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PROJECT F3: GEOLOGICAL ASPECTS OF SUSCEPTIBILITY OF THE BEAUFORT SEA COAST TO OIL SPILLS

1. INTRODUCTION

1.1 General

SLIDE 1

(Map of Southern Canadian Beaufort Sea Coast)

(1) For the purposes of this study I have defined the coastal zone as the area between the highest storm tide line on land and the 10 m. isobath, commonly assumed to be the seaward limit of wave-induced sediment transport.

(2) We have already seen that this zone contains relatively large bird and fish populations and thus, from the biological point of view at least, might be greatly affected by an oil spill reaching the coast.

(3) It is also the part of the Beaufort Sea most used by man, both by industry and by natives, and, if it is inundated by oil, the effects will be highly visible.

1.2 Topics to be Covered

(1) I will discuss the geological aspects of coastal susceptibility to oil spills under the following headings:

1. Evidence of the directions of movement of coastal sediment and the implications for nearshore movement of oil; and

2. The types of coastal landform susceptible to the effects of an oil spill, either because they are subject to inundation by sea water or are capable of entrapping oil.

Specifically, I hope to discuss their distribution, geometry, composition, stability and relative susceptibility to a spill.

(2) There is a third major aspect to the susceptibility question that I won't mention in any detail because I can claim no expertise in it,

and that is the reaction between the oil, once present, and the sediments and vegetation which make up the coastal zone.

(3) I would hope that some of the botanists and chemists present could provide some input here.

(4) The area I intend to cover is shown on the map and extends from the Alaskan border to the eastern end of the Tuk Peninsula at Cape Dalhousie.

2. SEGMENTS OF THE BEAUFORT SEA COAST

2.1 Criteria for Subdivision

① Let me begin by trying to divide the coast into segments based on criteria which might be relevant to the movement of an oil spill in the nearshore zone.

② Except where rivers enter the sea, the nature of the Beaufort coast has been conditioned primarily by the erosion and redistribution of unconsolidated Quaternary sediments of the Arctic coastal plain.

SLIDE 2
(Topkak Spit)

③ The position and orientation of resultant depositional features, like this spit just east of Tuktoyaktuk, can be used to infer the dominant direction of sediment movement and thus the dominant current direction at any location where they are present.

④ Please note that I use the term dominant direction.

⑤ I don't mean to imply that this is the only direction in which nearshore currents can flow.

⑥ It is probable, though, that the dominant directions are those in which oil would move during major sediment transport events, that is to say during summer and fall storms when low lying areas could be flooded by the storm surges discussed by Dr. Henry this morning, and thus could be open to inundation by oil.

⑦ The fall 1970 storm raised the water level between 2 and 3 m. at Tuktoyaktuk and moved sediment supplied by up to 15 m. of cliff retreat, almost as much as had occurred during the previous 20 years.

SLIDE 3
(Map of Southern Canadian Beaufort Sea Coast)

⑧ I have plotted dominant current directions for the Beaufort coast on this map as black arrows and, on the basis of these directions, I've divided the coast into segments.

⑨ Each segment consists of a sediment sink toward which sediment is being moved and the contributing source area.

⑩ Their boundaries are indicated by the yellow lines on the map and each segment is labelled by the black letters with yellow backgrounds.

⑪ I will be referring to these throughout the remainder of this talk.

2.2 Coastal Segments

① Let's look briefly at these segments.

② Along the Yukon coast, sediment is transported to four main sediment sinks:

1. West to Demarcation Bay in Alaska (AREA A);
2. To between Herschel Island and the mainland (AREA B);
3. To Phillips Bay (AREA C); and
4. East to Shoalwater Bay on the west side of the Mackenzie delta (AREA D).

③ In AREAS E to I, current directions appear to be related to Mackenzie River discharge or to local factors such as coastal orientation and nearshore bathymetry.

④ Further east, in AREAS J and K, large spits and barriers suggest dominant westerly sediment movement except for a minor sink in McKinley Bay.

⑤ I would be very interested in the opinions of the oceanographers present as to the relationship between these nearshore directions and offshore conditions.

⑥ For the moment, though, let me suggest that, particularly during storm events, oil reaching the nearshore zone will tend to remain within the coastal segments I have identified and to move toward the sediment sink of each segment.

3. COASTAL LANDFORMS

3.1 General

① Let us move now to a discussion of the major landform types found along the Beaufort Sea coast and of their relative susceptibility to oil spills.

② Within each of the defined coastal segments one or more of the following types of landform dominate the coastline:

1. Steep cliffs, often containing significant amounts of ground ice, and fronted by narrow beaches;
2. Thermokarst lakes breached by coastal erosion;
3. Spits and barriers up to 10 or more kilometres in length and several hundred metres wide; and, lastly
4. Estuarine, arcuate and fan-type river deltas.

3.2 Coastal Cliffs

① Of these landform types, coastal cliffs occupy the largest portion of shoreline in all coastal segments except AREA E, the modern Mackenzie delta, and AREAS J and K at the eastern end of the Tuktoyaktuk Peninsula.

② This is fortunate in the present context because the cliffed shorelines offer, at most, only small areas which are regularly covered by sea water and thus subject to inundation by oil.

③ As I have already mentioned, though, these cliffs are retreating rapidly and, within most coastal segments, are the prime source of sediment for beaches, spits and barriers.

④ I should say, at this time, that we have, published or on file, a number of maps showing photogrammetrically-determined coastal change over the past 20 or 30 years.

SLIDE 4
(Kay Point)

⑤ Cliff retreat of 25-50 m. over that time period is common, most of which, as I have already suggested, occurring during relatively extreme storm events.

⑥ This view is of Kay Point in AREA C where about 90 m. of retreat occurred between 1952 and 1970.

⑦ Note the undercut bluff in the photo, taken during a storm last August.

3.3 Breeched Thermokarst Lakes

SLIDE 5
(Phillips Island Photomosaic)

① In addition to the coastal cliff sections, there is a second type of coastline which is basically erosional in nature and which is probably much more susceptible to the effects of an oil spill than are the cliffs.

② This photomosaic is typical of the coast in AREA K at the eastern end of the Tuktoyaktuk Peninsula.

③ At first glance the coastline appears drowned but, in fact, its outline reflects the breaching by coastal erosion of the lakes which cover much of this part of the Peninsula.

④ These lakes are commonly thermokarst in origin, resulting from ponding and resultant differential melting of excess ice in the sands and silts which form their boundaries.

⑤ Breaching leads to at least partial draining of the lakes and, if this drop in water level is sufficient to enable the lake to freeze to the bottom in winter, to the formation of pingos.

⑥ The "two-pingo lake" on this slide is about 1 m. deep.

(7) As coastal erosion continues, the former lake area is deepened, partly because of nearshore marine processes and partly because of continued melting of excess ice in the sediments.

(8) The area between the barrier bar and the "two-pingo lake" on this slide is flat-bottomed and about 3 m. deep but low-frequency echo sounding shows an irregular sub-bottom, generally less than 4 m. beneath the present bottom.

(9) This reflector may represent the boundary between nearshore sediments and the older and perhaps still frozen coastal plain deposits.

(10) In any case, a newly breached lake provides an excellent trap for an oil spill.

(11) Oil could be carried into a lake during normal flood tides or storm surges.

SLIDE 6
(Two-Pingo Lake)

(12) Granted it might be pulled out again by ebb currents but, unfortunately, AREA K, where breached lakes are most numerous, is also the only coastal segment, except for river deltas, which contains extensive tidal flats.

(13) This slide shows tidal flats in and near the "two-pingo lake" of the last photograph.

3.4 Spits and Barriers

(1) Let us turn now to the depositional features found along the Beaufort Sea coast.

SLIDE 7
(Kay Point Spit)

(2) Spits, like this one at Kay Point in AREA C;

SLIDE 8
(Cape Dalhousie Barrier)

and barriers, like this one at Cape Dalhousie in AREA K, front significant portions of most of the coastal segments I have identified.

[SLIDE 1]

(3) They are particularly extensive in AREA B on the Yukon coast and in AREAS H, I and J on the Tuk Peninsula, where they reach lengths of more than 10 km. and subaerial widths in excess of 200 m.

(4) Most importantly, in the context of this talk, these features lie, in their entirety, below the highest storm tide line and thus are susceptible, at any time, to inundation by oil.

(5) As well, the shallow lagoons behind them could function in much the same way as thermokarst lakes and act as traps for oil.

(6) The size of spits and barriers is a function of both offshore gradient and sediment supply.

(7) They are largest where gradients are low as they are off all of the Tuk Peninsula or where the supply of sediment is large as it is at Nunaluk spit in AREA B where material from the Firth and Malcolm rivers is added to that supplied by updrift cliff erosion.

SLIDE 9
(Spit Cross-sections)

(8) Their height and cross-sectional form, on the other hand, are at least partially dependent on sediment size.

(9) The upper cross-section in this diagram, of shingle spit in AREA D, is typical of the sandy gravel spits and barriers found along the Yukon coast and along the Tuk Peninsula west of Tuktoyaktuk.

(10) Four morphologic components are usually present:

1. A relatively steep and coarse-textured foreshore subject to wave activity throughout the open water season;
2. A backshore 1 component, consisting of washover deposits laid down during major storm events; and which overlies
3. The third component, labelled backshore 2, whose sediments are finer, often containing a significant proportion of silt, and which is often vegetated; and
4. The lagoon shore, coarser than backshore 2, but lower and finer than the foreshore because of shallow depths and short fetches in the lagoons.

(11) The contrast between sections like this where gravel is present and those of pure sand is well illustrated by the lower two profiles in this diagram, both from Nunaluk spit in AREA B.

(12) The sandy distal island is much lower in elevation and lacks the backshore 2 component of the gravel proximal section.

SLIDE 10
(Nunaluk Spit, Proximal Foreshore)

(3) This is a view of the foreshore at the proximal or landward end of Nunaluk,

SLIDE 11
(Nunaluk Spit, Distal Island)

and this of the distal island.

(4) Pure sand features like this are rare along the Yukon coast but the form of this island is very similar to that of sand spits and barriers east of Tuktoyaktuk on the Tuk Peninsula.

(15) To this point, I have discussed these spits and barriers as if they were static features.

(16) They are, in fact, far from that but the details of their instability are difficult to evaluate in a large area, short-term study.

(17) Our photogrammetric data indicates that pronounced changes in form have occurred during the past 20 or so years and that many spits and barriers have lengthened, some as much as 500-600 m.

(18) Like cliff erosion, sediment movement on depositional features is undoubtedly most significant during storm events which occur when the sea ice is far offshore but, as yet, we have almost no quantitative data on the changes caused by particular synoptic-scale events.

3.5 River Deltas

SLIDE 12
(Mackenzie Delta, Outer Plain)

(1) Our knowledge of the short-term dynamics of river deltas, the fourth and last major landform type I intend to discuss, is equally minimal.

(2) This is a serious gap because, except for the high angle fan deltas of the Firth and Malcolm rivers in AREA B, the major Beaufort deltas offer extensive vegetated flats which lie below the highest storm tide line and thus are susceptible to inundation by oil.

(3) These inter-levee flats also contain numerous lakes, some with connecting channels to delta distributaries, in which oil could be trapped.

(4) The largest Beaufort delta is, of course, the Mackenzie itself, with an area of almost 800 km.^{2} lying below the green 3 m. levee height contour plotted on the map (Slide 1).

(5) This view is typical of this seaward portion of the Mackenzie.

SLIDE 13
(Babbage River Delta)

(6) The other two important deltas are the estuarine Babbage in AREA C, shown here during spring flood when the delta plain is mostly submerged,

SLIDE 14
(Blow River Delta)

and the arcuate Blow in AREA D which protrudes out from the coastal cliffs rather than being protected by them as are the Babbage and the Mackenzie.

(7) Despite the disparities in size and outline form among these three deltas, they are remarkably similar in morphology in their lower portions and probably in long-term stability as well.

SLIDE 15
(Blow Delta, Organic Scarp)

(8) Sediments are predominantly frozen silts and fine sands, often with a very high organic content, and with only minor amounts of excess ice.

(9) This scarp, at the front of the Blow delta, is almost completely organic in nature.

(10) Less information is available on the stability, either long- or short-term, of the lower portions of these deltas.

(11) Both historical records and aerial photographic sequences, though, suggest remarkable stability, probably due largely to the inhibiting influence of frozen ground on catastrophic channel shifts.

(12) Hydrologically, the three deltas are not as similar.

(13) Unlike the Blow and the Babbage, the Mackenzie flows all winter and is exotic, its break-up and flow being influenced by non-Arctic conditions to the south.

SLIDE 16
(Babbage Estuary, First Flow)

(14) On the Blow and Babbage, first flow in spring occurs well before sea ice break-up and is commonly over bottomfast winter ice.

(15) This view is of the Babbage estuary on May 20th of last year.

(16) But like the two smaller deltas, though, significant sediment transport events on the Mackenzie are confined to the break-up and summer flow periods and storm tides greatly influence sedimention on the outer delta.

(17) As I have said, it is during these storm surges that a delta plain might be inundated with oil.

(18) What we don't know is how and under exactly what conditions oil on salt water could penetrate the outflowing, surface, fresh water wedge and reach the delta plain.

(19) That it can do so is highly probable.

(20) Many of the inter-levee lakes are brackish and Mackenzie River driftwood is found far up the Blow and Babbage deltas.

(21) Dick Herlinveaux called the southern Beaufort Sea an estuary.

(22) I hope I have made you aware that this estuary extends well above the normal shoreline and that study of the circulation in this upper estuary should be an important part of the Beaufort Sea Project.

CONCLUSIONS

① To conclude then, I have tried, in the brief time available to me, to skim the highlights of our study of coastal susceptibility to oil spills.

② I hope that I have been able to leave you with the following impressions:

1. That oil reaching the nearshore in a given coastal segment will tend to move toward the sediment sink of that segment;
2. That coastal features subject to inundation by storm tides or capable of trapping oil are most susceptible to the effects of an oil spill - specifically deltas, spits and barriers, and breached thermokarst lakes;
3. That the Arctic environment plays a major role in coastal dynamics, both on the process side through the exaggerated importance of extreme events and the effects of sea ice, and on the response side through the role played by permanently frozen ground; and finally
4. That, at present, our knowledge of extreme synoptic-scale events and of the reaction of coastal features to these events is inadequate.

THANK YOU