Offshore Drilling for Oil in the Beaufort Sea: A Preliminary Environmental Assessment

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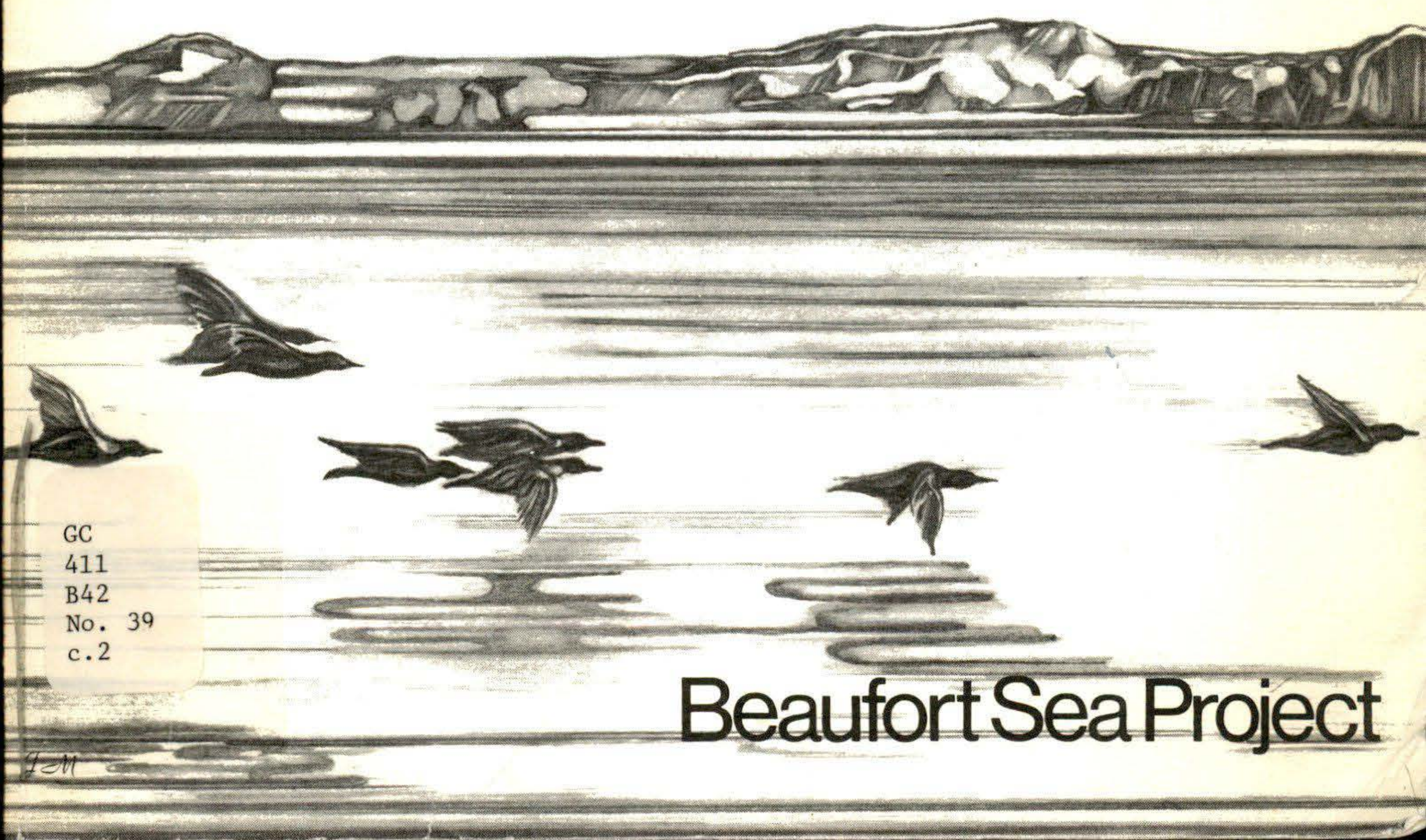
Technical Report No. 39



Beaufort Sea Project

OFFSHORE DRILLING FOR OIL
IN THE BEAUFORT SEA

A PRELIMINARY ENVIRONMENTAL ASSESSMENT

(Revised January 20, 1976)

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This ASSESSMENT of 20 January, 1976 has been prepared by the staff of the Beaufort Sea Project Office. The contents attempt to reflect faithfully the essence of the technical reports of the Beaufort Sea Project, and where these were not available, the valued distillations from communications with Project Investigators. Acknowledged is the assistance given by the Steering Committee and the Advisory Committee of the Beaufort Sea Project.

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INTRODUCTION

Drilling for oil using ice-strengthened drill ships is proposed for ice-free periods starting in the summer of 1976 at two sites. These sites, shown in Figure 1, are inaccessible during the winter and spring to any existing drilling systems. The scale of activities for 1976 is small, therefore the only really major impact on the environment would result from oil discharged into the sea in the event of an underwater blowout. Although the possibility of a blowout occurring is remote, it cannot be ignored. There is a whole series of possibilities and conditions that will determine the severity of the impact of a blowout on the environment such as:

- whether it is just a gas blowout;
- if it is gas and oil, what is the discharge rate of the oil;
- whether or not it is self-sealing;
- when during the drilling season the blowout occurs;
- how long it will run wild before a relief well could shut it off;
- what kind of oil it is;
- the probable effectiveness of proposed oilspill countermeasures;
- where the escaped oil would spread to;
- how weather conditions, such as storm surges, wind and sea state would affect the spread of oil and the ability to contain oil;
- once spread to coastal areas and in the sea ice, what its affect would be on organisms;
- would there be any changes in the climate;
- how long would it take for wildlife populations to recover;
- would there be local and possibly international ramifications to depletions of some wildlife species.

This report is an *environmental assessment* and by assuming hypothetical oil well blowout scenarios, examines the nature of the transport and fate of oil in the Beaufort Sea and draws conclusions regarding the impact of the oil on the environment, including climate, seabirds, marine mammals and other marine organisms.

This report does not:

- describe or assess the drilling technology;
- describe in detail the oilspill countermeasures proposed for use in the event of an oil well blowout;
- describe past offshore drilling blowout events or deduce blowout statistics;
- comment on the socio-economic aspects of exploratory drilling in the Beaufort Sea;
- assess policy issues related to alternative energy sources;
- judge whether or not a drilling authority should be issued.

Assuming a "worst-case"* sub-sea oil well blowout, major conclusions are as follows:

- The blowout would run wild for at least one year, until a relief well could bring it under control;
- Access to either site for relief well drilling in any summer is not guaranteed;

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*In the sense that the blowout maintains its full rate of oil flow and does not self-seal.

- Even though a wild well could discharge oil for a year or more into the Beaufort Sea's ice, any premature melting which would be caused would be indistinguishable from natural ice-cover fluctuations; hence, no climate changes should be attributed to oil in the volumes expected;
- Oilspill countermeasures for 1976 will not greatly decrease the impact of oil on wildlife;
- The wildlife most seriously damaged would be seabirds;
- It is judged that none of the damage would be irreversible but that recovery would be as long as a decade in some cases;
- Except for birds the economic values of Beaufort Sea wildlife are small compared to oil industry expenditures. The birds are a continental resource with a high indirect economic value. The major values threatened must be judged primarily on sociological and environmental grounds, not economic.

EXPLORATORY DRILLING, 1976

The Concern: Almost the whole of the Canadian portion of the continental shelf of the Beaufort Sea has been subject to permits by oil companies for a number of years. Seismic and other geophysical surveys have been carried out fairly intensively over the whole area. It is regarded as promising with respect to gas and oil reserves. To date the only drilling which has taken place offshore in the Beaufort Sea has been from artificial islands constructed in shallow water close to the Mackenzie Delta. However at least some sectors of the industry are now anxious to see exploratory drilling in areas of deeper water farther offshore.

The Canadian Marine Drilling Ltd. (Canmar), a wholly owned subsidiary of Dome Petroleum, plans to drill two wildcat wells in the southern Beaufort Sea during the summer of 1976. Two drill ships, currently under modification in Galveston, Texas, expect to be simultaneously "spudding in" on two continental shelf sites by the 1st of August (Figure 1).

In the future, an expansion of exploratory drilling, perhaps followed by the drilling of production wells and the laying of pipeline networks will clearly have extensive environmental and sociological implications which will have to be dealt with by appropriate authorities. However, of immediate concern is how the Beaufort Sea environment might be degraded by Canmar's proposed exploratory drilling in 1976. The major immediate environmental threat is a marine oil well blowout, which overshadows all others, connected with this limited exploratory drilling program.

Three questions arise: What is the probability of a blowout? What are the probable consequences of a blowout? What is the capability to control the blowout and to clean up oil which escapes control? This preliminary assessment is mainly concerned with consequences and clean-up, but it must also deal with the nature of ice conditions in the Beaufort Sea as it influences the viability of drill ships' operations, and in particular, their ability to drill a relief well.

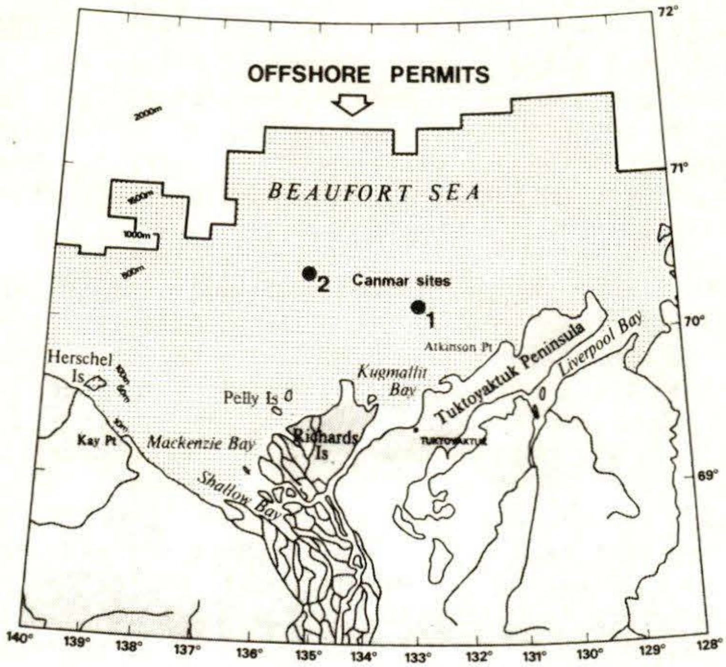

Figure 1. Offshore permits and Canmar's proposed exploratory drilling sites.

Drilling Authority and the Beaufort Sea Project: A Cabinet decision in July, 1973, granted "Approval-in-principle" for Dome Petroleum to conduct exploratory drilling using drill ships in the Beaufort Sea. Before actual drilling can take place the "Approval-in-principle" must be followed by a "drilling authority" issued by the Department of Indian and Northern Affairs. Because of inadequate knowledge of the Beaufort Sea environment, two riders were subsequently attached to the Cabinet decision: first, the actual drilling would not take place before the summer of 1976; second, the authority would be issued conditional on constraints which would be determined on the basis of a regional environmental assessment, which was subsequently called the Beaufort Sea Project.

The Department of the Environment's Beaufort Sea Project required an estimated 5.3 million dollars in new funds. In the spring of 1974, the Government, in a policy decision, requested that the petroleum industry provide 4.1 million dollars of these funds. The petroleum industry subsequently agreed and spread their support over 21 of the studies under APOA (Arctic Petroleum Operators' Association) Project No. 72 with 18 companies participating. Provisions under which the 4.1 million dollars were to be transferred to the Government were set out in an Industry-Government Agreement with December, 1975 being the target date for completion. The total cost of the Beaufort Sea Project will exceed 12 million dollars by the time the project has been completed and includes the value of in-house Government expenditures added to an actual 6.0 million dollars of new funds.

The Beaufort Sea Project includes many studies aimed at filling major gaps in existing information. The assessment has nevertheless depended heavily upon data acquired over past years by Government scientists, and to some extent on earlier studies conducted for the industry. The project accelerated the pace of baseline studies of wildlife, oceanography and marine geology and included studies on sea-ice, the behaviour of oil in ice, oilspill countermeasures, climatology and environmental prediction. The Industry-Government Agreement requires all reports to be made public. The industry has been able to publicize its participation by means of a contracted "Public Interface Program" which acquainted the northern communities with the Beaufort Sea Project.

While the completion of the Beaufort Sea Project is a prior condition to the granting of a drilling authority, the final conditions with respect to this authority will depend not only upon environmental conditions revealed by the Beaufort Sea Project but upon other factors of a technical nature such as the drilling program proposed for each site and the type of equipment used. These other factors lie outside the scope of the Beaufort Sea Project.

The nature of drilling in the areas where Canmar proposes to drill in 1976 is to some degree different from other offshore drilling in Canadian waters. To date drilling authorities for wildcat wells in the Arctic and elsewhere offshore have been granted where it is possible to extend the drilling season sufficiently long in order to implement measures to control a wild well. However, such precedences cannot be strictly adhered to at the proposed drilling sites. It is evident from the description to follow that if a blowout were to occur in the latter part of the drilling season of 1976, the earliest completion date for a relief well would be toward the end of September, 1977, and there is no assurance that the well would not run wild for yet another year.

Canmar's Sites and Relief Well Drilling: Drill ship operations on the continental shelf of the Beaufort Sea differ significantly from those in areas explored hitherto. The major difference is the presence of sea ice which probably precludes drilling operations from ships for the greater part of the year, and in some years for the whole year. For example, if Canmar had been granted a drilling authority for operating with two drill ships starting the summer of 1973, they could possibly have completed two wells in 1973, would have been able to conduct virtually no drilling in 1974 and could have started two, but at most completed only one, in 1975. If a blowout had occurred in late 1973, and had not been self-sealing, it would not have been possible to start a relief well in 1974. One could have been started in 1975, but it is not certain that it would have been possible to complete it.

Canmar has incorporated special ice resisting features in their drill ships and supply vessels in order to combat ice intrusions. The extent to which these features may be successful is touched on in "relief well drilling" in the context of the oil well blowout scenarios developed later on.

The problem of drilling a relief well is aggravated by the fact that both of the Canmar sites are located within a transition zone between the offshore polar pack to the north, and what late in winter, becomes landfast ice to the south. Other than in the short summer's drilling season, the transition zone contains ice which is moving and actively shearing. Although ice breaking vessels could be used to extend the drilling season into the fall, the ice in this region can be too thick in winter to be handled by any existing ship, including the largest icebreakers, but at the same time it is too mobile to permit the use of ice as a platform from which to drill a relief well. Only in a summer period of perhaps three months, and sometimes not even then, is there a time interval in which drill ships can operate.

Probability of a Blowout in the Summer of 1976: It is very difficult to ascertain the probability of a blowout, since the number of offshore blowouts worldwide which produced substantial oil pollution has been too small to produce a satisfactory statistical base, and the particular conditions in the Beaufort Sea are unusual. Nevertheless, on the basis of information given by representatives of the industry and by DINA and DEMR the probability of an oil or an oil and gas well blowout is judged to be in the range of 10^{-3} to 10^{-4} for each well drilled. As more wells are drilled, the cumulative probability of a blowout would increase. However, if experience is gained in drilling in the Beaufort Sea, the risks per well could be reduced.

Some Effects of Crude Oil on the Aquatic Ecosystem: The effects of the interaction of crude oil with marine organisms are complex and are extremely difficult to predict in advance of a polluting incident. Direct mortality of marine life through poisoning, coating and asphyxiation is usually associated with coastal oil spills. There is also physiological damage to organisms such as reduced fertility and lower body resistance to infection, generally resulting from prolonged exposures to sublethal levels of oil. Disruption of normal migratory and spawning behaviour and feeding habits can occur due to the animals' avoidance reactions to oil. Sometimes there is absorption of oil particles into suspended solids which eventually settle to the sea bottom. These sedimented oil particles could be chemically re-introduced into the food web by benthic feeders. Changes in water chemistry resulting from the introduction of water-soluble components of crude oil can upset the natural balance of dissolved gases and nutrients.

The extent and severity of damage to arctic marine organisms by crude oil depends on numerous factors such as the amount and type of crude oil spilled, the location of the spill, the time of year, the presence of sea ice, water turbidity, and obviously the abundance and distribution of plant and animal life and their exposure time to the oil.

Blowout Scenarios and the Effectiveness of Oil Countermeasures: Canmar has taken the question of countermeasures in the event of a blowout seriously. To what extent can their proposed countermeasures reduce the damage which is to be expected in the event of a blowout? A realistic examination of this question leads to the conclusion that although under very favourable conditions a large fraction of the oil released might be successfully dealt with, the percentage of the time of a blowout when these very favourable conditions would occur is an estimated 45% so that a large fraction of the oil would escape. Indeed since the rate of flow of oil used in a scenario is entirely hypothetical, the actual flow could vary from a small fraction of a hypothetical 1500 barrels a day to several times this, it would seem necessary to assume in any blowout scenario that the oil which escapes is not much less than the oil released by a blowout. No control systems at present available, including the ones proposed by Canmar, (other than sealing off the well by the drilling of a relief well or some other technique), shows promise of reducing the possible damage from an oil spill by a factor of ten.

The Preliminary Environmental Assessment: The method adopted in this preliminary assessment is to compare the potential for damage which would result from an oil well blowout occurring at either of Canmar's sites #1, #2 and at a hypothetical site #3 located in the landfast ice zone. Pathways and fates of oil are described in scenarios, or narratives; these are used as the foundation for assessing the impacts on wildlife.

THE BEAUFORT SEA

Geographical Setting: The Beaufort Sea, named for Admiral Sir Francis Beaufort, generally includes the waters off the north coasts of Canada and Alaska, bounded in the east by Banks Island and in the west by the Chukchi Sea. The region of immediate concern is the southeastern Beaufort Sea which lies between the Alaska-Yukon border on the west to Cape Dalhousie in the east and northward to 72°N. Offshore permits, granted to oil companies in this region, (Figure 1) extend 170 km seaward to depths of 1000 m, but generally do not reach beyond the upper continental shelf.

During the months of July, August and September there is often extensive open water navigable by ice-strengthened vessels to varying distances offshore depending on the distance the polar pack recedes northward. In the summer, the inshore surface waters are turbid, fairly warm and fresh because of the vast flow of the Mackenzie River, but are cooler and more saline further offshore where Arctic Ocean waters are encountered.

Three main physiographic features are present: the *continental shelf* which grades gently toward depths of 100 m; the *continental slope* which falls steeply from the shelf edge; and, the V-shaped *Mackenzie Canyon* which transects the continental shelf. Features on the continental shelf are ice-scour marks and pingos. Ice-scours (Figure 2) are linear troughs produced mainly by the keels of pressure ridges* in the winter and are evident in all depths to 75 m or so. Pingos, occurring sporadically on the shelf, are ice-cored conical mounds up to 300 m in diameter at their base and rise within 15 m of the sea surface. Another feature of the shelf is the existance of sub-seabottom permafrost (Figure 3). While drilling through sub-sea permafrost is more related to drilling technology than ecology, it is a factor which makes offshore drilling in the Beaufort Sea different from other areas. Discontinuous permafrost is generally less stable than continuous permafrost because it is closer to the melting point.

The coast is generally low-lying; the Yukon coast, west of the Mackenzie River, differs from the outer coast of Richards Island and Tuktoyaktuk Peninsula. The Yukon coast is characterized by three main features: steep coastal cliffs containing ground ice and fronted by narrow beaches; spits and barrier beaches up to 10 km long and a few hundred meters wide; and partially vegetated deltas of coastal rivers, such as the Babbage and the Blow. In contrast, the north shorelines of Richards Island and Tuktoyaktuk Peninsula have deep embayments

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* Ridges of sea ice which originally form when ice floes move against each other.

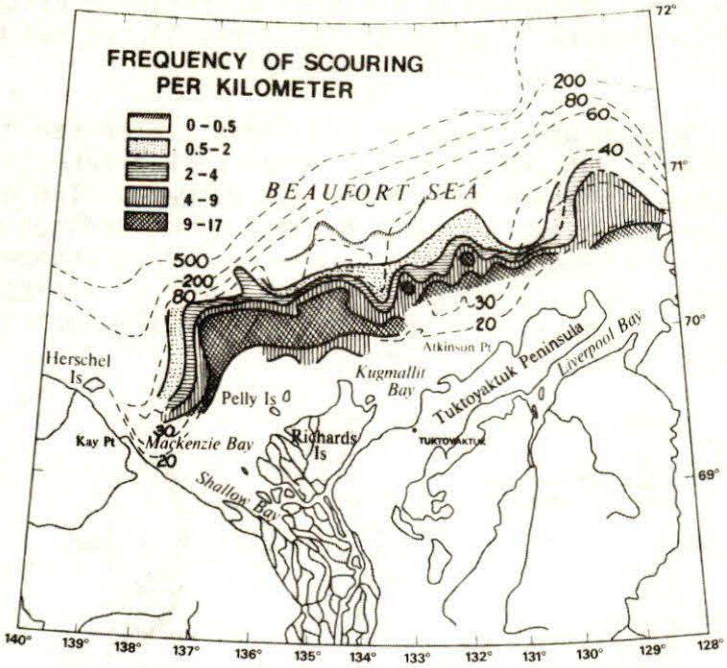

Figure 2. Bottom scouring by sub-ice projections on the continental shelf. Shaded areas depict the number of scours per km measured perpendicular to the depth contours. Depths are in meters.

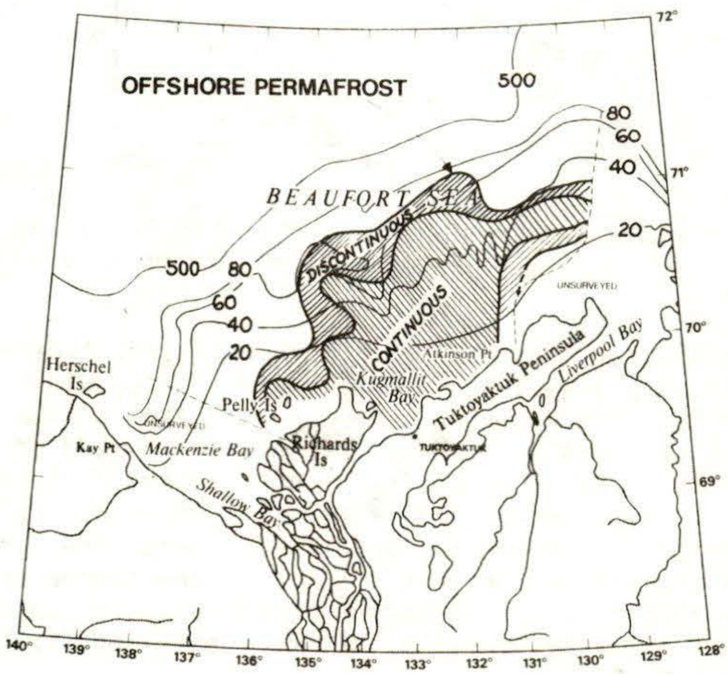

Figure 3. Surveyed portion of the continental shelf showing areas of continuous and discontinuous ice-bonded sediments as inferred from seismic refraction records. Depths are in meters.

caused by the breaching of thermokarst lakes* which are particularly common on the Mackenzie River delta. Sediments from coastal retreat move locally up and down the coast.

Sea Ice Features: The growth, movement and decay of the sea ice in the eastern Beaufort Sea is influenced by the polar pack interacting with the coastlines, the Mackenzie River and the arctic climate. The average movement of the offshore pack ice is caused by mean wind stresses over the Arctic Basin, resulting in a clockwise gyre or ringlike movement (Figure 4). The clockwise speed of the ice near the rim of the gyre varies from zero at times, to as much as 25 km/day for short periods in the springtime. Its average yearly speed is about 3 km/day.

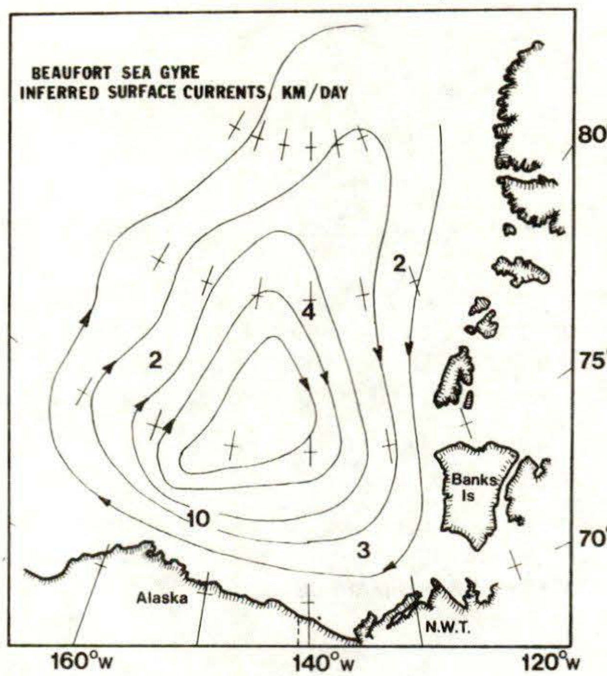

Figure 4. Average yearly surface currents in km/day inferred from the analysis of weather systems over the Beaufort Sea.

In summer, the polar pack consists mainly of multi-year floe ice, pressure ridges, rotted 1st year ice, leads and polynyi. In the winter, growing 1st year ice replaces the open water and the wind-stresses on the ice produce flaw-leads and new pressure ridges. Under short-term wind stresses, the centre of the gyre can shift, resulting in onshore or offshore movements. Onshore movements in the winter and spring are limited by the growth of landfast ice in the coastal bays and shallow shelf waters; the landfast ice generally extends seaward to depths of 25 m. In the summer however, excursions of polar pack ice into the southeastern Beaufort Sea are controlled by the vast flow of fresh water from the Mackenzie River, local wind fields and the shallow shelf waters.

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* Lakes which form in depressions left by the melting of ground ice.

Extensive scours are produced on the sea-bottom of the shelf by the onshore and alongshore movements of sea ice. These are produced mostly in the winter and spring by the grounding of under-ice projections such as pressure ridge keels. Side-scan sonar surveys have revealed the ancient and more recent history of scouring. These results are summarized in the map of Figure 2. This figure shows the variation of the number of scours observed per km. Scour trenches generally do not exceed 2 m in depth, but in places are as much as 6 m deep. Scours in waters deeper than 50 m probably formed during the end of the glacial period when sea level was much lower than at present. The common orientation of scour tracks is 105°T. Scouring is common in water depths of 15 m to 45 m with the maximum activity at 30 m within the transition zone. These depths can be viewed in the light of recent knowledge of depth dependent sea ice features such as the following. In the springtime, the landfast ice extends seaward to depths of 25 m. Submarine upward-looking sonar records show that the deepest pressure-ridge keel so far observed in the Arctic Ocean drew 49 m of water. It is inferred, from observations of the prevalence and heights of pressure ridges in the Beaufort Sea, that each point on the 27 m depth contour on the continental shelf is likely to be contacted, but not necessarily scoured, once a year, unless protected by bottom topography.

Another sea-bottom feature, perhaps related to scours, or possibly related to a sub-aqueous slump, was observed from the submersible Pisces IV during the summer of 1975. A 20 m deep, rimmed, conical-shaped hole was observed in 100 m of water near the edge of the continental shelf north of Kugmallit Bay. The prevalence of this feature is unknown.

During November and December, the landfast ice grows in thickness and increases its area in a series of steps seaward depending partly on onshore winds. These winds consolidate loose floes at the fast ice edge where they remain in place during offshore drifts. By April, the landfast ice has grown to a thickness of 2 m.

Although the polar pack is sometimes blown well offshore in a light ice year, its nearshore boundary in winter usually lies over the 500 m depth contour near the edge of the continental shelf. Lying between this pack edge and the fast ice is a *transition zone* of deforming, sporadically moving, heavily ridged and highly irregular ice. This zone of active shearing provides open water, albeit temporary and variable, in winter and spring. The transition zone ice often resembles the polar pack but includes an increasing number of pressure ridges and more first-year ice as the landfast ice is neared.

The beginning of break-up in the southern Beaufort Sea is first evident as early as March with the widening of flaw-leads west of Banks Island, under the thrust of E and SE winds. The simultaneous westward and clockwise movement of the gyre away from Amundsen Gulf produces another long flaw-lead at either the seaward edge of the landfast ice or further offshore in the transition zone. Additional radial leads, perpendicular to the coast, also open in the transition zone, forming part of an extensive interconnecting lead system. By April, ice from Amundsen Gulf moves westward to fill the increasing spaces of open water between the fractured ice of the transition zone. This process is illustrated in Figures 5 to 9 which show major ice movements observed in NOAA satellite imagery from March 11 to June 21, 1975.

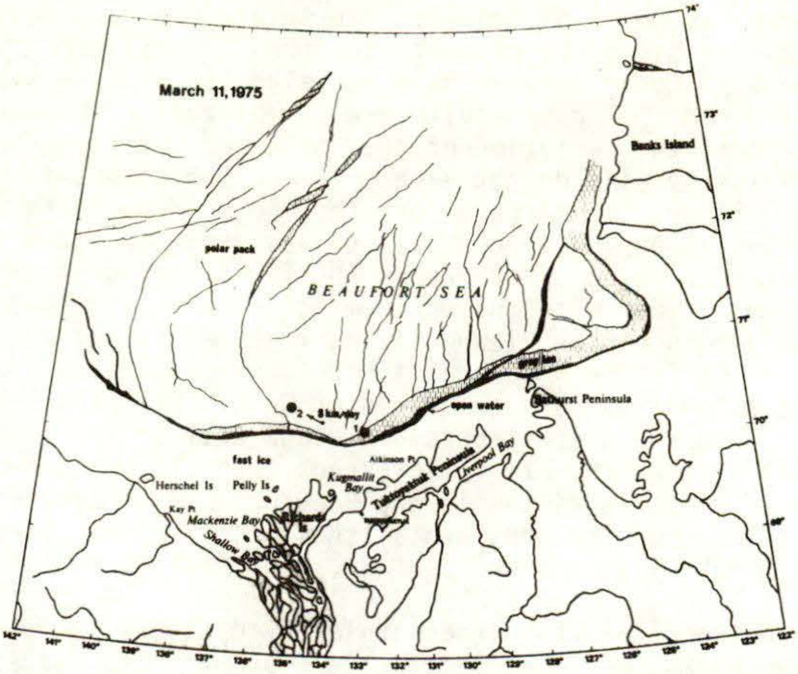

Figure 5. Ice configuration on March 11, 1975 from NOAA satellite imagery. The ice drift rate near the Canmar site was 8 km/day.

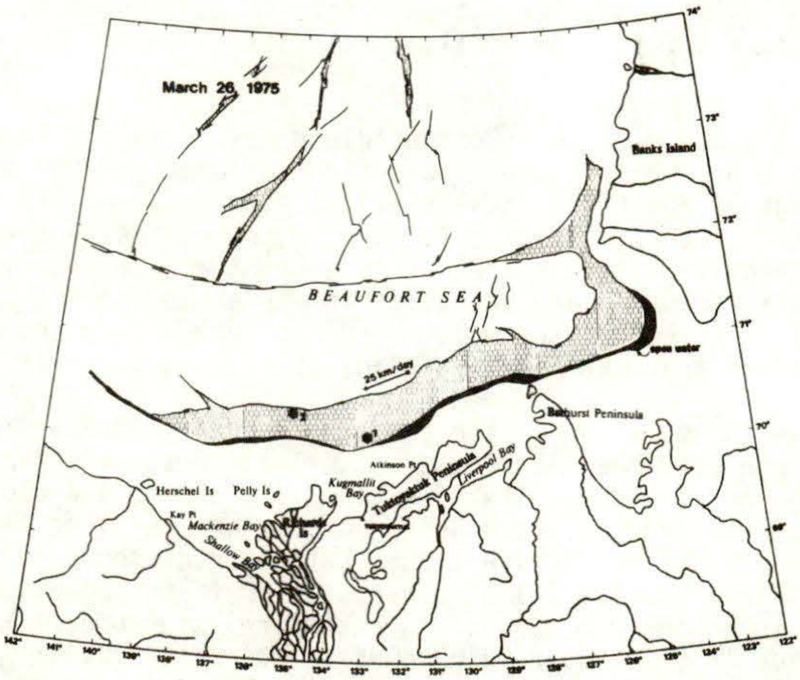

Figure 6. Ice configuration on March 26, 1975 from NOAA satellite imagery. Both Canmar sites are located within a wide E-W lead partially covered with new grey ice. The ice drift rate to the west was 25 km/day.

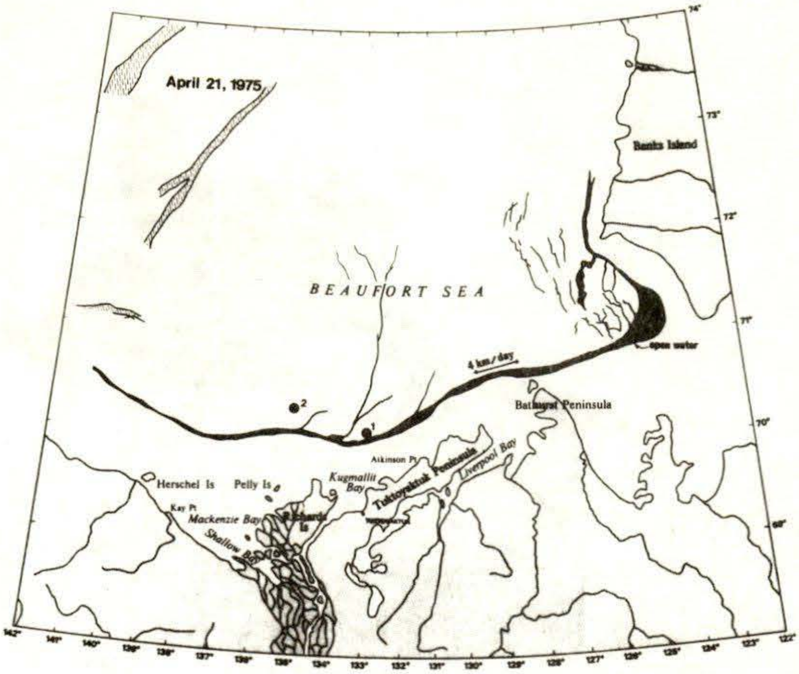

Figure 7. Ice configuration on April 21, 1975 from NOAA satellite imagery. The main E-W lead has narrowed and the ice drift rate has diminished to 4 km/day.

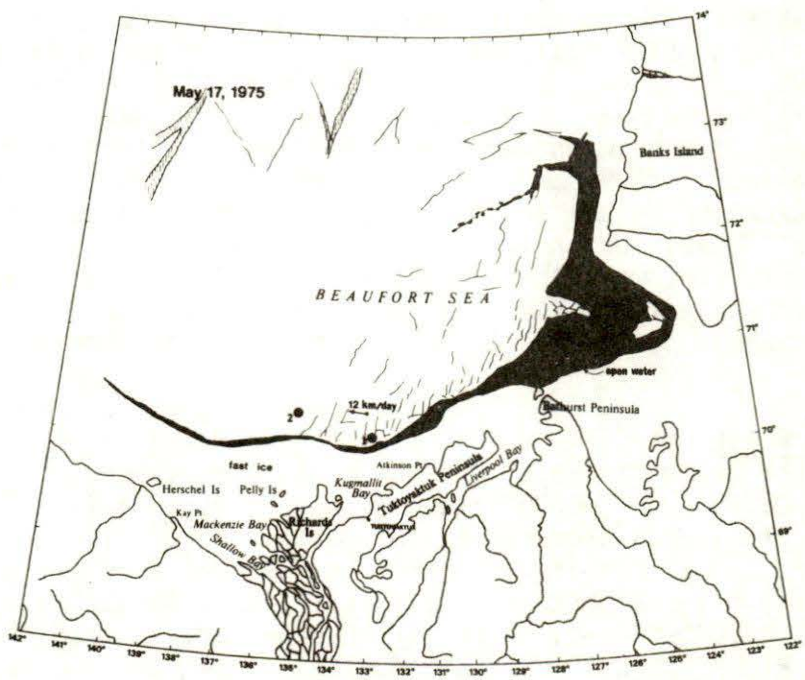

Figure 8. Ice configuration on May 17, 1975 from NOAA satellite imagery. A huge polynya has opened north of the Baillie Islands and the westward ice drift near the Canmar sites has increased to 12 km/day.

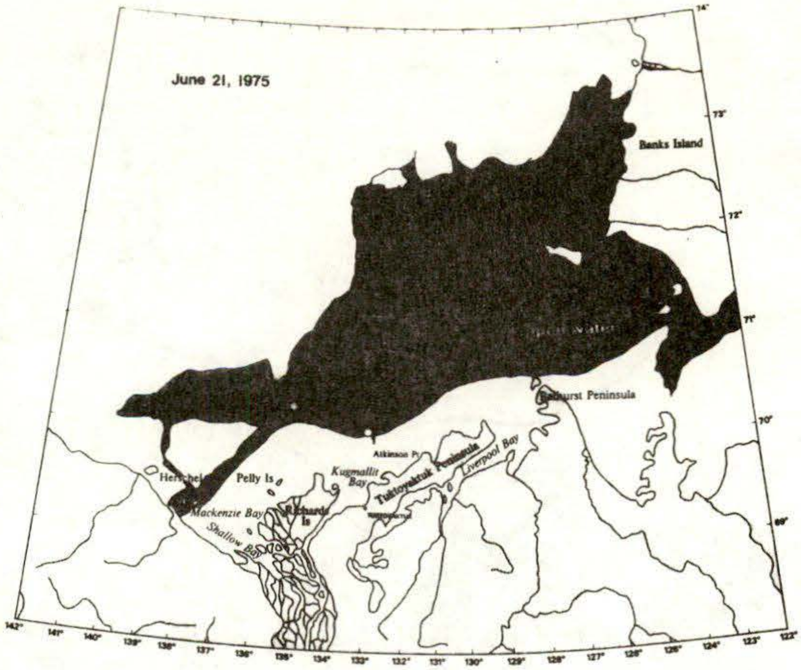

Figure 9. Ice configuration on June 21, 1975 from NOAA satellite imagery. The polar pack had moved well offshore, however most of the landfast ice had remained in place.

By mid-May, the Mackenzie River is in freshet and one month later, considerable open water exists in the nearshore waters of the Mackenzie and Kugmallit Bays. By early July the coastal fast ice has disintegrated and moved offshore with the polar pack. If, however, westerly winds prevail throughout most of the summer there will be a heavy ice year such as in 1974 when the ice boundary was roughly on a line between Herschel Island and Atkinson Point on Tuktoyaktuk Peninsula. Generally the summer and fall pack ice edges are distorted southward with protruding tongues and eddies of floe ice. It is likely that the floe tongues will cause extensive interruptions to drill ship operations at the Canmar sites. The main characteristic of the ice in the southeastern Beaufort Sea is the extreme variability of its extent and movement which render terms such as "average ice concentrations" and "average ice year" of little use.

Oceanographic Features: The southeastern Beaufort Sea is partly an estuarine system where the Mackenzie River outflow meets and mixes with the salt water of the Arctic Ocean over much of the wide continental shelf. In fact, the shallow shelf itself was produced by the deposition of river sediments and the resulting delta formations are thought to contain vast reserves of oil. The Mackenzie River is in freshet from mid-May to early August with an average discharge rate of 25,000 m^3/sec, which for this period, is more than double that of the Fraser River (Figure 10). During the late winter and spring the flow is reduced to 1/10th of this rate as it spreads out under the landfast ice. The river flow through the delta separates into several channels, one into Kugmallit Bay, east of Richards Island, the others enter Mackenzie Bay to the west. The plume of fresh, turbid water flows out over the more saline ocean waters, but when the Beaufort Sea is covered with ice or in the absence of winds,

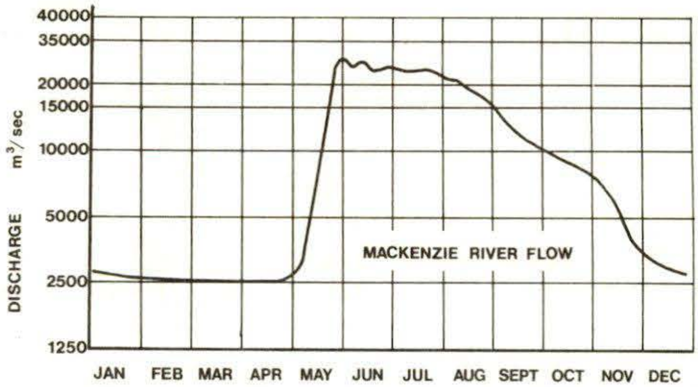

Figure 10. Mackenzie River flow rate; typical flows measured at Norman Wells, N.W.T. The discharge rate into the Beaufort Sea is approximately 15% greater.

will turn eastward along the shore of Richards Island and Tuktoyaktuk Peninsula toward Amundsen Gulf, under the influence of the Coriolis effect.

The turbid river plume is normally from 2 to 5 m in thickness, however this thickness increased to 10 m or so in the heavy ice year of 1974, as a result of the damming effect of the polar pack pressing close to shore. The waters of the plume and those beneath can have quite different currents, both in direction and speed. When offshore winds drive surface waters north, deeper oceanic waters must replace them in an underflow. Conversely, the fresh surface layer thickens with onshore winds with a resulting expulsion of saline waters offshore. These counter-currents can cause deep-draught floes and thin brash ice to move in opposing directions.

An important consequence of the river flow in the winter and spring is that the shallow inshore waters are brackish east of Richards Island and along Tuktoyaktuk Peninsula. Hence there is over-wintering habitat in the shallow lagoons, estuaries and breached thermokarst lakes well suited to non-oceanic species of fishes, invertebrates and micro-organisms.

Another feature of the river is its high mud load, hence low light penetration which probably inhibits primary biological production except where river borne nutrients can be utilized outside the turbid plume.

Storm surges (wind tides) occur frequently in the southeastern Beaufort Sea. These are increases (and decreases) in sea level other than tidal, caused by a wind-driven pile-up of water on the continental shelf. At Tuktoyaktuk, between 1962 and 1973, 22 positive and 5 negative surges (offshore winds) were recorded. Two exceeded 2 m above normal tidal fluctuations of 0.3 m. Ten occurred during the light ice year of 1963. The offshore condition necessary for a storm surge is a fetch of 50 km or so of open water containing ice in concentrations of 3/10 or less with minor floes. Surges are normally accompanied by large wind-waves, rapid coastal erosion and inundation of coastal lowlands. Driftwood strand lines, 2 m or more above sea level, show that the coastline from Herschel Island to Cape Bathurst has been subjected to storm surges. A winter surge of 1 m was recorded on January 6, 1974, generated by the passage of an intense low pressure weather system through the northern Beaufort Sea. The ice slackened toward the north with offshore winds, then closed with strong inshore winds. After the wind shift, the ice concentration was low enough to generate water movements toward the shore. Although this surge was not in itself a damaging event, winter surges could cause unusual displacements in the landfast ice and complicate the prediction of oil transport in the event of a blowout.

In summary, large positive storm surges require extensive open water and are caused by strong W or NW winds. Open water is also desired for offshore drilling using ships. High winds are more likely in September and October (the 2 m surges at Tuktoyaktuk occurred on 4 September, 1962 and 4 October, 1963). Therefore any oil from a blowout near the end of the drilling season could co-exist with a storm surge to transport oil inshore onto the lowlands.

Wildlife in the Southeastern Beaufort Sea: Compared to adjacent Bering and Chukchi Seas, the Beaufort Sea has been described as a "cold, biological desert characterized by nutrient-poor waters, year-round presence of ice and long winter darkness".* Although this description was specifically written in context with the growth of arctic marine primary organisms, the phytoplankton, this general concept is commonly, but mistakenly, applied to all trophic levels of plants and animals and to all seasons of the arctic year.

This region does fall under the influence of pronounced seasonal changes in temperature, sunlight, precipitation, run-off, sea ice and snow cover. Winter production of phytoplankton, the basic food supporting all higher animals is nearly zero in the dark waters beneath snow-covered sea ice. However the sea ice is a potentially important site of primary production. Along the underside of offshore first-year ice is found a dense community of diatoms adapted to low light intensitites. These are grazed upon by copepods and amphipods which, in turn are the prey of arctic cod, probably the most abundant marine fish in the Beaufort Sea.

Beginning with the first light penetration through the ice and the warming of ice-free waters, active plant production begins, especially in the relatively small and isolated leads of the transition zone ice. Here the critical nutrients, phosphorous and nitrogen, are quickly depleted by the photosynthetic process. The period of high primary productivity is consequently short and the total yearly production is probably low, less than 10 grams of carbon under a square meter of sea surface. This figure may be compared with 100 grams in waters near south Baffin Island or with 200 or 400 grams produced in the temperate North Atlantic Ocean.

The biological nature of the southeastern Beaufort Sea is highly dependent upon the balance between the Mackenzie River outflow and offshore marine waters. The muddy river water stops about 90% of the light from penetrating more than one meter below the surface. The bleak nearshore plant production results from insufficient light even though there are plentiful river-contributed nutrients. Consequently the zooplankton primary consumers, consisting mostly of crustaceans, especially copepods, are found in low numbers within the Mackenzie River plume but increase in numbers further offshore. The low-salinity coastal waters along Tuktoyaktuk Peninsula comprise the summer, as well as the winter habitat of many anadromous and freshwater fish, predominantly of the whitefish family. The deeper bays and lagoons such as Liverpool Bay, Mason Bay and Tuktoyaktuk harbour

* Mathews, D., A Baseline for Beaufort, Exxon U.S.A. 12(1), pp 2-7, 1973.

are sites of high secondary production, 50% to 90% greater than in Mackenzie plume waters. The biomass of bottom-dwelling organisms, mainly molluscan bivalves, is at least two-fold greater (2 to 5 g of animal weight/m^2) in these coastal embayments compared to the shallow continental shelf waters. However, by far the richest waters in terms of benthos diversity (60 to 80 species) and biomass (30 to 70 g/m^2) are offshore at depths between 30 and 100 m, particularly north of Bathurst Peninsula. In both nearshore and offshore areas, the zoobenthos community is comprised mostly of burrowing infauna such as annelid worms and clams, and more sparsely of epifaunal animals such as starfish and large crustacea.

About 150 species of fish have been recorded from northern Canada. The Mackenzie drainage and adjacent waters contain 40 marine and 33 freshwater species, of which 17 are anadromous. The Pacific herring is largely restricted to this area of low salinity and positive temperature for spawning. Other marine species which frequent the inshore areas for some requirement of their life history are the Greenland and saffron cod, the flounders, capelin, smelt and some sculpins. The most abundant offshore species is the small pelagic arctic cod. Freshwater species, such as grayling, pike and burbot, are found in the Mackenzie Delta lakes and channels along with such anadromous species as whitefish, lake herring and inconnu. In the vicinity of Tuktoyaktuk Peninsula, a biomass of 1.7 tonnes of bottomfish per square kilometer exists within 4 km of shore. Beyond 4 km, this figure drops to about 0.5 t/km^2. In Mackenzie Bay and Liverpool Bay, crude total biomass estimates of herring, arctic sole and capeline range up to 7500 tonnes. Offshore pelagic fish consist largely of the small polar cod and the larval forms of groundfish species.

In the western Arctic where the Mackenzie River is a major influence, large numbers of anadromous fish move into the Beaufort Sea to feed on marine animals. Most of these migrations are confined within relatively low-saline coastal waters. Tuktoyaktuk, Mason and Mallik Bays or any of the numerous bays and lagoons with sea access serve as nurseries for large numbers of young fish in summer and winter. The principal fishing effort by Inuit of the Mackenzie region is concentrated to take advantage of the migratory stocks passing through the area. Resident stocks of fish are available throughout the delta, while migratory fish are found close to the river mouth. Broad and humpback whitefish, arctic cisco and inconnu are the fish commonly caught, but marine forms such as herring and flatfishes which penetrate into fresh water are also taken. The minimum consumption of fish by Indians and Inuit is about 68 kg per person for a year, while the remainder is consumed by dogs. The estimate of domestic fishing for human use is about 100 tonnes per year for Aklavik, Inuvik and Tuktoyaktuk. In contrast, total fish consumption by dogs is estimated today at 175 tonnes per year. In the past decade the fisheries of the Mackenzie Delta region have decreased in importance, the decline likely associated with the introduction of snowmobiles, the decline of dog teams and the migration of people to larger settlements and wage employment.

More important animals to other communities bounding the Beaufort Sea such as Paulatuk, Holman and Sachs Harbour are ringed and bearded seals. In 1973, Inuit of Holman harvested 8,000 ringed seals, ninety-four percent of the total seal harvest of the region. The seal skins are the primary source of cash income.

Food of the ringed seal is planktonic, nektonic or benthonic, depending on the time of year and whether offshore or nearshore. This seal feeds on many points of the arctic food web from at least two trophic levels, macroplankton and polar cod, and is not apparently restricted geographically by its food supply. In contrast the bearded seal is limited to an effective feeding depth of 90 to

100 meters. It feeds almost entirely on large burrowing or sedentary bottom invertebrates of shallow continental shelf waters. Although this seal is as well adapted as the ringed seal in keeping air holes open in thick landfast ice, it does not choose to do so. In winter, bearded seals, young and old alike are often found concentrated along the edges of leads in the transition zone ice.

In the fall, ringed seals of different ages often undergo different migrations; the seal pups and yearlings move westward along the mainland coast, presumably searching for the more favourable winter ice conditions closer to the Bering Sea and offshore Alaska. The older, but non-breeding animals numbering tens of thousands move offshore and spend their winter and spring in the southeastern Beaufort Sea closely associated with the leads of the transition zone ice. An aerial survey covering this zone in the spring of 1974 estimated the numbers of ringed seals on the ice at about 50,000. The breeding and larger seals concentrate in the stable landfast ice of coastal waters, mostly to the east of the Mackenzie Delta. The fast ice in Prince Albert Sound and Minto Inlet on Victoria Island, Darnley, Franklin and Liverpool Bays on the mainland is known to be important breeding habitat with the necessary snow cover and food supply. Pupping occurs in March or April, followed by the annual moult for adult animals. In the eastern Arctic, maximum densities of 6 seals per square kilometer of the sea ice are common, especially on landfast ice suitable for breeding. In contrast, the Beaufort Sea offshore ice, including Amundsen Gulf is not a prime breeding area: probably supporting less than 1.5 seals per square kilometer. Nevertheless, because of the large area of the Beaufort Sea, this population contributes significantly to the total.

Other than seals, year-round residents are the polar bear and arctic fox, both predators of the ringed seal. The arctic fox spends a large part of its life on the sea ice, often hundreds of kilometers offshore in seas bordering western Banks and Victoria Islands. The sale of fox furs contributes as much as 30 to 79 percent to the annual income of trappers in Sachs Harbour and Holman in most years. Although foxes scavenge on polar bear leftovers, this small and efficient predator also probably accounts for a significant proportion of the mortality of seal pups.

Sea ice habitat supporting seals is also the habitat of the polar bear. When possible, polar bears remain with the ice because of the accessibility of seals. With the exception of females, giving birth to cubs, polar bears do not den in winter. In the autumn, the bears travel south with the onshore movement of the pack ice, where more favourable seal hunting conditions are found on the newly-forming ice of coastal waters, while the pregnant adult females seek maternal denning sites on Banks Island and western Victoria Island. In winter and early spring, bears tend to concentrate in the transition zone ice, where ice movements form leads and polynyi. Areas known for the abundance of bears and their prey, the ringed seal, are the west coast of Banks Island, north of Tuktoyaktuk Peninsula, and north of Herschel Island. Except for a few bears stranded onshore most of the animals have moved north with the pack ice edge by July. Localized movements of bears on the sea ice is extensive but a small part of the Beaufort Sea population is shared between Canada and Alaska. This fact, in part, prompted the 1973 International Agreement on the Conservation of Polar Bears between Canada, the United States and other nations which states in part: "Each contracting party shall take appropriate action to protect the ecosystems of which polar bears are a part, with special attention to habitat components such as denning and feeding sites and migration patterns."

The arctic spring is heralded by the arrival of migrant wildlife which capitalize on long hours of sunlight, relatively few predators, and the seasonal abundance of food necessary for their successful propagation. Bowhead and beluga whales are almost the first arrivals, travelling from the north Pacific eastward into the Beaufort Sea. Their migration occurs in May or June through the network of leads and open water north of the landfast ice. Both species pass by the Mackenzie Delta, exploiting the flaw leads between the landfast ice and the polar pack.

Bowheads spend the summer in the vicinity of Banks Island and near the mainland coast, more specifically Cape Parry and Cape Bathurst. Many white whales or beluga are found in these same waters searching for their nektonic prey, squid and cod. In July and early August, beluga move to warm estuarine waters of the Mackenzie River where calving is believed to occur and where feeding intensity is low. Before freeze-up beluga depart westward along the Alaska coast. Present numbers of bowhead whales, a species recovering from near extinction caused by 19th century whaling practices, probably are in the low hundreds in this region. Groups of up to 30 animals have been sighted on migration routes. Numbers of beluga are better known, estimated to be at least 5,000. Compared to numbers of beluga in the eastern Arctic, this is a small population, possibly a result of the long migration route to suitable winter habitat of broken ice and polynyi in the Chukchi Sea west of northern Alaska. The Inuit of the Mackenzie region hunt beluga during their concentration in the Mackenzie Delta region, harvesting about 150 animals each year. The animals shot but not recovered may in fact be twice this number. The majority of whale products are subsistence foods including the meat, oil, muktuk and flippers.

Beginning in May, several millions of birds converge to nest in the western Arctic from wintering grounds representing one third of the globe. Most bird species are aquatic, migratory and important locally for native subsistence or for the recreation of North American hunters and birdwatchers. Of the approximately 100 species nesting around the rim of the Beaufort Sea and the Arctic Islands, approximately two-thirds migrate through the Great Plains, Mackenzie Valley or northern Great Lakes, while the other third pass the Bering Straits and follow the coasts of Alaska, Yukon and Northwest Territories. Along this coastal route, some geographic and biological features tend to concentrate birds when migrating, feeding, nesting or moulting. For spring migrants the patches of open water, ice leads and melt ponds of the transition zone ice are most important for resting and feeding. The leads of shallower water depth are particularly popular stop-overs where the diving birds such as loons, oldsquaws and eiders can easily feed on the bottom marine organisms. One of the more permanent open water areas is the polynya north of Bathurst Peninsula; in the spring of 1974, over 175,000 diving birds; eiders and oldsquaws were observed here, within one week. Strong coastal currents occur along the Tuktoyaktuk Peninsula and Mackenzie Bay, and tend to bring together arctic and brackish waters in the shallows. In late summer of some years, these are ideal feeding and moulting places for approximately 600,000 scaup, oldsquaws and scoters. The barrier beaches, and sand bars extending from Tuktoyaktuk Peninsula and Mackenzie Delta west to Herschel Island, and along the Alaska coast to Point Barrow are important nesting grounds wherever they form islands inaccessible to predatory animals such as fox. Eiders, oldsquaws, gulls and terns are usually found nesting in such places. The sheltered lagoons behind barrier beaches and sand bars serve as rearing and moulting places for seabirds, as well as habitats for fish and other marine fauna upon which seabirds feed. The deltas and tide flats of the Mackenzie and other nearby rivers are also major Canadian nesting grounds for ducks, geese and swans.

In June, the density of seabirds offshore is about 5 birds/km^2, or about 5 times more than that of other summer months. In July, the decline in density is due to early departures of non-breeding birds. By September, there are less than 0.5 birds/km^2 in the Beaufort Sea region. At times over 30 birds per km^2 have been observed concentrated in the leads.

SCENARIOS FOR OIL AND GAS WELL BLOWOUTS IN THE BEAUFORT SEA

Exploratory Drilling in the Summer of 1976: The present plans of Canadian Marine Drilling Ltd. (Canmar) are to send their two drill ships into the southeastern Beaufort Sea as early as possible in the summer of 1976. Assuming that 1976 will be a year of light ice, the earliest date that the ships may begin drilling is about the 1st of August. If it is a heavy ice year, it is unlikely that the ships could proceed to their drilling sites at all.

The two drilling sites proposed for the summer of 1976 are shown in Figure 1. Site #1 is in a water depth of 26 meters and located about 46 km seaward of Tuktoyaktuk Peninsula; Site #2 is in a depth of 58 meters at a distance 83 km offshore of Pelly Island. Both sites are situated in the transition ice zone. The drilling season is not likely to extend beyond mid-October, allowing only 2½ months at either site to drill down to possible petroleum-bearing strata. The likelihood of a blowout of oil is increased toward the end of the drilling season as petroleum is encountered.

Assuming the postulated blowout occurs on the 5th of October, the second drill ship, could at most, begin work on drilling a relief well but would be unable to drill down to the petroleum-bearing horizon to control the wild well before freeze-up. In this event we would be faced with a free-running blowout and little hope of controlling it until at least 10 months later, in the following summer. Even then it would depend on having a favourable ice year to bring it under control.

In some geological oil-bearing structures, debris entrained in the gas and oil within the well-bore can gradually bridge or reduce the flow of a wild well. However in the worst case the well could free-run throughout the fall, winter and spring, until the summer of 1977 when action could resume to drill a relief well to bring the blowout under control by that season's end.

The Underwater Oil and Gas Well Blowout: What would this blowout be like? It is postulated that the initial flow of crude oil could be 2500 barrels* per day and that this flow could decline to 1500 barrels per day in one month's time as the local region of the reservoir is drained. 1500 barrels per day equals 240 cubic meters of oil per day or 87,600 cubic meters per year assuming the well does not self-seal. About 1.2 million cubic feet (34,500 m^3) of gas per

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* 1 m^3 is approximately 3/4 tonne; 1 barrel = .159 m^3.

day are also likely to accompany the crude at the sea surface.

Since the blowout orifice is at the sea bottom, the gas rises to the water surface in bubbles, carrying the oil with it, in effect creating a bubbler system which circulates bottom water toward the surface. At the well-head orifice on the bottom the oil is churned into droplets which rise toward the surface at varying rates. Some of them will coalesce to form larger drops; others, being very small, will remain suspended in the water column for some time and therefore will be moved at the whim of the sub-surface ocean currents. A contingency decision may be made at this point to fire the blowout if it is not already on fire. Assuming calm waters, little ice and negligible currents, it is possible that 90% of the oil could be burned off, although this has not been demonstrated. The tarry residue would be retained locally by the natural water-circulation generated by the rising bubble stream. This simplification breaks down when we consider ocean currents, surface waves and moving ice floes. The following paragraphs will describe the possible transport and eventual fate of oil following such a blowout.

<u>Transport of Oil During the Fall and Winter</u>: The two proposed drilling sites are strongly influenced by the Mackenzie River. When offshore winds blow, the fresh water of the river moves over the more saline, cooler sub-surface waters. This surface layer of river water is muddy and can be up to 8 meters thick. Often the currents in these thin surface waters are quite different from those beneath the sub-surface more saline water. The surface waters are driven mainly by the wind, while the sub-surface waters are moved by oceanic influences. To complicate flow predictions, young ice or thin rotten floes, which draw little water, commonly move in the direction of the surface currents while deep-draft old floes travel against this surface current, under the influence of sub-surface currents. Often, there will be no simple puddle of oil to burn. If a large ice floe happened to float over the site of a burning blowout, the fire is likely to be extinguished.

Violent storms are common in the fall of the year. In October, offshore winds drive the newly-forming ice away from the shore and out to sea. Strong NW winds follow in November, whipping up the waves and driving the ice back to the coast. It is not likely during the late fall that an ignited blowout will remain on fire. The oil will be weathered and emulsified to a small extent, and eventually be wind-driven toward the shoreline of Tuktoyaktuk Peninsula. Here the Mackenzie River flow will transport the oil along the shore of the peninsula to the northeast. Modest, 1 m storm surges occur in mid-October under the thrust of onshore winds so that the innermost reaches of breached thermokarst lakes, bays and lagoons could be contaminated by oil. As the sea calms between storms and the landfast ice begins to form from new grey ice and floe fragments, some of the oil will remain mixed-in with the surface of the landfast ice. The most rapid reduction of the flow of the Mackenzie River occurs in November and by mid-month the flow is 15% of the mid-summer flow (Figure 10). At this time, the ice forming on the continental shelf can move westward as the offshore influence of the NE river flow diminishes.

Marine inshore and offshore oil clean-up equipment, consisting of floating booms, devices to separate oil from water and floating incinerators, will be completely inoperable much beyond freeze-up in October. Canmar may attempt to re-ignite the blowout by dropping incendiary material from aircraft at the site. These efforts could be frustrated by intruding ice floes which frequently snuff out the flames. There will be discontinuous movements of multi-year pack ice over the site, remnants of the past season's first-year ice and new ice. Leads in this ice can form, freeze and be compressed, the new ice being crushed and mixed with oil.

Storm surges sometimes occur during the winter in the southeastern Beaufort Sea. These would not necessarily result in oil reaching the frozen shoreline but could produce a rim of oil along the coastal landfast ice. Since a winter surge can cause a 1 meter rise in sea level at Tuktoyaktuk, oil would contaminate any ice-free shores but would not enter ice-covered bays and lagoons.

By late January, the landfast ice has formed, though incompletely, to seaward and the ice in the transition zone is moving irregularly westward. Within the transition zone there is often a wide lead or network of leads and cracks caused by the offshore retreat of the arctic pack when S or SE winds blow. It is estimated from satellite imagery (Figures 5 to 8), that Canmar's Site #1 will be in open water or water covered with new grey ice an estimated 50% of the time from late January through early May. In contrast, Canmar's Site #2 will be covered with transition zone ice an estimated 90% of the time for this period. Therefore, the two proposed sites are distinguished by their position relative to this predictable offshore lead, with the result that a large fraction of the oil released from a sub-sea blowout would have distinctly different histories during the winter and spring.

In some years, (possibly 1 in 10 years) Site #1, closer to shore, could be incorporated in the landfast ice. Satellite imagery has been examined which showed that the edge of the landfast ice on June 11, 1973 and June 14, 1974 was well shoreward of Site #1. However if this site were in landfast ice in the spring of 1977, the action of the blowout would maintain an open pool above the well which would directly contain a depth of oil equal to one-half the ice thickness. Oil accumulated beyond this volume would flow out over the top of the ice and be absorbed in the surrounding snow cover. Up to 90% of the oil contained within the pool could be burnt, but this, as a proportion of the total oil flow will depend on the diameter of the pool and the rate at which it can be burned. These will be determined by local conditions and the accessibility of the site.

<u>Distribution of Oil on May 5, 1977:</u> Focussing now on a blowout at Canmar Site #1 in the period from late January to early May, oil will rise into any lead over the site left by the northern retreat of the pack and will mix with newly forming frazil ice blown toward the north side of the lead. Should this lead close, the oil rising will also flow under the ice. The lead could vary in width as the offshore pack moves westward so that the new ice which forms in the lead could be compressed as the lead closes to form oiled pressure ridges along the N boundary of the landfast ice. Early in the winter some of these ridges could attach themselves to the seaward extending landfast ice, but by late January they will move westward as part of the transition zone ice and will exist as multiple lines of narrow ridges adjacent to the N boundary of the landfast ice.

Apart from active shear leads and northward branching flaw leads, ice concentrations in the transition zone will be 10/10ths. Hence, with minor exceptions, ice excursions over Site #1 will inhibit ignition of the blowout unless extraordinary and costly efforts are made to maintain open water artificially in this region by moving ice. (Canmar proposes to fragment the ice with explosives to promote more effective burning. This technique is likely to be effective during times when the ice motion has temporarily ceased.) Gas accompanying the oil, though eventually escaping through cracks and narrow leads, will fill under-ice voids and provide a smooth surface to aid in spreading the oil rapidly and thinly under the ice. Beyond the horizontal range of gas escapement, the oil will flow under the ice to fill voids and cavities. The actual under-ice area contaminated would depend largely on the speed of the ice cover moving over the blowout site.

An estimate of this speed is 1 km/day to the west when Site #1 is ice covered. For an oil discharge rate of 1500 bbls/day or 240 m^3/day, the width of the swath of oil* under the ice is likely to vary between 70 m and 200 m depending on the permeability of the ice to gas. On the other hand, when the offshore ice retreats and then advances, the westward motion could average 10 km/day and the oil could be more localized in E-W ridges and displaced under adjacent ice. The total length of the oiled ice trail to the west from late January to early May would range between 300 km and 500 km.

In summary, assuming a blowout occurred on October 5, 1976, at Canmar Site #1, the oil could be dispersed in early May as shown in Figure 11. Assumptions are that: 3500 m^3 will be blown toward the coast by winds associated with a storm surge on October 10; 5,000 m^3 will have been dispersed NE toward Banks Island in the fall, 22,000 m^3 will be dispersed in the growing and seaward extending landfast ice, part toward the NE until mid-November and the remainder to the west until late January; finally 23,000 m^3 will be distributed along the north edge of the landfast ice 400 km to the west or 75 km west of the Alaska-Yukon border as far as Barter Island.

A blowout at Canmar Site #2 on the 5th of October, 1976 would likely produce a somewhat different distribution of crude oil by May 5th, 1977, as shown in Figure 12. Site #2 would seldom be in open water in the late winter so that from late January to early May, the oil would be mostly encapsulated within the ice of the transition zone. Prior to this, much of the oil would be incorporated in the landfast ice as depicted for Site #1, although somewhat less since the westward ice circulation would be established sooner offshore.

For comparison with the two Canmar sites, a hypothetical landfast Site #3, at a depth of 18 m is shown in Figure 13. The only significant difference in the distribution of the crude oil from an October 5th blowout at Site #3 would be the containment of the oil within a restricted area in the landfast ice by late January. If all the oil from late January until break-up of the landfast ice is eventually burnt, the disposition of the oil could be as depicted in Figure 13 on the 5th of May, 1977.

In Figure 11, the oil contaminated landfast ice covers an area of approximately 7700 km^2. Most of the 22,000 m^3 of oil in the landfast ice would likely be concentrated in narrow bands or ridges parallel to the coastline. A useful visualization is that the oil coverage would be equivalent to forty bands of oil 0.3 cm thick and 1 m wide, each spaced 1 km apart. In the area south of Banks Island, shown contaminated by 5,000 m^3 of oil, the average oil concentration would be one-half the amount computed for the landfast ice. These concentrations also apply to the oil dispersals shown in Figures 12 and 13.

Any consideration of weathering which would apply to a large fraction of the total oil discharged from a blowout at Site #1, and which could reduce the oil

* The expression "swath of oil" is employed in the absence of a better term. However the distribution of oil within the swath is by no means uniform. The main concentrations are expected to be on the edges, with irregularly scattered quantities between.

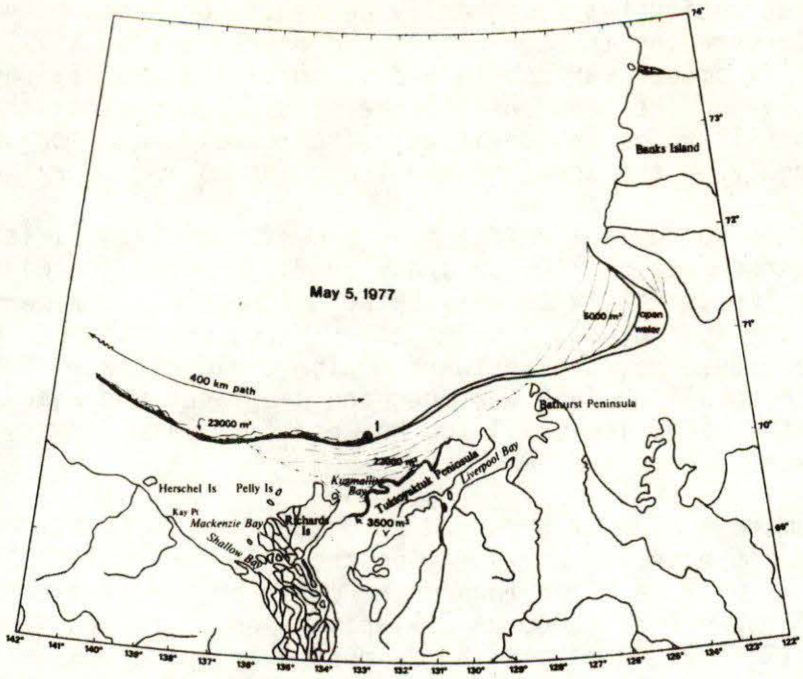

Figure 11. Oil dispersal on May 5, 1977 from an October 5, 1976 blowout at Canmar Site #1.

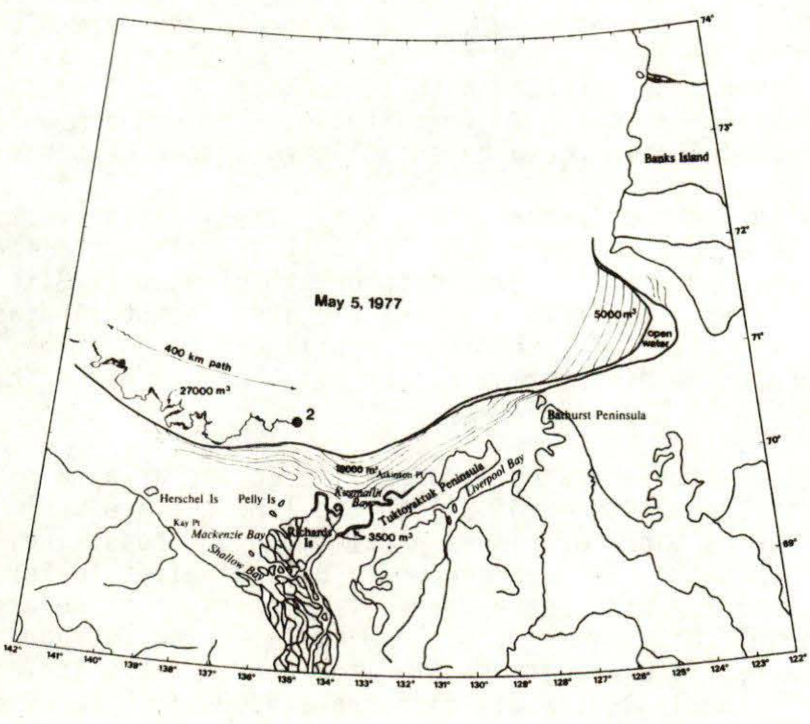

Figure 12. Oil dispersal on May 5, 1977 from an October 5, 1976 blowout at Site #2.

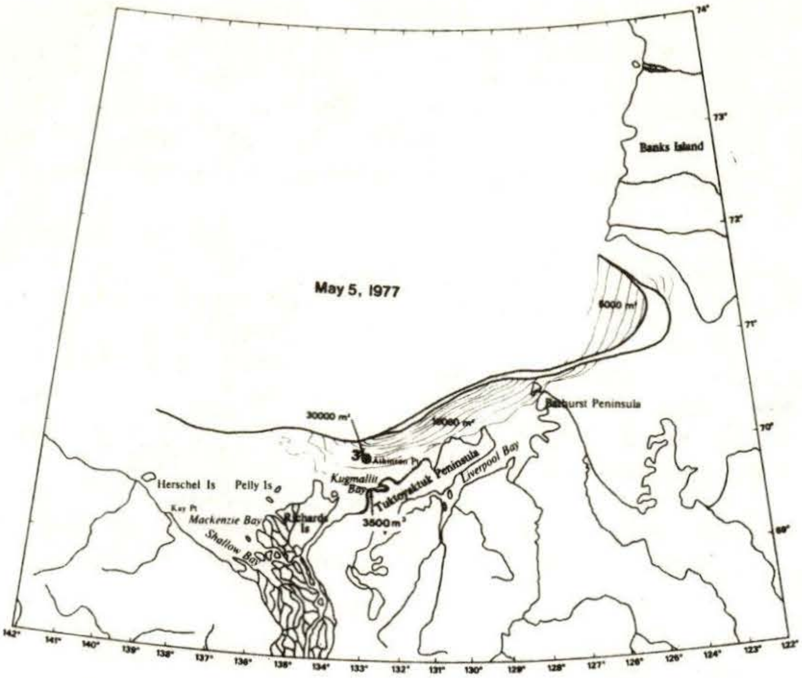

Figure 13. Oil dispersal on May 5, 1977 from an October 5, 1976 blowout at hypothetical Site #3 in the landfast ice zone.

volume by 30% has been ignored. Weathered oil would be difficult to burn. In contrast, oil trapped in the ice remains in its original state. Oil droplets which rise from the seabottom well-head have different residence times in the water column and can be dispersed widely depending on subsurface currents. These have been ignored. Therefore one might expect to have a considerable number of droplets, perhaps 2% of the total oil volume, incorporated into the ice sheet well beyond the estimated swath widths. It must be emphasized that the swaths of oil under the transition zone ice would not be continuous ribbons of oil but would often consist of disjointed segments. It is likely that the detection in the spring, of the fragmented oil trails originating from Site #2 in particular could be aided by radio beacons deployed near the blowout site at intervals throughout the winter.

Seasonal Effects on Oil in Ice during May, 1977: Early May is a critical time in the Beaufort Sea. The sea ice ceases growing; the brine in the ice would be replaced by oil which will slowly rise to the surface of the ice. The sun's heat, absorbed by the dark-colored oil within the ice, will create melt pools which form natural containers for the surfacing oil. At the same time, the offshore leads form a network of highways and feeding locations for migratory and resident wildlife. Much of the oil locked into the ice throughout the winter and spring resulting from a blowout at Site #1, would be released precisely in the main migration routes.

Early May is also the optimum time to initiate disposal of oil by burning. The oil which has been trapped within the ice in a fresh state will burn easily as it emerges; however, the weathered oil at the surface will not burn readily.

Judging from the scenarios of oil dispersal, 60% to 70% of the oil from Site #1 could be weathered and about 40% from Site #2. The unweathered portion would emerge from within the ice as small scattered patches and pools along paths extending 400 km to the west. Burning significant fractions of this oil, perhaps at most 20%, is questionable in view of the vast areas to clean up, the short two weeks or so of time available before the oil surfacing would become too weathered to burn, and the poor flying weather existing toward mid-May.

Oil Movement in June to early July, 1977: In June, the ice is rotting rapidly and constantly moving at the whim of the wind. Gradually, in early July, the landfast ice breaks up and moves offshore. Larger floes break up into smaller floes. With air support, maintenance of a conflagration at a blowout site would become easier since the floes will be rotten and more permeable to gases. By early July the Canmar tugs and oil clean-up equipment could attempt to proceed to the blowout site to corral the oil. However, in heavy ice years, migrations of floes near Site #1 and more so at Site #2, would frequently frustrate the effectiveness of oil clean-up activities. At hypothetical Site #3 (Figure 13), oil containment and burn-off would be interrupted briefly as the landfast ice breaks up and moves offshore allowing marine equipment to approach the blowout site.

In spring 1977, the Mackenzie River will be at its maximum flow. The surface waters, in calm weather, will carry the landfast ice offshore and to the northeast while prevailing winds will tend to move the pack ice to the northwest. A likely result will be that prior to early July, this interaction of winds and currents will move the oil fixed in the landfast and transition zone ice into the arctic pack. There the oil will weather and merge with rotting floes and reside within the polynyi and leads at the southern periphery of the gyre. Consequently most Canadian shoreline contamination other than that from mid-October, 1976, could be caused by oil escaping containment and clean-up from early July to the end of summer. Much of the oil discharged earlier will have travelled westward with the pack ice to north of the Alaska coast as far as Point Barrow.

Climatic Effects: The amount of weathered oil which would be dispersed from a single oil well blowout running wild for a year would be unlikely to have any effect whatever on global or even local climate. While it is certain that oiled ice will melt much faster than clean ice, natural fluctuations in the yearly ice cover would mask the extremely small changes which would be caused by oil in the volumes assumed.

Relief Well Drilling in the Summer of 1977: In the meantime, plans for relief well drilling will be laid by Canmar. Following news of a blowout in October, two of Canada's largest icebreakers may be overwintered in the southeastern Beaufort Sea to assist a Canmar drill ship to maximize its 1977 drilling season. Plans will have been set for burning the oil expected to emerge from the sea ice in early May. Also, supplementary offshore and inshore booms, skimmers and burners will be mobilized in the delta. Ice-strengthened tugs and aircraft support will be prepared for the anticipated oil countermeasures operation in the summer. Steps will be taken to set up a comprehensive environmental prediction system to support marine operations and to predict oil-slick movements.

Drilling a relief well to control a blowout is a more complex operation than either wildcat or delineation drilling. Despite better knowledge of geological formations, it cannot be expected that less time will be taken to drill to the oil reservoir than it did to drill the original well. The scenario assumed 60 days of drilling in 1976 before the hypothetical blowout occurred. Spudding-in for a relief well at either Canmar site could occur on July 15, 1977. Assuming there were no significant interruptions, control could be gained by October 1, 1977. From early July to October 1, the blowout could have discharged 21,000 m^3 of oil and $3.1 \times 10^6 m^3$ of gas at the sea surface.

As with the original well, the blowout preventor (BOP) stack of the relief well will be placed in a jetted-out cavity or in a silo in the sea bottom to protect it from intruding polar floes in the summer. Figures 14, 15 and 16 show tracings from satellite imagery of ice floe intrusions in the vicinity of the Canmar sites in late August of the years 1973, 1974 and 1975. Few clear images of the Beaufort Sea are available in the summer because of cloud cover. However on the dates shown, serious delays would have occurred at Site #1, in all three years while Site #2, visible only in Figures 15 and 16, was covered by large floes. The circles scribed around Site #2 depict Canmar's 24 hr, 12 hr and 4 hr alert zones (ranges 18, 10 and 5 nm) for winds ranging between 10 to 20 kts. At Site #1, but more often at Site #2, large icebreakers would have found difficulty providing protection to a drill ship attempting to maintain its position. Hence, in heavy ice years, such as 1974, a relief well could not have been drilled using a drill ship. In contrast, during light ice years such as 1970 and 1971 (although only aircraft reconnaissance exists to confirm this speculation) the drilling season at both sites could have been a clear 120 days.

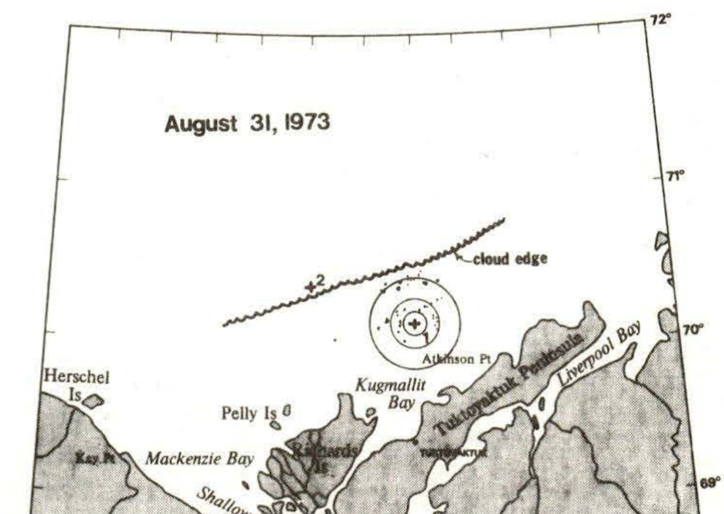

Figure 14. Ice floe intrusions on August 31, 1973 from satellite imagery. Small dots represent floes 1 km in diameter. Circles around Canmar Site #1 depict 24 hr, 12 hr and 4 hr alert zones assuming winds in the 10 to 20 kt range.

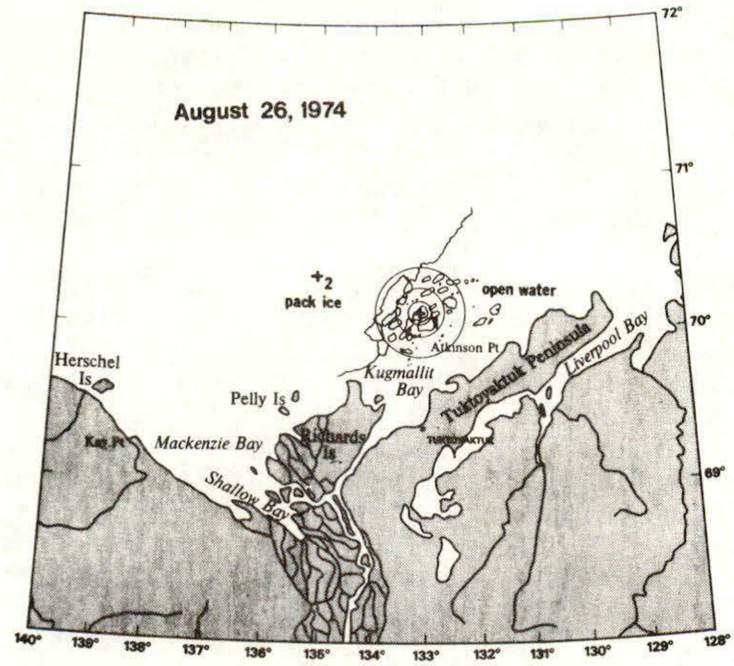

Figure 15. Ice floe intrusions on August 26, 1974 from satellite imagery. Circles around Canmar Site #1 depict 24 hr, 12 hr and 4 hr alert zones assuming winds in the 10 to 20 kt range.

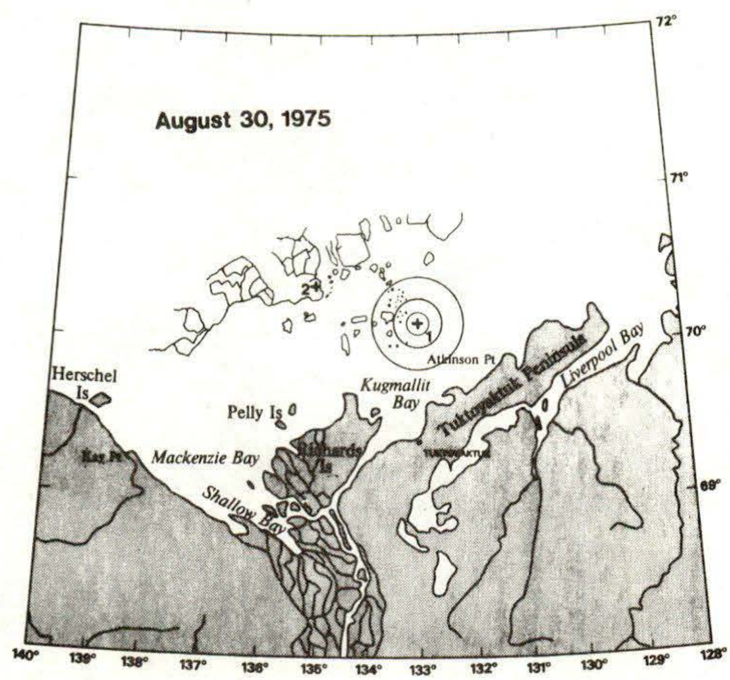

Figure 16. Ice floe intrusions on August 30, 1975 from satellite imagery. Circles around Canmar Site #1 depict 24 hr, 12 hr and 4 hr alert zones assuming winds in the 10 to 20 kt range.

Estimates of Oil Escapement During the Summer of 1977: In addition to the weathered residue of the 3500 m^3 of oil reaching the shores in mid-October of 1976, the next oil to reach the coast could be expected from oil escaping containment from early July to early October, 1977. This assumes the relief well is successful in 1977. Except for periodic intrusions of pack ice from the north over the blowout, it is also assumed that the southeastern Beaufort Sea will be ice-free in 1977, therefore the movements of the free oil will be governed by the winds and local surface currents. In the absence of winds, the surface currents have minor tidal components but are mostly from turbid fresh river water extending to beyond the Canmar sites and trending to the northeast to Amundsen Gulf. Onshore and offshore winds modify this flow as outlined earlier. It is clear that west and northwest winds will drive floating oil to the sea coast along the shores of Richards Island and Tuktoyaktuk Peninsula. If coincident with these winds there is a large expanse of open water, a storm surge will be generated. Minor surges of 1.0 to 1.5 m are common throughout the summer; for example, in 1963 between July 5 and October 16 there were ten surges. One exceeded 2 m and seven had amplitudes in excess of 1 m. Most years experience three or more surges in the summer.

Weather systems move through at approximately 2-week intervals in the summer resulting in an equal probability of northwest and southeast winds, therefore the 21,000 m^3 of oil, if not burnt or contained, will fan out in all directions to the boundaries and edges of the ice-free waters of the southeastern Beaufort Sea, with a slight bias to the northeast due to the river flow. Assuming a paraffinic crude oil, 30% of this volume, or the more toxic light ends or aromatics, could evaporate within 48 hours. Of the remaining 14,700 m^3, 50% or 7,350 m^3 could impinge directly on the shorelines of Richards Island and Tuktoyaktuk Peninsula. The greatest concentrations would paint the exposed coasts, lowlands and inlets between Kugmallit Bay and Baillie Islands.

Oilspill countermeasures can reduce this quantity substantially, although their effectiveness both offshore and along the shore will depend almost entirely on periods of relative calm. The oil and gas blowout envisaged is unlikely to remain ignited in winds and waves since the wide-spread oil film could remain below its flash point. Winds, waves and accompanying surface currents would also reduce the effectiveness of containment booms. For the months of July, August and September of the years 1953 to 1972, offshore winds with speeds less than 11 kts (5.7 m/sec) were recorded about 45% of the time, hence a rough estimate of oil escapement from the blowout site is 55%. Inshore, the countermeasures' effectiveness could be poorer. In selected bays where efforts could be concentrated, 55% escape is likely, but in the worst case where few inshore areas could be protected, the overall escapement could be 95%. Using percentages of 55% offshore and 95% inshore, the 7350 m^3 originally destined to reach the shoreline during the summer windy period would be reduced to 3800 m^3 flowing to the shore at a rate of 1300 m^3 per month.

This volume of oil could be added to the weathered residue of the 3500 m^3 of oil already on the coast from the fall of 1976. Assuming that weathering will leave 70%, the fall contribution will have been 2450 m^3 of oil. Taking into consideration the 400 km of coastline between Kugmallit Bay and Baillie Islands most likely to be affected, the 2450 m^3 from October, 1976 will paint the coasts with an amount of oil equivalent to a swath 1 m wide by 0.6 cm thick. Then the 1300 m^3 per month could build this swath in thickness at the rate of 0.4 cm per month during the summer of 1977. It is probable that half of this oil would be immobilized on spits, bars and headlands, leaving the remaining half to contaminate estuaries, lagoons and low-lying coastal plains. During storms, oil can be incorporated into the sediments of bars and spits and can later be re-exposed to float on the water as these sediments erode some indeterminate time later.

Blowout Site Environmental Threat Comparisons: The fate of oil from both Canmar sites and hypothetical Site #3 has been described under the assumption that a blowout occurred on October 5, 1976. There would appear to be significant differences amongst sites regarding potentially damaging effects on marine wildlife. These effects will be detailed later. Referring to Figures 11, 12 and 13, and to the foregoing description of summer conditions it is evident that:

- Oil blowouts at any of the three sites could be equally damaging to the coastal environment along Tuktoyaktuk Peninsula;

- Oil from hypothetical Site #3, in the landfast ice zone, would be least damaging to offshore migratory and resident wildlife, assuming that the oil can be burnt off or otherwise disposed of in a polynya in the fast ice during the springtime;

- Oil from Site #1 would be most damaging to offshore migratory and resident wildlife because of its proximity to the main east-west lead immediately offshore of the fast ice. A large fraction, perhaps 60%, of the 23,000 m^3 of crude oil discharged from late January to May 5 could be remobilized in this lead;

- Oil from Site #2 would appear to be less damaging than from Site #1 to offshore wildlife since much of the oil discharged offshore in the transition zone ice would be more widely dispersed and less available to contaminate the main east-west flaw lead used by resident and migratory marine mammals.

EFFECTS OF OIL ON BIOTA

Recent knowledge about arctic marine plants and animals in the Beaufort Sea permits broad generalizations to be made about their life habits and relative importance to the food chain. The next step of predicting each organism's response individually, but more so as a community, to offshore drilling activities is of necessity a 'best guess'. Such predictions are required to identify potentially acute or chronic damage, and factors which may affect the recovery of wildlife populations following an oil well blowout. Even in the more familiar temperate oceans of the world, it is still difficult to predict the effect of crude oil on marine ecosystems.

Of direct concern in this impact assessment are the highly visible animals at the top of the food chain, such as birds, polar bears, seals, foxes and whales. Not only is there more known about these animals and their vulnerability to oil, but we also know they are valued wildlife resources to northern peoples. In contrast, much less is known about the vulnerability to oil of lower life forms, such as planktonic and benthic organisms. While the lower life forms are of no direct economic importance, they are the foundation upon which the higher life forms are dependent for their existence.

Further complications arise in assessing sublethal effects of oil on lower organisms. Chronic long-term alterations of animal behaviour and physiology are difficult to detect and interpret but sometimes are of more ecological significance than rapid and massive animal mortality.

In the following impact assessment the effects of oil on seasonal and resident biota of the southeastern Beaufort Sea are considered. Short-term and chronic responses to oil contaminated habitats at different seasons of the year are predicted. Emphasis is on critical niches and life patterns, such as migrations in leads, and overwintering in coastal bays.

Autumn (September and October): The imaginary blowout on October 5, 1976 at either Canmar site would deposit several thousand cubic meters of weathered oil on the northwest shoreline of Tuktoyaktuk Peninsula, in Kugmallit Bay and along the northeast coast of Richards Island. Compared to predicted quantities discharged offshore in the landfast ice and transition zone the coastal spill would be relatively small; nevertheless it would produce significant contamination of about 400 km of shoreline and embayments. A reduced impact of this pollution on the marine mammals and birds is predicted in autumn. Most seabirds, geese and shorebirds have migrated out of the Mackenzie Delta area by late September and October. The density of birds offshore has decreased to about 0.12 birds/km^2, these being renesting and late moulting stragglers. Ringed and bearded seals are present but not concentrated, and could probably avoid slicks or contaminated inshore waters. The arctic fox is confined to the coastal tundra until the landfast ice forms. The intertidal zone of the Beaufort Sea is virtually barren and damage to invertebrate fauna would be minimal. During October or November, depending on when freeze-up occurs, the bears immediately migrate south, thus reaching more seals. Eighty-six percent of bear tracks observed in October are headed south. Many bears move out onto young sea ice barely thick enough to support them. In years when large amounts of pack ice are blown south to the mainland coast, such as in 1970 and 1975, bears are more abundant nearshore. It is not known whether or not polar bears actively avoid oil contamination. However, it is predicted that tens of bears could be in contact with oil, especially in the landfast ice zone and near the blowout site.

However, the major ecological concerns in coastal waters are the freshwater and marine fishes which, during October and on through winter, feed or migrate along the shallow inshore waters of Richards Island and Tuktoyaktuk Peninsula. From October to December, large numbers of broad whitefish, humpback whitefish, inconnu, arctic cisco, least cisco (all members of the whitefish family) undergo a downstream post-spawning migration to the Mackenzie Delta and finally move into deeper, low-salinity coastal bays and lagoons. Overwintering concentrations exist in Mason and Mallik Bays on Richards Island, Tuktoyaktuk harbour and in the numerous interconnecting embayments of Tuktoyaktuk Peninsula. An estimate of the standing crop for Mackenzie region freshwater and anadromous fishes is over 500 tonnes.

The same protected waters are nurseries or rearing habitat for fry which are swept down the Mackenzie River soon after hatching. Fisheries surveys have revealed that over 60% of the total fry catch from the lakes, streams, channels, and coastal waters of the Mackenzie Delta region are concentrated in low-salinity, shallow inshore waters. Here also are found several species of normally marine fishes such as herring, four-horned scuplin and arctic flounder, which are able to tolerate low-salinity waters. Standing crop estimates range up to 7500 tonnes, mostly herring. These move inshore as large schools by early summer to spawn in the shallow coastal waters of Tuktoyaktuk Peninsula. By autumn large numbers of herring fry are still inshore and could be subject to oil contamination.

Coastal bays and lagoons behind barrier beaches are natural traps for oil floating to the shore. Features of these habitats are frequent fall storm surges and between times, low rates of water exchange; both increase the chance of oil persisting in these highly productive fish habitats. Depending on the volume of oil and its weathered state, fish kills could occur from suffocation and poisoning to indeterminate numbers of immature freshwater and marine fish, to overwintering adult whitefish and smelt, and to lesser numbers of adult herring, flounder and cod.

Some fish species such as inconnu, arctic cisco and broad whitefish comprise an important domestic and small commercial fishery in the Mackenzie Delta area. Water in contact with oil even in low sub-lethal concentrations, can produce disagreeable tastes and odours in fish flesh, rendering the resource either unmarketable or unaesthetic.

The significance of heavy fish kills of both breeding and juvenile components of arctic freshwater and marine stocks may be high. Undoubtedly the recovery of some populations to pre-spill status will be slow. Growth of the fishes is slow over a life span of 15 to 20 years. Maturity is usually delayed until age 5 years or older. Only once in every 5 or more years are successful year classes produced by many species. Repopulation in local areas of fish depletions is possible by immigration of unaffected fish from unpolluted areas of the Mackenzie drainage and nearshore waters. This assumes the fishes' food supply, mainly benthic invertebrates have recovered from oil pollution of the embayments. If considerable quantities of oil are buried in the bottom sediments, thus acting as persistance toxicants to bottom dwelling organisms, recuperation of fish stocks could be delayed for at least a decade, or the duration of the effects of the toxicants.

Winter (November to April): Up to 15,000 ringed seals and 2,500 bearded seals are concentrated in leads of the transition zone from Herschel Island along the mainland and north to the west coast of Banks Island. Of these numbers, 35% of the ringed seals and 50% of the bearded seals are distributed along the active E-W shear leads between Herschel Island and Cape Bathurst which could be contaminated by tens of thousands of cubic meters of oil in the event of an oil well blowout at either Canmar site, but more so from Site #1. It is highly likely that these mobile animals will be in contact with oil to varying degrees.

Whether or not large seal kills will result from an oil blowout will depend on the duration of the seals' exposure to oil and their general state of health. Both species travel the network of leads in attempts to remain in ice free ones, thus minimizing the maintenance of breathing holes. As a result the probability of oil contact is high. The time of exposure to oil may, however, be short, depending on choices of escape routes. Experimental oiling of ringed seals has demonstrated that healthy animals are not permanently damaged by short periods of physical contact with Norman Wells type crude oil.

Bearded seals feed mainly on zoobenthos such as gastropods, sea cucumbers and large crustaceans, hence oil contamination of the ice or water surface will not deplete their food supply.

In winter, ringed seals feed almost exclusively on arctic cod, the most abundant offshore fish which inhabits the under-ice surface and surface waters of the leads. Extensive oil contamination of the lead network will directly or indirectly degrade the local cod population by smothering under-ice algae and crustaceans upon which they prey.

Lack of food, lack of snow cover for birth lair construction, and heavy winter ice in the transition zone cause large natural fluctuations in productivity, nutritional states and population sizes of ringed seals. These, in turn, reflect on the distribution and survival of their major predators, the polar bears. For example, there was almost a 50% decline in numbers of ringed and bearded seals as well as a 10-fold reduction in the pupping success, possibly due to the heavy ice year of 1974. This resulted in redistribution of polar bears and poor survival of cubs. Environmental stresses will compound the debilitating effects of oil pollution; laboratory experiments show that ringed seals stressed by transportation and handling succumb within a few hours of exposure to oil pollution levels which are relatively harmless to unstressed animals. Natural wildlife mortality as opposed to that attributed to exploratory drilling activities will be difficult, if not impossible to determine. Unless there are continuing observations made of fluctuations in seal populations, unfair blame could be attached to industrial activities should major declines in populations and nutritional states take place. However, it is critically important to ensure that detrimental effects of exploration do not coincide with, and thus aggravate, stresses that seal and other wildlife populations may already be experiencing through natural causes.

If oil-related seal kills did take place north of Richards Island and Tuktoyaktuk Peninsula, the recovery of bearded seal populations would be slow. Since offshore leads are used for feeding as well as for breeding by this species, substantial numbers of breeding adults, adolescents and pups would be killed simultaneously. In contrast, the ringed seals' prime pupping habitat is the stable landfast ice to the east of the Mackenzie Delta and beyond potential winter contamination from a free running oil well blowout. The potential kill of the sub-adult ringed seal population could be 30% greater, although its recovery is insured by isolation of its breeding stock.

The offshore leads in the transition zone, critical to the survival of over-wintering ringed seals and breeding and feeding bearded seals, are consequently important areas for feeding polar bears and scavenging arctic foxes. Even though a major seal kill might not affect the eventual recovery of their populations, reduced numbers over several years will certainly affect the distribution and possibly the survival of the polar bears, and to a lesser degree, arctic foxes. The harm caused by oiling a bear's insulating fur or by the ingestion of oiled seal flesh and blubber is not known.

Spring (May and June): Wildlife in the Beaufort Sea exists in a harsh environment, not in the sense of low temperatures alone, but from a very abbreviated season of phytoplankton production. In this regard, May, June and July are the most important months of the entire year, when intense spring illumination permits photosynthesis to proceed at a high rate. Animal life, particularly the zooplankton, are adapted to a short feast and thereafter to a long famine. Within a few weeks, the invertebrates accumulate nutrient reserves for the production of eggs and to sustain them through the winter. Unweathered oil encapsulated in sea ice is released in the springtime as the ice warms. This fresh oil could impair the ability of invertebrate communities to capitalize successfully on the peak availability of food. The quantities of oil and its dispersion from a single blowout from either Canmar site are not likely to threaten long-term survival and recovery of the Beaufort Sea plankton communities. However, local depletion of the important spring production and of dependent invertebrates in the leads and ice of the transition zone could directly affect the migrant whales and seabirds which rely exclusively on these habitats for spring feading. As in winter, the active leads off the mainland coast of Amundsen Gulf and west of Banks Island are also important spring habitats of polar bears and seals. Adult ringed and bearded seals breed from mid-March through mid-May. Although not gregarious animals, there is a seasonal aggregation of over 50,000 animals in the transition zone when they haul out to moult in late June, immediately prior to break up. The annual moult is known to be stressful for the seal; in spring the decrease in blubbler can reduce an animal's weight by 23% to 40%. Oil from a previous seven months' accumulation in the transition zone and fresh pollution in the vicinity of the drill site could contaminate large numbers, potentially the majority, of bearded and ringed seal population. The added stress of contact with oil during the moult may be potentially lethal because of the low state of health of the animals.

It is not surprising that over 80% of polar bear sightings from late March to mid-May are concentrated on 9/10 to 10/10 ice cover near active leads, such as those in the vicinity of Bathurst Peninsula. Ringed and bearded seals are concentrated here where the combinations of currents and winds form a persistent polynya, providing the animals easy access to the air. This type of habitat is mainly restricted to the transition zone where leads are widening in the springtime. A blowout at either of the two Canmar sites could contaminate, to varying degrees, up to one-third of this critical habitat during the winter of 1976-77. Avoidance of contaminated leads by moulting seals is not assured, hence if seal kills occurred they would affect dependent polar bear populations, some of which are international.

Annual spring migrations into the southeastern Beaufort Sea by whales and birds occur in May and June, when the impact of an oil well blowout would be greatest. Five thousand beluga whales and several hundreds of bowhead whales push through the leads and cracks of the transition zone in late April through to June. They feed on the concentrations of arctic cod and macro-invertebrates which are attracted to the leads by increased light and food. Beluga time their arrival for calving in Shallow and Kugmallit Bays, and rely on the early spring food supply to prepare them for their month-long fast in estuarine waters. The modes of oil interaction with whales are unknown; possibly a local depletion of the white whales' food in the network of leads along the mainland coast (by about 25,000 m^3 of oil) could alter the health of pregnant cows and subsequently the success of the year's calving. The presence of an oil slick contaminating the leads could complicate the whales' freedom to maneuver and delay their arrival in the calving grounds. Beluga whales calve about once every three years and have an annual birth rate of 0.12 calves per adult. The loss of an entire year's calves, either from short-term human disturbances, or by natural causes would be of moderate significance to the population. To the Inuit who depend on the white whales' presence in Kugmallit and Shallow Bays for income and the recreation of the annual hunt, any displacement from traditional calving grounds would be unfortunate. It is clear however that oil from a blowout at either Canmar site is likely to greet large numbers of whales moving in leads; for example, 1,500 whales were observed in a polynya 25 km north of Toker Point (or about 35 km south of Canmar Site #1) in July, 1974. The prevailing ice conditions of the transition zone blowout will dictate the degree to which migrating whales would be exposed to oil.

Migrating seabirds will die in large numbers if oil, almost regardless of its type, quantity and state of weathering is encountered in the transition zone. Several million seabirds, geese and shorebirds migrate eastward along the mainland coast during May and June. The leads along the edge of the landfast ice are particularly important; here the diving birds such as oldsquaws and eiders, comprising as much as 90% of the entire offshore bird migrants, can rest and then feed on the benthic and nektonic fishes and invertebrates found in shallow continental shelf waters. Often the birds search at high elevations for patches of open water, including surface melt-ponds, when leads are scarce. Open water attracts most birds which have been observed to change their intended direction of flight to alight. During the peak eastward migration in early June, about 125 birds per hour pass by any given coastline point. Over 30 birds per square kilometer have been observed from aircraft, usually grouped within narrow leads or in water covered with 3/10 to 5/10 ice. Oil contaminated leads, open water and melt-ponds appear to attract diving birds if the oil is in sufficient quantities to calm the water surface. Since very small quantities of oil, often a few drops, can destroy the birds' thermal protection and waterproofing, the kill of seabirds could be very great. In late May, oldsquaws, eiders and other diving birds often concentrate just north of Baillie Islands (Figure 17); the numbers estimated range from 120,000 to 175,000, representing 10% to 15% of the Beaufort Sea seabird population. A blowout at either Canmar site will pollute this small polynya with several thousand cubic meters of weathered oil, released either by the springtime rotting of landfast ice or by a surface slick of fresh oil driven along the leads by the Mackenzie River freshet and by southeast winds. The ecological significance of the resulting kill, possibly 15% or more of the entire seabird population, would not be disastrous over the long term. This assumes that no population depletions occurred during the earlier migration along the Alaska and Yukon coasts, that

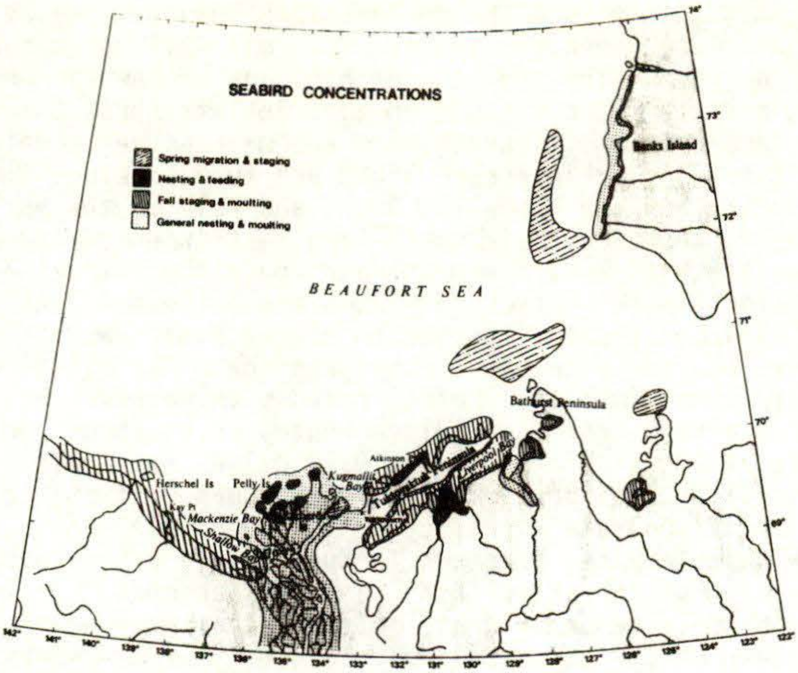

Figure 17. Major concentrations of seabirds including diving ducks, geese and swans in spring, summer and fall, throughout the southeastern Beaufort Sea.

there would be little additional mortality of nesting, feeding, staging and moulting birds, and that there would be only localized, short-lived pollution of the barrier beaches, river estuaries and coastal bays.

These latter assumptions are poor. The hypothetical blowout as viewed on May 5 could contaminate the leads and ice of the transition zone with an estimated 25 thousand cubic meters of oil, spread as far west as the Alaska mainland. The American coastal barrier beaches and lagoons are extremely crucial resting, and feeding stops for migrating birds. Large numbers of eiders, oldsquaws, loons and gulls would have further chances of encountering polluted melt ponds on the ice surface, and along portions of the mainland coast such as Richards Island, Tuktoyaktuk Peninsula and the Yukon coast which will be polluted with oil, especially during the open water season of 1977. The impact of this contamination on nesting and moulting birds is described in the next section Summer, July to September.

In 1964 a 10% natural kill of migrating birds was reported along the Yukon coast. An estimated 100,000 eiders and other diving birds starved when the leads of the transition zone closed and refroze. Such a high natural mortality may not be common, however bird populations appear to recover quickly provided the lead habitats are available in subsequent years. If a large reduction in birds were to occur during the 1977 spring migration, the population could probably recover, if staging, feeding and breeding habitats are protected. The transition zone would be oil free in following years assuming that a relief well successfully quenches the blowout in 1977. If there is a heavy ice year, such as in 1974, and a drill ship is not able to return to the blowout site, the wildlife mortality would be several times greater.

Summer (July to September): During the summer, the hypothetical blowout of 1976 could contaminate 400 km of mainland coast with the partially weathered remnants of 3800 m^3 of oil. The barrier beaches, sandpits, lagoons and bays of Richards Island, Tuktoyaktuk Peninsula, and, to a lesser degree, parts of the Yukon coast would be most directly affected. Colonial nesting birds such as terns and gulls as well as some shorebirds could be affected by oil fouling nesting sites. Many other bird species could be oiled during marine feeding forays in the nesting phase. Later, from mid-July to late August, many birds seek protection in coastal waters during the moult period. A general movement of birds occurs from freshwater lakes, where they nested and raised young, to coastal bays. This movement is likely connected with the moulting of flight feathers; as a result tens of thousands of flightless oldsquaws, scoters, scaups, mergansers and other species are concentrated in lagoons and other sheltered areas behind barrier beaches, especially along Tuktoyaktuk Peninsula.

Swans and geese which nest in river mouths, estuaries and salt marshes (Figure 17) may suffer long-term damage to their nesting and feeding sites. Inundations from storm surges and high river water levels occasionally flood nests and drown young. Oil carried inshore in concert with a storm surge would not only eliminate the annual production of young but could also pollute nesting sites in successive years. Chronic damage to vital nesting areas would significantly delay the recovery of bird populations following offshore kills.

Fall staging is another critical time for shorebirds, geese, brant, oldsquaws, scoters and scaups. These birds concentrate in traditional coastal habitats, particularly along the Yukon coast from Shallow Bay to the Blow River. Their staging areas are usually coastal marshes which are frequently water-covered each summer and offer nutritious sedges and grasses for birds prior to their migration southward. Snow geese, for example, gain up to one quarter of their body weight during staging, in preparation for long distance flights over unproductive taiga. Brant are even more dependent on the coastal littoral zone for their diet of aquatic plants. Oil which contaminates shoreline and lagoon vegetation could be redeposited in bottom sediments, thus affecting long-term plant productivity and benthic invertebrate foods. Oil could even be directly ingested by grazing swans and geese in search of roots and bulblets.

It is evident that hundreds of thousands of seabirds, shorebirds, geese and swans would be affected by a blowout flowing oil for one year or more. The springtime leads and melt-ponds of the transition zone and the bays most frequented by moulting birds in late summer would be the sites of greatest bird mortality.

During the peak of the summer insect season, large herds of caribou and reindeer retreat to the Beaufort Sea coast, including Richards Island and Tuktoyaktuk Peninsula. The onshore winds of the arctic coast reduce the severity of insect attacks, but more often the animals wade and swim in nearshore waters and bays seeking relief. It is probable that these large ungulates could encounter floating oil along the mainland coast and protected bays however, the result of such encounters is unknown.

In July and early August, white whales approach the Mackenzie Delta seeking the warm water of the river estuary necessary for the survival of calves. The whales are congregated in groups of 100 to 1,000 at this time in Shallow and Kugmallit Bays. Numbers of newborn calves are difficult to observe in the turbid waters. Observers on aerial surveys have reported that the far northward extent of the river plume allows calving to occur at some distance from shore. Oil contamination of the nearshore waters in the outer Mackenzie Delta is probable during the calving season; strong northeast winds can drive the oil slick against the river flow and eventually inshore. The effects on the whales concentrated here cannot be predicted. An oil spill in open water could presumably be avoided by these animals, as apparently occurred with migratory grey whales off Santa Barbara, California. Since whales apparently do not feed in the river plume waters, any depletion of summer fish stocks and benthic organisms by inshore oil pollution would likely go unnoticed by beluga. If the whales are forced to leave the contaminated part of the estuary, this interruption could reduce the survival rate of calves for that season. The subsequent recovery of the population may be only a matter of years. More harmful to white whales than oil pollution may be the future levels of summer noise and activity from machinery, ship and aircraft. If focussed in Shallow and Kugmallit Bays the whales could be forced into less suitable calving grounds.

In summer, the ringed and bearded seals are scattered along the mainland coast, offshore and near Banks Island. Oil slicks could easily be avoided by these animals. Although their food habits are varied, the coastal bays and lagoons east of Cape Bathurst are common feeding sites. If heavily polluted with oil, these highly productive waters containing benthos and fishes could be rendered useless to seals. Franklin Bay, for example, southeast of Bathurst Peninsula, seems to be a nursery for large decapod crustaceans. These invertebrates are important in the bioeconomics of the Arctic as they are part of the food of beluga whales, seabirds and fishes as well as of seals. The decapods themselves feed on phytobenthos, detritus and small crustaceans, forming a close link to the primary part of the marine food chain.

Biodegradation of Oil: The ability of micro-organisms to degrade fractions of crude petroleum is well documented for the world's oceans, now including the southern Beaufort Sea. Biodegradation depends on several factors: the availability of oleoclastic bacteria, oxygen concentration, nutrient availability and temperature. In the Beaufort Sea, oleoclastic bacteria appear to be ubiquitous. Bacteria collected from the Beaufort Sea and cultured in the laboratory demonstrated a capacity for degradation at 0°C. The bacteria multiply at the expense of the aliphatic fraction of the oil. Whether or not bacteria can further break down the asphaltates or tarry oil fractions is not clear. Much of the oil will be entrained in growing first-year sea ice, which will drastically reduce the amount of its biodegradation during the winter. When the ice is rotting in June, unfortunately, the melt pools and ponds on the ice are filled with warm but relatively fresh water and since the oleoclastic bacteria found in the waters of the Beaufort Sea are predominantly marine forms, they are unlikely to grow well in the low-salinity melt water. Another summer feature of this region which tends to discourage biodegradation is the very low level of nutrients such as nitrate and phosphate in the marine surface waters after the phytoplankton bloom. It would be unfortunate, from the viewpoint of biodegradation, if spilled oil were sunk to the bottom in offshore waters. Oleoclastic bacteria are not found in the sea floor sediments in depths of 50 meters or more. Any oil which is naturally precipitated, for example, by the suspended Mackenzie River silt would be rendered unavailable to oil degrading bacteria and thus toxic to the environment for a longer period of time, although preliminary data indicates that the river silt would not play a significant role in precipitating oil to the bottom. The nearshore sediments within the plume of the Mackenzie River contain oleoclastic bacteria. The eventual biodegradation of petroleum should be assured in the cold temperatures encountered in the Beaufort Sea, albeit at a rate yet to be determined.

THE VALUE* OF ARCTIC MARINE WILDLIFE TO HUMANS

Whaling: In the Mackenzie Delta region fishes and whales are the main marine resources used by the Inuit and Indians of Inuvik, Aklavik and Tuktoyaktuk. The socializing and recreation associated with the annual whale hunt in Shallow and Kugmallit Bays are as important as the hunt and the harvest, annually valued at about $5,000. About 150 beluga are harvested per year, providing food in summer when the Inuit is less mobile and is restricted to waterways, and when fish is the only other available fresh food. Whale products such as muktuk, meat and oil provide a varied diet but are not a staple food because they are only available seasonally.

Domestic Fishing: Domestic fishing in the Mackenzie region has declined with a decreased dependence on dog teams, resulting from the movement of people to main settlements, improved air travel and the snowmobile. However, in some areas almost everyone seems to be a fisherman. Virtually the entire population lives near the water and boats are used for summer transportation. Freshwater and anadromous fish such as arctic char, whitefish, inconnu and herring are caught with relatively little effort or investment in equipment. Fishing continues almost year round and offers a dependable source of fresh food, Most fishing is centred on the delta proper and in the vicinity of Tuktoyaktuk rather than in coastal waters. The community of Tuktoyaktuk consumes 50 to 75 tonnes per year, with 40 to 50 tonnes of herring caught for dog food alone. The annual domestic fish harvest on the Mackenzie Delta was once as much as 750 tonnes valued at about $170,000 or $42 per capita, as human and dog food.

Although the main sites of domestic fishing on the inner Mackenzie Delta are isolated from offshore waters, the major fish species harvested grow as fry and overwinter in brackish coastal waters which could be polluted by an oil well blowout. Oil pollution in the bays in the vicinity of Richards Island and Tuktoyaktuk Peninsula could deplete fish populations and in turn destroy a sizeable portion of the domestic fishery.

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* Beaufort Sea resources are directly used by Indians and Inuit for subsistence, barter or commercial sale. The dollar values quoted represent the value of the wildlife harvest based on domestic barter within the communities and on commercial sales for export. These prices reflect the cash income that would be lost to the hunter, trapper and fisherman if future offshore industrial activities seriously degrade the environment and not the cost of buying imported goods to replace the domestic utilization of fish, mammals and birds. Replacement or substitute values are speculative since the prices must anticipate how the northern consumer would react if, for example, muktuk, whitefish or seal meat were not available. However substitute prices better reflect the cost of maintaining the northerners' present level of well-being or standard of living. In most cases, the cost of substitute foods would be very high, possibly ten to one hundred times greater than the present export and trade value of the marine resources.

Commercial Fishing: Fish from the Beaufort Sea commercial fishery are sold to southern or export markets, primarily the prairie provinces, and also to northern and domestic markets. Commercial fishing during the past 10 years has failed to produce a self-sufficient fishery of substantial size. Its development has been hampered by erratic catches, perishability, poor transportation facilities and high fishing costs. One of the first attempts to establish a commercial fishery in the Beaufort Sea was in the Mackenzie Delta at Holmes Creek. The quota of 25 tonnes is usually 60 to 100% filled. This fishery provides three fishermen and their families each with an average income of $4,000 to $6,000 per year. The catch, mainly whitefish, is sold to Inuvik hotels, caterers and hospitals.

The smaller Paulatuk fishery was established in 1966 with a quota of 2.5 tonnes, usually comprised of char, whitefish and burbot. Total revenue to the 17 licensed fishermen was $2,500 in 1973, providing an average income per man of about $150. Although small, this income represents a major fraction of the cash income for the settlement which has virtually no other employment opportunities. There is not likely to be any degradation of Paulatuk's commercial char fishery as a result of an oil and gas blowout at Canmar's proposed drilling sites.

Polar Bears: Polar bears have changed from being a traditional subsistence resource to a valuable commercial one. The total quota is 55 bears for the four settlements of Holman, Paulatuk, Sachs Harbour and Tuktoyaktuk. The average bear provides the hunter with 180 kg of meat worth $100. In contrast, the hides range in price from about $570 to over $1,000. The mean total annual harvest between 1969 and 1973 for these four settlements was 48 animals. In 1973 the polar bear harvest was conservatively valued at about $28,000. Sports hunting is also a lucrative endeavour for the village outfitters, who charge $1,750 for an unsuccessful hunt and $2,500 for a successful one. The total sports hunting revenue from the entire southeastern Beaufort Sea was $12,500 in 1973. Polar bear hunting, like commercial fishing, provides cash income from marine resources without large investments or changes in lifestyle.

Seals: Seals are little utilized in the settlements of Aklavik, Inuvik and Tuktoyaktuk which are mainly fishing and whaling communities. The sealing centers of the Beaufort Sea are Sachs Harbour, Paulatuk and Holman. Traditional uses such as meat for dogs, oil for heat and light, and skins for clothing have diminished or disappeared. With the appearance of snowmobiles, fuel oil and manufactured clothing, the incentive for sealing has shifted from domestic uses to the export of skins. Seals are an important resource of income in the subsistence economy, especially east of the Baillie Islands where employment opportunities are least and marine resource utilization maximum. Each seal landed provides 23 kg of meat and organs valued between 33¢ and 48¢ per kg, or a minimum of $7.50 per seal. The estimated ringed seal harvest from the 4 villages was 8,500, with nearly 94% of the catch taken from Holman.

In years of poor fox trapping, seal furs contribute as much as 50% ($36,000) of the total income for Banks Island residents. Here, the availability of seals is stable relative to fluctuations in fox populations. Gross profit is much higher for foxes. The value of fox pelts traded in 1967 was almost $190,000, providing 80% of the total cash income for Sachs Harbour trappers. In general, the portion of their total income attributable to fur trade, whether seals, foxes or polar bears is relatively stable, usually between 78% and 91%.

It appears that the presence of seals is an insurance against lean years of fox trapping. Seals may be the key to the entire income opportunity east of Baillie Islands as a consequence of the foxes' dependence on them for food, and their availability when fox trapping is poor.

Prime sealing areas and the people who benefit most from the seals are outside the geographical regions which might benefit from employment or economic development resulting from offshore oil and gas exploration. Seals, polar bears and foxes are vulnerable to oil discharged by a blowout in the transition zone. These animals are almost the only source of earned income in Paulatuk, Sachs Harbour and Holman. The potential benefits of offshore petroleum activity are found mainly in the Mackenzie Delta area. The result could be an assymetry of benefit and risks.

Migratory Waterfowl: The number of migratory birds hunted along the Beaufort Sea coast is not well known. Although the culture is changing from subsistence living to a community life style, hunting for geese and sea ducks remains a popular spring and fall activity. Traditionally, the native bird hunters concentrated their hunt on the migratory birds in the spring, when bird meat furnished a change of diet and a source of food during break-up and thaw when it is difficult to hunt for larger game. The spring hunt still occurs every season, but with fewer participants than before. An estimated 8,000 snow geese, 750 white-fronted geese, 2,000 eiders and 9,000 ducks are taken annually along the Canadian Arctic coastline. Up to 6,000 eiders are harvested by Holman residents in some years.

These migratory birds are designated by treaty as an international resource, because of their value to the rest of Canada and the U.S.A. The American and Canadian goose harvest is about 1.5 million birds each year, with a direct economic value of over 1 million dollars per year.

The Values: It is clear that the economic value, in absolute terms, of the harvest of fish and wildlife resources in the Beaufort Sea is very small indeed when compared with the expenditures involved in oil exploration or with the value of resources which it is hoped will be revealed by this exploration. On the other hand, it is also clear that to the people involved these resources have meaning and importance which greatly exceeds their economic value. The same can probably be said of the importance of the birds to people in southern Canada and the United States. The significance of the effects of an oil spill on these fish and wildlife populations therefore depends very strongly upon subjective value judgement, and is not easily quantified.

CONCLUSIONS

Extensive drilling operations in the Beaufort Sea will have substantial environmental and sociological impacts whether or not any major polluting incident occurs. The situation will have to be examined and dealt with by appropriate authorities as it evolves. However the drilling of two holes in the summer of 1976, which is the subject of immediate urgent concern, will not produce a sufficiently large increase of activity in the Beaufort Sea that a major impact will result unless an oil blowout should occur. Therefore attention is focussed on that possibility.

Probability of a Blowout in the summer of 1976: It is very difficult to ascertain the probability of a blowout, since the number of offshore blowouts worldwide which produced substantial oil pollution has been too small to produce a satisfactory statistical base, and the particular conditions in the Beaufort Sea are unusual. Nevertheless, on the basis of information given by representatives of the industry and by DINA and DEMR the probability of an oil or oil and gas well blowout is judged to be in the range of 10^{-3} to 10^{-4} for each well drilled.

Environmental Threat from a Blowout at Proposed 1976 Drilling Sites: It is unlikely that oil discharged into the Beaufort Sea from a single oil well blowout running for several years would have any effect whatever on global or even local climate. Hence the main environmental threat is to the biota of the Beaufort Sea region. Both of the Canmar drilling sites are in the "transition zone", where winter ice is subject to movement of the order of kilometers per day, and where leads open, freeze over, and close throughout the winter in a manner which is not predictable in detail.

- Canmar Site #1 is positioned in the transition zone where a blowout is comparatively *most damaging* to plant and animal life because of the likelihood of winter and spring pollution of the active leads north of the mainland fast ice.

- Canmar's Site #2 is located in the transition zone where a blowout is *marginally less damaging* to overwintering wildlife since much of the winter oil discharge will be dispersed under the ice, at least until spring.

For comparison, a scenario was developed for a hypothetical Site #3 to reveal the effects of a blowout from a well drilled nearer shore where the ice is landfast in the winter. This scenario showed that a blowout is comparatively *least damaging* to overwintering marine mammals and spring migrants, assuming that burning at the blowout site is effective in the spring.

Drilling a Relief Well in 1977: The environmental threat ratings assume that the imaginary oil and gas blowout is controlled by drilling a relief well before October, 1977. This may not be possible since the 1977 ice year may be heavy and the subsequent open water season may be short. It is not possible usefully to predict the likelihood of light or heavy ice years. A blowout site can be continually ice-covered or ice-infested. This is more probable at Canmar's Site #2 than Site #1, and less likely at the landfast Site #3.

Considerations Affecting the Escape of Oil into the Environment: Available technology is severely limited in its capability of mitigating the threat to the environment arising from the loss of control of an offshore oil well, particularly in the Beaufort Sea transition zone. Unless a blowout were self-sealing, damage from released oil could only be prevented in one of three ways:

a) The flow can be stopped by the drilling of a suitable relief well.

b) The oil could be contained at or near the bottom.

c) The oil could be contained or disposed of after it has reached the surface.

At present no technology exists for drilling a relief well in the Beaufort Sea transition zone except during the brief summer open water period. In some years no suitable open water period occurs.

There exists no technology for containing the oil near the bottom which is suitable for controlling escaping oil and gas in the Beaufort Sea transition zone.

Containment and disposal of oil at the surface is possible under certain limited circumstances. However existing technology is known to fail in modest sea and wind states such as occur for 55 to 60% of the time during the summer in the Beaufort Sea. According to scenarios developed in the Beaufort Sea Project, existing technology is unlikely to be successful in disposing of a large fraction of the oil which escapes during the winter period of moving ice.

The environmental prediction system which will be in place in the Beaufort Sea during 1976 and 1977 will not be sufficiently complete to permit prediction of the movement of escaped oil as accurate as is allowed by the state of the art. Thus the deployment of devices such as booms for the protection of especially vulnerable areas will be less efficient than is technologically possible.

Oil Spill Countermeasures in 1977: Canmar has endeavored to assemble equipment and develop methods to mitigate damage of oil pollution from a blowout. However, the harsh arctic conditions place severe constraints on the effectiveness of clean-up activities in 1976. New technologies adapted to arctic marine waters are in embryonic stages of development. As a consequence of an imaginary blowout on 5 October, 1976, and assuming a "standard blowout" (based on information received from the industry) in which the initial flow is 2500 barrels* per day, reducing in a month to 1500 barrels a day and then continuing at that rate until the well is brought under control, it is concluded that:

- Most of the oil discharged from October, 1976 to early July, 1977 will escape containment and disposal at both Canmar sites. Approximately 25,000 m^3 of oil will be mixed with the ice and water of the transition zone. Spring burning will have only very limited success. Spring burning of the oil might on the other hand be very effective for a blowout occurring in the landfast ice region.

- Fifty-five to sixty percent of the 21,000 m^3 of oil discharged from July, 1977 to October, 1977, (the assumed month of well control), would be likely to escape containment and disposal at either Canmar site. Of the total amount blown by winds towards the coastlines, inshore oilspill countermeasures are unlikely to eliminate more than

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* 1 barrel = .159 m^3.

5 percent. On the other hand, where protection of specific bays and lagoons is sought, countermeasures would be effective for at least 45% of the summer.

- Oil spill countermeasures proposed for 1977 are not likely to decrease significantly the estimates of environmental impact of an oil and gas blowout occurring at either Canmar site.

Threats of a Blowout to the Arctic Marine Food Chain: An autumn oil well blowout at either Canmar site, but more so from Site #1, just north of the landfast ice zone, could pollute active leads and open water in the ice of the transition zone through the winter and spring. Assuming the blowout is controlled within one year, the oiling of these active leads, vital to the survival of marine mammals and birds will be shortlived. By the winter of 1977-78 the oil will have been dispersed northward into the Beaufort Sea Gyre and southward to the inshore waters and coastlines.

- It is predicted that primary production will be inhibited where oil collects in the ice of the transition zone so that a localized depletion of fish stocks, invertebrates and sub-ice algae will occur. This depletion would have significance if it occurred in the main E-W leads used for migration and in zones of active shearing used by resident seal populations. Seals, whales, some marine fishes and birds depend on the spring influx of food to recover from a winter's fast, a migration or an annual moult.

- The mortality of overwintering ringed and bearded seals concentrated in the ice of the transition zone cannot be predicted; however, it is certain that a large fraction of the sub-adult and adolescent seal populations, perhaps 30% or more, in the southeastern Beaufort Sea will encounter oil. Adult seals in good condition are not particularly sensitive to oil. However it is possible that for seals under natural stress, short exposures to floating oil could be deadly. Natural stresses occurred in the winter of 1974-75 which were attributed to the heavy ice year, little open water and insufficient snow cover. Bearded seals, up to 50% of the population, could contact oil because of the winter and spring concentration of the entire population in active leads. In contrast, breeding ringed seals would remain relatively isolated from, and therefore be unaffected by, oil discharged during the winter because the landfast ice in which their birth lairs occur is a natural barrier to offshore oil. The significance of a reduction in the seal population caused by oil-related stresses will be reflected in subsequent decreases in the numbers of polar bears and white foxes caused by emigration to marginal habitats elsewhere, and low offspring survival. These populations can recover, in time, if the key leads and polynyi used for feeding and breeding are not chronically polluted.

- The predicted contamination of offshore leads for at least one spring season and the more chronic, long-lived pollution of the coastal bays and shorelines will have the greatest impact on the bird life of the southeastern Beaufort Sea. Hundred of thousands of eiders, oldsquaws and other diving birds could be killed during the spring migration along the mainland coast. Large natural bird kills have occurred during offshore migrations in heavy ice years, however in the case of oil-related kills recovery of these bird populations would be further inhibited by the pollution of critical nesting, moulting and staging sites.

- Coastal fishes comprise other wildlife populations sensitive to oil pollution. Large numbers of cisco, inconnu, whitefish, smelt, cod and herring concentrate in the low-salinity coastal bays and inshore waters. Especially in the fall and winter of the year these marine and fresh-water fish will likely encounter oil. The recovery from an initial fish kill is predicted to be slow, perhaps a decade, a result of the persistent toxicity of oil in lagoon and embayment sediments. There could be a depletion of benthic food, mortality of the breeding fish stock as well as subadults. Slow growth rates, and frequently, unsuccessful year classes could further aggravate recovery. The significance in the food chain of coastal and inshore fish is unknown; some diving birds, seals and possibly beluga whales prey on these fishes in shallow waters.

It is evident that the effects of an oil blowout could be severe on some portions of the ecology and on some populations, particularly sea birds. However none of these effects is likely to be permanent, although recovery might take as long as a decade in some cases. Except for birds, the economic values of marine wildlife resources threatened is of the order of tens of thousands of dollars per annum which is very small compared with the magnitude of the investment in the oil industry. Various estimates have been made of the economic values of migratory birds as a renewable continental resource -- in the order of millions of dollars per annum. Economic valuations of birds are exceedingly difficult to make on a sound basis, but the birds are visible throughout the continental flyways and are a substantial recreational resource having a high social and indirectly a high economic value. Even so, the importance of these consequences will have to be judged on largely sociological and environmental grounds, not economic ones.