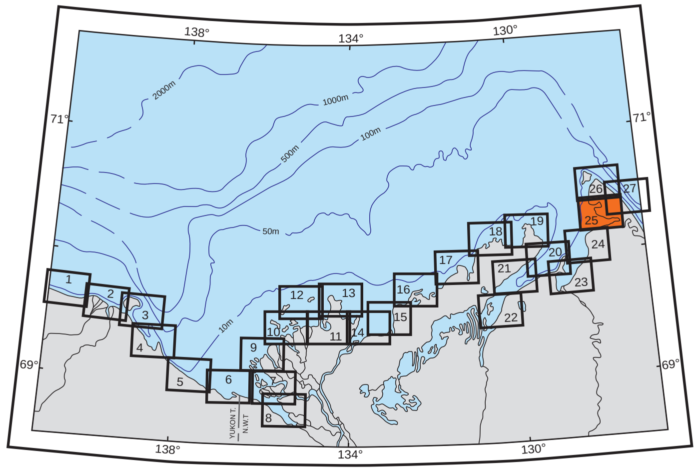
Topographic elevations (m) .... 183 △

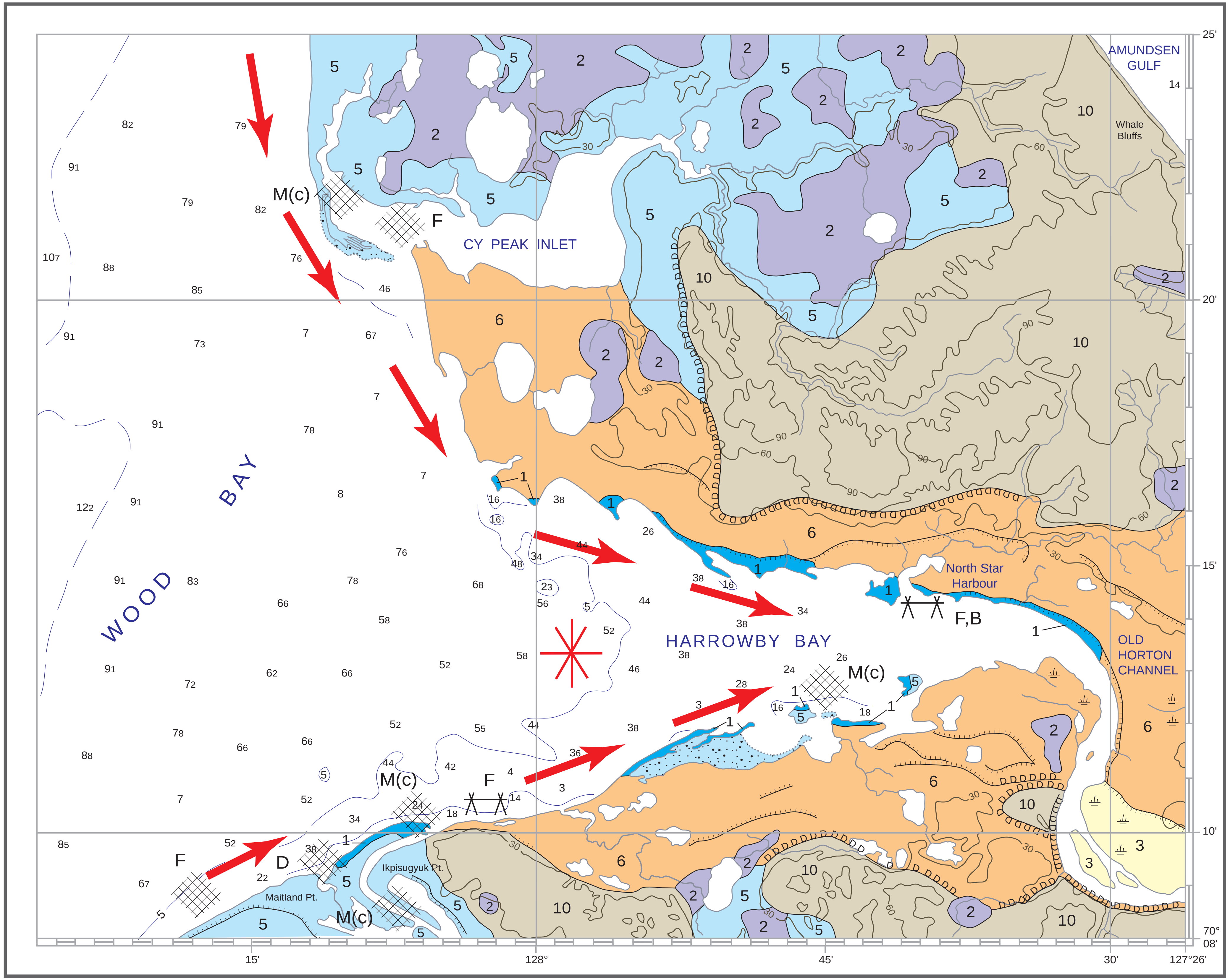
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M

Camps for whaling(W), hunting(H), fishing(F)................. W,H, F

Oil and gas exploration (oil, gas, oil & gas,
dry & abandoned wells) see (Oil and Gas Discoveries)... ●,●,●,✕





Coastlands Map 25. Harrowby Bay

scale = 1:150 000

COASTLANDS MAP 26. Baillie Islands

Physical Setting

Except for a small portion in the southeastern corner of this map area, the entire landmass lies within the Coastal Plain. This latter feature is characterized by low elevations, some of which exceed 30 m in the southeastern half in the vicinity of McKinley Lake. Generally, the land slopes seaward and terminates as cliffs along most of the coast. Drainage on the Coastal plain is comprised of short, irregular water courses, which may interconnect with numerous small, thermokarst lakes. The highlands to the southeast form the northern hills of the Anderson Plains, and are greater than 60 m in height. They are terminated, as well, by cliffs extending along the coast.

Immediately adjacent to shore, the longshore currents flow around the Baillie Islands and through Snowgoose Passage. Spits and barrier bars have grown in response to these currents; however, current directions are variable in this area as indicated by the direction in which the spits have been extended north of Cape Bathurst.

This map depicts the wide contrast in water depths lying offshore around the landmass as follows: toward the west, opposite Cape Bathurst, the 10 m isobath occurs up to 10 km from shore; again toward the west but opposite the Baillie Islands, water depths are greater than 15 m at a distance of 8 km from shore; and directly northwest of the Baillie Islands, the 20 m isobath is only 2 km from shore. In contrast to these shallow depths, the depth of water in Amundsen Gulf is somewhat greater. For example, the 10 m isobath parallels the coast only 10 km from shore. These waters deepen uniformly to 50 m about 10 km from shore, which is about the same distance the 10 m isobath is reached west of the mainland. Toward the centre of Amundsen Gulf about 5-6 km distant from the 50 m isobath, the water deepens to 200 m. Such depths are not part of the coastal waters around the Beaufort Coastland, and clearly have a different structural and glacial origin.

Surficial Geology and Hazards (Units 1,2,5 and 10)

The clays and silts comprising the marine and lake plains of Unit 5 occupy more than half this map area, including about 90 percent of the Baillie Islands. On the mainland, coverage occurs on all coasts and over much of the inland area. Some of the slopes, which may have elevations higher than 30 m, are occupied by swamps in their lower portions. Generally the low-lying beds of Unit 5 terminate at the coast, where they commonly form cliffs, and are undercut by wave action and topple onto the narrow beaches, in time. A hazard here is the presence and subsequent thawing of permafrost soil, a process that leads to slumping and subsidence of these beds. The soils are low in strength and, therefore, are inadequate as building and infrastructural foundations. Except in localized areas, this unit is unsuitable as a source of granular material.

Unit 2 is the next major surficial deposit in the map area, and consists of thermokarst lake beds comprising clay, silt, peat and, locally, sand and gravel. These beds all lie below an elevation of 30 m, and are swampy throughout their mainland occurrences. They occupy about 30 percent of the land, including a few reaches along the coast. Because of poor drainage, some hazards are associated with the occurrence of tundra ponds and the formation of thermokarst around the steep slopes of such lakes, especially when coalescence of these water bodies takes place. Removal of thawed material along ice-wedge cracks, lake and river cliffs, and degraded permafrost leads to slumping and subsidence in beds of Unit 2. The soil is weak and, therefore, is unsubstantial as an engineering foundation base. This unit is a poor source of granular and burrow material.

All barrier bars, spits and beaches of Unit 1 are a response to the action of longshore currents that erode and transport sediments around the Baillie Islands and the northern part of the mainland. Consisting of sand and gravel mainly, these landforms are subject to over-flooding and shifting of depositional sites. Excessive exploitation can devastate these features, so that such practices should be undertaken with caution.

The rubble and bedrock of Unit 10 occurs in one area only, and that is situated in the extreme southeastern portion of the map. These beds abut the shores of both McKinley Lake and Amundsen Gulf, and are in contact with the lower-lying deposits of Unit 5 on the north and Unit 2 on the west. Along the coast they form high bedrock cliffs that are subject to erosion; inland, these beds are affected by minor detachment slides. Because of the occurrences of near-surface shaly bedrock, coarse boulders and disintegrated blocks of outcrop, Unit 10 is a suitable source of burrow material but lacks sufficient supplies of aggregates for constructional purposes.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

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2	Thermokarst lake beds
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4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
8	Till plains
9	Hummocky till-capped terrain
10	Upland and pediment complexes
11	Mountainous and rocky areas

Geological boundaries of surficial units ....

Eroding river or shore cliffs (one or both walls)............

Eroding river or shore cliff (one or both valley bedrock)... D D D

Pingos (major ones) ....

Lowland swamps or weedy foreshore ....

Breached lakes on shoreline.....................................

Main sediment transport direction .... →

Coastal sediment sinks ....

Barrier deposits, spits and bars ....

Bathymetric contours (m) 2

Hydrographic soundings (m) 94

Topographic contours (m) 30

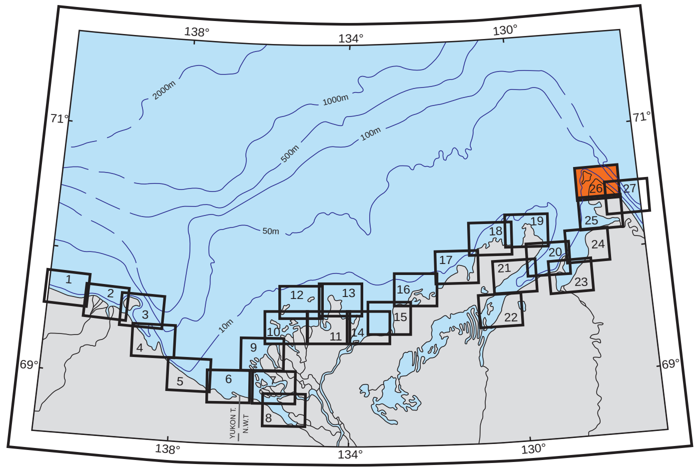
Topographic elevations (m) .... 183 △

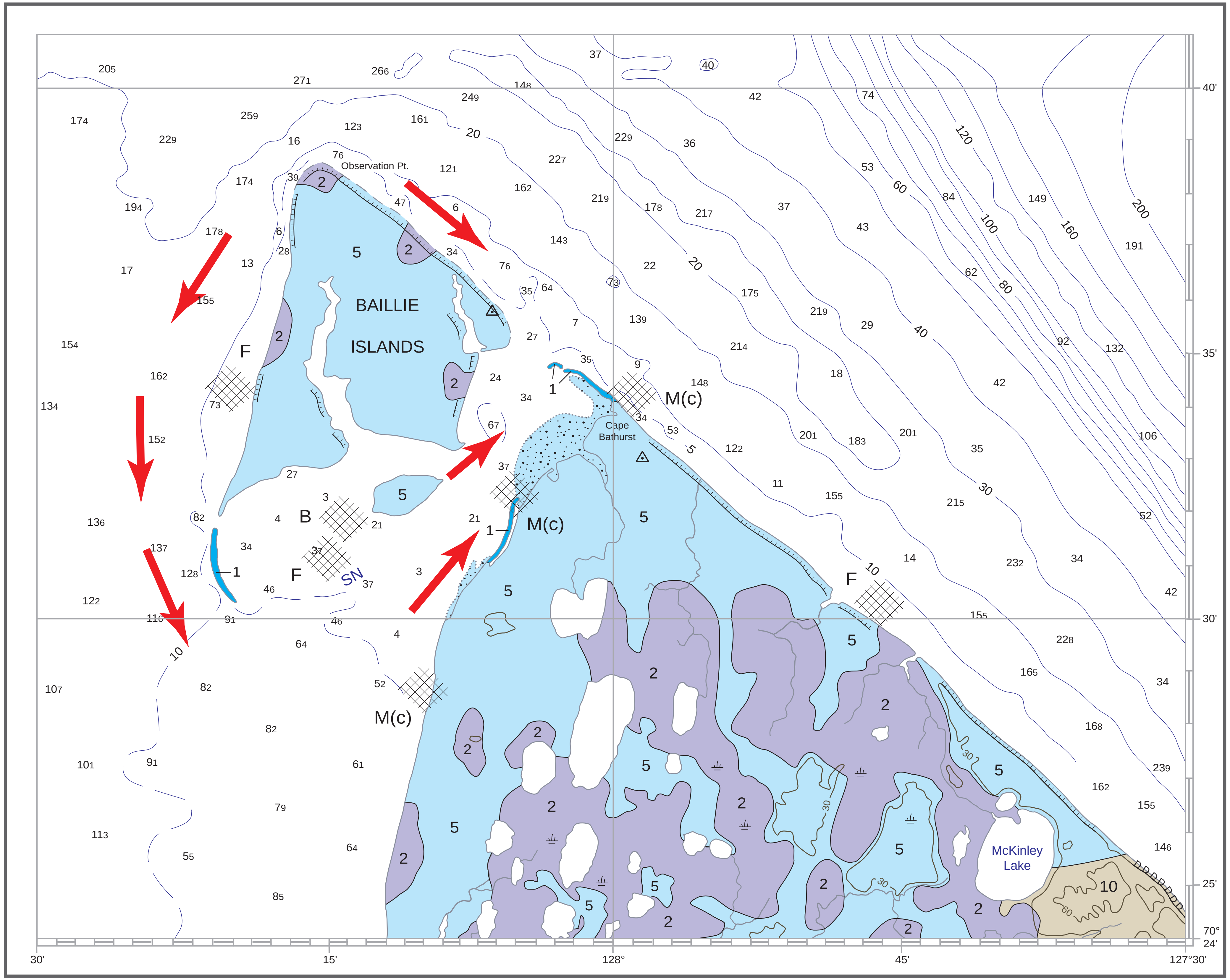
RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M

Camps for whaling(W), hunting(H), fishing(F)................ W,H, F

Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries).... ●,●,●,✕





Coastlands Map 26. Baillie Islands

scale = 1:150 000

COASTLANDS MAP 27. Traill Point

Physical Setting

In this map, only the extreme eastern portion of the Beaufort Coastlands is shown. Marine bodies such as Mackenzie, Beluga, Kugmallit, McKinley ,Liverpool, Wood, and Harrowby bays, which lie adjacent to the Beaufort Sea, are absent from this map because they all lie to the west. Amundsen Gulf is the only marine body displayed, and it is actually unrelated to the general landmass of the Beaufort Coastlands. On land all the area south of McKinley Lake is part of the Anderson Plain, and that to the north comprises the eastern portion of the Coastal Plain that is part of the Arctic mainland.

Good examples of an integrated drainage system are present in that part of Anderson Plain that lies athwart the northeastern Arctic mainland. In this map area most rivers flow to the sea on either side of the landmass, from an elevation exceeding 90 m. In the north, drainage is less integrated and generally comprises small lakes in the low country (less than 30 m elevation), with short, interconnecting streams providing the water courses. Swamps are present in all low-lying areas, particularly in the north.

Cliffs are a major feature and occur along the entire eastern coastline that lies adjacent to Amundsen Gulf. They also extend across the mainland in the south, as they follow an old glacio-fluvial waterway. Most cliffs are associated with bedrock, particularly near Amundsen Gulf; however, some are cut into the soils that lie along the stream channels in the south, and into the sea coast in the north.

Surficial Geology and Hazards (Units 2,5,6 and 10)

This map is included in the Coastland Series in order to complete the overlap of the surficial units shown in Coastlands Maps 25 and 26. The upland and pediment complexes of Unit 10 contain bedrock, and are overlain by a thin veneer of bedrock rubble, sand and some gravel. This unit is the most dominant on the map, and is centrally located on the landmass shown; a small exposure occurs in the extreme southeast as well. The central occurrences of Unit 10 are the highest surficial units in the area (> 90 m) and comprise the northernmost areas of the Anderson Plains in the Beaufort region. Unit 10 is the eastern, more-or-less anchor of the Beaufort Coastlands, and is terminated by relatively high cliffs that are present along the coast. Its southern margin also terminates as cliffs that are formed adjacent to less-consolidated surficial units. Because of good drainage in the highland areas, gullying may take place that is accompanied by moderate occurrences of mud flows. However, ice may be absent in the higher slopes so that hazards such as slumping and subsidence are rare events. The material comprising this unit is unsuitable as a supply of aggregates, but the rubble may be a good source of burrow fill.

Unit 6, with its glacio-fluvial sediments and landforms comprising terraces and eskers, occupies the bordering, southern portion of this map area. It is marked by cliffs that are cut into the glacio-fluvial valley that extends east-west across this southernmost area, and is partly occupied by Old Horton Channel (see Coastlands Map 25). Ground ice is present at depth and, on some slopes during warming periods of both air and ground temperatures, the permafrost thaws and thermokarst topography develops, subsequently. These processes are accompanied by slumping and subsidence of the soil cover. The beds of Unit 6 are a major source of burrow and granular material; however, their extraction should be exercised with caution in view of the indigenous terrain hazards.

Occurrences of Unit 2 are found in the Coastal Plains and the lower elevations of the Anderson Plain. These surficial deposits consist of thermokarst lake beds, which contain clay, silt and peat. The lakes owe their origin to the thawing of the permafrost, and the development of a thermokarst. Erosion along ice-wedge boundaries may induce slumping, particularly around the rims of lakes. Beds in this unit are generally weak in terms of loading strength and, therefore, are an unsuitable base for constructional purposes and the installation of infrastructures. These beds have negligible use as a source of aggregates, or even burrow materials.

The disposition and composition of Unit 5 has been described in the overlapping Coastlands Maps (nos. 25 and 26). In the present map area Unit 5 is characterized by the presence of marine and lake plains, occurring at elevations exceeding 30 m. These exposures are found in the southeastern part of the map, particularly in the area adjacent to the sea and the McKinley Lake area. Cliffs are prominent adjacent to Amundsen Gulf but, in the lower elevations at which this unit is found, swamps are widespread. Usually, hazards are associated with the thawing of ice-wedge borders and permafrost, all of which can induce slumping and subsidence. The low strength of the soil engenders a poor q uality of foundation for building purposes. This unit is an unsuitable source of granular materials and coarser aggregates for construction purposes.

LEGEND

SURFICIAL GEOLOGY AND PROCESSES

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2	Thermokarst lake beds
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4	Coarse-grained river deposits
5	Marine and lake plains
6	Gravelly and sandy hills, ridges and terraces
7	Ice-thrust hills and ridges
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Geological boundaries of surficial units ....
Eroding river or shore cliffs (one or both walls)............
Eroding river or shore cliff (one or both valley bedrock)...
Pingos (major ones) ....
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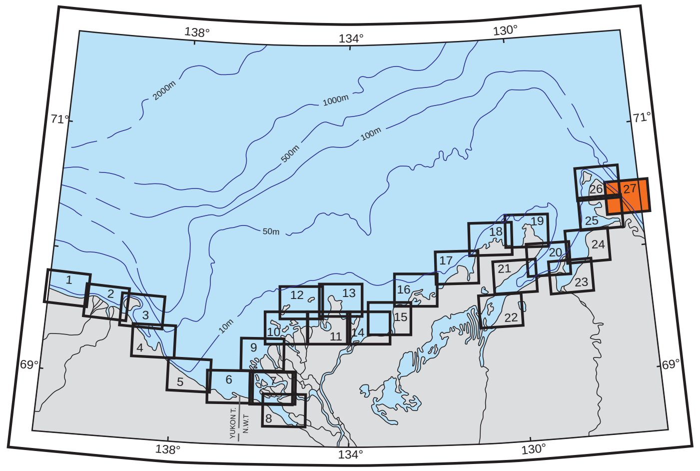
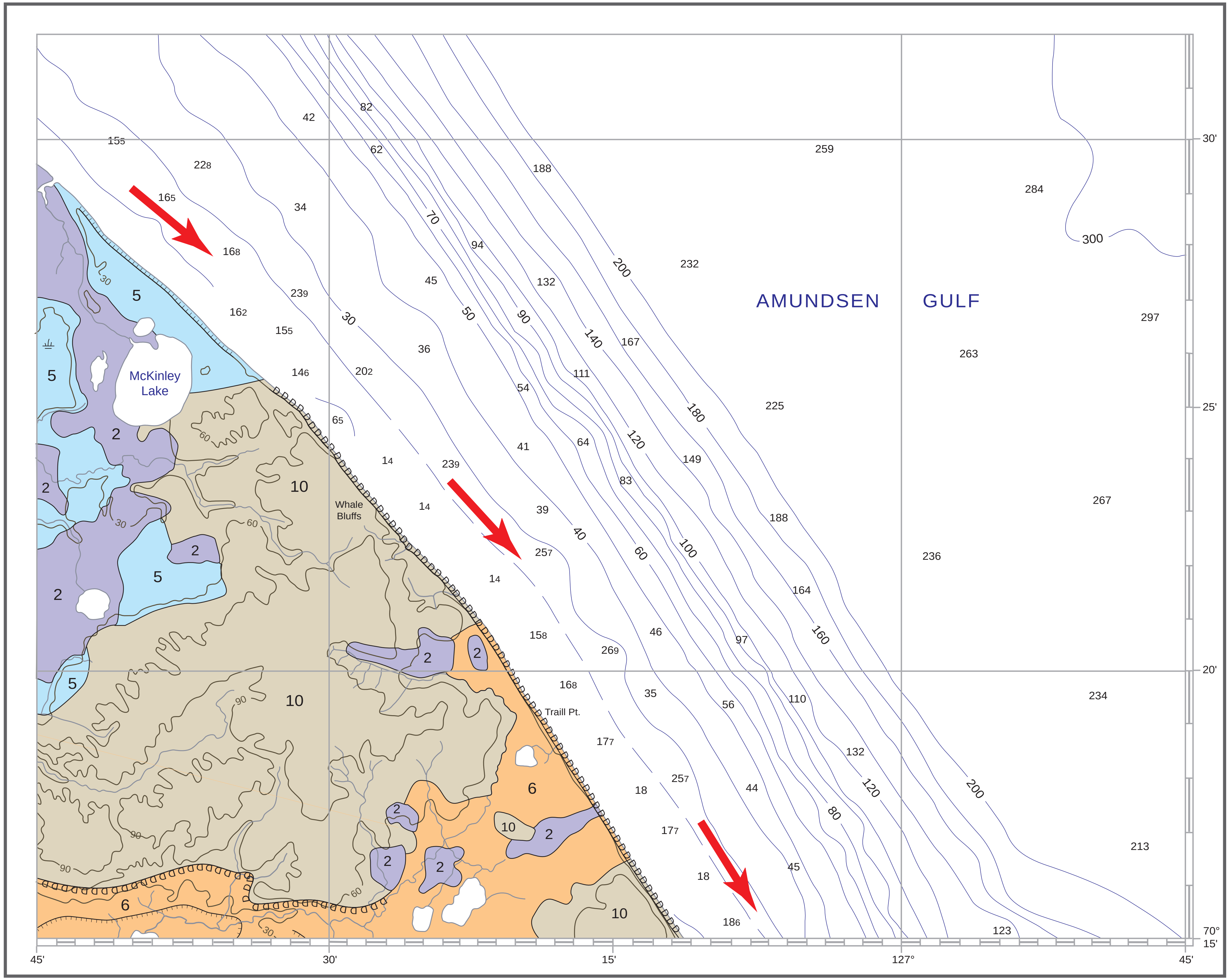
Main sediment transport direction ....
Coastal sediment sinks ....
Barrier deposits, spits and bars ....
Bathymetric contours (m) 2
Hydrographic soundings (m)................................... 94
Topographic contours (m) 30
Topographic elevations (m) 183

RESOURCES AND USES

Marine and wildlife:fish(F), mammals(M), birds(B) .... F,B, M
Camps for whaling(W), hunting(H), fishing(F)................ W,H, F
Oil and gas exploration (oil, gas, oil & gas, dry & abandoned wells) see (Oil and Gas Discoveries)... ●,●,●,✕





Coastlands Map 27. Traill Point

scale = 1:150 000

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