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SEDIMENTS AND SEDIMENTARY PROCESSES YUKON BEAUFORT SEA COAST

INTERIM REPORT DECEMBER 1974

BEAUFORT SEA PROJECT

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YUKON BEAUFORT SEA COAST

Interim Report of Beaufort Sea Project Study F3

December, 1974

C.P. Lewis and D.L. Forbes
Terrain Sciences Division
Geological Survey of Canada
Department of Energy, Mines and Resources
601 Booth St.
Ottawa, Ontario

Beaufort Sea Project, 512 Federal Building
1230 Government St., Victoria, B.C. V8W 1Y4
(604) 388-3331 or (604) 388-3521

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A.R. Milne

A.R. Milne
PROJECT MANAGER
Beaufort Sea Project

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1. SUMMARY

1.1 Objectives of the Study

Fieldwork in 1974 represented the third year of investigations by the Geological Survey of Canada into the geometry, composition, origin and stability of coastal landforms bordering the Beaufort Sea from the Alaska-Yukon border to Cape Dalhousie, N.W.T. The purpose of the study is to provide information which will be of use in making decisions about future development in the area. The 1974 study follows general reconnaissance investigations of the northwest coast of the Tuktoyaktuk Peninsula in 1973 and of the Yukon coast in 1972 (McDonald and Lewis, 1973).

This interim report covers only the Yukon coast, with emphasis on data collected during the spring and summer of 1974. The purposes of this work were twofold:

1. The general reconnaissance studies raised many questions about the detailed nature, magnitude and frequency of processes and responses in this arctic coastal zone, questions which could best be answered by a longer term instrumented study at a representative sample location. Kay Point, Y.T. (Figure 1) was chosen as the sample site because it offers a wide range of coastal features in a small area. Concentrated fieldwork at this location will continue through the summer of 1976 with occasional visits thereafter. Scientific studies include (see Figure 1, inset, for locations):

   a. Erosion of and sediment transport from the coastal cliffs southeast of the point;
   b. Growth, migration and short period changes in Kay spit;
   c. Morphology, sedimentology and hydraulics of the Babbage River delta, an estuarine delta of the Mackenzie type; and
   d. Sediment transport and deposition in Phillips Bay, a nearshore sediment sink.

2. The second objective of 1974 fieldwork was to examine the geological aspects of coastal susceptibility to oil spills, a part of the joint industry - government Beaufort Sea study of the potential environmental hazards of proposed exploratory offshore drilling. In this context, the intentions of this study were to:

   a. Identify and determine the extent of those areas of the coastal zone most susceptible to inundation by sea water;
   b. Determine the present geometry, nature of sediments and vegetation of these areas;
   c. Examine patterns of sediment erosion, transportation and deposition; and
   d. Identify and discuss conditions peculiar to an arctic coastal environment relating to potential damage from an oil spill.

   During the summer of 1974, fieldwork was carried out on the major spits at Shingle and Kay Points, on Nunaluk spit in the Firth River region, on the Blow and Babbage River deltas and, as examples of sediment source areas, on cliff segments at Shingle Point and Kay Point (Figure 1).

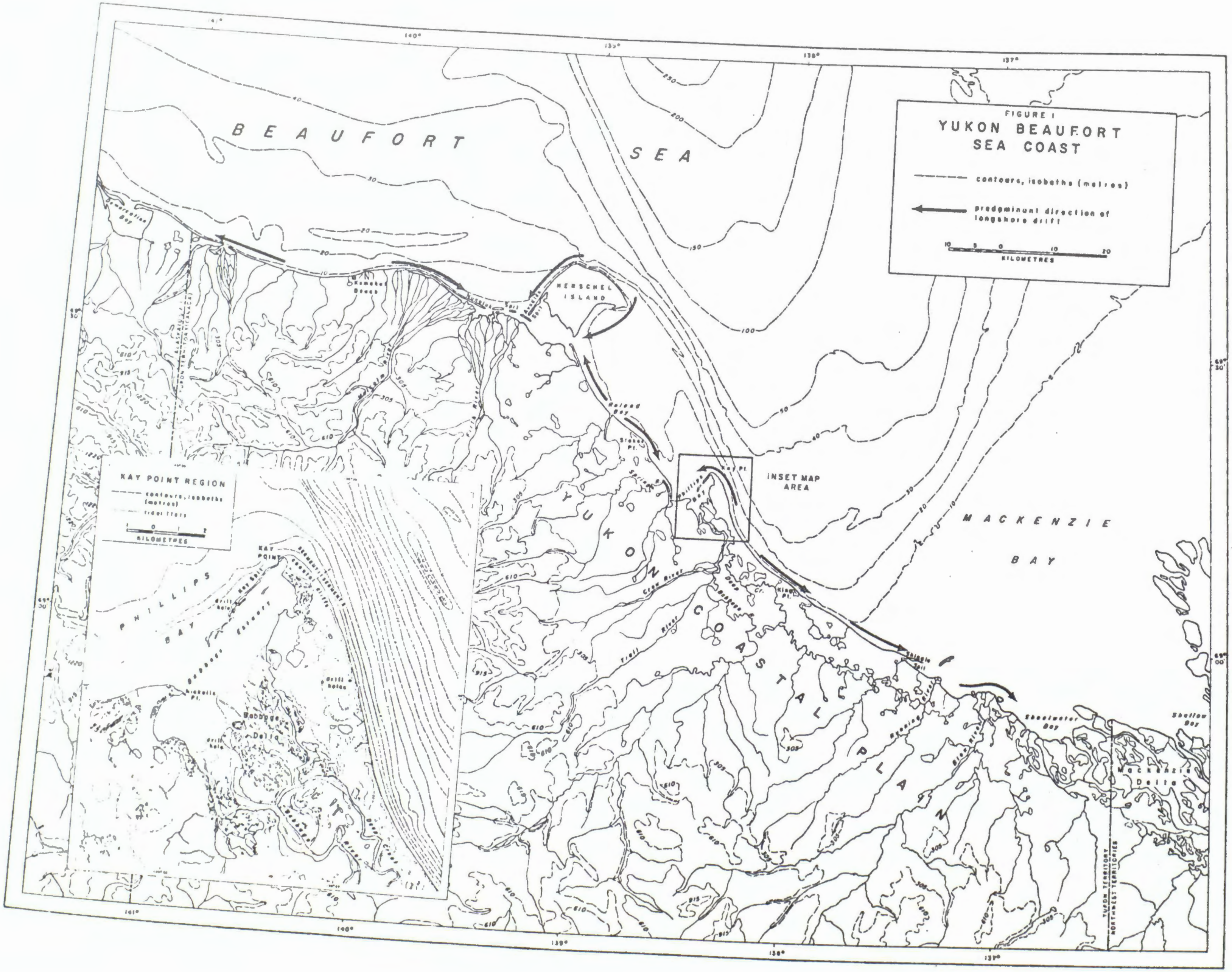
FIGURE I
YUKON BEAUFORT SEA COAST
contours, isobaths (metres)
predominant direction of longshore drift
KILOMETRES
BEAUFORT SEA
HERSCHEL ISLAND
INSET MAP AREA
MACKENZIE BAY
YUKON COASTAL PLAIN
KAY POINT REGION
contours, isobaths (metres)
tidal flats
KILOMETRES
KAY POINT
PHILLIPS BAY
Babbage Delta
Mackenzie Delta

1.2 Scientific Conclusions

The main scientific conclusions resulting from this study are:

1. The major geomorphologic features of the Yukon Beaufort Sea coast are: (a) steep coastal cliffs, often containing significant amounts of ground ice, and fronted by narrow beaches; (b) spits and barriers up to 10 or more kilometres in subaerial length and several hundred metres wide; and (c) deltas of coastal plain rivers with vegetated or partially vegetated subaerial delta plains up to 50 $km.^2$ in area.

2. Cliff sediments range from gravel to icy clay. The fine material is moved off shore and beaches, spits and barriers are usually composed of remnant gravels and sands. Coastal plain rivers have gravel beds but this gravel does not reach the lower delta plains where sediments are primarily organic-rich silts and fine sands.

3. Cliff retreat of up to 90 m. in 16-18 years has occurred, largely through undercutting and subsequent block slumping, gulleying, and mud flow associated with ground ice slumps. Sediment derived from this retreat is moved along shore and has led to hundreds of metres of spit and barrier extension over the same time period.

4. Significant sediment transport events are associated with spring break-up and storm floods on the rivers and with meteorological tides and wave activity during these storms along the coast. Berm elevations of over 1.5 m. on spits and driftwood lines more than 2 m. above normal high tide on subaerial delta plains attest to the rise in sea level and inundation of coastal depositional features during these storms, most commonly in the summer and fall but occasionally during winter.

5. First flow in rivers, deltas and estuaries occurs well before sea ice break-up and is commonly over bottomfast winter ice. This ice inhibits bed scour during early flooding. Following spring break-up, river discharge declines except for brief rises during storm events.

6. The direct effects of sea ice on the stability of coastal features appear to be small. Only minor examples of the movement of beach sediment by ice push and scour of the nearshore sea bed by ice have been observed, this latter phenomenon apparently ceasing shoreward of the 10 m. isobath. Indirect effects, particularly the influence of the amount and location of ice on storm surges and associated wave activity, are much more important.

7. Offshore gradients can be quite steep off many portions of the Yukon coast, most commonly where the shoreline is cliffed. Profiles are generally concave upward and few nearshore bars exist. Off river deltas, though, depths are very shallow, seldom exceeding 2 m. a kilometre or more from shore. Shallow depths in the Babbage estuary prevent the development of significant vertical variations in water temperature and salinity.

8. Rapid coastal retreat, shallow water depths and low water temperatures have enabled the preservation or formation of permanently frozen ground beneath estuary and nearshore areas.

9. Unlike the Yukon coast, the northwest coast of the Tuktoyaktuk Peninsula is deeply embayed along its length, its shape reflecting the breaching of thermokarst lakes which cover large portions of the delta plain. Major spits and long barrier bar sequences have formed because of the much lower offshore gradient than off the Yukon coast. Sediments in coastal depositional features are mixed gravels and sands west of the settlement of Tuktoyaktuk and, most commonly, pure sand east of Tuktoyaktuk. Like the Yukon coast, the shoreline of the Tuktoyaktuk Peninsula is retreating, with most of the derived sediment being moved northeast toward Liverpool Bay.

1.3 Implications and Recommendations

1.3.1 General Scientific

In an average year, the southern Beaufort Sea coast, particularly east of Herschel Island, has a relatively long open water season and cannot be considered true arctic in nature. Normal marine processes dominate for about three months of the year. During this time period, the arctic environment influences these processes only through the increased relative importance of extreme storm events, the occasional movement of sea ice near shore during these events and, as was so well demonstrated during the summer of 1974, through the major year to year variations in climate and sea ice conditions which may occur.

The response of coastal materials to summer marine processes, however, is conditioned by the arctic environment. Frozen ground plays an important role in the coastal zone, most importantly through its influence on rates of coastal retreat and, along the Tuktoyaktuk Peninsula, through the control by thermokarst lakes of coastal configuration.

1.3.2 Matters Relevant to Development

Development is considered here primarily with respect to the potential effects on the Beaufort Sea coastal zone of an oil spill during exploratory offshore drilling. Consideration is given as well, however, to the possible use of the coast for staging areas or other shore installations associated with petroleum exploration and development. and oil spill clean-up ?

The details of coastal processes and responses, particularly for short-period events, are not yet well understood in the Beaufort Sea area. The studies undertaken at Kay Point will go far toward remedying this situation. The discussion which follows, however, precedes the completion of these studies and its value must be considered in the context of this lack of knowledge.

1. The coastal zone is a dynamic one, particularly so in this part of the arctic where shore materials are unconsolidated and often contain significant quantities of ground ice. Its instability must be taken into account in considerations of both oil spills and coastline development.

2. The largest areas subject to frequent inundation by sea water and thus, potentially, by oil in that water are the river deltas, particularly the Mackenzie itself and, along the Yukon coast, the Blow and Babbage deltas. These deltas have a high silt content and their sediments are often rich in ground ice. Thermal disturbance through vegetation damage could lead to considerable thaw consolidation. Because the delta plains are major wildfowl nesting areas, oil <u>must</u> be prevented from reaching them.

3. Oil is most likely to reach the <u>coast during summer and fall</u> but open water and wave activity are possible even during winter. The sea ice was broken up off Kay Point and the Babbage estuary flooded during a severe storm in early January 1974 (R. Mackenzie, pers. comm.).

4. Shoreline materials are constantly in motion during the open water season and, with the continuous possibility of storm surges, oil from a spill could cover depositional coastal features at any time, be buried by subsequent sediment accumulation, exposed again, transported along the shore, re-buried, and so on. ? oil [illegible]

5. In the event of an oil spill approaching the coastline, it may be possible to use lagoons behind spits and bars or, along the Tuktoyaktuk Peninsula, breached thermokarst lakes to contain it. The resultant potential for destruction of fish and wildlife is critical to this suggestion but, if other methods of containment are less reliable or cause even greater destruction, use of natural features may become viable.

6. Shore installations must be carefully located so as to avoid areas where large amounts of ground ice are present. Disturbance of the ground thermal regime will only serve to further increase already rapid rates of coastal retreat. Construction off shore must take into account the likely presence of and, because of low sea water temperatures, the possible growth of sub-bottom frozen ground.

7. Beach material is primarily local in origin, its maximum travel defined by the distance to the outer boundary of the feeder area of the near-shore sediment sink toward which it is moving. Removal of material or blockage of longshore drift for construction purposes will have effects both up- and down-drift. Because many natural features are important nesting areas and because disturbance at one construction site may affect conditions at another, final selection of sites should be made only after the detailed nature of sediment supply in the area is known.

2. INTRODUCTION

2.1 General Nature and Scope of Study

Fieldwork in 1974 represented the third year of investigations by the Geological Survey of Canada into the geometry, composition, origin and stability of coastal landforms bordering the Beaufort Sea from the Alaska-Yukon border to Cape Dalhousie, N.W.T. The purpose of the study is to provide information which will be of use in making decisions about future development in the area. The 1974 study follows general reconnaissance investigations of the northwest coast of the Tuktoyaktuk Peninsula in 1973 and of the Yukon coast in 1972 (McDonald and Lewis, 1973).

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2. The second objective of 1974 fieldwork was to examine the geological aspects of coastal susceptibility to oil spills, a part of the joint industry - government Beaufort Sea study of the potential environmental hazards of proposed exploratory offshore drilling. In this context, the intention was to examine those coastal features most susceptible to inundation by sea water. Because of extremely poor weather and sea ice conditions during the summer of 1974, work was confined to the Yukon coast.

2.2 Specific Objectives

Specific objectives can conveniently be divided into two parts: those concerned with the Kay Point process-response study and those concerned with coastal susceptibility to oil spills.

2.2.1 Kay Point

Work at Kay Point is focussed on the nature, magnitude and frequency of stresses exerted on a variety of coastal sedimentary environments and on the response of these environments to the imposed stresses. The emphasis is on system responses to storms or floods but seasonal and longer term changes are being examined as well. In all cases, greatest attention is given to those characteristics which differ from coasts in more temperate locations and which might make an arctic coast a special case from a development point of view.

Specific studies include (see Figure 1, inset, for locations):

1. Erosion of and sediment transport from the coastal cliffs southeast of the point;
2. Growth, migration and short-period changes in Kay spit;
3. Morphology, sedimentology and hydraulics of the Babbage River delta, an estuarine delta of the Mackenzie type; and
4. Sediment transport and deposition in Phillips Bay, a nearshore sediment sink.

2.2.2 Coastal Susceptibility to Oil Spills

The degree and duration of damage to the coastal zone resulting from an offshore oil spill are dependent primarily on: (a) whether or not the oil reaches the coastline, (b) the frequency and duration of inundation of coastal features by sea water containing oil, and (c) the reaction between the oil, once present, and the sediments, vegetation and wildlife existing within the coastal zone.

In this context, the intentions of this study are to:

1. Identify and determine the extent of those areas of the coastal zone most susceptible to inundation by sea water;
2. Determine the present geometry, nature of sediments and vegetation of these areas;
3. Examine patterns of sediment erosion, transportation and deposition; and
4. Identify and discuss conditions peculiar to an arctic coastal environment relating to potential damage from an oil spill.

During the summer of 1974, fieldwork was carried out on the major spits at Shingle and Kay points, on Nunaluk spit in the Firth River region, on the Blow and Babbage River deltas and, as examples of sediment source areas, on cliff segments at Shingle Point and Kay Point (Figure 1).

2.3 Relevance to Development Problems

The coastal zone is one of the most complex and dynamic environments with which development must contend. Because of the importance of the Beaufort Sea for transportation, harbours, staging areas and perhaps pipelines will accompany the development and movement of resources on land. This study is intended to provide both reconnaissance-level and detailed process-response information relevant to construction at the coast.

The development of resources at sea will also affect the coastal zone, both through the need for support facilities on land and because of the dangers of and need to protect the coast against pollution associated with offshore development. An oil spill during offshore drilling could reach the coastline and have serious detrimental effects on vegetation, wildlife and man. It is the intention of this study to provide background information relevant to an evaluation of the nature, magnitude and duration of potential damage and of methods of minimizing this damage.

2.4 Acknowledgments

The authors are indebted to many people for co-operation in the field during 1974. Assistance at Kay Point was provided by B. Hawley, M. Krastman, S. Nichols, and A. Pinsonnault. G.R. Bernyk led the sub-party investigating coastal susceptibility to oil spills and was assisted by B. Gamble, D. Hunter, R. Jurchuk and P. Smale. Dr. J.A.M. Hunter of the Geological Survey provided advice and support for shallow water seismic studies at Kay Point carried out by J. Carson and S. Carson. Electrical resistivity sounding and profiling on coastal spits done by L.E. Stannard was helped greatly by advice and support from Dr. W.J. Scott of the Geological Survey. Vegetation studies in all areas were carried out by J.M. Teversham of the University of British Columbia. Dr. R. Gilbert of the University of Alberta supervised the March 1974 drilling program at Kay Point. Logistic support offered by the Inuvik Research Laboratory and by the Polar Continental Shelf Project is also gratefully acknowledged.

Thanks are due also to H. Kerfoot and L. Lightstone for assistance in preparations for the field season, to G.R. Bernyk for help in the reduction of field data and to D.J. Egan and the Geological Survey Cartography and photography sections for assistance in illustrating this report.

3. CURRENT STATE OF KNOWLEDGE

Geomorphic and sedimentologic studies of the Yukon coast are few. Rampton (1974a) has mapped surficial materials at and landward of the coast. Hughes (1970) discussed the history and features of glaciation and Mackay, Rampton and Fyles (1972) reported on coastal exposures indicative of glacially-deformed relic Pleistocene permafrost. Mackay (1960, 1963) commented on the nature of small boat harbours and noted evidence of shoreline retreat along the Yukon coast. Walker and McCloy (1969) and McCloy (1970) examined the morphology and hydrology of the Blow River delta with emphasis on the role played by the arctic environment in morphologic change. McDonald and Lewis (1973) discussed the distribution and variety of marine sediment types along the coast, inferred from coastal depositional features the broad patterns of nearshore sediment movement and storage, and produced several maps showing photogrammetric measurements of coastal change and typical stratigraphic sections of segments of coast.

The types of knowledge of the Yukon coast which presently exist, therefore, are primarily stratigraphic, very localized or reconnaissance-level in nature. Detailed mapping of coastal depositional features has not been attempted and the characteristics of shore and nearshore processes and responses can only be inferred by extrapolation from the Alaskan portion of the Beaufort Sea coast (eg. Wiseman et al, 1973; Walker, 1974).

4. STUDY AREA

The nature of the Yukon Beaufort Sea coastal zone has been conditioned primarily by erosion and redistribution of the unconsolidated Quaternary sediments of the Yukon coastal plain. These deposits are greater than 30 m. thick and consist mainly of: lacustrine silty-clay; alluvial fan sands and gravels; plus, east of the Firth River (Figure 1), marine, estuarine and fluvial silt, sand and gravel, commonly glacially-contorted and capped by till; and glaciofluvial gravel and sand (Rampton, 1974b).

Coastal plain rivers also supply significant amounts of sediment to the coastal zone. Of these, the largest are the Firth, the Babbage and the Blow (Table I). No estimates of annual sediment load are available for these rivers but differences in this together with contrasting physiographic settings, history and coastal current conditions must account for the great dissimilarity of their deltas.

In addition to the deltas, two other major coastal types can be distinguished: steep cliffs fronted by narrow beaches and large spits and barriers. Erosion of the cliffs has been rapid in recent years, particularly where the sediments contain considerable pore, wedge or massive ice. Material derived from this erosion and from the coastal plain rivers is dispersed by well developed longshore currents to four main sediment sinks: (a) Demarcation Bay, (b) between Herschel Island and the mainland, (c) Phillips Bay and (d) Shoalwater Bay (Figure 1). Photogrammetric data indicate recent extension of the spits and barriers, evidence of this longshore movement of sediment (McDonald and Lewis, 1973).

TABLE I[a]

Yukon Coastal Plain Rivers

	Firth	Babbage	Blow
Basin area ($km.^2$)	6200	5000	3700
Maximum probable flood ($m.^3/sec.$)	1000	910	710
Delta type	fan	estuarine	arcuate
Delta plain area ($km.^2$)	-	25	50

[a]After McDonald and Lewis, 1973 and Church, 1971.

5. SOURCES, METHODS AND RATIONALE OF DATA COLLECTION

The purpose of this section of the report is to detail the specific types of information collected, the methods by which this information was obtained, and the uses to which it has been put.

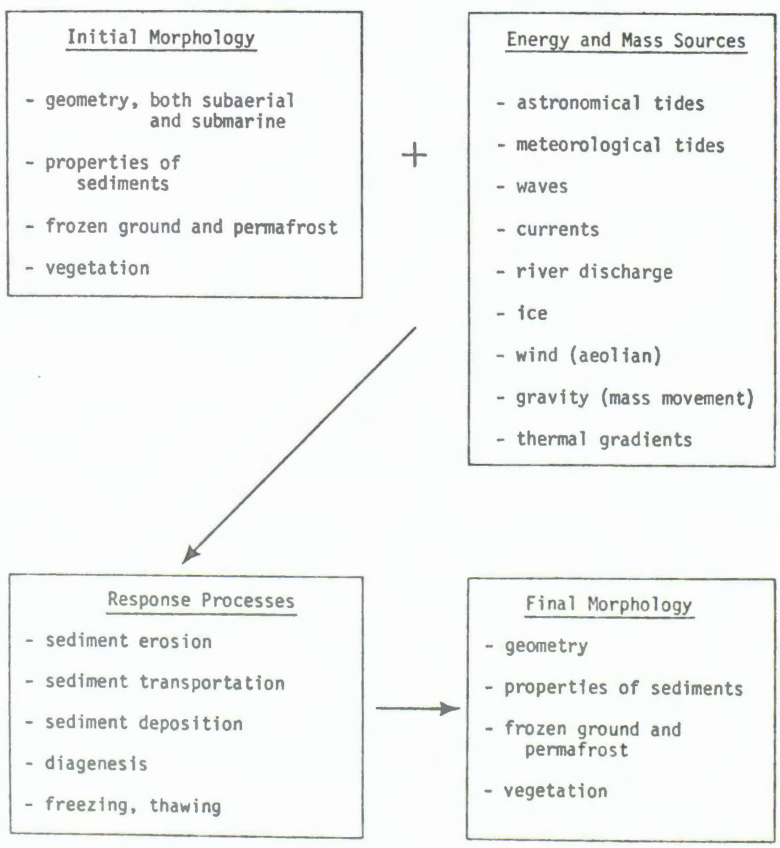
5.1 Kay Point

The evolution of a coastal landscape can be examined in the context of any of several different time scales. As has been mentioned previously, the scale of most concern in the various components of the Kay Point study is that of the storm event - changes over several hours to several days. The seasonal scale - changes over weeks and months - is also of great importance, however, because of its relevance to the question of the role played by the arctic environment in coastal processes and responses. Of lesser interest to this study but still essential to it are changes which have occurred over periods of years. These can only be determined indirectly but, if reliable evidence is available, attest to the sum effect of shorter period events.

The framework for data collection in each component of the Kay Point study is detailed in the process-response model shown in Figure 2.

FIGURE 2

Generalized Process - Response Model



In a practical sense, measurement to the necessary accuracy of all variables relevant to a particular event at any of the time scales of interest is not possible. The model is idealized and will indicate the weaknesses of specific studies as well as their strengths.

Initial investigations in the Kay Point region were oriented primarily toward establishing a grid network for data collection and obtaining the detailed background information necessary for future studies - ie. the initial morphology. In addition to qualitative observations of coastal morphology and processes, the following data have been collected:

1. Meteorological information, most importantly continuous recording of atmospheric pressure and wind speed and direction to relate to waves, currents and meteorological tides;
2. Continuous tide gauge data (through the co-operation of the Marine Sciences Directorate, Department of the Environment);
3. Continuous recordings of water levels on the Babbage River and Deep Creek above their junction to define water inputs to the Babbage delta;
4. Spot measurements of water transmissivity, salinity, conductivity and temperature in the Babbage estuary and delta channels;
5. Survey profiles both along and across Kay spit, the cliffs and the Babbage delta and across the delta channels;
6. Establishment of detailed study zones with permanently marked profiles at 500 m. intervals along Kay spit to enable morphologic change during storm and seasonal time periods to be monitored;
7. Echo sounding (Raytheon DE-719-B with 200 kHz. narrowbeam transducer) and side scan sonar profiles up the largest Babbage delta distributary and along 1000 m. grid lines in the Babbage estuary and in the nearshore zones (out to a maximum of 10 m. water depth) off Kay spit and the coastal cliffs;
8. Seismic refraction profiles along the above grid lines to locate the upper boundary of sub-bottom frozen ground;
9. Surface sediment samples of the Babbage delta and estuary on a 1000 x 500 m. grid, supplemented by more detailed sampling at selected sites including channel cross-sections;
10. Drilling (up to 60 m. depth) on the cliffs, the spit and the delta to define stratigraphy and sediment properties and to permit installation of ground temperature cables; data from these and future cables together with surface temperature, drill log and seismic refraction information will be used in the development and testing of a model of the perturbation in the ground temperature field caused by the presence and migration of the coastal cliff and spit; and
11. Vegetation mapping on the Babbage delta plain, the spit and the cliffs.

Analysis of much of this data is still in progress.

5.2 Coastal Susceptibility to Oil Spills

Fieldwork for this portion of the project was designed to augment the 1972 reconnaissance study (McDonald and Lewis, 1973) in the particular context of the goals discussed previously. The research design used in each region investigated was made consistent with that being used in the Kay Point process-response study so that comparisons and, perhaps, extrapolations could most easily be made.

The approach taken was spatially hierarchical in nature with progressively more detailed work being done with each step down in the hierarchy. The highest level, the region, was defined as the segment of coastline providing sediment to each of the nearshore sediment sinks discussed earlier (Figure 1). Within each region studied, areas - ie. coastal types such as cliff segments, major spits and bars, deltas, etc. - were selected and examined in more detail. Intensive fieldwork was carried out in two to four 80 m. wide zones in an area, each zone extending, if practical, from the offshore-nearshore boundary (10 m. isobath) well into the backshore (beyond the limit of marine activity).

The geomorphologic data collected in a zone include the following:

1. Sketch map and photographs - of general topography, major geomorphic features, abrupt changes in sediment properties, etc.;
2. Definition of subaerial stratum boundaries - between portions of the zone which appear homogeneous with respect to type or gradient of processes, eg. foreshore, backshore and subdivisions of each;
3. Subaerial profile surveys - three to five, oriented normal to the trend of the shoreline;
4. Subaerial sediment samples - five surface samples in each stratum, positioned systematically within strata along the zonal centre-line;
5. Active layer thicknesses - mean of five probings at each sediment sample site;
6. Bathymetric profiles - high frequency echo sounding and side scan sonar along the extension of the zonal centre-line to the offshore-nearshore boundary;
7. Submarine stratum boundaries - as for subaerial , subdivisions of the nearshore; and
8. Submarine grab samples - as for subaerial.

This data will be used to produce a topographic map of each zone, to estimate mean grain size and grain size gradient for the zone and for each stratum within it and, when data for all zones in an area are combined, to infer areal gradients and the type and nature of active processes.

In addition to the geomorphologic studies, botanical work was carried out in connection with surveyed profiles in the Shingle Point and Kay Point regions and on Nunaluk spit. Collections of all vascular plants and representative bryophytes were made for all areas studied. The distribution of the vegetation was examined in relation to the varied geomorphic units within each study zone using a quadrat method for continuous vegetated areas and by a line transect method for discontinuous areas. The collections are presently being identified and, when completed, plant communities present will be described and discussed in terms of their geomorphic significance (J.M. Teversham, pers. comm.).

As well, electrical resistivity sounding and profiling were completed on Shingle, Kay, Spring River (Figure 1) and Nunaluk spits. The aim of this experiment was to test the usefulness of this geophysical method in distinguishing the top and bottom of permafrost and the thickness of gravel in coastal spits.

Finally, general observations on river and sea ice break-up and on the morphology of portions of each region not included in the study areas were made, the surface area of coastal features subject to frequent inundation by sea water measured, and spot surveys taken of the elevation of high water driftwood lines.

Figure 3. View east over the Babbage delta during spring break-up; note the floating channel ice. (8 June 1972; GSC 202717-J)

6. RESULTS

6.1 Kay Point

6.1.1 Babbage Delta and Estuary

The estuarine Babbage delta (Figure 3) receives discharge and sediment directly from both the Babbage River and from its tributary, Deep Creek. These streams drain a 5000 km.^{2} catchment on the Barn and British mountains and the Yukon coastal plain. Data on total water and sediment discharge from the drainage basin are lacking, but indirect estimates (Church, 1971) suggest maximum probable floods of 910 m.^{3}/sec. for the Babbage and 220 m.^{3}/sec. for Deep Creek. Total annual precipitation averages 200 mm. (Shingle Point, 1962-1971) and four months (June through September) have mean temperatures over 0^{o}C. Most sediment movement probably occurs during spring break-up in late May and June and during summer and fall storm floods. The delta plain may also be flooded by storm tides, most commonly in the summer and fall but occasionally during winter (R. Mackenzie, pers. comm.). As a result, some marine sediment, including a large amount of driftwood, is also incorporated in the delta.

Morphology and sediments

A generalized surface facies map of the Kay Point area is given in Figure 4. The subaerial Babbage delta comprises by far the largest land area below the highest driftwood line, the upper limit of storm surge flooding (2-3 m. above mean high tide). On two sides, the delta and its estuary are bounded by upland glacial, marine and lacustrine sediments of the Yukon coastal plain. Alluvial surfaces in the valley above the highest storm line are associated with a variety of sediments: from channel gravels of the braided Crow River on the south to fine-grained overbank deposits of Deep Creek on the north (Figure 1). Polygonal ice-wedge structures are common on this facies and winter or spring accumulation of aeolian sediment, apparently derived from channel bars, was noted along some banks.

The delta plain, as mapped here, includes all deltaic surfaces above normal high tide which are subject to storm surge flooding. The lower floodplain, generally less than 1 m. above mean high tide, comprises vegetated levees and interlevee flats and partially vegetated shallow flood basins, interspersed with numerous tidal ponds and connecting channels. Levees, except along minor channels have negligible relief: vegetation mapping (J. Teversham, pers. comm.) revealed little consistent contrast between levee and interlevee flora and a complex distribution of the few species present over the floodplain. Included in the delta plain facies are scattered higher surfaces, inactive levees flanking abandoned channels and a major abandoned channel at the head of the delta, all subject to driftwood accumulation under occasional storm flooding.

Little is known of the stratigraphy of the delta plain. Channel banks expose stratified silt and organic detritus including occasional large driftwood logs. A borehole at the delta front (Figure 4, drill hole #4) drilled in March, 1974 was logged as follows:

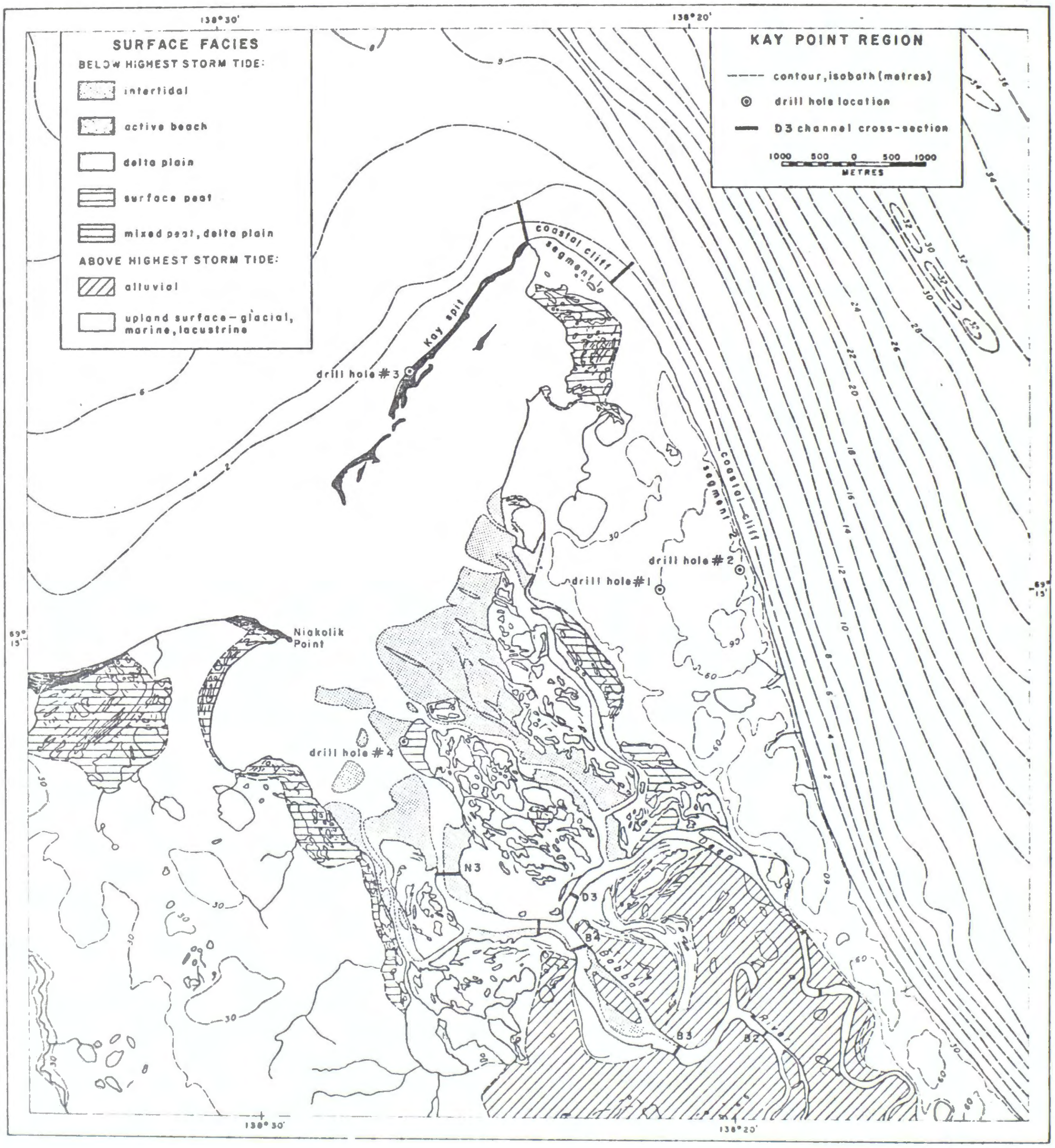


Figure 4. Kay Point Region: Generalized Surface Facies.

0-2.6 m.	peat, medium sand with 30-40% ice by volume
2.6-6.1 m.	90-100% ice by volume
6.1-22.9 m.	medium gravel with less than 20% ice by volume
22.9 m.	abundant salt water encountered

The gravel may derive from the Babbage River but is more probably fluvio-glacial valley fill associated with late-Wisconsin ice at King Point (Figure 1).

Sediments in the several major distributary channels which cross the delta are predominantly sand. Gravel, present in both the Babbage and Deep Creek above the delta, is absent from delta channels. The main distributary was sounded in August 1974 and scour holes up to 7.5 m. deep were encountered. It is probable that frozen ground underlies the delta channels. Hand probing at section N3 (Figure 4) revealed frozen substrate 0.5-2.0 m. beneath the channel bottom at least out to 3 m. water depth and possibly continuing beneath the thalweg at 5.5 m. McDonald and Lewis (1973) interpreted as frozen ground a prominent reflector observed in July 1972 echograms from Babbage delta channels.

Surface peat (Figure 4) occurs extensively at or near sea level around the estuary and as relic inliers on the modern delta plain. It also occurs beneath silts in cut-bank exposures in and above the delta. In several places (Figure 4) peat and delta plain facies are mixed. The age or ages of the peat exposures is unknown at this time.

Intertidal surfaces are essentially unvegetated (Figure 7). Sediments of this facies range from silt to sand, with rare ice-rafted gravel, little driftwood, and occasional clasts of peat. Bedforms exposed at low water attest to upstream sand movement on channel bars under low-stage flood-tide conditions. Initial impressions suggest that the intertidal areas may be expanding in places at the expense of the delta plain.

The Babbage estuary between the delta and Kay spit is both very shallow and flat; except near shore, water depths are consistently in the 1-2 m. range and only one bar, 500 m. behind the spit and parallel to it, was found. Bottom surface sediments are largely well sorted fine sands and coarse silts. Neither echo sounding nor side scan data showed any evidence of ice or strudel scour (Reimnitz et al, 1974), although the estuary probably freezes to the bottom in many places in winter and a strudel vortex was observed near the distal end of Kay spit in June 1972 (McDonald and Lewis, 1973). Seismic refraction data indicate sub-bottom frozen ground within the estuary (J. Carson, pers. comm.).

Seasonal flow characteristics

A break-up and summer flow sequence similar to that reported for Alaskan rivers (Barnes and Reimnitz, 1972; Walker, 1974) was observed on rivers of the Yukon north slope in 1974. Three phases were distinguished: (a) pre-break-up flooding over winter ice, (b) break-up accompanied and followed by snowmelt flooding with pronounced diurnal fluctuation, and (c) general summer flow recession interrupted by brief storm floods.

Figure 5. Blow River delta: pre-break-up flooding over winter ice.
(20 May 1974; GSC 202717-O)

Figure 6. Babbage River estuary: pre-break-up flooding over winter ice; Kay spit at extreme left centre, Niakolik Point at right centre.
(20 May 1974; GSC 202717-D)

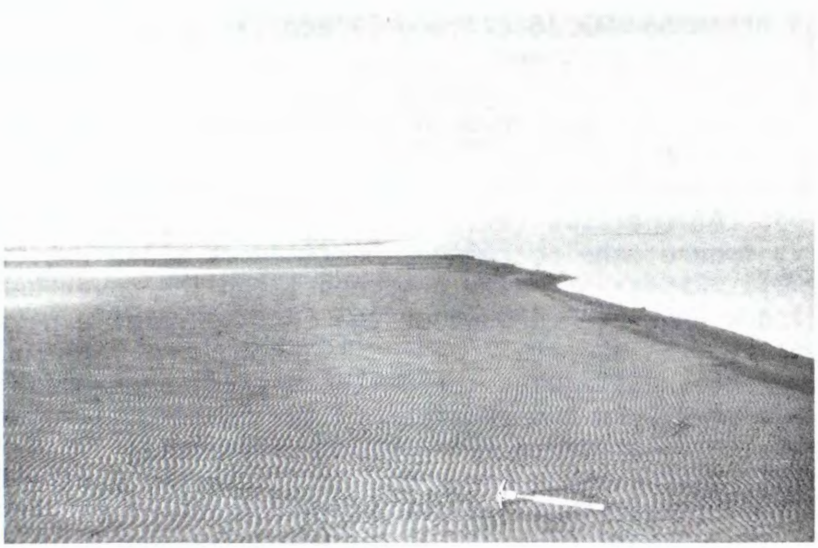


Figure 7. Unvegetated intertidal flat at the mouth of the main distributary of the Babbage delta. (10 July 1972; GSC 202717-C)

Figure 8. Sediment covered winter ice with thermo-erosional bedforms which has risen to the surface in the Babbage estuary. (12 June 1972; GSC 202717-B)

Pre-break-up flooding began at the head of the Babbage delta on May 16, 1974. Flow in the Firth River had already advanced over ice to Nunaluk spit (Figure 1), but other rivers along the coast, including the Malcolm, Spring, Running and Blow, showed no evidence of flow. Pre-break-up flooding in the Blow Delta began by May 18 (Figure 5) and was well advanced by May 30 in the Malcolm and Spring rivers.

On the Babbage, the flow front advanced through the delta at a rate of about 3 km. per day and, by May 20, the southern part of the estuary and a zone of sea ice outside Kay spit, to or beyond the 2 m. isobath, were water covered (Figure 6). At the same time, winter ice in some delta distributaries began to lift free of the bottom but remained in place until mid-June or later (Figure 3). Repeated frosts produced fresh ice cover behind and around the floating winter ice throughout the early part of June.

At B2 (Figure 4), just above the delta, channel ice approximately 1 m. thick began to lift on May 28 but remained in the reach until June 1. Soundings to bottomfast ice suggested a late autumn water level 3.5 m. below the top of the cut bank. Water stage after May 28 fluctuated generally between 2.8 and 2.2 m. below bank top but rose to a peak of 1.9 m. on June 8 and again on June 10. Snow against cut banks indicated that no higher flooding had occurred before regular observations began. The June 8 peak produced the first extensive flooding of the Babbage delta plain and flooded the entire estuary over the winter ice. The estuary ice subsequently floated and cleared completely by July 9. Ice remained close against the seaward side of Kay spit until the last week in July, however. It should be noted in this context, though, that sea ice break-up in the Beaufort Sea was exceptionally late in 1974.

Suspended sediment concentrations during break-up flooding at B2 ranged from 50 mg./l. on June 2 to less than 5 mg./l. on June 6 to a maximum of 300 mg./l. twelve hours after the flood peak on June 8. Much of this sediment is deposited on top of bottomfast winter ice in the estuary (Figure 8). In the river and delta channels some bedload movement prior to break-up also occurred over bottomfast ice. This movement was very limited, however. Soundings encountered hard ice surfaces with only occasional patches of sediment except above late autumn water levels where the bottom was soft. Emergent bottom ice in the channels was clean except for rare patches of sand with some gravel. In a few instances, well formed, asymmetrical ripples were observed in the upper surface of bottomfast ice; the lee faces of some of these ripples carried thin slip-face accumulations of sand but the ripple surface itself is apparently thermo-erosional in origin. Thermo-erosional bedforms were also observed in floating bottom ice in the Babbage estuary (Figure 8) by McDonald and Lewis (1973). Bottomfast ice in channels clearly inhibits bed scour during pre-break-up flooding. Peak spring discharge may occur after break-up, however, and the extent to which scour may then be inhibited by a frozen channel perimeter is not known.

Continuous water stage records were obtained for Deep Creek from July 4 to August 22 and for the Babbage River over the same period with some breaks. The data indicate an initially strong durnal fluctuation on both streams, diminishing with time, but persisting into August. These fluctuations were also noted by McDonald and Lewis (1973) on the Babbage in June and early July 1972. The general reduction in discharge throughout the 1974 record was interrupted by brief floods on five occasions: the largest, August 13-15, produced a rise in stage on the Babbage of 1.25 m. in 48 hours, of which 1.00 m. occurred in 14 hours. Babbage discharge exceeded 60 $m.^3$/sec. during less than 10 per cent of the 50 day record and 20 $m.^3$/sec. during 75 per cent of the record. Deep Creek showed the same pattern as the Babbage, but with lower more attenuated peaks.

In late June, suspended sediment concentrations were higher in Deep Creek than in the Babbage: typical values on June 19 at D3 and B4 (Figure 4) were 100 and 10 mg./l. respectively. This difference was also noted during storm floods later in the summer. Except for these floods, suspended sediment discharge decreased with water discharge through the summer, concentrations in August being generally less than 1 mg./l. Surface water and sediment discharge to the delta probably ceases in late autumn or early winter, although extensive icings on the Crow and upper Babbage in August 1974 attest to winter discharge at some points in the basin.

Preliminary measurements of salinity, conductivity and temperature were made in the Babbage estuary in mid-July. The maximum salinity, 2.5‰, was recorded in the estuary behind Kay spit and the minimum, 0.2‰, in river water off Niakolik Point (Figure 4). Water temperatures varied from 7.0°C in river water to 2.5°C in water of intermediate salinity off the distal end of Kay spit. No significant vertical variations in salinity, conductivity or temperature were encountered.

6.1.2 Coastal cliffs

To both the east and west of the Babbage estuary the shoreline is fronted by rapidly retreating coastal cliffs. Sediment is fed from both directions into the Phillips Bay sediment sink. The coastal cliff southeast of Kay Point (Figure 4), probably the most rapidly retreating along the entire Yukon coast (McDonald and Lewis, 1973) has been chosen for detailed study.

This portion of cliff may be divided into two segments (Figure 4). In segment 1, the cliff is 5-10 m. high, vertical, often undercut and has no visible beach at normal water levels (Figure 9). A generalized section is given in Figure 11a. Retreat has ranged from 25-90 m. in 16-18 years (McDonald and Lewis, 1973) and is controlled by melting and gulleying along ice wedge lines, undercutting, and subsequent block slumping.

In segment 2, the cliff (Figure 10) rises to 90-100 m., becomes less steep, changes in stratigraphy and is fronted by pocket beaches. A 60 m. drill log section near the edge of the cliff (Figure 4) taken in March 1974 is shown in Figure 11b. Sediments are finer and ice content higher than in segment 1. Ground ice slumps and associated mudflows play an important role in retreat which has been in the order of 25-50 m. over the last 16-18 years (McDonald and Lewis, 1973). Similar slumps are encountered west of the Babbage estuary (Figure 12).

Figure 9. Undercut cliff at Kay Point during August storm; view northeast from Kay spit. (20 August 1974; GSC 202717-A)

Figure 10. Cliffs southeast of Kay Point; view southwest along March 1974 drilling line. (16 May 1974; GSC 202717-M)

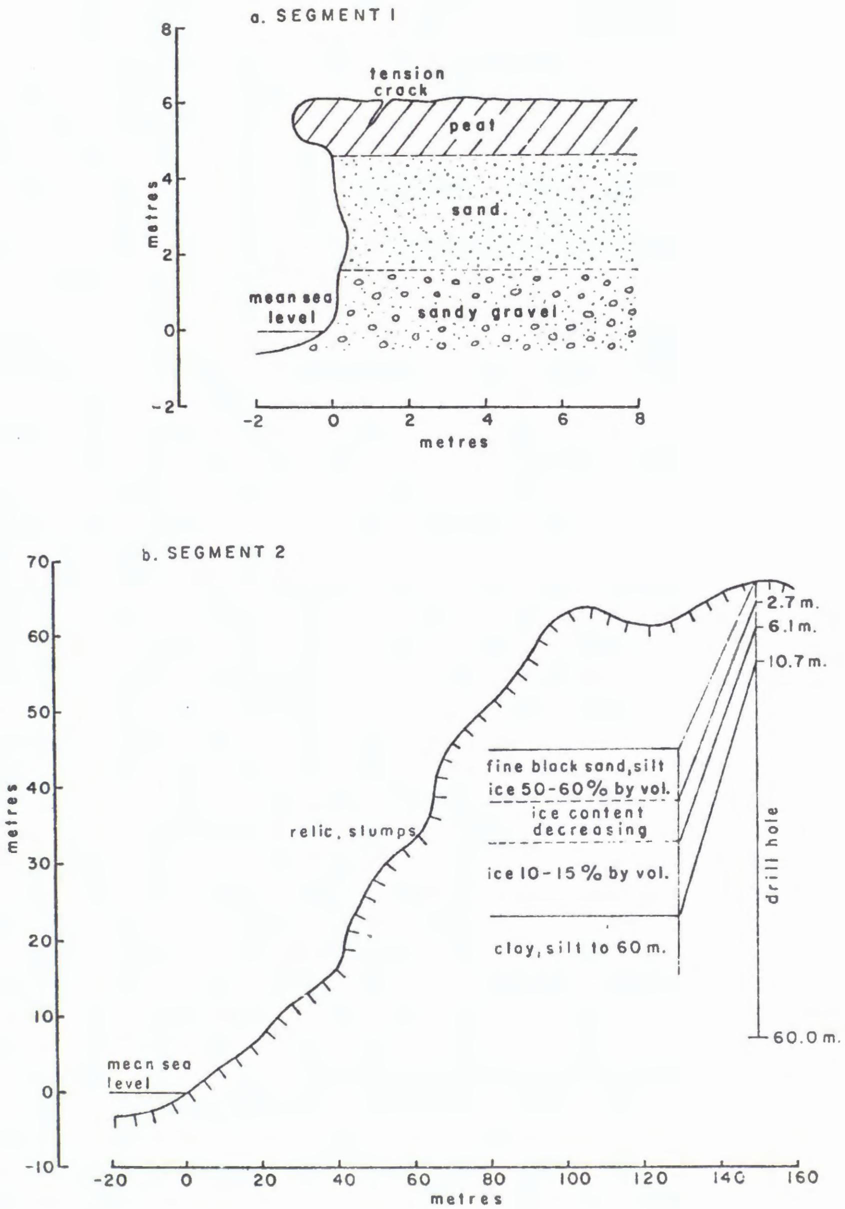


Figure 11. Generalized Sections and Stratigraphy, Cliffs southeast of Kay Point.

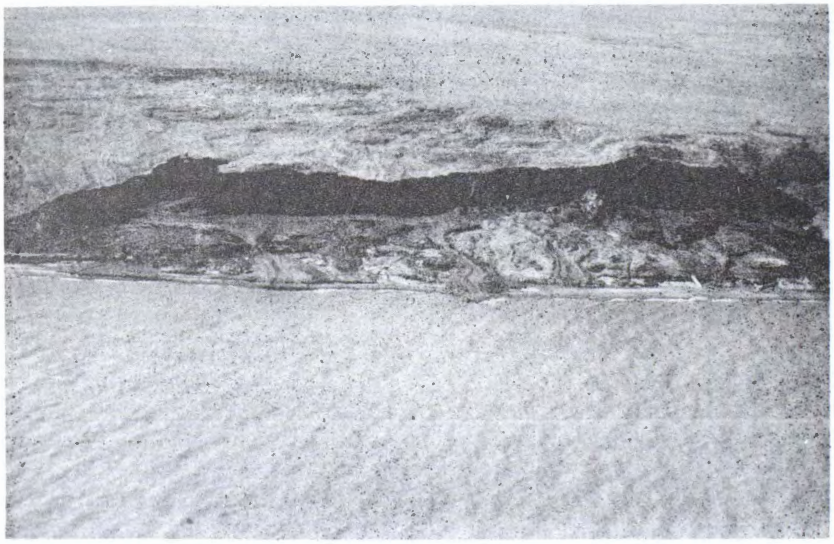


Figure 12. Coastal ground ice slump and associated mudflows, Spring River area. (8 August 1974; GSC 202717-G)

Bathymetric profiles off both cliff segments are concave upward with the 5 m. isobath 150-200 m. from the shoreline. Preliminary analysis of seismic refraction data indicates the presence of sub-bottom frozen ground in nearshore areas.

6.1.3 Kay Point spit

how high is the spit?

Much of the coarser sediment eroded from the cliff segments is carried northwest around Kay Point and deposited on Kay spit (Figure 1). This linear feature (Figure 13) is approximately 4.9 km. long, averages 61 m. in subaerial width and consists largely of gravelly sand (Figure 14) deposited over the estuarine sandy silts. A March 1974 drill hole (Figure 4) showed sand and medium gravel to a depth of 5.2 m., gravel decreasing to zero at 10.7 m. and silt content increasing with depth. A typical spit cross-section near the drill hole is given in Figure 15. Permanently frozen ground exists along the length of the spit but the drill hole penetrated a thin talik (unfrozen zone) beginning at 11.0 m.

The spit protects much of the Babbage estuary from marine wave activity and appears to be quite active, having extended about 400 m. and retreated on line with Kay Point between 1952 and 1970 (McDonald and Lewis, 1973). Most sediment movement occurs during storm surges. A surge which reached the high driftwood line on the Babbage delta, several metres above the astronomical tide of about 0.7 m., would completely inundate the spit. The transport of sediment is also greatly influenced by sea ice, both directly, through the movement of sediment by ice push - observed in 1972 but not in 1974 - and indirectly, through the effect of the ice on storm surges and associated wave activity. As has been mentioned, ice conditions during the summer of 1974 were among the worst on record. The sea ice remained solid off Kay spit until late July and, although broken, persisted near shore for the rest of the summer. A storm in late August, with winds exceeding 64 km./hr., caused only a slight surge and only small waves (Figure 9) because of the very short ice-free fetch. Because of the ice protection, the upper foreshore of the spit beach maintained its winter profile throughout the open water season.

?

See P. 3 para 6.

As off the coastal cliffs, bathymetric profiles off the spit are concave upward but the 5 m. isobath is 400-600 m. from the shoreline, two to three times its distance from the cliffs. One or two nearshore bars, 0.5-1.0 m. in height, parallel the spit for most of its length and occasional sand wave fields with lee faces toward shore lie seaward of the bars. Side scan sonar showed little evidence of ice scour out to the 10 m. isobath, the maximum depth scanned. Again, seismic refraction data indicate sub-bottom frozen ground, in this case extending offshore to a distance of at least 400 m., its upper surface 20-30 m. below the bottom 200 m. from shore (J. Carson, pers. comm.).

6.2 Coastal Susceptibility to Oil Spills

This portion of the project represents, basically, an extension, in considerably less detail, of the Kay Point study to other areas of the Yukon coast subject to frequent inundation by sea water.

Figure 13. Kay Point spit; view southwest.
(26 June 1974; GSC 202717-H)

Figure 14. Kay spit, distal island; view southwest along foreshore.
(12 June 1972; GSC 202717-K)

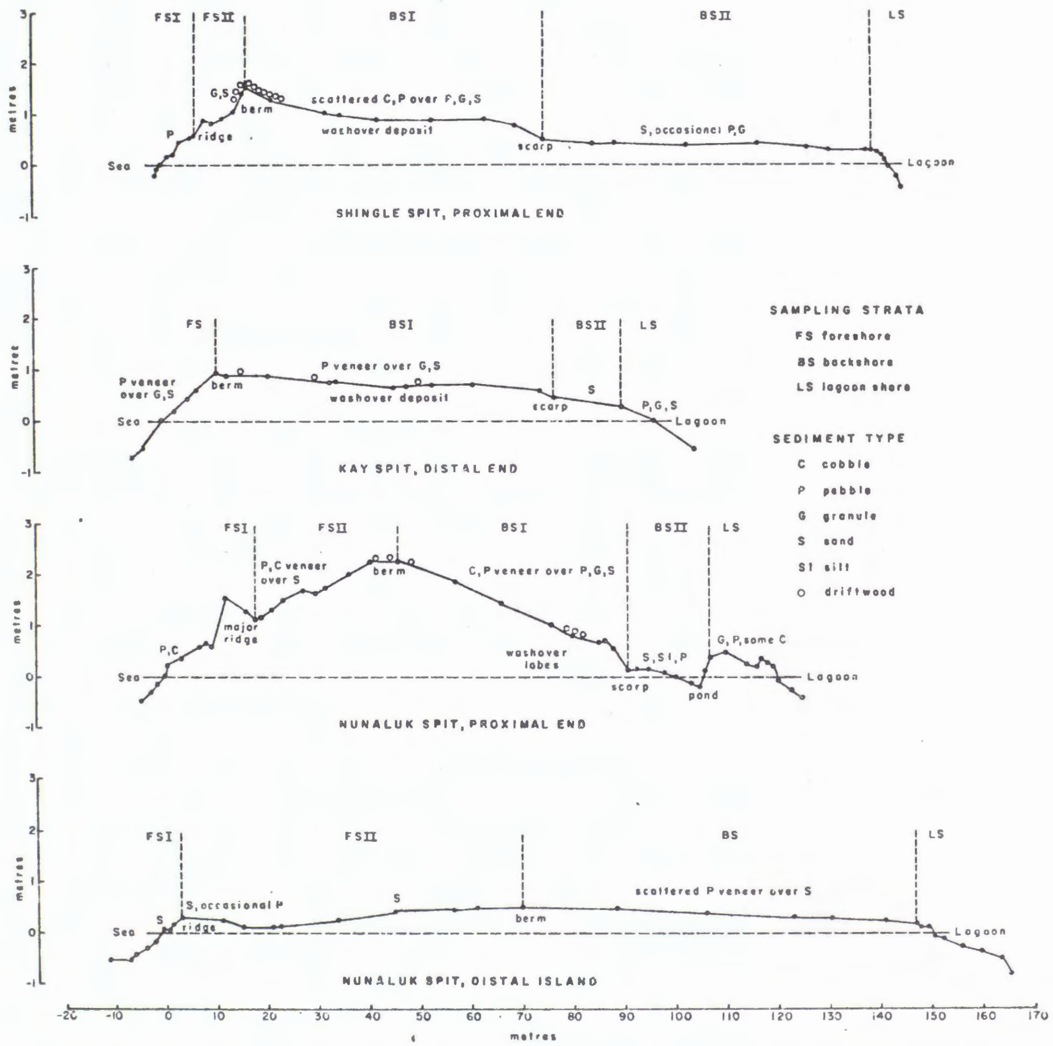


Figure 15. Selected Cross-sections with Sediment Types, Yukon Coast Spits.

6.2.1 Blow River Delta

The Blow River is somewhat smaller than the Babbage but its delta has approximately twice the subaerial extent of the Babbage delta (Table I). Unlike the estuarine Babbage delta, the Blow delta is arcuate in form, protruding out from the coastal cliffs rather than being protected by them.

Except in outline and exposure, the two delta plains are quite similar. Both contain several major distributary channels, extensive vegetated inter-levee flats and numerous lakes, some with connecting channels to the distributaries. Like the Babbage, levees in the lower Blow delta are almost indistinguishable, their relief seldom exceeding 0.5 m. Because of its proximity to the Mackenzie, much more driftwood has been stranded on the surface of the Blow delta than on the Babbage. The highest driftwood line on the Blow was formed during a storm surge which reached more than 2 m. above normal high tide and covered considerably more than 50 per cent of the subaerial surface in front of the coastal cliffs.

Texturally, the two deltas are also alike. Fine gravel in the upper Blow delta changes abruptly to silt in the lower (Walker and McCloy, 1969). Organic detritus appears to be more prominent in the Blow than in the Babbage, however. All lower delta plain samples show a high percentage of organics,with low scarps (up to 0.8 m. in height) cut into the vegetated delta-front alluvial islands being composed almost entirely of organic material (Figure 16).

These scarps, together with the absence of significant inter-tidal flats except near the mouths of active distributaries, suggest retreat of the subaerial front of the Blow delta, perhaps even more rapidly than the Babbage. Water depths off the front of the Blow are very shallow, though, so the retreat may depend upon the temporary location of distributary mouths and thus be more apparent than real. At one site near the major western distributary mouth, water depth was less than 1.0 m. out to 1.2 km. off-shore, increased in a series of steps to 2.5 m. at 1.3 km. and was constant at 2.5 m. depth to at least 2.1 km. from shore.

6.2.2 Shingle Region Coastal Cliffs

Cliffed shorelines offer only small areas which are regularly covered by sea water. They are, however, the prime sources of sediment for the major spits to be discussed in the next section of this report. Between Shingle spit and the Blow River delta the coastline is cliffed except at the delta of the Running River. Two areas of this cliff were examined in 1974, primarily for comparison with the Kay Point cliff study.

East of the Running River a largely unvegetated gravel scarp, gul-leyed at intervals along its length, rises at an angle of 32-35^{o} to an elevation of 15-20 m. Sediment eroded from this scarp is moved eastward along the narrow beach which fronts it and is the source of gravel found in a sequence of beach ridges on the western Blow River delta. West of the Running River the scarp reaches elevations of more than 30 m. but is

Figure 16. Blow River delta plain, east side; view southeast of organic coastal foreshore scarp. (7 July 1974; GSC 202717-I)

Figure 17. Shingle Point spit; view west; note shoreline pressure ridge at upper right and prominent driftwood line. (21 June 1974; GSC 202717-N)

less steep, mostly vegetated and composed predominantly of silts. Material reaches sea level primarily by mudflows and by erosion in gulleys. This cliff segment is similar in many ways to segment 2 at Kay Point.

6.2.3 Coastal Spits

The three spit areas studied - Shingle, Kay and Nunaluk (Figure 1) - are among the most prominent depositional features found along the Yukon coast. Of these, Kay has already been discussed. Shingle (Figure 17) and Nunaluk are longer, wider and higher (Table II) but are similar in form

TABLE II

Yukon Coast Spit Morphometry

Spit	Length (km.)	Mean Subaerial Width (m.)	Mean Berm Height (m.)	Foreshore[a] Slope	Nearshore[b] Slope
Shingle	5.4	141	1.53	0.085	0.006
Kay	4.9	61	0.96	0.066	0.010
Nunaluk	12.2	163	1.49	0.041	0.017

[a]Berm crest to shoreline

[b]Shoreline to 5 m. isobath

and, with localized exceptions, in the presence of both sand and gravel sediment types. The lower berm elevation of Kay spit may be due to the protection against the dominant southeasterly moving storm waves offered by Herschel Island and the bar between it and Kay Point (Figure 1). It does not appear to be related to nearshore slope (Table II).

Typical subaerial profiles and sediment types for each spit are shown in Figure 15. Four morphologic components (sampling strata) are common to most of the spit zones examined: foreshore, backshore I, backshore II, and lagoon shore. The significance of the surveyed foreshore geometry is difficult to evaluate because the upper portion is relic, undisturbed during the 1974 open water season. Berm elevation over the length of all spits is relatively constant except for a sudden drop from the end of the main Nunaluk spit to the distal islands (Figures 15, 18 and 19). Behind the berm crest, the backshore I stratum consists of washover deposits which overly older backshore II sediments. The boundary between the two is commonly an abrupt scarp. In the proximal zones of Shingle (Figure 20) and Nunaluk spits, the washover deposits appear to be transgressing, possible evidence of shoreline retreat. The lagoon shore stratum in all cases is lower and displays fewer and smaller ridges than the foreshore because of shallow depths, seldom exceeding 2 m., and short fetch in the lagoons.

Figure 18. Nunaluk spit, proximal end; view west along foreshore storm ridge, berm at far left.
(22 August 1974; GSC 202717-E)

Figure 19. Nunaluk spit, second distal island; view west along foreshore.
(16 August 1974; GSC 202717-L)

Figure 20. Shingle spit: unvegetated backshore I sediments (washover lobes) advancing over backshore II.
(7 July 1974; GSC 202717)

No consistent pattern of lengthwise variation in mean sediment size is apparent among the spits. Preliminary observations show Shingle to be relatively constant along its length; Kay coarsest at its proximal end and constant thereafter; and Nunaluk (Figures 18 and 19) with a gradual increase toward its distal end and a sharp decrease to almost pure sand on the second and third distal islands. Laterally, the foreshore stratum is both coarsest and most variable. Backshore II is much finer than backshore I with silt commonly present in addition to the usual sand and some gravel. Mean size increases, but not to foreshore levels, on the lagoon shore. These lateral changes are normal for spits at any latitude.

Nearshore bars exist off Shingle as well as off Kay, but are neither numerous nor prominent. No bars were found off the attached segment of Nunaluk spit in 1972 but a complex system of bars and channels existed seaward and between the distal islands, probably due, at least in part, to Firth River discharge (McDonald and Lewis, 1973). As at Kay, little evidence of ice scour was found in the nearshore areas of Shingle and Nunaluk spits, this phenomenon apparently ceasing at about the 10 m. isobath where winter shorefast ice begins (J.M. Shearer, pers. comm.). Nor were significant ice-related sedimentological features observed on the beaches of these two spits in 1974 but Alaskan observations (Hume and Schalk, 1964 and 1973; etc.) and 1972 observations on Kay spit (McDonald and Lewis, 1973) suggest that 1974 was an unusual year in this regard. A major shoreline pressure ridge lay off the proximal half of Shingle spit for most of the summer of 1974 (Figure 17) but, while it undoubtedly moved considerable quantities of sediment in the nearshore, it had no direct effect on the subaerial beach.

7. DISCUSSION

Because the areal extent of 1974 fieldwork represents only part of that covered by Geological Survey coastal investigations in the Beaufort Sea, it seems appropriate in this section to briefly discuss previous work to the east of the Yukon-Northwest Territories border in the context of the Yukon coast results. ?

The estuarine Babbage delta appeared to be of particular interest because, in a morphologic sense, it is similar to the modern Mackenzie delta. Hydrologically, however, the two are not nearly as similar. Unlike the Babbage, the Mackenzie flows all winter along its full length and is exotic, its break-up and flow being influenced to some extent by non-arctic conditions to the south. But like the Babbage, significant sediment transport events are confined to the break-up and summer flow periods and storm tides on the Beaufort Sea play an important role in deltaic sedimentation.

East of the Mackenzie delta, the northwest coast of the Tuktoyaktuk Peninsula, unlike the Yukon coast, is deeply embayed along much of its length, its shape reflecting the breaching of thermokarst lakes which cover large portions of the coastal plain. Large spits and long barrier bar sequences have formed because of the low offshore gradient, much lower than off most of the Yukon coast. These features protect much of the coast from direct wave attack. ?

Not well explained

The materials in the spits and bars reflect largely the nature of nearby and underlying deposits. To the south and west of the settlement of Tuktoyaktuk, beach materials are similar to those of the Yukon coast: pebble gravel in a medium sand matrix, derived from gravel lenses in fluvial outwash and from a pebbly clay till. To the north and east of Tuktoyaktuk, the gravel disappears and beaches are composed of medium to fine sand eroded from the more distal portions of fluvial and deltaic outwash deposits. Because of the predominance of sand, it can be difficult to distinguish stratigraphically between the depositional features and the underlying outwash (McDonald, Edwards and Rampton, 1973). Stabilized and partially stabilized dune zones are common along this segment of coast.

Like the Yukon coast, the northwest coast of the Tuktoyaktuk Peninsula is retreating, with both rates of retreat and resulting coastal configuration affected greatly by the nature and distribution of frozen ground. This effect is both direct, in that local rates of retreat are greatest where coastal cliff sediments contain considerable ground ice, and indirect, in that the shape of a large part of the coastline is controlled by apparent retreat due to the breaching of thermokarst lakes. Relic submarine frozen ground exists in many nearshore areas (Mackay, 1972; McDonald, Edwards and Rampton, 1973) because of this coastal retreat.

Although steep, cliffed shorelines occupy a much smaller proportion of the total length of the Tuktoyaktuk Peninsula than of the Yukon coast and no major rivers enter the sea along it, the size and number of depositional features suggest, even with the low offshore gradient, a ready availability of sediment. Much of this material is moved northeast, under the control of offshore currents and of discharge from the East

Channel of the Mackenzie River. In Kugmallit Bay, the effect of this regional drift on depositional shore features is very weak and these deposits primarily reflect local factors such as wind direction, nearshore bathymetry and coaatal orientation. To the east, however, the regional transport direction has more influence and large spits and barrier bars suggest coastal sediment transport northeast to Liverpool Bay.

8. CONCLUSIONS

The main scientific conclusions resulting from this study are:

1. The major geomorphologic features of the Yukon Beaufort Sea coast are: (a) steep coastal cliffs, often containing significant amounts of ground ice, and fronted by narrow beaches; (b) spits and barriers up to 10 or more kilometres in subaerial length and several hundred metres wide; and (c) deltas of coastal plain rivers with vegetated or partially vegetated subaerial delta plains up to 50 km.^{2} in area.

2. Cliff sediments range from gravel to icy clay. The fine material is moved off shore and beaches, spits and barriers are usually composed of remnant gravels and sands. Coastal plain rivers have gravel beds but this gravel does not reach the lower delta plains where sediments are primarily organic-rich silts and fine sands.

3. Cliff retreat of up to 90 m. in 16-18 years has occurred, largely through undercutting and subsequent block slumping, gulleying, and mud flow associated with ground ice slumps. Sediment derived from this retreat is moved along shore and has led to hundreds of metres of spit and barrier extension over the same time period.

4. Significant sediment transport events are associated with spring break-up and storm floods on the rivers and with meteorological tides and wave activity during these storms along the coast. Berm elevations of over 1.5 m. on spits and driftwood lines more than 2 m. above normal high tide on subaerial delta plains attest to the rise in sea level and inundation of coastal depositional features during these storms, most commonly in the summer and fall but occasionally during winter.

5. First flow in rivers, deltas and estuaries occurs well before sea ice break-up and is commonly over bottomfast winter ice. This ice inhibits bed scour during early flooding. Following spring break-up, river discharge declines except for brief rises during storm events.

6. The direct effects of sea ice on the stability of coastal features appear to be small. Only minor examples of the movement of beach sediment by ice push and scour of the nearshore sea bed by ice have been observed, this latter phenomenon apparently ceasing shoreward of the 10 m. isobath. Indirect effects, particularly the influence of the amount and location of ice on storm surges and associated wave activity, are much more important.

7. Offshore gradients can be quite steep off many portions of the Yukon coast, most commonly where the shoreline is cliffed. Profiles are generally concave upward and few nearshore bars exist. Off river deltas, though, depths are very shallow, seldom exceeding 2 m. a kilometre or more from shore. Shallow depths in the Babbage estuary prevent the development of significant vertical variations in water temperature and salinity.

8. Rapid coastal retreat, shallow water depths and low water temperatures have enabled the preservation or formation of permanently frozen ground beneath estuary and nearshore areas.

9. Unlike the Yukon coast, the northwest coast of the Tuktoyaktuk Peninsula is deeply embayed along its length, its shape reflecting the breaching of thermokarst lakes which cover large portions of the delta plain. Major spits and long barrier bar sequences have formed because of the much lower offshore gradient than off the Yukon coast. Sediments in coastal depositional features are mixed gravels and sands west of the settlement of Tuktoyaktuk and, most commonly, pure sand east of Tuktoyaktuk. Like the Yukon coast, the shoreline of the Tuktoyaktuk Peninsula is retreating, with most of the derived sediment being moved northeast toward Liverpool Bay.

9. IMPLICATIONS AND RECOMMENDATIONS

9.1 General Scientific

In an average year, the southern Beaufort Sea coast, particularly east of Herschel Island, has a relatively long open water season and cannot be considered true arctic in nature. Normal marine processes dominate for about three months of the year. During this time period, the arctic environment influences these processes only through the increased relative importance of extreme storm events, the occasional movement of sea ice near shore during these events and, as was so well demonstrated during the summer of 1974, through the major year to year variations in climate and sea ice conditions which may occur.

The response of coastal materials to summer marine processes, however, is conditioned by the arctic environment. Frozen ground plays an important role in the coastal zone, most importantly through its influence on rates of coastal retreat and, along the Tuktoyaktuk Peninsula, through the control by thermokarst lakes of coastal configuration.

9.2 Matters Relevant to Development

Development is considered here primarily with respect to the potential effects on the Beaufort Sea coastal zone of an oil spill during exploratory offshore drilling. Consideration is given as well, however, to the possible use of the coast for staging areas or other shore installations associated with petroleum exploration and development.

The details of coastal processes and responses, particularly for short-period events, are not yet well understood in the Beaufort Sea area.

The studies undertaken at Kay Point will go far toward remedying this situation. The discussion which follows, however, precedes the completion of these studies and its value must be considered in the context of this lack of knowledge.

1. The coastal zone is a dynamic one, particularly so in this part of the arctic where shore materials are unconsolidated and often contain significant quantities of ground ice. Its instability must be taken into account in considerations of both oil spills and coastline development.

2. The largest areas subject to frequent inundation by sea water and thus, potentially, by oil in that water are the river deltas, particularly the Mackenzie itself and, along the Yukon coast, the Blow and Babbage deltas. These deltas have a high silt content and their sediments are often rich in ground ice. Thermal disturbance through vegetation damage could lead to considerable thaw consolidation. Because the delta plains are major wildfowl nesting areas, oil <u>must</u> be prevented from reaching them.

3. Oil is most likely to reach the coast during summer and fall but open water and wave activity are possible even during winter. The sea ice was broken up off Kay Point and the Babbage estuary flooded during a severe storm in early January 1974 (R. Mackenzie, pers. comm.).

4. Shoreline materials are constantly in motion during the open water season and, with the continuous possibility of storm surges, oil from a spill could cover depositional coastal features at any time, be buried by subsequent sediment accumulation, exposed again, transported along the shore, re-buried, and so on.

5. In the event of an oil spill approaching the coastline, it may be possible to use lagoons behind spits and bars or, along the Tuktoyaktuk Peninsula, breached thermokarst lakes to contain it. The resultant potential for destruction of fish and wildlife is critical to this suggestion but, if other methods of containment are less reliable or cause even greater destruction, use of natural features may become viable.

6. Shore installations must be carefully located so as to avoid areas where large amounts of ground ice are present. Disturbance of the ground thermal regime will only serve to further increase already rapid rates of coastal retreat. Construction off shore must take into account the likely presence of and, because of low sea water temperatures, the possible growth of sub-bottom frozen ground.

7. Beach material is primarily local in origin, its maximum travel defined by the distance to the outer boundary of the feeder area of the near-shore sediment sink toward which it is moving. Removal of material or blockage of longshore drift for construction purposes will have effects both up- and down-drift. Because many natural features are important nesting areas and because disturbance at one construction site may

affect conditions at another, final selection of sites should be made only after the detailed nature of sediment supply in the area is known.

10. NEEDS FOR FURTHER STUDY

Work which has been completed to date has largely been descriptive in nature. Both the Yukon and Tuktoyaktuk Peninsula coasts have been covered in some detail. There remains possibly the most critical area of all: the modern Mackenzie delta below the highest storm surge driftwood line and the rapidly retreating Pleistocence islands which border it. Field operations will be more difficult to carry out in this area but should be completed before any judgements on the susceptibility of the Beaufort Sea coast to oil spills are made.

The second important gap in present knowledge has been mentioned several times in this report: the lack of information on the details of sediment movement during short-period storm events. Some data on this question will be available following the 1975 summer field season at Kay Point.

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