Overview of Historical Canadian Beaufort Sea Information

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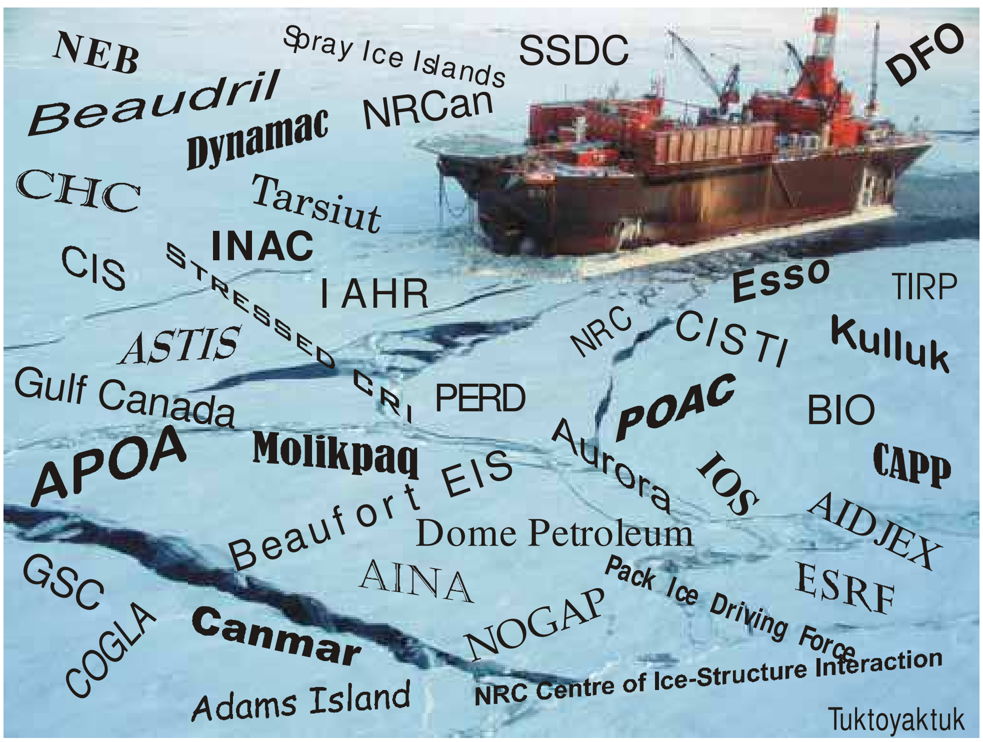

NRC Canadian Hydraulics Centre
Technical Report CHC-TR-057

February 2009

CHC CANADIAN HYDRAULICS CENTRE
CENTRE D'HYDRAULIQUE CANADIEN

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ABSTRACT

A considerable amount of information and knowledge was gained during the exploration phase of the Beaufort Sea during the 1970s through to the 1990s. However, this information can be difficult to locate. This report provides a broad summary of the oil and gas activities in the Canadian Beaufort Sea. Information is provided on the environment in this region, the types of drilling platforms used for exploratory and delineation drilling, the support agencies that funded research, the large-scale field measurement programs, as well as other relevant Arctic field programs. Descriptions are also given on the numerous resources that can supply this detailed information including libraries, databases and organizations that have Arctic expertise.

RÉSUMÉ

L'exploration pétrolière en mer de Beaufort durant les années 70, 80 et 90 a généré une quantité considérable de données, lesquelles ne sont pas toujours faciles à retracer. Ce rapport fait le point sur ces activités, en répertoriant les conditions environnementales, le type de structures utilisées pour effectuer les forages d'exploration et de délimitation, les organismes ayant subventionné les travaux de recherche, les programmes d'essais de terrain à grande échelle, ainsi que d'autres programmes de terrain ayant eu cours dans l'Arctique. On dirige le lecteur vers de nombreuses sources de renseignements en la matière, incluant centres de documentation, bases de données et des organisations qui se spécialisent dans ce domaine.

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LIST OF ACRONYMS

Acronym	Description	Section
AGOA	Alaskan Oil and Gas Association	4.2
AIDJEX	Arctic Ice Dynamics Joint Experiment	5.2
AINA	Arctic Institute of North America	7.2.2
APOA	Arctic Petroleum Operators Association	4.1
ASTIS	AINA Arctic Science and Technology Information System	7.2.3
ATPP	AINA Arctic Technology Preservation Project	7.2.4
Beaudril	Beaudril Ltd. (subsidiary of Gulf Canada)	3.0
BIO	Bedford Institute of Oceanography	7.3.1
BSStRPA	Beaufort Sea Strategic Regional Plan of Action	7.2.14
Canmar	Canadian Marine Drilling Limited (subsidiary of Dome Petroleum)	3.0
CAPP	Canadian Association of Petroleum Producers	4.3
CASES	Canadian Arctic Shelf Exchange Study	5.7
CCG	Canadian Coast Guard	7.3.5
CHC	NRC Canadian Hydraulics Centre	7.3.6
CIDS	caisson structure	3.4.5
CIS	Canadian Ice Service	7.3.4
CISTI	Canada Institute for Scientific and Technical Information	7.2.1
COGLA	Canada Oil and Gas Lands Administration	7.2.10
COOGER	Centre for Offshore Oil and Gas Environmental Research	7.3.2
CRI	Caisson-Retained Island	3.4.3
CRREL	US Cold Regions Research and Engineering Laboratory	7.2.15
DFO	Department of Fisheries and Oceans	7.3.1
EIS	1982 Beaufort Sea Environmental Impact Statement	4.6
ESRF	Environmental Studies Research Funds	4.4
Explorer	Canmar floating drillship	3.2
GSC	Geological Survey of Canada	7.2.9
IAHR-ice	IAHR Symposium on Ice	7.5.2
INAC	Indian and Northern Affairs Canada	7.2.11
IOS	Institute of Ocean Science	7.3.1
IOT	NRC Institute for Ocean Technology	7.3.7
ISOPE	International Society of Offshore and Polar Engineers	7.5.4
Kulluk	floating conical drillship	3.3
MMS	USA Minerals Management Service	7.2.16
Molikpaq	Mobile Arctic Caisson structure	3.4.4
NEB	National Energy Board	7.2.10
NOGAP	Northern Oil and Gas Action Plan	4.8
NRC	National Research Council of Canada	4.7, 4.10
NRCan	Natural Resources Canada	7.3.3, 4.5
OMAE	Offshore Mechanics and Arctic Engineering	7.5.3
PERD	Program of Energy Research and Development	4.5
POAC	Port and Ocean Engineering under Arctic Conditions	7.5.1
SHEBA	Surface HEat Budget of the Arctic Ocean	5.6
SIMI	Sea Ice Mechanics Initiative	5.5
SSDC	caisson structure	3.4.2
Tarsiut	concrete caisson structure	3.4.1
TC	Transport Canada	7.2.12
TIRP	Tarsiut Island Research Program	5.1

Overview of Historical Canadian Beaufort Sea Information

1.0 INTRODUCTION

Recently there has been renewed interest in the exploration and possible development of the oil and gas resources in the Canadian Beaufort Sea. It is important that the knowledge gained during the previous exploration phase in this region during the 1970s and 1980s is not lost and its use is maximized. However, newcomers with an interest in this region often do not know the history of the Beaufort exploration phase, nor the wide-ranging information that was generated during that time. The Canadian Hydraulics Centre of the National Research Council of Canada (NRC-CHC) has been active in ice engineering issues for many years. Their involvement with northern offshore issues pre-dates the initial exploration phase of the Canadian Beaufort Sea in the 1970s and 1980s. They have participated in, and led, a number of projects related to the Beaufort Sea activities. Because of this involvement, they have detailed knowledge of many of the activities that took place during that time period. Because of this experience, Indian and Northern Affairs Canada (INAC) asked the CHC to prepare an overview report that summarizes the past information obtained in the Beaufort Sea. This report represents a very broad look at previous information based on the authors' experience.

To fully document the Beaufort Sea experience and knowledge is certainly not possible in a single report. Instead, this report will provide general knowledge in several areas with specific references for the reader to pursue if additional information is required. The report focuses on the Canadian Beaufort Sea but reference is made to some parallel studies in the U.S. Beaufort. This report covers the following topics:

- Chapter 2.0 presents a short overview of the environmental conditions in this region;
- Chapter 3.0 provides a summary of the types of offshore drilling platforms used during the exploratory phase in the 1970s to 1990s. The previous exploration activities will be reviewed and information will be supplied on the data available.
- Chapter 4.0 provides information on the major Canadian support agencies that provided financial support and research co-ordination.
- Chapter 5.0 reviews some of the larger Beaufort Sea field measurement programs
- Chapter 6.0 provides an overview of other relevant research programs that were carried out in the Canadian Arctic.
- Chapter 7.0 provides details on resources that would be useful for further information in this area, including books, libraries and databases, research organizations and conferences that deal with Arctic science and engineering.

2.0 BEAUFORT SEA ENVIRONMENTAL DATA

During the intense exploration of the Beaufort Sea in the 1970s and 1980s, a considerable amount of environmental information was collected by the Oil Industry. A large amount of the data was processed and published as part of the Environmental Impact Statement (Beaufort Sea EIS, 1982). Copies of this report are not easily obtained now, but they can be viewed at the Arctic Institute of North America (AINA –see Section 7.2.2) at the University of Calgary, Calgary, Alberta. More recently, Devon Canada developed an environmental assessment for its operations (Devon Canada, 2004a). This report can be obtained through the website of the National Energy Board of Canada. (http://www.neb-one.gc.ca). The following sections provide a brief overview of the environment in this region. This is not a comprehensive review; instead it is intended to give an overview of the environmental conditions, especially highlighting the knowledge during the exploration phase in the 1970s and 1980s. In some cases, the reader is directed to other sources for more up-to-date research and knowledge.

2.1 Temperature

Figure 1 shows the mean daily air temperature for the period of January 1, 1975 to December 31, 1979. The measurements were recorded by the Canadian Ice service (CIS) at Tuktoyaktuk. The data shows high temperatures that reach typically +15ºC in the summer and low temperatures reaching -40ºC in the winter. There are often very strong winds in the Arctic which combined with the low temperatures, produce very extreme wind chill factors.

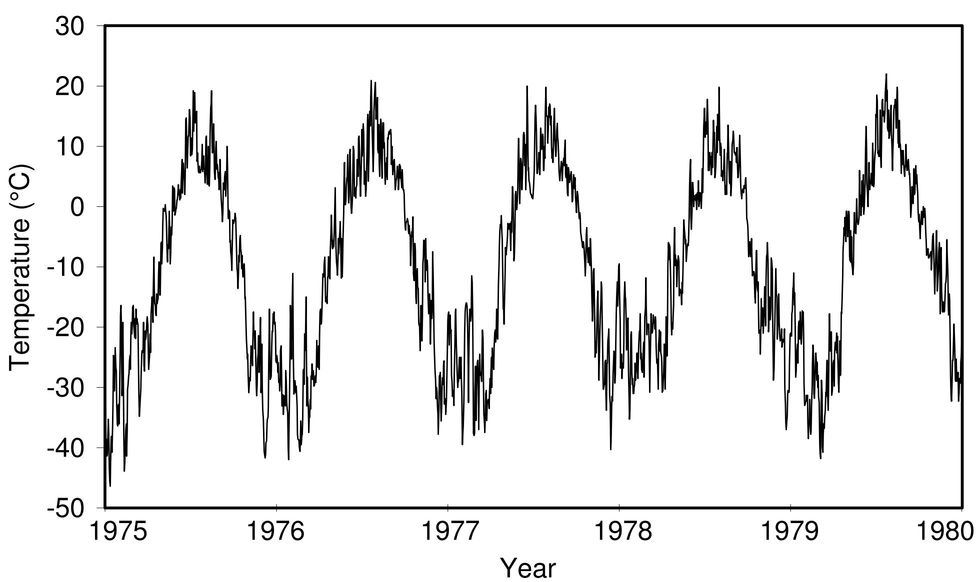

Figure 1: Mean daily air temperature at Tuktoyaktuk from 1975 to 1980.

2.2 Daylight Hours

Figure 2 shows an illustration of the duration of sunlight at latitudes from 30º to 90º (after Burns, 1973). The figure also shows the duration of sunlight at Inuvik. As shown in the figure, the sun does not rise above the horizon for up to three months during the winter in the Beaufort Sea. Conversely, in the summer months, the sun does not set and provides 24 hours of daylight.

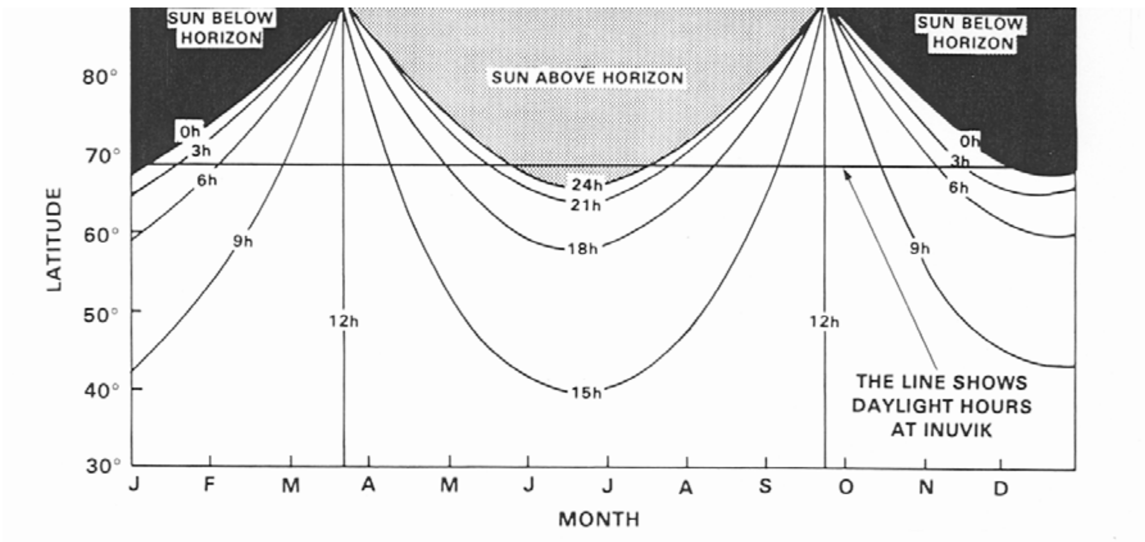

Figure 2: Number of daylight hours as a function of latitude. The sun does not rise above the horizon for approximately three months in mid-winter in the Arctic (after Burns, 1973).

2.3 Ice Conditions

The ice in the Beaufort Sea can be sub-divided into three regions – the Arctic polar pack zone, the seasonal or transitional (shear) zone, and the landfast ice zone (see Figure 3 after Kovacs and Mellor, 1974).

The Arctic Polar Pack is comprised of Old or multi-year ice with a level ice thickness up to 4.5 m, and ridges that can be 25 m thick (see Figure 4 after Wadhams and Horne, 1978). The Polar Pack continuously circulates with currents and winds in the Arctic Ocean, and is present year round. Its degree of penetration into the Beaufort Sea at any given time is dependent on the wind regime of the year. On average, the boundary of the Arctic Pack lies from near Cape Prince Alfred southwestward to some 200 km north of Herschel Island and then westward some 200 km off the Alaska North Coast.

The seasonal transitional zone extends from the edge of the (stationary) landfast ice to the edge of the moving polar pack ice. The width of this zone can vary from a few kilometers to over 300 km both within a season and from year to year (Spedding, 1978). Although this region is primarily comprised of first-year ice, there can be a large number of multi-year and second-year ice floes. This ice is highly dynamic and movement can take place throughout the winter. Movements of 3 to 13 km/day are likely (see Figure 5 after McGonigal, 1978). The moving ice results in deformations in the ice sheet and the creation of both ridges and leads. The number of ridges increases rapidly in the first part of the winter and remains relatively constant after February. Ridge heights (sails) can range up to 6 meters (see Figure 6 from Beaufort Sea EIS (1982) after Wright and Schwab, 1979). The majority of the ice (the keel) is below the water and typical keel-to-sail ratios are 4.4 (Timco and Burden, 1997). During the summer months, these ridges may melt. If they survive the summer, they largely desalinate. A ridge that survives two or more summer season is usually highly consolidated and forms a multi-year ice ridge. Due to their low salt content, these ridges are considerably stronger than first-year ridges. Their shape is smoother with a keel-to-sail ratio of about 3.3 (Timco and Burden, 1997).

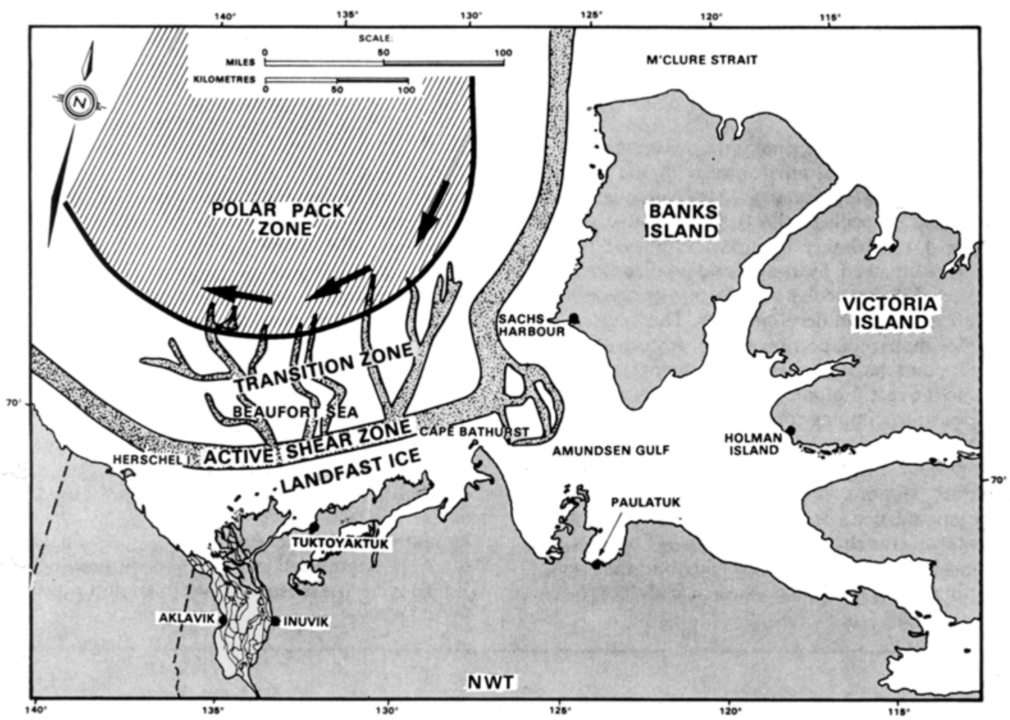

Figure 3: Map showing the three zones in the Arctic (after Kovacs and Mellor, 1974).

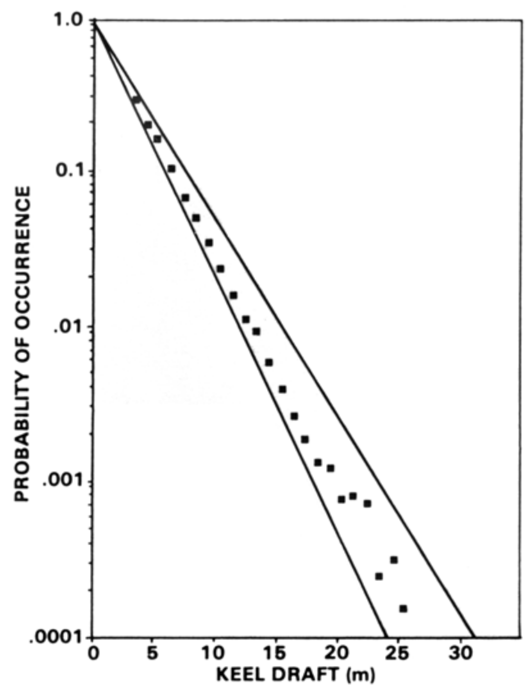

Figure 4: Probability of finding pressure ridge keels in the Polar Pack (after Wadhams and Horne, 1978).

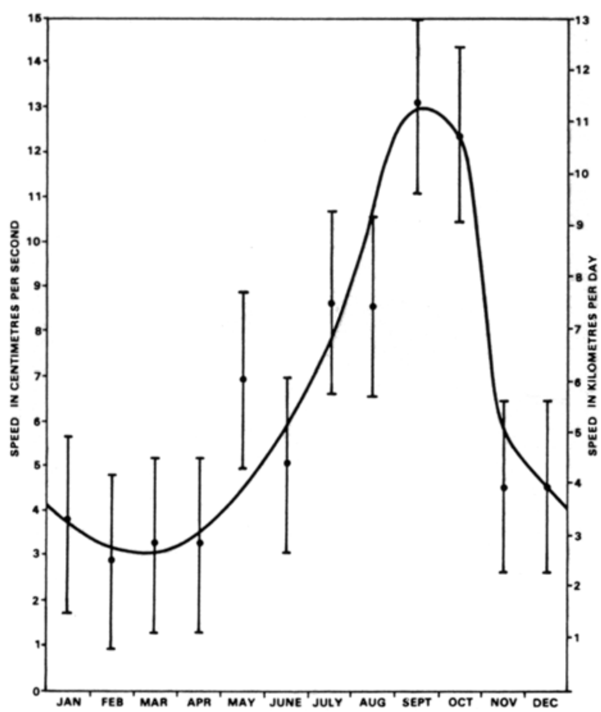

Figure 5: Mean drift speed (in cm/s) of pack ice in the seasonal ice zone (after McGonigal, 1978)

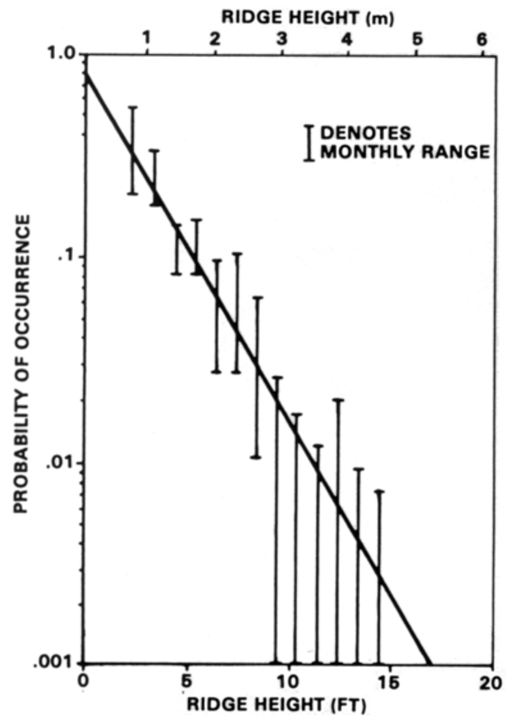

Figure 6: Probability of finding a first-year ridge of a given height in the seasonal ice zone in winter 1973-1978 (after Wright and Schwab, 1979). The monthly range indicates the variability during the winter months.

The landfast ice is extensive and forms out to a water depth of approximately 20 m. The edge of the landfast ice varies slightly from year to year (see Figure 7). This region is comprised primarily of first-year ice. Multi-year ice, if present during the freeze-up period, will be frozen into the sheet. The ice begins to grow in late September and reaches a maximum thickness of approximately 1.9 m in late April (Figure 8, Devon Canada, 2004b). In spring, northwest winds die off, and east and southeast winds become predominant, so that a polynya develops along the edge of the landfast ice. In June, melt begins in the Mackenzie Delta and an open water area also develops quickly there. Typically, ice in the Amundsen Gulf fractures in late June and then drifts out and decays. The fast ice along the Tuktoyaktuk Peninsula fractures in early July. During a cold summer, the landfast ice along the Tuktoyaktuk Peninsula may not completely break until mid July. These cold summers occur because northwesterly winds keep the Arctic Pack close to shore.

Open drift ice conditions do not develop along the coast until the first week of August and an open water route does not develop until the first week of September. Freeze-up in the Beaufort depends to a very great extent upon the location of the southern limit of the Arctic Pack. New ice formation starts among the multi-year floes in late September and spreads southward while it also spreads seaward from the coast. By late October much of the ice is at the first-year stage right out to the Arctic Pack.

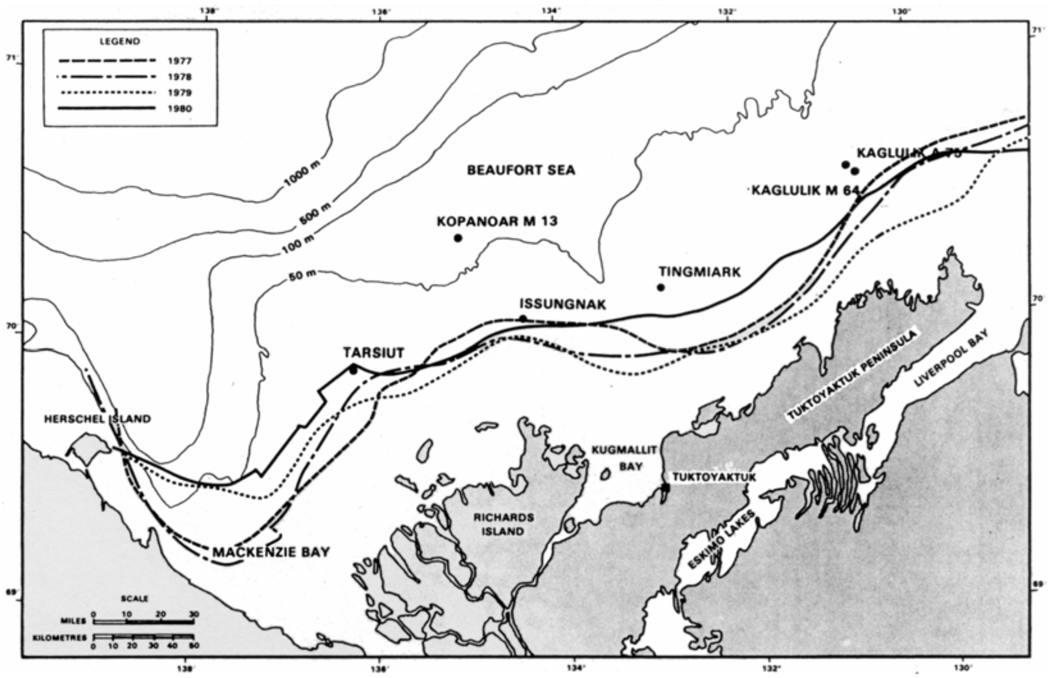

Figure 7: Extent of the landfast ice from 1977 to 1980 (after Spedding, 1978).

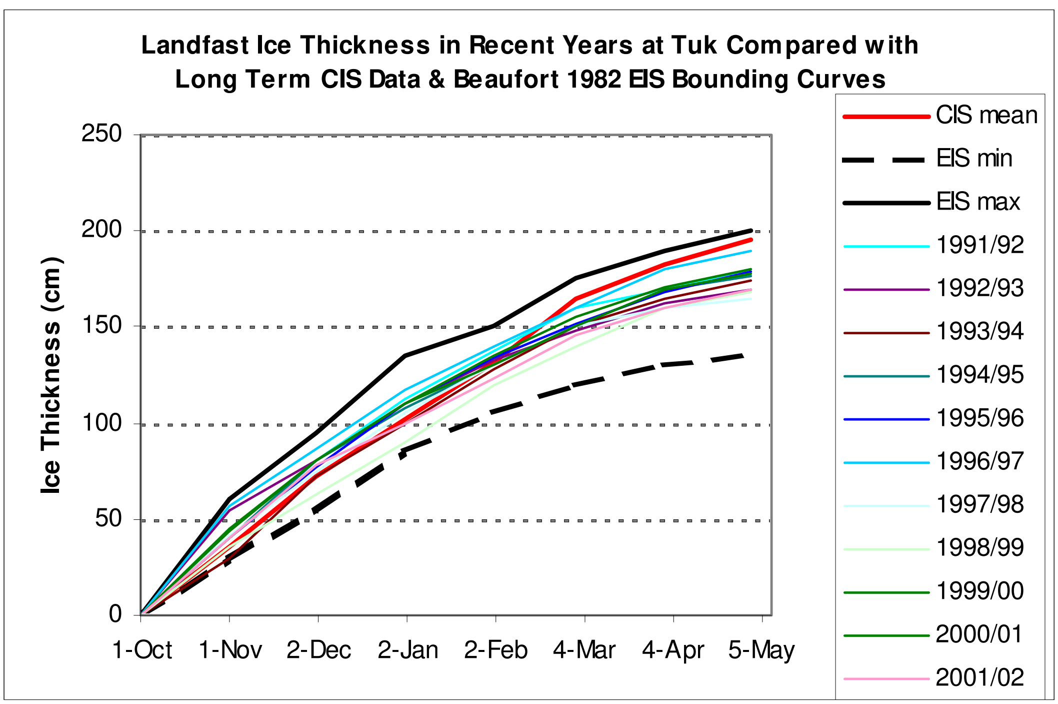

Figure 8: Ice thickness in the Beaufort Sea from 1991 to 2002. The Canadian Ice Service (CIS) mean curve and the EIS min and max curves are also shown (after Devon, 2004b).

Ice property and strength information for sea ice has been analyzed and summarized with a good understanding of sea ice density (Timco and Frederking, 1996), compressive strength (Timco and Frederking, 1990) and flexural strength (Timco and O'Brien, 1994).

The ice conditions described here do not include recent research on ice conditions in the Beaufort Sea (see e.g. Dumas et al., 2005; Melling et al, 2005; Kubat et al. 2006). Interested readers should review these publications and the information supplied by the Canadian Ice Service (see Section 7.3.4).

2.4 Winds

Winds in the Beaufort Sea are influenced by the sharp thermal contrast between the land and water, and the high coastal lands. MEP (1981) analyzed the winds at ten different sites to determine the magnitude of the winds in the Beaufort Sea. Table 1 provides information on the results for the hourly average and the 1-minute average respectively. It can be seen that once every 50 years, winds with an hourly average of 105 km/hr and a 1-minute average of 140 km/hr can be expected. The dominant wind direction ranges from the northeast to southeast during any month of the year (Berry et al., 1975). Southerly winds are rare during the summer months. From July to September, westerly to north-westerly winds in excess of 36 km/hr become persistent. Fifty percent of all strong winds with speeds exceeding 50 km/hr are from the west or northwest. These winds are responsible for the multi-year ice pack ice intrusions into the coastal waters (Berry et. al, 1975).

Table 1: Wind speed analysis for the Beaufort Sea (after MEP, 1981).

hourly average		1-minute average	
return period	wind speed	return period	wind spped
years	km/hr	years	km/hr
1	60	5	107
10	86	10	116
25	97	25	129
50	105	50	140
100	114	100	150

2.5 Currents

The mean circulation pattern in the Beaufort Sea is shown in Figure 9 (Beaufort Sea EIS, 1982). In the offshore Beaufort, the surface flow is dominated by the clockwise circulation of the Beaufort Gyre. Estimates by Newton (1973) indicate that flow speeds reach 5 to 10 cm/s at the southern rim of the Gyre over the western Beaufort Sea. Figure 10 shows the pattern of currents in the nearshore region for both northwest winds and east winds. During the summer season, measurements of currents made at the Kopanoar location indicate values of 0.3 to 0.4 m/s at 5 m depth, and decreasing to 0.1 to 0.2 m/s at 12 m depth (Fissel, 1981).

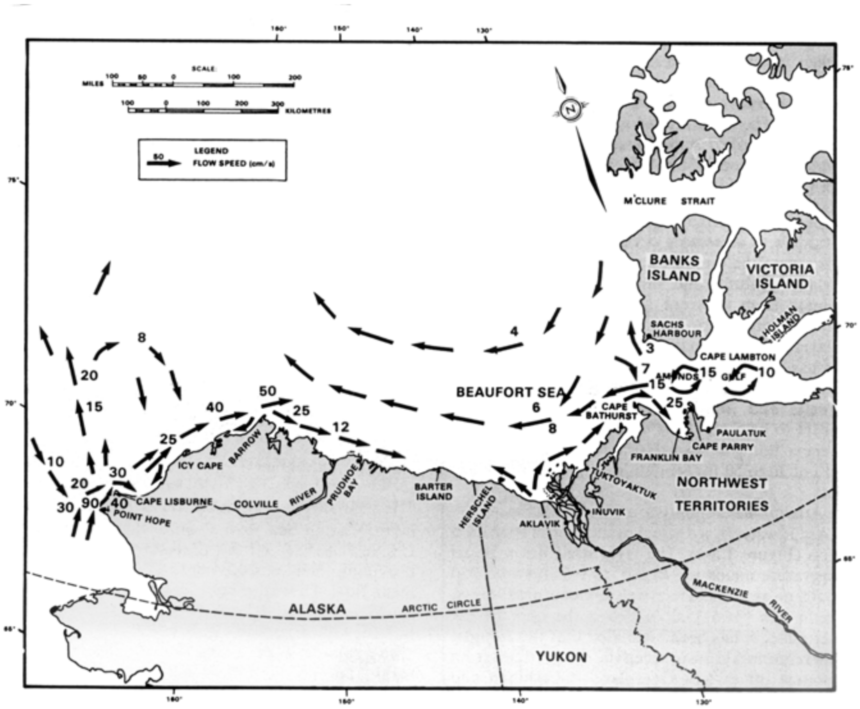

Figure 9: Mean general summer circulation of the surface water in the Beaufort and Chukchi Seas (after Beaufort Sea EIS, 1982).

In recent years, the Institute of Ocean Science, which is a part of the Department of Fisheries and Oceans (see Section 7.3.1), has been continuously measuring the ocean currents in the Beaufort Sea. Interested readers should contact them for additional information.

2.6 Waves

The height of wind-generated waves depends on the wind strength, wind duration, water depth, and the extent of open water over which the wind blows. In the Beaufort Sea, this open water fetch is limited by the presence of sea ice and local landmasses. As a result, the normal sea states are not too severe and the wave heights are limited.

Baird and Hall (1980) performed a hind-cast calculation of the wave climate in Beaufort Sea. Figure 11 shows a plot of the percentage of time that the significant wave heights exceeded a given wave height during the open water season. This analysis was performed for the Kopanoar site. The plot shows that the significant wave height exceeded 2 m only 2.5% of the time during the open water season.

Although the wave heights are not large in this region, waves played an important role in Beaufort Sea operations. For example, waves caused problems with the placement and stability of the sand and gravel islands (see Section 3.1), and the deployment and operation of the Tarsiut caissons (see Section 3.4.1). Most recently, a large storm surge caused damage along the (very shallow) shore line in this region. Steve Solomon of the Bedford Institute of Oceanography investigated this event.

In recent years, Val Swail of Environment Canada has re-examined the wave climate in this region and produced a new hind cast (Swail et al, 2007). He should be consulted for the most recent information on waves in the Beaufort Sea.

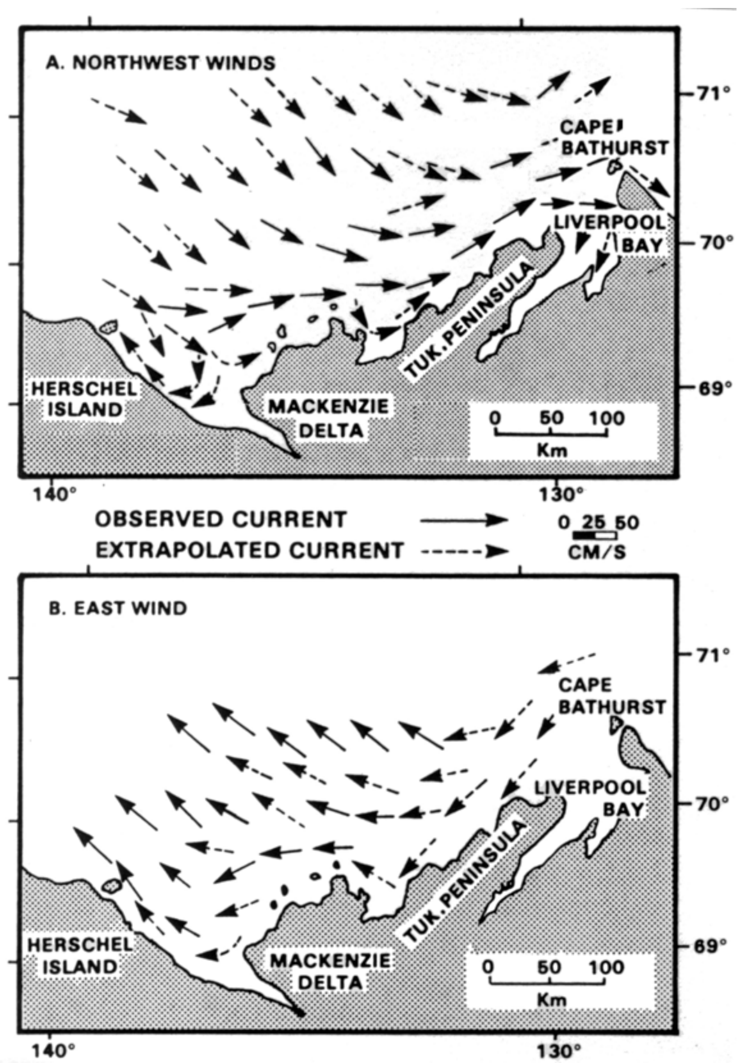

Figure 10: Surface circulation in the south-eastern Beaufort Sea for northwest and east winds from surface drift studies (after McNeill and Garrett, 1975).

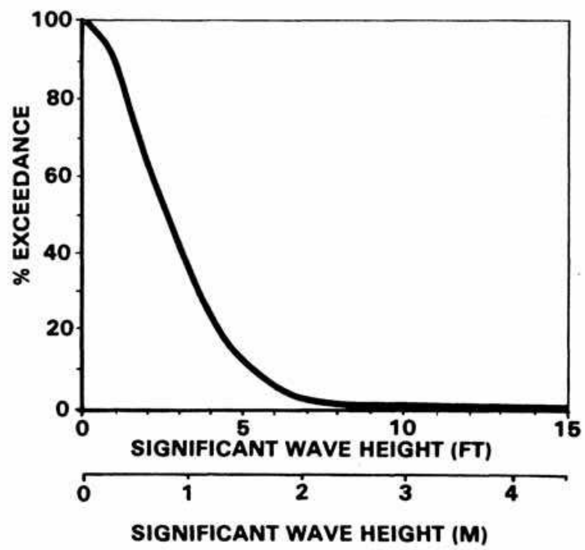

Figure 11: Percentage of time that the significant wave heights exceeded a given wave height during the open water season at the Kopanoar site (after Baird and Hall, 1980).

2.7 The Sea Bottom

There are three main bathymetric features in the southeastern Beaufort Sea: the continental shelf which slopes gently from the coastline to water depths of approximately 100 m, the continental slope angling steeply from the edge of this shelf to depths of 1000 m, and the trench-like Mackenzie (or Herschel) Canyon which transects a portion of the shelf (EIS, 1982). There have been numerous boreholes drilled to evaluate the seabed materials both to assess foundation conditions and to find borrow material for the construction of artificial islands. In most locations, the seabed consists of 0.5 to 35 m of recent marine clays or silty clays which have been carried onto the continental shelf from the mouth of the Mackenzie River. These sediments are gray to black, soft-to-firm and often contain traces of fine sand and organics. Coarse materials such as sands and fine gravels may also be encountered (O'Connor, 1980).

Permafrost is widespread beneath the Beaufort Sea (Judge et. al., 1976). Ice lensing and visible intergranular ice is often observed in boreholes. In addition, there are a number of large pingo-like features on the floor of the southern Beaufort Sea. The Canadian Hydrographic Service has identified over 200 of these features between the 20 and 200 m isobaths and from 128º to 136ºW longitude. Most of these features are between 200 and 1000 m in diameter, have sloped sides of less than 5º, and can rise to within 18 m of the sea surface (Beaufort Sea EIS, 1982).

The seabed of the Beaufort Sea is heavily scoured by large ice features, both first-year and multi-year ice ridges. Table 2 provides information on several scour parameters.

Scour depths up to 7 m deep have been measured in 45 m water depth (Lewis and Blasco, 1990). The spatial frequency of ice scours varies significantly across the Beaufort shelf. Sonar records indicate that the maximum spatial frequency of the scours, expressed as a linear density, is 16.6 scours/km in water depths of 20 to 30 m (Lewis and Blasco, 1990). The impact rates for scouring and the time interval to re-scour 90% of the seafloor are given in Table 3. New technology using multi-beam sonar is continually improving the knowledge of scouring of the Beaufort Sea. The Geological Survey of Canada at the Bedford Institute of Oceanography in Dartmouth, NS maintains an up-to-date database on information related to scouring in the Beaufort Sea (see Section 7.3.3).

Table 2: Statistics for Ice Scours in the Beaufort Sea (after Lewis and Blasco, 1990).

Parameter	Dimension	Population
Mean Scour depth	0.5 m	10,385 events
Mean Scour Width	26 m	66,549 events
Scour Orientation Mode	115 / 295°	66,459 events
Scour Length	5 - 10 km ?	estimated
Mean Berm Width	15.3 m	100 events
Mean Berm Height	0.7 m	100 events

Table 3: Seabed Scour Statistics for the Beaufort Sea (after Lewis and Blasco, 1990)

Water Depth (m)	5 - 8	14 - 18	22 - 26	30 - 35	34 - 50
Location		Pullen Block	Tarsiut - Newktoralik	Corridor	
Maximum Scour Impact Rate (events/km)	0.8	2.0	8.2		0.0
90% rescouring interval (years)		36	22	109	

2.8 Environmental Guidelines

The National Energy Board (see Section 7.2.10) has produced guidelines for monitoring the environmental conditions during an offshore drilling program. The report “Guidelines Respecting Physical Environmental Programs during Petroleum Drilling and Production Activities on Frontier Lands” can be obtained from the National Energy Board.

3.0 OVERVIEW OF EXPLORATION PLATFORMS

Many approaches were used to provide platforms for oil exploration drilling in the Arctic regions. In the Beaufort Sea off both Canada and Alaska, over 140 wells were drilled during the 1970s to early 1990s. Innovative technology and good management allowed exploration of this sensitive and harsh region. The drilling activity took place over a fairly short time span, but care was always taken to ensure safe and environmentally secure techniques were used. Although most of the major oil companies were involved, the main players were Dome Petroleum and its marine arm, Canmar; Gulf Canada Resources Ltd. and its marine arm Beaudril; and Imperial Oil (Esso). There was both competition and collaborative work to investigate the ice characteristics, the ice loads and types of offshore structures that could be used. There was an extensive network of infrastructure established for these activities including marine and air support. The key vessels in the Canmar fleet were the *Canmar Kigoriak* and the *Robert Lemeur*. The Beaudril fleet consisted on two icebreakers (*Terry Fox* and *Kalvik*) and two supply icebreakers (*Ikaluk* and *Miskaroo*). Each company also established a base camp at Tuktoyaktuk. Some excellent overviews of this activity can be found in Hnatiuk (1983) and Masterson et al. (1991).

As evidenced in Chapter 2.0, the Beaufort Sea has a very harsh ice climate. The ice conditions can be very different in different regions of the Beaufort Sea and at different times of the year. For this reason, many different approaches were used for exploration drilling platforms. Consideration had to be given to the water depth at the drill site, the anticipated ice conditions, the time of year when drilling would take place, and methods for supplying the drill site. Furthermore, in Canada it was necessary to have a means for being able to drill a relief well in the same season in the event of a blowout at the main well. Thus, this often implied that two different independent drill platforms were required. Because of these factors, different systems were used as drilling platforms. These are briefly described in the following sections.

3.1 Artificial Islands

The development of the Beaufort was initiated in the early 1970s in quite shallow water using artificial islands (see Figure 12). These islands were constructed by either dredging the local sea bottom and building-up an island, or by trucking gravel from the shore and dumping it to form an island. The latter approach was carried out during winter months across ice roads. These structures were placed in shallow water (up to 12 m). For most of these islands, the ice was landfast, with first-year ice having little movement during the winter months. They were very expensive to construct and they were not without problems. Decisions had to be made regarding the slope of the islands and the protection scheme (if any) to avoid having the waves wash away the island before it could be used as a platform. There was a considerable amount of documentation on the construction and the behaviour of these islands. Further information can be found in deJong et al (1975), Croasdale and Marcellus (1978), Garratt and Kry (1978), Exxon (1979) and Chen and Leldersdorf (1988).

Figure 12 Photograph of the Esso dredged island at Issungnak.

3.2 Floating Drillships

Starting in the mid 1970's, floating drillships (see Figure 13) were employed during the summer months in deeper waters. Canmar deployed three drillships (**Explorer**, **Explorer2** and **Explorer3**). These were moored on site during the summer (open water) months. It sometimes took two years to drill and test the well. With these ships and support icebreakers, Canmar developed considerable expertise in offshore Arctic operations.

These drillships required the support of ice management icebreakers. These icebreakers would break any oncoming ice and reduce the size of the floe that could impact the vessel. The vessels could vane into the direction of the oncoming ice. Usually drilling started in late June and could extend into November.

Figure 13: Photograph of a drillship in the Beaufort Sea. There were three of these ice-strengthened drill ships operated by Canmar.

3.3 Conical Drillship – Kulluk

Gulf Canada Resources Ltd. built an inverted-cone shaped floater, the **Kulluk** which could be used throughout the summer and early autumn months. The vessel was towed to the drill site (see Figure 14) and moored with a twelve-point anchor system that was capable of resisting ice forces from any direction. Usually ice management was necessary to break the ice locally in the region of the Kulluk (see Figure 15). This technique extended the drilling season. Pilkington et al. (1986) have provided a good overview of the performance of the Kulluk. Wright (2000) has analyzed the mooring loads for various conditions. The Kulluk has recently been purchased by Shell Oil for planned use in Alaska.

Figure 14: Kulluk in 8/10's ice under tow to a drill site.

Figure 15: Ice management around the Kulluk in the Beaufort Sea.

3.4 Caisson Structures: Overview

In the early 1980's, special-built caisson structures were designed and built to allow year-round drilling, and development of regions further offshore in harsher ice conditions. There were five different caisson structures used in Arctic regions:

- Tarsiut Caisson
- Single-Steel Drilling Caisson (SSDC)
- Caisson-Retained Island (CRI)
- Molikpaq
- Glomar Beaufort Sea I (CIDS)

Table 4 provides some information on the size and the wells that were drilled using these platforms. A brief description of each of the structures follows:

Table 4: Details of the five caisson structures used in the Beaufort Sea

	Tarsiut	SSDC	CRI	Molikpaq	CIDS
Drilling Days (per year)	365	365	365	365	365
Base Area (m^2) (including core)	7947	18590	10875	12383	8551
Oceanographic Limitations (wave height - m)	12	12.2	15	12.2	5.2
Limiting Level Ice Conditions (m)	5.6	10	3	10	2
Ice Concentrations	10/10s	10/10s	10/10s	10/10s	10/10s
Design Ice Load - Global (MN)	560	900	436	640	640
Design Local Ice Pressure (MPa)	4.1	8.3	2.8	3.0	6.2
Area for Local Pressure (m^2)	3.7	3.7	0.7	2.3	2.3
Wells Drilled	Tarsiut N-44 Tarsiut N-44A	Uviluk P-66 Kogyuk N-67 Phoenix #1 Aurora #1	Kadluk O-07 Amerk O-09 Kaubvik I-43	Tarsiut P-45 Amauligak I-65 Amauligak I-65A Amauligak I-65B Amauligak 2F-24 Amauligak 2F-24A Amauligak F-24 Amauligak 2F-24B Isserk I-15	Antares #1 Antares #2 Orion #1

3.4.1 Tarsiut Caissons

The Tarsiut caisson structure was operated by Gulf Canada Resources Ltd. and was the first caisson-type structure used in the Arctic. It was first deployed at the Tarsiut site in 1981 (see Figure 16). The structure consists of four individual concrete caissons. These caissons were floated to the drilling site and ballasted down with sand to form a square. The inner core was filled with dredge material. This structure is not regarded as a "mobile" structure since the difficulty of resetting and connecting the four caissons limits its mobility. The structure is about 100 m across at the water line and has a vertical outer surface. Each caisson is 10 m high. It was used to drill a well at the Tarsiut N-44 site in 1981/82. At that location, the caissons were placed on a berm that was within 6 m of the water surface. The structure was extensively instrumented to measure ice loads (Pilkington et al, 1983) both for operational safety reasons and for future design.

It was left onsite for the next year and during the winter of 1982/83 when a dedicated research program was carried out from this platform. The program was known as the Tarsiut Island Research Programme (TIRP). It will be described in Section 5.1. Although this structure did not have a problem with the ice loads, it did have considerable problems due to waves. The structure is a low freeboard, flat-sided structure. There were never any issues with wave loads on it, but wave splash was a big problem during the summer months. To remedy this, a large number of rock-field gabions were transported and installed around the perimeter of the island (see Figure 17). This was a very costly remedy. Later caisson structures always had a wave deflection collar. This structure was only used to drill one well since it was very difficult to deploy. In 1984, the four concrete caissons were relocated to Herschel Island in the Canadian Arctic.

Figure 16: Overhead view of Tarsiut Island in the Beaufort Sea. Note the large ice pad at the bottom of the photogrpah. This was built as a pad for releif well drilling, if required.

Figure 17: Photograph of the Tarsiut caisson showing the rock-filled gabions that were used to prevent wave overtopping during the summer months.

3.4.2 SSDC/MAT

The Single-Steel Drilling Caisson – SSDC (see Figure 18 and Figure 19) was operated by Canmar. It was constructed from a disused tanker and brought to the Beaufort Sea in 1982. In the winters of '82-83 and '83-84, it drilled at two different locations in approximately 30 m of water. In 1985-86, a new steel base, the MAT, was designed and built. This eliminated the restrictions imposed by the SSDC by the requirement for a sand berm. The SSDC/MAT was then deployed with the MAT at the Phoenix, Aurora, Fireweed and Cabot sites in the U.S. Beaufort Sea. This structure is capable of operating year round in water depths of 7 to 24 m, and a wide variety of soil conditions. It is still in the Beaufort Sea region and was recently used by Devon Canada to drill a well at the Paktoa site in 2005-06. It has since been renamed the **SDC**.

Figure 18: SSDC at the Kogyuk site with a protective spray ice pad.

Figure 19: Cut-away view showing the SSDC and the MAT.

3.4.3 Stressed CRI

This structure was originally built by Esso Resources Canada Ltd. but it is now owned by Arctic Transportation Ltd. It was developed in the 1976/77 period as a means of reducing dredge quantities, as compared to the more traditional sand island. It was built in 1982/83 and first deployed in the Canadian Beaufort Sea in the summer of 1983 (see Figure 20). The design has 8 individual caissons (43 m long x 12.2 m high x 13.1 m wide) in a ring. These caissons are held together with two pre-stressed bands of steel wire cable. It was therefore called the stressed **Caisson Retained Island** (CRI). Overall it has an octagonal-shape about 118 m across on the flats, 12 m high and the outer face is inclined (30° from the vertical). A central core, 92 m across, was filled with sand.

The CRI was deployed for three seasons in the Canadian Beaufort Sea:

- From September 1983 to April 1984 it was deployed at the *Kadluk O-07* in the Mackenzie Bay site at a water depth of 14.5 m. A spray ice island was constructed to the north of the CRI to provide an emergency relief well drill site.
- In August 1984 the CRI was moved to the *Amerk O-09* site where it remained until March 1985.
- From October 1986 to January 1987, the CRI was deployed at the *Kaubvik I-43* site.

At the present time, it is sitting un-used in the harbour at Tuktoyaktuk (see Figure 21)

Figure 20: Esso Caisson Retained Island (CRI) with a grounded rubble field.

Figure 21: Photograph of the Esso CRI in Tuktoyaktuk Harbour, April 2007.

3.4.4 Molikpaq

This structure was developed by Gulf Canada Resources Ltd. and operated by Beaudril, a subsidiary of Gulf. The Molikpaq is a Mobile Arctic Caisson (MAC) and was first deployed in the Canadian Beaufort Sea in 1984 (see Figure 22 and Figure 23). The Molikpaq was used in support of exploration drilling for 4 winter seasons in the Canadian Arctic (see Table 5). It consists of a continuous steel annulus on which sits on a self-contained deck structure. The core of the annulus is filled with sand, which provides over 80 percent of the horizontal resistance. The outer face of the Molikpaq is designed for extreme ice features. The structure can operate without a berm in water depths ranging from 9 to 21 m. In greater water depths, the structure is designed to sit on a submerged berm which can vary in depth, as required. Ballasting is entirely by water. To achieve the design resistance under dynamic load, densification of the hydraulically-placed core was required.

Table 5 Details of the Molikpaq deployment in the Beaufort Sea.

Site	Year Deployed	Water Depth (m)	Setdown Depth (m)	Subcut Depth Below Seabed (m)	Berm Height Above Seabed (m)	Core Height Above MSL (m)	Fill Quantity (m^3)
Tarsiut P-45	1984	25.5	19.5	3.5	6.0	2.0	450,000
Amauligak I-65	1985	31.0	19.5	9.0	11.5	1.5	1,400,000
Amauligak F-24	1987	32.0	15.8	16.0	16.2	4.8	2,200,000
Isserk I-15	1989	11.7	13.4	1.7	N/A	-3.8	70,000

This structure was extensively instrumented with over 500 channels of measured data. This has provided extremely valuable information on ice loads on offshore structures. This data is owned by ConocoPhillips (who purchased Gulf Canada) and it resides at the NRC Canadian Hydraulic Centre (Timco, 1996). The Molikpaq was purchased by Marathon Oil. It has been modified and is now being used in the Sakhalin region offshore Russia at the Vityaz Production Complex.

Figure 22: Photograph of the Molikpaq with grounded rubble surrounding it.

Figure 23: Molikpaq structure in moving ice conditions.

The Molikpaq structure has, by far, been the one that has provided the most useful information on ice loads. Several authors have analyzed the data from this structure to provide information on global loads (Wright and Timco 2000; Klohn-Crippen, 1998; Timco and Johnston 2003, 2004), ice-induced vibrations and loads (e.g. Jeffries and Wright, 1988; Timco et al. 2005a; Frederking and Sudom 2006), local ice pressures (Frederking and Collins 2005; Jordaan et al. 2006) and evacuation procedures from vertical-sided structures in ice (Timco et al. 2006).

3.4.5 Glomar Beaufort Sea I (CIDS)

The CIDS structure was operated by Global Marine. It is made of a steel mud-base, concrete "brick" units through the ice zone and steel deck storage barges (see Figure 24). The steel units are not exposed to severe ice loading. The brick units are honeycomb construction which provides an optimum strength to weight ratio. The forces imposed by the ice are distributed evenly throughout the structure. The "silos" within the honeycomb structure are used only for water ballast, as are the tanks in the base. Ballast and deballast is entirely by water. The deballasting and reflotation process can be completed in 3 days under normal conditions. This structure was used only in the American Beaufort Sea. It was sold to ExxonMobil and was modified for use in the Sakhalin offshore region as the Orlan drilling and production platform.

Figure 24: Photograph of the CIDS in the American Beaufort Sea.

3.5 Spray Ice Islands

In the late 1980s, spray ice islands (see Figure 25 and Figure 26) were used for pads for drilling a few wells. These were deployed in landfast ice in both the Alaskan and Canadian Beaufort Sea. The ice pads were built by spraying the sea water using large pumps and nozzles to locally increase the ice thickness. This spraying was continued until the pad rested on the seabed and had sufficient freeboard (i.e. weight) to resist the ice loads that it would incur during the drilling season. The cost of these spray islands was approximately one-half the cost of a gravel island. Weaver and Poplin (1997) provide an excellent overview of the well at the Nipterk P-32 site.

Figure 25: Photograph showing an overview of the Nipterk spray island.

Figure 26: Photograph showing the Nipterk spray island from ice level.

3.6 Summary

The National Energy Board in Calgary has compiled a list of the wells drilled in the Canadian Beaufort Sea from 1972 to 1989. These are presented in Table 6. Based on this information, a “flow chart”, shown in Figure 27, has been produced that shows the activity in the Canadian Beaufort Sea. Note the progression from seasonal artificial islands and drill ships to the more robust caisson-type structures. Figure 28 shows a map of many of the drillsites.

There were significant oil and gas discoveries made in the Beaufort Sea including the Amauligak oil reservoir, but, to date, these reserves are insufficient to justify economic development. Current discovered reserves for this region are 12 TCF gas, and 1.6 billion Bbls of oil. During the drilling of the Amauligak well, 320,000 barrels of oil were shipped to Japan in the tanker "Gulf Beaufort", making it the first major shipment of crude oil from the Canadian Beaufort Sea.

Table 6: Summary of Beaufort Sea drilling activity from 1972 to 1989

Year	well name	operator	Platform	water depth (m)	spud date	rig release
1972	Roland Bay L-41	Pacific	---	20.1	72/12/22	73/04/20
1973	Immerk B-48	Imp	Sacrificial beach	3	73/09/17	73/12/22
1973	Adgo F-28	Esso	Sandbag retained	2	73/12/28	74/03/19
1974	Pullen E-17	Imp	Sandbag retained	1.5	74/04/21	74/07/11
	Unark L-24	Sun/BVX	Hauled Island	1.5	74/09/26	75/05/24
	Pelly B-35	Sun/BVX	Hauled Island	1.5	74/11/05	75/02/14
1975	Adgo P-25	Esso	Sandbag retained	2	75/01/02	75/03/28
	Nerlerk B-44	Imp	Sandbag retained	4.6	75/01/06	75/06/08
	Adgo C-15	Esso	Sandbag retained	2	75/04/21	75/07/25
	Garry P-94	Sun/SOBC/BVX	Hauled Island	2.5	75/08/25	76/01/05
	Ikattok J-17	Imp/Delta	Sandbag retained	2	75/10/07	76/02/28
	Nerlerk F-40	Imp	Sandbag retained	7	75/11/08	76/05/09
1976	Sarpik B-35	Imp	Sandbag retained	3.5	76/04/02	76/09/04
	Kopanoar D-14	Hunt/Dome	Drill Ship	60.3	76/08/08	76/09/26
	Nektoralik K-59	Dome/Hunt	Drill Ship	34	76/09/21	77/10/17
	Kugmallit H-59	Imp	Sandbag retained	5.2	76/09/30	76/11/10
	Arnak L-30	Imp	Sacrificial beach	8.5	76/10/05	77/03/16
	Tingmiark K-91	Dome/Gulf	Drill Ship	27.3	76/10/18	77/10/25
	Unark L-24A	Sun/BVX	Hauled Island	1.5	76/10/19	77/05/08
1977	Kannerk G-42	Imp/IOE	Sacrificial beach	8	77/03/30	77/05/13
	Ukalerk C-50	Dome/Gulf	Drill Ship	20	77/07/18	77/10/03
	Kopanoar M-13	Dome	Drill Ship	59.5	77/07/19	79/xx/xx
	Nerlerk M-98	Dome	Drill Ship	52	77/10/07	79/08/28
	Isserk E-27	Esso	Sacrificial beach	13	77/12/04	78/05/05
1978	Garry G-07	Sun/CCL/BVX	Hauled Island	2.5	78/02/10	78/05/13
	Natserk E-56	Dome//Petrocan	Drill Ship	34.1	78/07/10	79/10/16
	Ukalerk 2C-50	Dome/Gulf	Drill Ship	20	78/08/10	79/10/11
	Tarsuit A-25	Gulf	Drill Ship	20	78/10/18	80/07/28
	Kaglulik M-64	Dome	Drill ship	31	78/11/03	79/07/10
	Kaglulik A-75	Dome	Drill ship	32.6	78/xx/xx	78/xx/xx
1979	Adgo J-27	Esso	Sandbag retained	2	79/04/05	79/08/07
	Kenalooak J-94	Dome	Drill ship	49.3	79/09/20	82/11/01
	Kopanoar L-34	Dome	Drill Ship	60	79/10/11	79/11/25
	Koakoak O-22	Dome	Drill ship	49.2	79/11/05	81/10/31
	Kopanoar 2L-34	Dome/Gulf	Drill Ship	60.3	79/11/25	79/11/28
1980	Kilannik A-77	Dome	Drill ship	23.7	80/06/23	81/09/04
	Kapanoar I -44	Dome/Gulf/Hunt	Drill Ship	58	80/07/10	80/08/01
	Kopanoar 2I-44	Dome/Gulf	Drill Ship	57.9	80/08/03	80/10/29
	Issungnak 2 O-61	Esso	Sacrificial beach	18.6	80/10/02	81/08/13
1981	Issugnak L-86	Gulf	Drill ship	18.6	81/07/17	81/10/16
	Alerk P-23	Esso	Sacrificial beach	11.6	81/09/21	81/12/24
	Irkaluk B-35	Dome/Hunt	Drill ship	60.3	81/09/28	82/10/04
	Tarsuit N-44	Gulf	Caisson-concrete	19.2	81/12/11	82/06/07
1982	Issugnak O -61	Esso	Sacrificial beach	36.5	82/02/06	80/07/08
	West Atkinson L-17	Esso	Sandbag retained	7	82/05/01	82/06/25
	Tarsuit N-44A	Gulf	Caisson-concrete	19.2	82/06/18	82/09/19
	Kiggavik A-43	gulf	Drill ship	27.4	82/08/20	82/10/17
	Orvilruk O-03	Dome/Superior	Drill Ship	59.9	82/08/30	82/10/25
	Aiverk I-45	Dome	Drill ship	50.3	82/10/07	82/10/23
	Aiverk 2I-45	Dome	Drill ship	50.3	82/11/03	84/10/11
	Itiyok I-27	Esso	Sacrificial beach	14	82/11/05	83/05/02
	Uviluk P-66	Dome/Texaco	SSDC	30	82/11/10	83/05/21
1983	Natiak O-44	Dome	Drill Ship	44	83/07/16	84/09/25
	Havik B-41	Dome	Drill ship	35	83/07/17	86/08/24
	Siulik I-05	Dome	Drill Ship	49.4	83/07/25	84/10/18
	Arluk E-90	Dome	Drill ship	58	83/07/30	85/10/13
1983	Pitsiulak A-05	Gulf	Kulluk	27	83/08/22	84/07/26
	Kadluk O-07	Esso	CRI	13.6	83/09/25	84/04/24
	Kogyuk N-67	Gulf	SSDC	28.4	83/10/28	84/01/30
	Amauligak J-44	Gulf	Kulluk	19.5	83/11/16	84/09/23
	Univluk P-66					
1984	Amerk O-09	Esso	CRI	26	84/08/22	85/03/03
	Nerlerk J-67	Dome	Kulluk	45	84/09/16	85/10/24
	Tarsuit P-45	Gulf	Molikpaq	22.4	84/09/25	84/12/24
	Adgo H-29	Esso	Sandbag retained	3	84/09/27	85/01/12
	Nipterk L-19	Esso	Sacrificial Beach	11.3	84/10/03	85/03/23
	Akpak P-35	Gulf	Kulluk	20	84/10/17	84/11/08
1985	Nipterk L-19A	Esso	Sacrificial Beach	11.3	85/04/21	85/07/15
	Akpak 2P-35	Gulf	Kulluk	20	85/06/10	85/07/07
	Adlartok P-09	Dome	Drill ship	67.4	85/08/08	85/10/17
	Edlok K-56 N-56	Dome	Drill ship	31.5	85/08/10	85/09/16
	Amauligak I-65	Gulf	Molikpaq	22.9	85/09/24	86/01/28
	Adgo G-24	Esso	Sandbag retained	1.4	85/10/07	86/01/07
	Aagnerk E-56	Gulf	Kulluk	20	85/10/28	86/06/26

Date	Island		Drill Ships		Tarsiut	SSDC	Kulluk	Caisson Retained Island	Molikpaq
1972	Roland Bay L-41								
1973	Immerk B-48	Adgo F-28							
1974	Pullen E-17 Unark L-24	Pelly B-35							
1975	Adgo P-25 Nerlerk B-44 Adgo C-15	Garry P-94 Ikattok J-17 Nerlerk F-40							
1976	Sarpik B-35 Kugmallit H-59	Unark L-24A Arnak L-30	Kopanoar D-14 Nektoralik K-59	Tingmiark K-91					
1977	Kannerk G-42 Isserk E-27		Ukalerk C-50 Kopanoar M-13	Nerlerk M-98					
1978	Garry G-07		Natserk E-56 Ukalerk 2C-50 Tarsuit A-25	Kaglulik M-64 Kaglulik A-75					
1979	Adgo J-27		Kenalooak J-94 Kopanoar L-44	Koakoak O-22 Kopanoar 2L-34					
1980	Issungnak 2O-61		Kilannik A-77 Kopanoar I-44 Kopanoar 2I-44						
1981	Alerk P-23		Issugnak L-86 Irkaluk B-35		Tarsuit N-44				
1982	Issugnak O-61 West Atkinson L-17	Itiyok I-27	Kiggavik A-43 Orviluk O-03	Aiverk I-45 Aiverk 2I-45	Tarsuit N-44	Uviluk P-66			
1983			Natiak O-44 Havik B-41	Siulik I-05 Arluk E-90		Kogyuk N-67	Pitsiulak A-05 Amauligak J-44	Kadluk O-07	
1984	Adgo H-29 Nipterk L-19						Nerlerk J-67 Akpak P-35	Amerk O-09	Tarsuit P-45
1985	Nipterk L-19A Adgo G-24	Minuk I-53 Ellice L-39	Adlartok P-09 Edlok K-56, N-56				Akpak 2P-35 Aagnerk E-56		Amauligak I-65
1986	Arnak K-06							Kaubvik I-43	Amauligak I-65A Amauligak I-65B
1987	Angasak L-03								Amauligak 2F-24
1988									Amauligak 2F-24A, 2F-24B Amauligak F-24, O-68
1989	Nipterk P-32		Kingark J-54						Isserk I-15

Notation
sacrificial beach island
sandbag retained island
hauled island
spray ice island

Figure 27: Overview of drilling activity in the Canadian Beaufort Sea during the 1970s and 1980s.

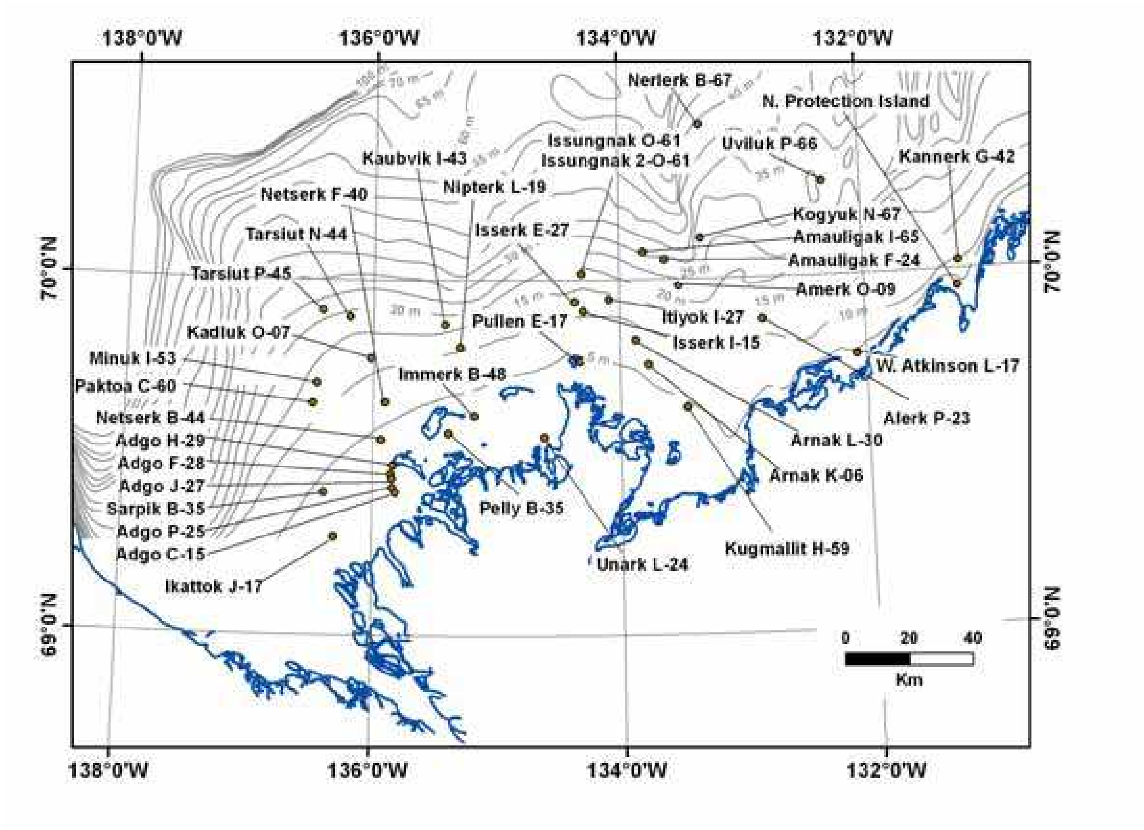

Figure 28: Map showing the location of a number of the drill sites in the Canadian Beaufort Sea.

4.0 MAJOR CANADIAN SUPPORT ACTIVITIES

During the development of this region, there was great effort placed in measuring the environmental conditions, types of ice features, ice strength, and ice loads on the structures. In Canada, the oil companies collaborated under the Arctic Petroleum Operators Association (APOA), and more recently, the Canadian Association of Petroleum Producers (CAPP). The Environmental Studies Research Funds (ESRF) was established and funded many research programs. In addition, the Canadian federal government, through the Program of Energy Research and Development (PERD) was a major supporter of offshore R&D.

The following sections describe a number of these activities. References and web links are provided for additional information.

4.1 Arctic Petroleum Operators Association (APOA)

In 1970, the industry players that were interested in the Beaufort Sea (and High Arctic area) recognized the need for collaboration and formed the Arctic Petroleum Operators Association (APOA). This Association was specifically dedicated to conducting joint industry research projects. Over the course of its fifteen year existence, the APOA carried out well over 200 projects that were related to various Beaufort Sea problems, ranging from ice conditions, to ice loads, to various structure designs and operations in ice.

The APOA was extremely effective at developing research cooperation amongst the industry members. Joint projects would be developed and any interested member could join or abstain. There was usually a confidentiality agreement on the projects but all of these project reports are now public. Many, unfortunately, exist only in microfiche format at various libraries. Both CISTI (see Section 7.2.1) and the AINA (see Section 7.2.2) have copies of many of these reports. In addition to the research reports, the APOA published a magazine "APOA Review". It contained articles with a more general content than the APOA reports to give the Industry an update on activities.

In the mid 1980s, as industry's interest in the Beaufort Sea and Arctic Islands regions began to wane, the APOA was absorbed into the Canadian Petroleum Association's Frontier Division (now CAPP), where its R&D focus was quickly lost.

Table 7 provides a list of the APOA projects. There 222 APOA projects. Most were completed but there were a few that were assigned a number but not carried out.

Table 7: List of APOA Reports

APOA	Title
1	Nutcracker Ice Strength Tests, 1969-70
2	Beaufort Sea - Ice Movement and Current Survey - 1970
3	Ocean floor Sampling Beaufort Sea 1970
4	Geological Analysis of Ocean Floor Samples
5	Study of Mackenzie Delta Tundra Disturbance
6	Summer Ice Reconnaissance - Project cancelled
7	Cross-Country Vehicle Study
8	Arctic Drilling Guidelines
9	Nutcracker Ice Strength Tests, 1970-71
10	Testing With Synthetic Ice - Project cancelled
11	Mackenzie Delta Ornithological Study
12	Feasibility Study Exploratory Drilling in the Beaufort Sea
13	Arctic Drilling Barge Study
14	Beaufort Sea Summer Ice Study
15	Mackenzie Institute - Travel Costs
16	Theoretical Analysis of Ice Failure
17	Beaufort Sea Pressure Ridge and Ice Island Scouring
18	Task Force to Investigate Arctic Drilling Systems - Project cancelled
19	Analysis of Sea-Bottom Iceberg Scouring Records
20	APOA Recommendations to DIAND on Arctic Drilling Regulations and the Preparation of an Arctic Petroleum Operators' Guide
21	Evaluation of Desert Type 6 x 6 Oilfield Truck in Arctic Conditions
22	Transportation of Hydrocarbons from Arctic Islands - Project cancelled
23	Beaufort Sea Soil Sample Analysis
24	Arctic Clothing Study
25	Model Tests to Simulate the Action of Ice on Fixed Structures
26	Model Test Simulating Ice on Drilling Barge - Project cancelled
27	Co-ordination of Arctic Environmental Research
28	Biological Effects of Oil in Arctic Seawater
29	Habakkuk - Investigation of Research on an Artificial Ice Island
30	Beaufort Sea Exploratory Drilling Systems
31	Aerial Reconnaissance of Ice - Beaufort Sea 1971
32	Beaufort Sea Scour Records - Phase II
33	Land Fast Ice Movement - Beaufort Sea 1971-72
34	Northern Resources Research Project
35	Baffin Bay - Davis Strait Environmental Study
36	Ice Islands Destruction - Beaufort Sea
37	Arctic Environmental Research, Tundra and Ecological Studies on the Mackenzie Delta and Devon Island
38	APOA - DIAND Transportation Study
39	Arctic Offshore Pipeline Feasibility Study
40	Evaluation of Mechanical Properties of Saline Model Ice

APOA	Title
41	Evaluation Of The Mechanical Properties Of Michel's Model Ice And Preliminary Ice-Structure Interaction Experiment
42	Mackenzie Delta Gravel Inventory
43	Environmental Impact Assessment Program - Mackenzie Delta
44	Photo Reconnaissance and Ice Movement Study - Beaufort Sea - Project cancelled
45	Arctic Clothing Study
46	Arctic Ice Trafficability: a) Photo Reconnaissance in the Beaufort Sea b) Photo Reconnaissance in the Arctic Islands
47	Ice Chipper Evaluation Test
48	Documentation of Vehicular Traffic on Mackenzie Delta Tundra - 1972: Freeze-Up and 1973 Thaw
49	Study of Arctic Transportation Equipment - Mackenzie Delta
50	Ice Thickness Measurement
51	Ice Movement in Beaufort Sea 1972-73
52	Crushing Strength of Ice
53	Count of Ice Islands - Beaufort Sea 1972
54	Ice Geology of the Southern Beaufort Sea
55	Arctic Environmental Research 1973 (Devon Island IBP Project)
56	Preparation of Specifications for Large Arctic Truck
57	Ice Adhesion (Adfreeze) Effects on a Conical Structure
58	Task Force Regarding Northern native Job Training
59	1973 Beaufort Sea Scouring Study Phase III - Project cancelled
60	Beaufort Sea Summer Ice Testing Project
61	Environmental Impact Assessment Program, Mackenzie Delta - Phase II
62	Beaufort Gas Plant Study Part 3 - Project cancelled
63	Arctic Institute of North America Beaufort Sea Symposium
64	Ice Mechanics and Ice Strengthening 1973-74 Arctic Field Test Program, Resolute Bay, N.W.T.
65	Small Prototype Cone Test
66	Ice Crushing Tests 1973-74
67	Ice Movement in Beaufort Sea 1973/74
68	Properties of Wax Model Ice Ridges
69	An Analytical Study of Ice Scour
70	Wind/Wave Hindcast, Canadian Beaufort Sea
71	Task Force on Training Natives 1974
72	Beaufort Sea Environmental Program
73	Research Program on Pollution from Drilling Fluids
74	Banks Island Development Environmental Considerations
75	Field Study of First-Year Ice Pressure Ridges
76	Summer Environmental Studies - East Mackenzie Bay - Mackenzie Delta
77	Modelling of Small Cone Prototype Tests
78	Environmental Data Gathering Program - Baffin Bay, Davis Strait and Arctic Islands
79	Arctic Island Ice Movement Study, 1974-1975
80	Development of a Semi-submersible Drilling System for the Arctic Offshore Area - Phase I
81	Ice Mechanics 1974-75, Arctic field Test Program, Resolute Bay, Northwest Territories

APOA	Title
82	Small Prototype Cone Test - Phase II
83	Landfast Ice Movement in the Beaufort Sea - 1974/75
84	In-Situ Ice Property Measurement In the Beaufort Sea
85	Adfreeze On Conical Structures
86	Study of Pressure Ridge/Cone Interaction
87	Computerize a Mathematical Model of Ice/Cone Interaction
88	Ya-Ya Lake Gravel Testing Program, 1975
89	Study of the Thickness of Multi-Year Pressure Ridges
90	Mobile Arctic Ice Chipper
91	Strength of Multi-Year Pressure Ridges
92	Arctic Islands Sea Ice Movement Analysis from Ice Reconnaissance and Satellite Imagery Data
93	High Aspect Ratio Crushing Tests
94	Development of a Semi-submersible Drilling System for the Arctic Offshore Area - Phase II
95	Arctic Islands Ice Movement Study, 1975-1976
96	Statistical Study of Late Winter Ice Thickness Distribution in the Arctic Islands from Seismic Data, 1971-1975
97	Tests of the Arctic Boat Configuration of the Lockheed Clean Sweep System in a Broken Ice Field
98	Arctic Science and Technology Information System
99	Ice Island Count - Southern Beaufort Sea 1974, 1975 and 1976
100	Test Program to Evaluate a New Concept of Oil Containment Boom for Use in Ice Infested Waters
101	Field Testing of the Mobile Ice chipper II
102	Multi-Year Pressure Ridge Study, Queen Elizabeth Islands
103	Interaction Between Ice Sheets and Wide Structures
104	Measurement of Ice Pressure on Artificial Islands - Phase I
105	In-Situ Ice Pressure Measurements Around Artificial Islands in Southern Beaufort Sea - Phase II
106	Continuous Crushing of an Ice Sheet by a Circular Indenter
107	A Study into the Practicability and Effectiveness of Burning Oil on Water in an Ice Environment
108	A Study into the Feasibility and Limits of Burning an Oil Blowout Plume
109	Model Ice Pile-up and Ride-up on Islands
110	Design Studies of Conical and Cylindrical Gravity Structures for Southern Beaufort Sea
111	Evaluation of Ice Defence Systems for Artificial Islands
112	Geometry of a Continuous Multi-Year Pressure Ridge - Project cancelled
113	Statistical Study of Passage into Beaufort Sea via Point Barrow
114	Preliminary Tests of Bird Scare Devices on the Beaufort Sea Cost
115	Support of Polar Bear Research
116	Drilling from Ships in Shorefast Ice - Project cancelled
117	Statistical Study of Late Winter Ice Thickness Distribution in the Arctic Islands from Seismic Data (1976)
118	Arctic Islands Winter Ice Movement Study 1977
119	Remote Detection of Oil In/Under Ice

APOA	Title
120	Safe Ice Detector - Project cancelled
121	Multi-Year Pressure Ridge Study, Arctic Islands, N.W.T. - Project cancelled
122	In-Situ Ice Pressure Measurements at Artificial Islands 1976/77
123	Experiments on Continuous Crushing of Ice, 1976/77
124	Study of Ice Pile-up 1976-77
125	Experimental Ridge CRI Interaction Study 1976/77
126	Literature Review of Biological Data in the Davis Strait Region
127	Winter Biological and Environmental Investigations in Davis Strait
128	Davis Strait Pack Ice Studies 1976/77
129	Measurement and Analysis Program of the Ocean Currents in the Vicinity of the Hudson Strait/Davis Strait Area
130	Design Studies for Production Structures for the Southern Beaufort Sea
131	Feasibility (Phase I) and Development (Phase II) of a Bottom Mounted Under Ice Profiling System
132	Study of the Disposal of Drilling Fluids - Project carried out under the Arctic Land Use Research (ALUR) program
133	Investigation of Sea-Bed Scouring in the Beaufort Sea (Phase III)
134	Late Winter and Spring Investigations in Davis Strait - 1977
135	Biological Observation, Sampling and Analysis Program of the Hudson Strait, Davis Strait and Labrador Sea Area, 1976
136	Shoreline Study of the Beaufort Sea, Komakuk Beach to Baillie Islands
137	Tests of Ignition and Herding Devices for Burning Oil on Ice
138	Environmental Investigations and Analysis in Davis Strait - Second Half 1977.
139	Development of High Resolution Ice Tracking System for the Southern Beaufort Sea [Phase 1: Test Prototype NAVSAT/NIMBUS-RAMS Sub-system]
140	Davis Strait Pack Ice Incursion Studies 1977/78
141	Ignition and Burning of Crude Oil on Water Pools Under Arctic Springtime Conditions, May 1977
142	Statistical Study of Late Winter Ice Thickness Distribution in the Arctic Islands from Seismic Data, 1977
143	Model Experiment to Determine the Forces and Behaviour of Moving Ice Fields Against a Concrete Drilling Caisson
144	Caisson Retained Island and Ice Ridge Interaction Studies 1977/78
145	Caisson Retained Island Design
146	Biological Environment Investigations and Analyses in Davis Strait 1978
147	Ice Keel Profiling in the Beaufort Sea
148	1978 Proposal to Conduct Studies of Continuous Crushing of Ice with a Segmented Indenter
149	Oil Spill and Iceberg Studies Conducted for Preparation of an Environmental Impact Statement for Davis Strait
150	Laboratory Model Tests of Sea-floor Scouring by Ice Features
151	Analysis of 1978 Beaufort Sea Side Scan Sonar Mosaics for Recent Sea Bottom Scouring
152	Beaufort Sea Well Completions in Permafrost
153	In-situ Gas Hydrate Survey
154	High Resolution Ice Tracking Buoys for the Beaufort Sea Phase 2: Field Trip, and Phase 3: Buoy Deployment

APOA	Title
155	Davis Strait Pack Ice Characterization
156	Ice Island Studies 1978/1979
157	Trace Metal Characterization in Barite for Drilling Operations
158	Beaufort Sea Repetitive Scour Mapping Analysis - 1979 and Comparison with 1972, 1974 and 1977 Mosaics
159	Portable Oil Burner - Project transferred to the Canadian Offshore Oil Spill Research Association (COORSA) research program
160	Fireproof Boom Development - Project transferred to COORSA
161	Bacterial Degradation Study
162	Under Ice Bubbler Test - Project cancelled
163	Literature Study - Bird Deterrent Techniques - Dyes
164	Air Deployable Ignitor Tests
165	Air Deployable Ignitor Improvements
166	In-situ Combustion of Oil Slicks Against Edges [Burning of Crude Oil Under Wind Herding Conditions] - Project transferred to COORSA
167	Mechanical Oil Recovery Systems in Ice - Project transferred to COORSA
168	Polar Bear Detector and Deterrent Devices - Project cancelled
169	Oil and Gas Under Beaufort Sea Ice Study - Project transferred to COORSA
170	A 1979 Investigation of Grounded Rubble Piles in the Beaufort Sea
171	A 1980 Investigation of Ice Conditions and Ice Behaviour Around Issungnak
172	1978 Davis Strait Weather/Sea-State Boy Program and Forecasting Studies
173	Ecology of the Southern Beaufort Sea and Mackenzie River An Annotated Bibliography
174	Statistical Study of Late Winter Ice Thickness Distribution in the Arctic Islands from Seismic Data 1978/1979/1980
175	Development of an Ice Thickness Profiler Using Acoustics
176	Beaufort Sea Seismicity Measurement Program
177	Ice Rubble Model Tests - Part I
178	Ridge Building Model Tests
179	Preliminary Assessment of Seismic Sources and Seismicity of Canadian Beaufort Sea and Preliminary Evaluation of Potential Behaviour of Sand Islands during Earthquakes
180	Ice Forces on Hans Island 1980
181	Ice Forces on Hans Island
182	Videotape of the Canadian Beaufort Sea from the Alaska/Yukon Border to the Baillie Islands
183	Beaufort Sea GEOPOC Study (Geotechnical Evaluation of the Effect of Permafrost on Casings)
184	Appraisal of Low Cost Side-Looking Airborne Radar for Sea Ice Reconnaissance in the Beaufort Sea
185	Natural Ice Rubble Studies
186	Ice Rubble Model Tests - Part 2
187	Surface Disposal of Drilling Fluids in Permafrost Regions
188	Computer Assisted Learning - Oil Spill Response Training
189	Tests of the Mitsui Archimedian Screw Tractor - Project cancelled
190	Cold Weather Pump Systems Study
191	Igniter Modifications II
192	Amundsen Gulf Shoreline Video Tape Recording

APOA	Title
193	North West Passage Shortline Video Tape Recording
194	Lancaster Sound - Baffin Bay Video Tape Recording - Project cancelled
195	Construction Strength and Stability of a Grounded Ice Island Drilling Platform in the Beaufort Sea
196	Analysis of Accidents in Offshore Operations Where Hydrocarbons Were Lost
197	Tarsiut Caisson Island Data Acquisition 1981-82
198	Tarsiut Caisson Island Data Acquisition 1982-83
199	Multi-Year Ice Floe Survey 1982
200	Multi-Year Ice Testing
201	Multi-Year Hummock Field and Floe Size Survey - 1982
202	Ice Forces on Hans Island 1983
203	Updated Beaufort Sea Wave Hindcast
204	Arctic Offshore Production Platform Evaluation
205	Environmental Design Criteria for Arctic Offshore Production Platforms
206	Indigenous Material Study for Arctic Offshore Construction In the Canadian Beaufort Sea
207	Arctic Crude Oil Transportation Systems Study (Pipeline and Tankers)
208	Icebreaking Technology (Icebreakers, Supply Vessels, etc.)
209	Production Through Permafrost
210	Simplification of Topside Facilities
211	Arctic Offshore Logistics Requirements
212	Dispersants - Areas of Application for the Beaufort Sea
213	Tarsiut Island Data Analysis
214	Recovery and Analysis of Upward Looking Sonar Data for the Winter 1982-83
215	Tarsiut Island Ice Stress Sensor and Telemetry Program
216	Tanker Mooring and Loading Study
217	Design Criteria and Ice Interaction Study
218	Arctic Production Platform and Foundation Study
219	Impact of Crude Oil Properties during Storage and Drilling on Facilities
220	Controlled Ice Floe Impacts Against and Offshore Drilling Structure
221	Arctic Escape System Project (Phase III)
222	Statistical Analysis of Ice Movement in the Beaufort Sea Using Argos Buoy Data

4.2 Alaskan Oil and Gas Association (AOGA)

There was a parallel organization to the APOA setup in Alaska. This was the Alaskan Oil and Gas Association (AOGA). This organization is still operational and information on it can be found at: http://www.aoga.org/ . Although they did not fund research in Canadian waters, they often funded Canadian scientists to perform research in Alaska. The information from these studies found relevance to the Canadian Beaufort Sea.

4.3 Canadian Association of Petroleum Producers (CAPP)

The Canadian Association of Petroleum Producers (CAPP) is an association of the upstream oil and natural gas industry in Canada. CAPP represents 130 member companies who explore for, develop and produce more than 95 per cent of Canada's natural gas, crude oil, oil sands and elemental sulphur. It covers both onshore and offshore issues. Information can be found on their website http://www.capp.ca/ . There is information on CAPP's activities but little information related to the Arctic regions.

4.4 Environmental Studies Research Funds (ESRF)

The Environmental Studies Research Funds (ESRF) is a research program that sponsors environmental and social studies. It is designed to assist in the decision-making process related to oil and gas exploration and development of Canada's frontier lands. The ESRF program, initiated in 1983, receives its legislative mandate through the Canada Petroleum Resources Act (CPRA). ESRF funds are obtained through levies on frontier lands paid by interested holders such as the oil and gas companies. The ESRF is directed by a joint government/industry/public Management Board and is administered by a small secretariat which resides in the National Energy Board (NEB) office in Calgary, Alberta.

The ESRF finances environmental and social studies pertaining to the manner in which petroleum exploration, development, and production activities on frontier lands should be conducted. The research is directed towards the frontier lands in the offshore areas of Canada's East and West Coasts and the areas north of 60 degrees latitude. Although there were a number of studies that focused on the Beaufort Sea in the early days of this fund, over the past several years, this work has been focused on biological issues, and has dealt with various marine mammal and fish considerations. Further information can be found at http://www.esrfunds.org .

Since its inception, the ESRF has funded over 162 reports subdivided into the following areas:

- Sediment Transport
- Environmental Effects and Monitoring
- Oil Spill Research and Countermeasures
- Ice/Icebergs/Ice Detection
- Sea Bottom Ice Scour
- Waves
- Frontier Social and Economic Issues
- Environmental Loading and Design
- Bibliographies

The reports are available free of charge from the NEB Secretariat. Full information on the ESRF is available on their website. Table 8 lists the report number, the title and the authors of the ESRF Reports. The reports are sorted according to a general category.

Table 8: List of ESRF Reports

ESRF Report #	Title and Author
SEDIMENT TRANSPORT	
17	Keith Philpott Consulting Ltd. with Acres Consulting Services Ltd. *Scour Around Seafloor Structures*. April 1986. 225 p.
27	Hodgins, D.O., D.A. Huntley, W.D. Liam Finn, B. Long, G. Drapeau and A.J. Bowen. *Sediment Transport - Present Knowledge and Industry Needs*. April 1986. 394 p.
29	Plasse, D. *Surficial Geology Surveys on the Scotian Shelf: Compilation of Maps from Government, Industry, University & Foreign Sources*. April 1986. 47 p.
41	Hodgins, D.O., G. Drapeau and L.H. King. *Field Measurements of Sediment Transport on the Scotian Shelf - Volume I. The Radio-isotope Experiment*. June 1986. 160 p. Hodgins, D.O. and O.J. Sayao - *Volume II. Boundary Layer Measurement and Sand Transport Prediction.* August 1986. 222 p.
54	Hodgins, D.O., O.J. Sayao, E.D. Kinsella and P.W. Morgan**.** *Nearshore Sediment Dynamics -Beaufort Sea.* December 1986. 195 p.
61	Judge, J.T., R.K. Watanabe and J.L. Warner. *Seafloor Stability Study, Inner Scotian Shelf.* May 1987. 88 p.
96	Gillie, R.D. *Beaufort Sea Artificial Island Erosion Data*. May 1988. 119 p.
ENVIRONMENTAL EFFECTS AND MONITORING	
1	McLaren, P.L. and R.A. Davis. *Distribution of Bowhead Whales in the Beaufort Sea.* Summer 1983. February 1985. 62 p.
5	Thomas, D.J., W.S. Duval, C.S. Johnston, G.S. Lewbel, A. Birdsall, M.S. Hutcheson, G.D. Greene, R.A. Buchanan and J.W. MacDonald. *Effects Monitoring Strategies and Program for Canada's East Coast*. May 1985. 88 p.
9	Harwood, L.A. and A. Borstad. *Bowhead Whale Monitoring Study in the Southeast Beaufort Sea***.** July-September 1984. August 1985. 99 p.
21	Tidmarsh, W.G., R. Ernst, R. Ackman and T. Farquharson**.** *Tainting of Fishery Resources*. January 1986. 174 p.
25	Kingsley, M.C.S. *Distribution and Abundance of Seals in the Beaufort Sea, Amundsen Gulf & Prince Albert Sound*. 1984. February 1986. 16 p.
28	Thomson, D.H., D.B. Fissel, J.R. Marko, R.A. Davis and G.A. Borstad. *Distribution of Bowhead Whales in Relation to Hydrometeorological Events in the Beaufort Sea.* March 1986. 119 p.
36	Norton, P. and L.A. Harwood**.** *Distribution, Abundance and Behavior of White Whales in the Mackenzie Estuary*. June 1986. 73 p.
57	Duval, W.S. (ed.). *Distribution, Abundance and Age Segregation of Bowhead Whales Relative to Industry Activities and Oceanographic Features in the Beaufort Sea, August-September 1985*. March 1987. 117 p.
60	Yunker, M.B. and R.W. Drinnan**.** *Dispersion and Fate of Oil from Oil-based Drilling Muds near Sable Island, N.S.* January 1987. 169 p.
63	Drinnan, R.W., M. Yunker, A. Gillam, N. Charchuk and S.R.H. Davis. *Options for Treatment and Disposal of Oil-based Mud Cuttings in the Canadian Arctic*. February 1987. 167 p.
66	Nenninger, R.D**.** *Monitoring a Sump Containing Drilling Mud with High Salt Content.* March 1987. 47 p.

ESRF Report #	Title and Author
75	Cross, W.E. and B. Humphrey. *Monitoring the Long-Term Fate and Effects of Spilled Oil in an Arctic Marine Subtidal Environment*. August 1987. 120 p.
80	Ernst, R.J., W.M.N. Ratnayake, T.E. Farquharson, R.G. Ackman and W.G. Tidmarsh. *Tainting of Finfish by Petroleum Hydrocarbons*. September 1987. 150 p.
89	Ford, J.K.B., J.C. Cubbage and P. Norton. *Distribution, Abundance, and Age Segregation of Bowhead Whales in the Southeast Beaufort Sea, August-September, 1986.* November 1987. 53 p.
90	Wainwright, P.F. and B. Humphrey. *Analysis of Sediment Data from the Beaufort Shorebase Monitoring Program, 1982-1984*. March 1988. 78 p.
93	Hardy BBT Limited and Stanley Associates Engineering Ltd. *Handling and Disposal of Waste Drilling Fluids from On-Land Sumps in the Northwest Territories and Yukon*. February 1988. 58 p.
101	Erickson, P., B. Fowler, and D. Thomas. *Oil-based Drilling Muds: Off Structure Monitoring-Beaufort Sea.* June 1988. 188 p.
102	Nakashima, D.J. and D.J. Murray. *The Common Eider of Eastern Hudson Bay: A Survey of Nest Colonies and Inuit Ecological Knowledge*. November 1988. 174 p.
109	Lawrence, M.J. (ed.) and S.L. Davies (ed.) *Wildlife and Wildlife Habitat Restoration and Compensation in the Event of an Oil Spill in the Beaufort Sea*. March 1993. 88 p.
110	Hurlbut, S.E., D.P. French and B.J. Taylor. *Evaluation of the Potential Effects of Major Oil Spills on Grand Banks Commercial Fish Species as a Result of Impacts on Eggs and Larvae***.** January 1991. 53 p.
117	Sekerak, A.D., N. Stallard and W.B. Griffiths. *Distribution of Fish and Fish Harvests in the Nearshore Beaufort Sea and Mackenzie Delta During Ice-Covered Periods, October-June*. November 1992. 157 p.
118	Thomas, D.J. *Considerations in the Design of Effects Monitoring Strategies: Beaufort Sea Case Study*. January 1992. 54 p.
121	S.L. Ross Environmental Research Limited and Ledrew, Fudge and Associates. *The Risk of Tainting Flatfish Stocks During Offshore Oil Spills*. January 1993. 67 p.
122	Mackinnon, D.S. and P.A. Lane. *Saltmarsh Revisited - The Long-Term Effects of Oil and Dispersant on Saltmarsh Vegetation.* September 1993. 24 p.
123	Duval, W.S. *Proceedings of a Workshop on Beaufort Sea Beluga February 3-6, 1992, Vancouver, B.C***.** March 1993. 26 p.
134	Richard, P.R., A.R. Martin and J.R. Orr. *Study of Summer and Fall Movements and Dive Behaviour of Beaufort Sea Belugas, Using Satellite Telemetry. 1992-1995*. 34 p.
137	Hatch Associates Limited and Griffiths Muecke Associates. *Workshop on Cumulative Environmental Effects Assessment and Monitoring on the Grand Banks and Scotia Shelf.* 2000. 61 p.
138	Montevecchi, W.A., F.K. Wiese, G. Davoren, A.W. Diamond, F. Huettmann, J. Linke *Seabird Attraction to Offshore Platforms and Seabird Monitoring from Offshore Support Vessels and other Ships Literature Review and Monitoring Design*. 1999. 56 p.
139	Thomson, Denis H., Jack W. Lawson and Anne Muecke. *Proceedings of a Workshop to Develop Methodologies for Conducting Research on the Effects of Seismic Exploration on the Canadian East Coast Fishery, Halifax, Nova Scotia, 7-8 September 2000.* April 2001. 92 p.
142	ERIN Consulting Ltd. and OCL Services Ltd. *Sheens Associated with Produced Water Effluents – Review of Causes and Mitigation Options*. March 2003. Calgary. 46 p.
143	Mortensen, Pål B., Lene Buhl-Mortensen, Susan E. Gass, Donald C. Gordon Jr., Ellen L.R. Kenchington, Cynthia Bourbonnais and Kevin G. Macisaac. *Deep-Water Corals*

ESRF Report #	Title and Author
	In Atlantic Canada: A Summary Of ESRF-Funded Research (2001-2003). December 2004. Calgary. 43 p.
144	Christian, John R., Anne Mathieu, Denis H. Thomson, David White and Robert A. Buchanan. *Effect of Seismic Energy on Snow Crab (Chionoecetes opilio).* November 2003. Calgary. 106 p.
145	Racca, Roberto G., David E. Hannay, R. Bruce Murray, William B. Griffiths, and Michael Muller. *Testing Fish Deterrents for Use Under-Ice in the Mackenzie Delta Area.* March 2004. Calgary. 118 p.
146	Buchanan, Robert A., Joanne A. Cook and Anne Mathieu. *Environmental Effects Monitoring For Exploration Drilling.* December 2003. Calgary. 86 p
147	Dillon Consulting Limited with DMT Cordah. *Pollution Prevention Opportunities in the Offshore Oil and Gas Sector - Final Report.* October 2003. Calgary. 73 p
149	Trudel, K. 2004. *Workshop on Dispersant Use in Eastern Canada***.** Environmental Studies Research Funds, Report No. 149, Calgary Alberta, 109 pp.
150	Martec Limited, CEF Consultants Ltd, DRDC Atlantic, St. Francis Xavier University. *Effects of Pipelines/Gathering Lines on Snow Crab and Lobster.* December 2004, Calgary, 61 p.
151	Lee, K., H. Bain, and G.V. Hurley, (eds). 2005. *Acoustic Monitoring and Marine Mammal Surveys in the Gully and Outer Scotian Shelf Before and During Active Seismic Programs*. December 2005. Calgary, 154 p + appendices.
152	Ellis & Associates. *Drilling Waste Management – Recommended Best Practices***.** January 2005. Calgary. CD-Rom.
154	AMEC Earth & Environmental. *Inuvialuit Settlement Region Drilling Waste Disposal Sumps Study*. February 2005. Calgary. CD-Rom.
155	Dillon Consulting Limited and Salmo Consulting. *Beaufort-Delta Cumulative Effects Project*. February 2005. Calgary. CD-Rom.
156	Moulton, V.D., and B.D. Mactavish. *Recommended Seabird and Marine Mammal Observational Protocols for Atlantic Canada.* March 2004. Calgary. 80 p
157	Christian, John R., Anne Mathieu, and Robert A. Buchanan, *Chronic Effects of Seismic Energy on Snow Crab (Chionoecetes opilio).* March 2004. 45 p.
159	Kemper, J. Todd. *Vegatation Changes on Seismic Lines from Recent (2000-2001) and Historic (1970-1986) Seismic Programs in the Mackenzie Delta Area*. May 2006. 29 p.
161	Kavik-AXYS Inc. *Review of the Ikhil Gas Development and Pipeline Regulatory and Environmental Process: Lessons Learned.* January 2007. 48 p
162	Harwood, Lois, Thomas G. Smith, Humfrey Melling. *Assessing the Potential Effects of Near Shore Hydrocarbon Exploration on Ringed Seals in the Beaufort Sea Region 2003-2006.* November 2007. 103 p.
OIL SPILL RESEARCH AND COUNTERMEASURES	
6	Belore, R.C. *Effectiveness of the Repeat Application of Chemical Dispersants on Oil***.** June 1985. 66 p.
12	Harper, J.R. and E.H. Owens. *Shoreline Monitoring Programs for Oil Spills-of-Opportunity*. September 1985. 50 p.
13	Abdelnour, R., T. Johnstone, D. Howard and V. Nisbett. *Laboratory Testing of an Oil-Skimming Bow in Broken Ice.* January 1986. 60 p.
18	S.L. Ross Environmental Research Ltd. *Testing of an Oil Recovery Concept for Use in Brash and Mulched Ice.* January 1986. 43 p.
19	Witherspoon, P., J. Swiss, R. Kowalchuk and J. Armstrong. *Oil in Ice Computer Model.*

ESRF Report #	Title and Author
	December 1985. 129 p.
31	Harper, J.R. and B. Humphrey. *Stranded Oil in Coastal Sediments: Permeation in Tidal Flats*. April 1986. 23 p.
33	Harper, J.R. *Practical Insights into Decision-Making for Shoreline Cleanup of Oilspills.* May 1986. 44 p.
34	Belore, R.C. *Development of a High Pressure Water Mixing Concept for Use with Ship-based Dispersant Application*. May 1986. 51 p.
51	S.L. Ross Environmental Research Ltd. and Energetex Engineering. *Decision-making Aids for Igniting or Extinguishing Well Blowouts to Minimize Environmental Impacts.* November 1986. 119 p.
53	MacNeill, M.R. and R.H. Goodman. *Oil Motion During Lead Closure*. January 1987. 13 p.
58	S.L. Ross Environmental Research Ltd. and Hatfield Consultants Ltd. *Countermeasures for Dealing with Spills of Viscous, Waxy Crude Oils*. October 1986. 59 p.
62	S.L. Ross Environmental Research Ltd. and D.F. Dickins Associates Limited**.** *Field Research Spills to Investigate the Physical and Chemical State of Oil in Pack Ice.* February 1987. 116 p.
64	Brown, H.M. and R.H. Goodman. *In Situ Burning of Oil in Ice Infested Waters*. February 1987. 27 p.
68	Belore, R.C. *Mid-Scale Testing of Dispersant Effectiveness*. April 1987. 82 p.
69	Hatfield Consultants Ltd. *Spills-of-Opportunity Research*. February 1987. 124 p.
70	Lane, P., M.J. Crowell, D.G. Patriquin and I. Buist. *The Use of Chemical Dispersants in Salt Marshes*. May 1987. 100 p.
72	Nawwar, A., A. Godon, H.W. Jones, E. Yeatman, J. Ohuja, M.B. Frish and I. Arvin. *Acoustical Methods for Measuring Thickness of Oil on Water*. April 1987. 57 p.
74	Bennett, J., I.R. McAllister, L. Pertile and D. McQuillan. *Removal of Stranded Oil from Remote Beaches by In-Situ Combustion.* March 1987. 122 p.
77	Comfort, G. *Analytical Modelling of Oil and Gas Spreading Under Ice*. August 1987. 57 p.
78	Reimer, E.M. and J.R. Rossiter. *Measurement of Oil Thickness on Water from Aircraft: A. Active Microwave Spectroscopy. B. Electromagnetic Thermoelastic Emission.* August 1987. 82 p.
79	S.L. Ross Environmental Research Ltd. and L.C. Oddy Training Design Ltd. *The Development of a Canadian Oil-Spill Countermeasures Training Program.* May 1987. 194 p.
82	Belore, R.C. and D. MacKay**.** *Drop Size and Dispersant Effectiveness: Small-Scale Laboratory Testing*. July 1987. 31 p.
83	Thorpe, J.W. and K.E. Hellenbrand. *Microbial Degradation of Hydrocarbon Mixtures in a Marine Sediment Under Different Temperature Regimes*. September 1987. 48 p.
84	S.L. Ross Environmental Research Limited and D. MacKay Environmental Research Ltd. *Laboratory Studies of the Behaviour and Fate of Waxy Crude Oil Spills***.** December 1988. 250 p.
86	Pelletier, E. and C. Brochu. *Prototype, Mesoscale Simulator for the Study of Oil Weathering Under Severe Conditions*. November 1987. 55 p.
92	Trudel, B.K., B.J. Jessiman, S.L. Ross and J.J. Swiss. *Guide to Dispersant - Use Decision Making for Oil Spills in the Canadian Southern Beaufort Sea.* February 1988. 227 p.

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95	D.F. Dickins Associates Ltd., S.L. Ross Environmental Research Ltd. and Seakem Oceanography, Ltd. *Evaluation of Hovercraft for Dispersant Application.* February 1988. 57 p.
98	Goodman, R.H. *Simple Remote Sensing System for the Detection of Oil and Water.* December 1988. 32 p.
100	Swiss, J.J. and N. Vanderkooy. *Beaufort Sea Dispersant Trial.* July 1988. 44 p.
106	S.L. Ross Environmental Research Ltd. *Proceedings of a Workshop to Establish Canadian Marine Oil Spill Research and Development Priorities*. April 1990. 56 p.
108	Harper, J.R. *Development of a National Directory of Canadian Oil Spill Specialists***.** October 1991. 62 p.
119	Guenette, C. *Modification and Testing of a Portable Reciprocating Kiln for Cleaning Oiled Sand and Gravel.* March 1992. 46 p.
120	Guenette, C. *Development and Testing of a Prototype Rock Washer for Cleaning Oiled Beach Cobble***.** January 1991. 45 p.
124	Englehardt, R. *Oil Base Drilling Mud Toxicity*. December 1989. 47p. (Unpublished)
126	Koski, W.R., S.D. Kevan and W.J. Richardson. *Bird Dispersal and Deterrent Techniques for Oil Spills in the Beaufort Sea.* December 1993. 122p.
127	Dempsey, J., A. Simms, J. Harper, E. Lambert, and R. Hooper. *West Coast Newfoundland Oil Spill Sensitivity Atlas*. March 1995. 62 p.
140	Jacques Whitford Environment Limited 2001. *Atlas of Ecologically and Commercially Important Areas in the Southern Gulf of St. Lawrence*. 2001. CD-Rom.
ICE/ICEBERGS/ICE DETECTION	
8	Ryan, J.P., M. Harvey and A. Kent**.** *The Assessment of Marine Radars for the Detection of Ice and Icebergs.* August 1985. 127 p.
11	Gammon, P.H. and J.C. Lewis. *Methods for the Fracturing of Icebergs*. July 1985. 91 p.
14	Buckley, T., B. Dawe, A. Zielinski, S. Parashar, D. MacDonald, H. Gaskill, D. Finlayson and W. Crocker. *Underwater Iceberg Geometry*. September 1985. 216 p.
16	Rossiter, J.R., L.D. Arsenault, E.V. Guy, D.J. Lapp, E. Wedler, B. Mercer, E. McLaren, and J. Dempsey. *Assessment of Airborne Imaging Radars for the Detection of Icebergs.* September 1985. 320 p.
22	Ryan, J.P. *Enhancement of the Radar Detectability of Icebergs*. January 1986. 83 p.
35	Harvey, M.J. and J.P. Ryan. *Further Studies on the Assessment of Marine Radars for the Detection of Icebergs.* June 1986. 82 p.
38	Marko, J.R., D.B. Fissel and J.R. Birch. *Physical Approaches to Iceberg Severity Prediction.* July 1986. 104 p.
42	Anderson, D.G., D. McDonald, P. Mitten, S. Nicholls and D. Tait**.** *Management of Small Ice Masses*. August 1986. 195 p.
44	Hay & Company Consultants Inc. *Motion and Impact of Icebergs*. September 1986. 146 p.
45	Canpolar Consultants Ltd. *Iceberg Detection by Airborne Radar: Technical Review and Proposed Field Program***.** Sept 1986. 235 p.
48	Davidson, L.W., W.I. Wittman, L.H. Hester, W.S. Dehn, J.E. Walsh and E.M. Reimer. *Long Range Prediction of Grand Banks Iceberg Season Severity: A Statistical Approach.* October 1986. 163 p.
52	de Margerie, S., J. Middleton, C. Garret, S. Marquis, F. Majaess and K. Lank. *Improvement of Iceberg Drift Forecast - Grand Banks.* November 1986. 86 p.
81	Warbanski, G. and E. Banke**.** *Evaluation of a Modified Water Cannon System to*

ESRF Report #	Title and Author
	Control Small Iceberg Masses. August 1987. 142 p.
91	Klein, K., J.P. Ryan and M. House. *Ryan Evaluation of Two Search Radar Systems for Detection of Ice Masses.* January 1988. 240 p.
104	Terry, B.F., D.J. Lapp, C.L. Balko, K.E. Hancock and P.A. Lapp. *Ice Data Management System.* July 1989. 151 p. + appendices.
113	Finlayson, D.J., J. Bobbitt, P. Rudkin and I.J. Jordan. *Iceberg Trajectory Model: Real-Time Verification.* March 1992. 47 p.
115	Pilkington, G.R., M.C. Hill, M. Metge and D. McGonigal. *Beaufort Sea Ice Design Criteria -Acquisition of Data on EIFs.* October 1992. 154 p.
125	Davidson, L.W. *Long-Range Ice Forecasting System (LRIFS) Applied for the Beaufort Sea.* May 1993. 58 p.
132	Rossiter, J.R., et al. *Remote Sensing Ice Detection Capabilities - East Coast.* April 1995. 172 p.
133	Davidson, S.H. and A. Simms. 1997. *Characterisation of Iceberg Pits on the Grand Banks of Newfoundland.* February 1997. 162 p
157	Sonnichsen, G.V., Hundert, T., Pocklton, P. and Myers, R. 2005. *Documentation of Recent Iceberg Grounding Evens and a Comparison with Older Events of Know Age, Northern Grand Bank, Canada,* April 2006. 206 p
SEA BOTTOM ICE SCOUR	
7	El-Tahan, M., H. El-Tahan, D. Courage and P. Mitten. *Documentation of Iceberg Groundings.* May 1985. 162 p.
32	Shearer, J., B. Laroche and G. Fortin. *Canadian Beaufort Sea 1984 Repetitive Mapping of Ice Scour.* May 1986. 93 p.
37	Comfort, G. and B. Graham. *Evaluation of Sea Bottom Ice Scour Models*. June 1986. 115 p.
39	Woodworth-Lynas, C.M.T., D.W. Bass and J. Bobbitt. *Inventory of Upslope and Downslope Iceberg Scouring.* July 1986. 103 p.
43	Geonautics Ltd. *Design of an Iceberg Scour Repetitive Mapping Network for the Canadian East Coast*. March 1987. 45 p.
49	Lewis, C.F.M., D.R. Parrott, P.G. Simpkin and J. T. Buckley (eds.). *Ice Scour and Seabed Engineering. Report on Calgary Workshop, February 1985*. November 1986. 322 p.
55	Gilbert, G. and K. Pedersen. *Ice Scour Data Base for the Beaufort.* December 1986. 93 p. + appendices
94	Hodgson, G.J., J.H. Lever, C.M.T. Woodworth-Lynas and C.F.M. Lewis (eds.). *Dynamics of Iceberg Grounding and Scouring. Volume I The Field Experiment. Volume II Maps and Charts.* June 1988. 316 p.
97	Gilbert, G.R., S.J. Delory and K.A. Pedersen. *Beaufort Sea Ice Scour Data Base (Scourbase).* Update to 1986. March 1989. 99 p.
105	Geonautics Limited. *Regional Ice Scour Data Base Update Studies.* October 1989. 177p. + appendices
107	Davidson, S.H., W.T. Collins and P.G. Simpkin. *An Experiment to Monitor Four Iceberg Scours on the Grand Banks of Newfoundland.* December 1991. 110 p.
128	Geonautics Limited. *East Coast Repetitive Seafloor Mapping* 1979/1990. March 1991. 49 p. + appendices.
129	Myers, R., S. Blasco, G. Gilbert, and J. Shearer. *1990 Beaufort Sea Ice Scour Repetitive Mapping Program.* March 1996. 147 p + appendices.

ESRF Report #	Title and Author
WAVES	
20	Brown, R.D., P. Roebber and K. Walsh**.** *Climatology of Severe Storms Affecting Coastal Areas of Eastern Canada*. February 1986. 233 p.
23	Murray, M.A. and M. Maes. *Beaufort Sea Extreme Wave Studies Assessment*. January 1986. 97 p.
56	Lemon, D.D. *Wind Speeds from Underwater Acoustic Measurements During the Canadian Atlantic Storm Program*. Dec 1986. 116 p.
59	Dobrocky Seatech Ltd. *Wave Climate Study - Northern Coast of British Columbia.* May 1987. 93 p.
65	LeDrew Environmental Management Ltd. (ed.). *Proceedings of the International Workshop On Wave Hindcasting and Forecasting*. *Halifax Workshop, September 1986.* February 1987. 370 p.
73	Hodgins, S.L.M. and D.O. Hodgins. *Evaluation of Wave Forecasting Models and Forecast Wind Fields in the Canadian Context***.** June 1988. 356 p.
76	Eid, B.M. and V.J. Cardone. *Operational Test of Wave-Forecasting Models During the Canadian Atlantic Storms Program (CASP).* August 1987. 256 p.
88	Penicka, F.X. *Wave Hindcast Sensitivity.* April 1987. 114 p.
99	Juszko, B.A. *Comparison of Directional Wave Spectra.* July 1988. 227 p.
103	Hodgins, D.O., C.T. Niwinski and D.T. Resio. *Comparison and Validation of Two Shallow Water Spectral Wave Models.* June 1989. 143 p. + appendices.
114	Eid, B.M. and V.J. Cardone. *Beaufort Sea Extreme Waves Study.* March 1992. 143 p.
FRONTIER SOCIAL AND ECONOMIC ISSUES	
2	Gardner, M. *Interaction Between the Fisheries & the Oil and Gas Industry off the East Coast of Canada.* March 1985. 70 p.
3	Cleland Dunsmuir Consulting Ltd., Community Resource Services Cooperative Ltd., Maritime Resource Management Services and H. Mills. *Petroleum Related Socio-economic Issues - Atlantic Canada***.** March 1985. 101 p.
4	Usher, P.J., D. Delancey, G. Wenzel, M. Smith and P. White. *An Evaluation of Native Harvest Survey Methodologies in Northern Canada.* April 1985. 249 p.
15	Gardner, M. *Construction Projects - Frame of Reference for Oil & Gas Developments in Atlantic Canada***.** November 1985. 86 p.
24	DPA Group Inc. and Intergroup Consulting Economics Ltd. *Northern Employment and Training in the Oil and Gas Industry.* March 1986. 105 p.
40	Storey, K., J. Lewis, M. Shrimpton and D. Clark. *Family Life Adaptations to Offshore Oil and Gas Employment.* July 1986. 207 p.
46	Constable, G.A., R.M. Griggs, N.E. Millbank and M.S Sinclair. *Business Opportunities Related to Oil and Gas Exploration and Production in Northern Canada***.** August 1986. 269 p.
47	IDP Consultants Ltd. *Public Information on Oil and Gas Activities*. September 1986. 170 p.
67	Pinfold, T. *An Evaluation of the Utility of Large-Scale Economic Models for Socio-economic Impact Assessment.* March 1987. 34 p.
71	Atlantic Consulting Economists Limited. *Local Business Adaptation to East Coast Offshore Energy Development.* July 1987. 57 p.
85	Groves, S., W.G. Green and J.R. Harper. *Queen Charlotte Islands Coastal Zone: Digital Mapping and Linked Data-Base System***.** September 1988. 115 p.

ESRF Report #	Title and Author
87	Storey, K. and M. Shrimpton. *Planning for Large-Scale Construction Projects: A Socio-Economic Guide for Communities, Industry and Government.* October 1987. 78 p.
153	Fedirchuk, Gloria J., S. Labour, N Nicholls, FMA Heritage Resources Consultants *Traditional Knowledge Manual Volume 1 & 2: Literature Review and Evaluation and Using Traditional Knowledge in Impact Assessments***.** August 2005. Calgary.
ENVIRONMENTAL LOADING AND DESIGN	
111	Maddock, B., G. Khng and M. Gerin. *Verification of CSA Code for Fixed Offshore Steel Structures.* October 1992. 92 p.
112	Allyn, N., W.J. Cichanski and P. Adebar**.** *Verification of CSA Code for Fixed Offshore Concrete Structures.* November 1992. 62 p.
116	Traynor, S. and S.R. Dallimore**.** *Geological Investigations of Proposed Pipeline Crossings in the Vicinity of Taglu and Niglintgak Islands, Mackenzie Delta, NWT.* May 1992. 115 p.
131	Allyn, N., et al. *Environmental Loading Studies for the CSA Offshore Structures Code.* January 1995. 86 p.
135	Dallimore, S.R. and J.V. Matthews, Jr. *The Mackenzie Delta Borehole Project.* April 1997. CD-Rom.
BIBLIOGRAPHIES	
10	Goodwin, C.R., J.C. Finley and L.M. Howard. *Ice Scour Bibliography.* July 1985. 99 p.
26	Young, S.C. *Bibliography on the Fate and Effects of Arctic Marine Oil Pollution***.** March 1986. 212 p.
30	Howard, L.H. *Icebergs: A Bibliography Relevant to Eastern Canadian Waters.* May 1986. 277 p.
50	Finley, J.C. and C.R. Goodwin. *The Training and Employment of Northern Canadians: An Annotated Bibliography.* November 1986. 206 p.
130	Hunter, S.P. and J.H. Vandermeulen**.** *Bibliography of Aquatic Oil Pollution Fate and Effects***.** December 1994. CD-Rom.

4.5 Program of Energy Research and Development (PERD)

The Program of Energy Research and Development (PERD) is a federal, interdepartmental program operated by Natural Resources Canada (NRCan). It is administered through the Office of Energy Research and Development (OERD). They fund research and development designed to ensure a sustainable energy future for Canada in the best interests of both our economy and our environment. It directly supports energy R&D conducted in Canada by the federal and provincial governments, and is concerned with all aspects of energy supply and use. The program has been in operation since its inception in 1972 at the time of the first Oil Crisis. Total funding reached up to $120 M per year but is currently about $55 M per year. About $ 6 M of this is devoted to oil and gas issues and of that, only a portion is Beaufort related. Over the years, a number of projects have been devoted to studying the ice environment of the Beaufort Sea as well as engineering issues such as pack ice driving forces, seabed scour, coastal erosion processes, multi-year ice properties, emergency evacuation from northern offshore structures, and ice forces on structures. Complete information regarding the PERD program can be found at http://www2.nrcan.gc.ca/es/oerd/ .

4.6 1982 Beaufort Sea Environmental Impact Statement (EIS)

In the early 1980s, Dome, Esso and Gulf prepared an Environmental Impact Statement (EIS) that was related to potential hydrocarbon developments in the Mackenzie Delta and offshore Beaufort Sea (Beaufort Sea EIS, 1982). The EIS reviewed various development plans for both the onshore and offshore parts of the region, and assessed the potential impacts of types of developments that were being considered at the time. All of the R&D needs that were considered to be important were itemized within the EIS. The key ice issues that were considered important are listed below:

- measurements of ice loads and interactions with offshore platforms
- the effect of offshore structures on the near-shore ice regime
- the strength of multi-year ice, and multi-year ice load levels
- driving forces on extreme ice features within pack ice
- ice scour on underwater berms
- protection of offshore structures by ice rubble
- growth and decay of ice rubble around offshore structures
- optimal island and structure geometries for ice (and waves)
- refinement of ice occurrence statistics and ice geometries (cited as a joint government and industry responsibility)
- methods for breaking extreme ice features
- ice conditions along tanker export routes (also cited as a joint government and industry responsibility)
- ice scour on the seafloor, and sub-sea pipeline design
- remote sensing of ice (detection, tracking, forecasting, etc.)
- oil spill countermeasures in ice area
- tanker design and transit operations in ice

The EIS reports (Beaufort Sea EIS, 1982) are a seven volume set that contains a wealth of very useful information and represent the state-of-knowledge at that time. They relate to Hydrocarbon Development in the Beaufort Sea with information in the following volumes:

- 2 Development Systems
- 3A Beaufort-Delta Setting
- 3B NW Passage Setting
- 3C Mackenzie Valley
- 4 Biological & Physical Effects

- 5 Socio-Economic Effects
- 6 Accidental Spills
- 7 Research & Monitoring

4.7 NRC Snow and Ice Subcommittee

The NRC Snow and Ice Subcommittee operated for about 35 years until 1988, as part of the Associate Committee on Geotechnical Research. It provided a focus for communication in the snow and ice community in Canada and sponsored workshops on a broad range of topics. A number of these workshops either focused on Beaufort Sea ice engineering issues or covered topics having application to Beaufort ice engineering. Table 9 lists the Technical Memoranda (TM), which have application to the Beaufort Sea. These may be obtained from CISTI (see Section 7.2.1).

Table 9: List of Relevant NRC Snow & Ice Subcommittee Reports

- TM No. 92, 1968. Ice Pressures against Structures. Proceedings of a conference held at Laval University, Quebec, 10-11 November 1966; compiled by L.W. Gold and G.P. Williams.
- TM No. 98, 1970. Ice Engineering and Avalanche Forecasting and Control. Proceedings of a conference held at the University of Calgary, 23-24 October 1969; compiled by L. W. Gold and G. P. Williams.
- TM No. 101, 1971. Workshop on the Action of Ice on Structures: Proceedings of a workshop held at NRC-DBR, Ottawa, Ont.
- TM No. 118, 1976. Summary of Current Research on Snow and Ice in Canada 1976; compiled by R. Frederking.
- TM No. 121, 1977. Workshop on the Mechanical Properties of Ice. Proceedings of a workshop held in Calgary, AB, 24-25 January, 1977.
- TM No. 123, 1979. Workshop on the Bearing Capacity of Ice Covers. Proceedings of a workshop held in Winnipeg, Manitoba 16-17 October 1978.
- TM No. 129, 1979. Workshop on Winter Roads. Proceedings of a workshop held at Ottawa, Ontario, 18-19 October 1979; compiled by N.K. Sinha.
- TM No. 134, 1982. Workshop on Sea Ice Ridging and Pile-Up. Proceedings of a workshop held in Calgary, Alberta, 22-24 October 1980.
- TM No. 136, 1985. Workshop on Ice Scouring. Proceedings of a workshop held at Montebello, Quebec, 15-19 February 1982; Editor R. Pilkington.
- TM No. 141, 1987. Workshop on Extreme Ice Features. Proceedings of a workshop held at Banff, Alberta, November 3-5, 1986; compiled by G.R. Pilkington and B.W. Danielewicz.
- TM No. 144, 1989. Proceedings of Workshop on Ice Properties. Proceedings of a workshop held in St. John’s, NL, June 21-22, 1988.

4.8 Northern Oil and Gas Action Plan (NOGAP)

The Northern Oil and Gas Action Plan (NOGAP) was initiated following the first set of impact assessment activities that marked the Mackenzie Corridor of the early 1970s and in the wake of the conclusions of the Berger Inquiry. NOGAP was initiated in 1984 as a seven year program to help government departments be prepared for northern oil and gas development. INAC was responsible for the program and seven government departments were eligible for funding. The programme was established as a means to accelerate scientific data gathering and to increase the capabilities and levels of expertise on the part of those government agencies which were already involved in carrying out long-term resource management or regulatory roles in this region. NOGAP funded the Beaufort Environmental Monitoring Program (1983-1987), the Mackenzie Environmental Monitoring Program (1985-1987), and the Beaufort Region Environmental Assessment and Monitoring Program which ended in 1993/94. NOGAP reports and bibliographies were published on an annual basis. Table 10 provides a partial list of NOGAP reports and illustrates the type of research that was performed under this program. The NOGAP reports are available through ASTIS (see Section 7.2.3).

Table 10: Partial List of NOGAP Reports

Year	Report Number	Title
1984		The Beaufort Sea, Mackenzie Delta, Mackenzie Valley, and Northern Yukon: A Bibliographic Review
1986		NOGAP Bibliography Volume 1
1987	52	Beaufort Environmental Monitoring Program 1986/1987 Final Report
1987		NOGAP Bibliography Volume 2
1987		NOGAP Bulletin; Annual Review of NOGAP Projects
1987	50	Bowhead Whale Food Availability Characteristics in the Southern Beaufort Sea: 1985 and 1986
1988	57	Yukon Fish and Effects Causeways
1988	60	Beaufort Environmental Monitoring Program 1987/1988 Final Report
1988	58	The Potential effects of Tanker Traffic on the Bowhead whale in the Beaufort Sea
1988	55	Sewage waste Discharge to the Arctic Marine Environment
1989		NOGAP Bibliography Volume 3
1991	67	Beaufort Region Environmental Assessment and Monitoring Program (BREAM) Final Report 1990/1991
1992	69	Beaufort Region Environmental Assessment and Monitoring Program (BREAM) Final Report 1991/1992
1992		NOGAP Bibliography Volume 4
1992		NOGAP Cumulative Bibliography
1994		Beaufort Region Environmental Assessment and Monitoring Program (BREAM) Final Report 1993/1994

4.9 R&D Review Reports

There were several review reports written to help identify the critical research issues for offshore development in the Beaufort Sea. These are briefly summarized below:

In 1992, Wright & Masterson (1992) wrote a review article for PERD entitled "A Review and Assessment of PERD and Other Ice/Structure Interaction Work". This was a detailed and specific assessment of ice interaction and ice loading issues for fixed and floating platforms on the Grand Banks, and bottom founded structures in the Beaufort Sea.

Croasdale (1993) edited the proceedings of a Workshop focused on the R&D requirements with an emphasis on focusing and planning research. Following this, Croasdale (1994) developed a subsequent evaluation and planning of R&D needs, with a much broader scope than the Wright and Masterson (1992) study. This work was sponsored by the Office of Energy Research and Development (OERD) and was intended to provide directions, priorities and economic justifications for PERD R&D expenditures, in relation to potential hydrocarbon developments in Canada's frontier regions.

Croasdale et al (1999) carried out another study to better focus and justify the R&D expenditures. This report covered the full spectrum of the hydrocarbon energy sector in Canada, not only in the frontiers. Although the study was primarily oriented towards technical needs, it also recognized the importance of greenhouse gas issues, which had become topical by that time.

Kavik-Axys (2001) prepared an overview related to the pipeline transportation of gas from the western Arctic and Alaska. Although it does not deal with the offshore Beaufort, it is an informative summary of the key research areas related to a pipeline to the south. Wright (2005) was contracted by the NRC-CHC through PERD funds to develop the current R&D requirements for Beaufort Sea production. This is an extremely informative and up-to-date report on the important research needs. It is available on the CHC website (www.chc.nrc.ca) in the Cold Regions Technology section. A summary of his recommendation is given in Table 11. Note that Wright did not include any potential activities in the deeper waters of the Beaufort Sea so these waters are not reflected in the relative priorities.

Timco et al. (2005b) did a scoping study to look at the central issues related to year-round shipping in the Canadian Arctic. This report summarized the ice information available to the marine industry, the state-of-knowledge of ice information systems, and Arctic operations by the Canadian Coast Guard. Also, several icebreaker Captains were interviewed to solicit their input on key research issues. The report concluded that the local and regional detection of multi-year ice was the major R&D issue to be addressed.

4.10 NRC Centre of Ice-Structure Interaction

When the downturn in interest for the Beaufort Sea occurred in the early 1990s, a Centre of Ice-Structure Interaction was setup at the Canadian Hydraulics Centre of the National Research Council of Canada (NRC-CHC). The NRC working with Industry and with support from PERD, transferred a large number of reports, data tapes and videos to Ottawa. Many of the reports were confidential. However, the companies agreed that the NRC-CHC could use this information to further their research and understanding of engineering issues related to the Beaufort Sea. The NRC-CHC has been very active in this area and has published numerous papers related to topics such as ice loads, local ice pressures, emergency evacuation, ice forecasting, marine transportation, etc. Their website contains over 250 published papers and reports related to ice engineering issues. It can be accessed through http://chc.nrc-cnrc.gc.ca/ and following the links through Cold Regions Technology and Reports.

Table 11: Summary of key ice-related R&D needs for the Beaufort Sea, their relative priorities and the present state of knowledge in each ice issue area. H, M and L mean high, medium and low while G, F and P means good, fair and poor (after Wright 2005).

	Near-Shore Zone		Intermediate Zone		Deep Zone	
	Priority	Knowledge	Priority	Knowledge	Priority	Knowledge
Fixed Offshore Structures						
Global loads from FY Ice	H	G	M	G	L	G
Global loads from MY Ice (& thick ice failure modes)	M - H *	F	H	P	H	P
Local & semi-local pressures from FY Ice	H	G	M	G	L	G
Local & semi-local pressures from MY Ice	M - H *	F	H	F	H	F
Ice rubble formation	H	F	L - H **	F - P	L	P
Load reduction from ice rubble	H	P	L - H **	F - P	L	P
Statistics on MY ice population/size/thickness	H	G - F	H	F - P	H	F - P
Sloped versus vertical-sided structure?	M	F	M	F - P	L	F - P
Spray ice technology	H	G	M - H **	G	NA	-
* depends on water depth, and the risk of multi-year ice interactions with a structure						
** depends on design philosophy of getting some protection from grounded ice rubble or spray ice, or otherwise						
Floating Vessel Station-Keeping						
Ice loads on floating vessels (moored and/or DP)	L	G - F	H	G - F	H	P
Ability to station-keep in prevailing ice conditions	L	G	H	G - F	H	F - P
Knowledge of ice management effectiveness	L	G	H	G - F	H	F - P
Vessel requirements for ice management *	L	G	H	G	H	F - P
* includes topic areas like number of vessels, levels of ice-srengthening and powering, utility of azimuth thrusters, etc.						
Seafloor Facilities & Pipelines						
Knowledge of ice scour statistics	H	G	M	G	NA	-
Ice keel strengths - FY & MY ridges	M - H	P	M - H	P	NA	-
Keel scouring processes & sub-scour deformations	H	F - P	M - H	F - P	NA	-
Marine Export Systems						
Tanker design & operation	L	G	H	G	H	F
Tanker station-keeping while loading	L	-	H	F	H	P
Tanker loading systems	L	-	H	F	H	F
MY ice impact loads & hull strength	L	-	H	F - G	H	F - G
MY Ice detection & optimum transit routing	L	-	M	G	M	G
Exploratory Drilling & Seismic						
Drilling system needs for extended season ops	L	G	M	G	M	P
Seismic methods in deep ice-covered waters	-		-		H *	F - P
Seismic methods in very shallow waters	M	P	-		-	
* this is not a short term priority, since there are no plans for deep water exploration in the Beaufort Sea at present						
Environmental Considerations						
Effects of climate change on ice conditions	H	F	H	F	H	F
Improved relief well capability	M	F	M	F	M	F
Dredging concerns	M	F	M	F	L	-
Oil spill countermeasures & clean-up	H	F	H	P	H	P
Other Considerations						
Emergency escape, evacuation & rescue systems	H	G - F	H	F -P	H	P
Marine systems for construction & re-supply	M	G	H	G	H	F - P
Ice-capable support vessel needs & availability	M	G	H	G	H	F - P

5.0 BEAUFORT SEA FIELD STUDIES

There were a large number of major field programs carried out in both the Canadian and American Beaufort Sea during the 1970s to 1990s. Each had its specific objectives. The following section describes some of these projects, and includes some of the more recent large field experiments. Most of them were highly successful. However, obtaining access to the data and results of the older programs is often very difficult.

5.1 Tarsiut Island Research Program (TIRP)

The Tarsiut caisson structures have been described in Section 3.4.1. During the winter of 1982-83, there was no drilling activity and the structure was left on-site and used as a test platform to study ice interaction with a wide offshore structure. This project was known as the Tarsiut Island Research Program (TIRP). The island was manned with approximately 6 to 10 people with helicopter shuttle for crew changes. During that winter, a large grounded rubble field formed around the island (see Figure 29). Measurements were made of the ice loads, ice failure behaviour and ice movements. The ice load measurements were primarily obtained from the output of a large number of MEDOF panels that were used to circle the structure. In addition, a few panels were placed further out in the grounded rubble field (see Figure 30). During March to May, measurements were made by British Petroleum (BP) around the grounded rubble field to provide information on the local strain and strain rates in the adjacent ice sheet. Based on this information, the global loads on the island and rubble pile were inferred. A particular aspect of this work was the determination of the attenuation of loads through grounded rubble. In spite of the extensive work program, this question was not quantitatively answered (Timco and Wright, 1999).

The information from this study was not widely distributed. There were a large number of BP and Gulf Canada reports that summarized the measurements. Copies of the reports from this project reside in libraries of the participating oil companies and at a few other locations. The NRC Centre of Ice-Structure Interaction (Timco 1996) has a set of these reports. In spite of the large effort in terms of people and dollars on this project, very little analysis was done on the data. There have been a few papers on the mechanical properties of the ice (Frederking and Timco, 1983; Timco and Frederking, 1983; Blanchet et al., 1997) and on the load measurements (Timco and Wright, 1999; Timco and Johnston, 2004). The authors are not sure why this is so since the data collected were of high quality and unique. There could be two reasons for this. First, the grounded ice rubble protected the caissons so there was no direct loading on them, and this gave very low loads. The loading was primarily thermal in origin so the loading events were long and not very exciting. Second, other caisson structures were deployed in more dynamic ice conditions and the focus was shifted to these structures.

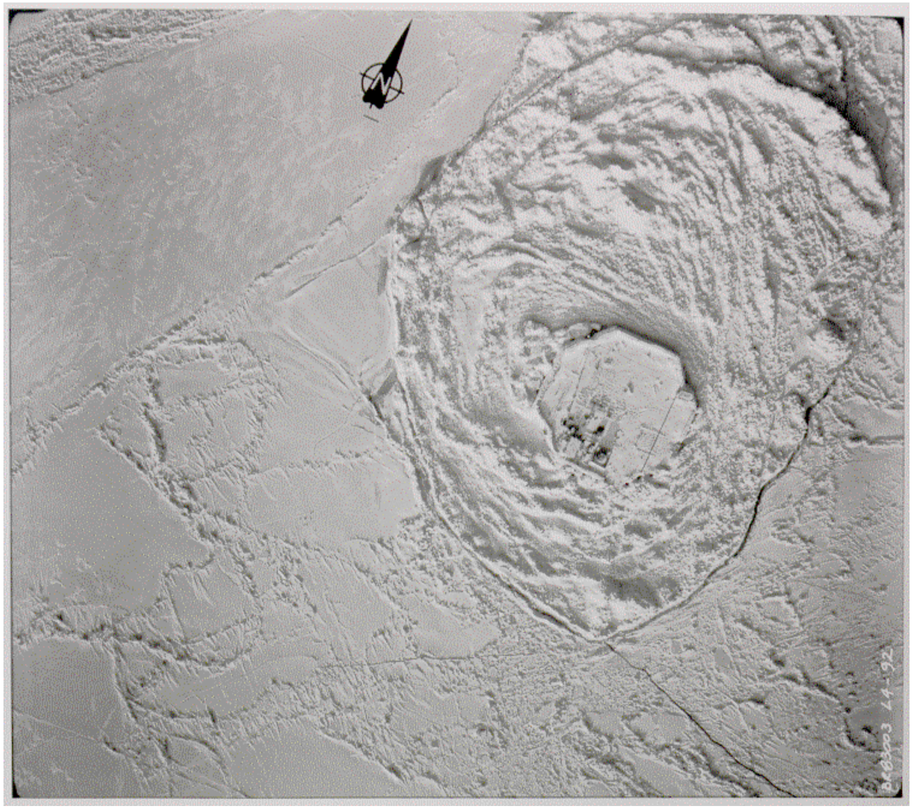

Figure 29: Photograph showing an overhead view of Tarsiut on March 2, 1983. Note the large grounded rubble field around the caisson structure.

Figure 30: Photograph showing the grounded ice rubble and markers around Tarsiut where load and deformation measurements were made.

5.2 Arctic Ice Dynamics Joint Experiment (AIDJEX)

The Arctic Ice Dynamics Joint Experiment (AIDJEX) program was the first major western sea ice experiment constructed specifically to answer emerging questions about how sea ice moves and changes in response to the influence of ocean and atmosphere. A pilot study in 1972 was followed by the AIDJEX field program in 1975 and 1976. Figure 31 shows a photo (taken from the AIDJEX website) of the camp in 1972.

Figure 31: Photograph showing the AIDJEX field camp in 1972 (photo taken from the AIDJEX website).

Researchers maintained four manned camps on ice floes in the Beaufort Sea. The scientists collected meteorological and oceanographic data from instruments located at the camps and on floating data buoys. The experiment was designed to collect coordinated measurements over at least one year, in order to have the right combination of data for understanding atmosphere and ice interactions. The submarine USS Gurnard participated by collecting ice draft data from upward-looking acoustical soundings (sonar). Ice draft (the depth of the ice below the water surface) is an estimator of ice thickness.

The University of Washington led the logistics and research work of the program, which was a collaboration between the United States, Canada and Japan. Norbert Untersteiner was instrumental in the design of AIDJEX, and served as Project Director from 1971 to 1978. The Polar Science Center at the University of Washington maintains an AIDJEX electronic library. It includes downloadable copies of the contents of all 40 AIDJEX Bulletins, beginning in 1970 and ending in 1978.

Further information can be found at http://nsidc.org/data/aidjex/ . The full set of the AIDJEX Bulletins were converted to PDF files at the Jet Propulsion Laboratory in Pasadena CA under the direction of Dr. Ron Kwok and with financial support from NASA. They are available from: http://psc.apl.washington.edu/aidjex/toc.html

5.3 Molikpaq Ice Dynamics Project

During the winter of 1985-86, the Molikpaq was subject to a number of cyclic ice loading events in which dynamic ice loading behaviour was observed. This type of loading caused concern and consequently a joint industry "Ice Dynamics Project" was initiated to study the behaviour of the Molikpaq during interaction with first-year and multi-year ice during the winter of 1985-86 at Amauligak I-65. The project was split into three Phases, Phase la, lb and Phase 2. Reports were prepared describing the as-deployed conditions, instrumentation and data acquisition system, validation of force measurements, on-ice investigations, first year and multi-year ice event data, geotechnical data, environmental monitoring, operational records, review of instrumentation, data reduction, data interpretation, analysis of the April 12, 1986 multi-year ice loading event, centrifuge testing, finite element modelling of the static and dynamic response of the Molikpaq, laboratory testing of sand core properties, and modelling of the response of the sand core.

The reports and data from this project were distributed to the participants and they are not generally available in the public domain. A set of the reports resides at the NRC Centre of Ice-Structure Interaction (see Section 4.10).

5.4 Hobson's Choice Tests

In 1989 and 1990 Medium Scale Field Ice Indentation tests were carried out at Hobson's Choice Ice Island north of Ellef Ringnes Island (Frederking et al 1990; Masterson et al., 1993). The tests were conducted in a 3-meter deep trench cut into a multi-year floe (see Figure 32). The loading system could generate a maximum force of 12 MN. Indenters, representing the local area of an offshore structure, were forced against specially-shaped ice faces. Average pressures of 5 MPa were attained at a contact area of 1.5 m^2. The test results were used to establish requirements for the design of local pressures on ships and offshore structures exposed to multi-year ice.

Figure 32: Ice loading apparatus in 3-m deep trench in multi-year ice.

5.5 Sea Ice Mechanics Initiative (SIMI)

The Sea Ice Mechanics Initiative (SIMI) was a five-year U.S. Navy Office of Naval Research program. The main SIMI field experiment was in the Beaufort Sea from September 1993 through April 1994, with numerous other small field experiments, laboratory experiments, and modelling efforts. The goals of this program were to understand sea ice constitutive laws and fracture mechanics over the full range of geophysical scales, to determine the scaled responses to applied external forces, and to develop physically-based constitutive and fracture models. About twenty principal investigators worked to achieve these goals along with their associates. The SIMI experiments include ice stress, strain, strength, tilt, motion, temperature, and response to controlled load experiments. Many papers have been published on the results of the SIMI program including a Special Issue of the Journal of Geophysical Research, Vol. 103, No. C10, pp 21737-21,925, September 15, 1998 and the Sea Ice Mechanics and Arctic Modeling Workshop which was held in Anchorage, Alaska, April 25 - 28, 1995.

5.6 Surface HEat Budget of the Arctic Ocean (SHEBA)

SHEBA was a large, interdisciplinary study that was motivated by climate change issues. The program was sponsored by the National Science Foundation and the Office of Naval Research. The name of the project comes from **S**urface **HE**at **B**udget of the **A**rctic Ocean. The project was carried out from October 1997 to October 1998 and used the *CCGS Des Groseilliers* as a base. One hundred and fifty researchers from 20 institutions were involved. Ice Station SHEBA was installed on a multi-year floe on October 2, 1997 at 75 N, 142 W. During the course of the year it drifted hundreds of kilometers to the west and north. The general location and trajectory are shown in Figure 33.

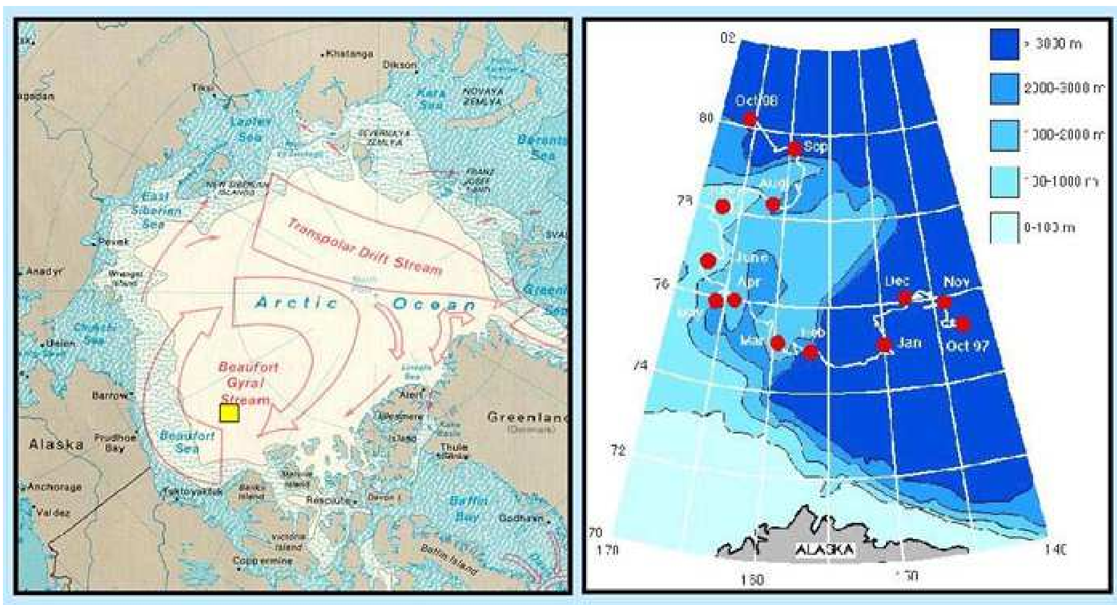

Figure 33: General location and drift track of Ice Station SHEBA

The SHEBA project had two goals:

1) understand the ice-ocean-atmosphere process
   - ice-albedo feedback mechanism
   - cloud radiation feedback mechanism
2) use this understanding to improve models
   - simulation of present day Arctic climate
   - simulation of "future" Arctic climate using GCM's

Comprehensive data on sea ice, ice drift, snow and ice properties, cloud properties, energy flux, radiance, boundary layer meteorology, mass balance, and ocean momentum at a range of scales can be accessed through the following website: http://www.eol.ucar.edu/projects/sheba/

5.7 Canadian Arctic Shelf Exchange Study (CASES)

The Canadian Arctic Shelf Exchange Study (CASES) was an international effort under Canadian leadership to understand the biogeochemical and ecological consequences of sea ice variability and change on the Mackenzie Shelf. The central hypothesis of this project was that the atmospheric, oceanic and hydrologic forcing of sea ice variability dictates the nature and magnitude of biogeochemical carbon fluxes on and at the edge of the Mackenzie Shelf. The research was mainly university-based and several universities in Canada were involved. The project received a great deal of support from the Canadian Coast Guard through the use of their vessels *Amundsen*, *Sir Wilfred Laurier*, and *Pierre Radisson*. CASES began in 2002 so it is a quite recent study. Details can be found at: http://www.quebec-ocean.ulaval.ca/cases/welcome.asp

5.8 Circumpolar Flaw Lead System Study

As part of the International Polar Year, the Canadian Government has funded the Circumpolar Flaw Lead System Study (CFL) through the University of Manitoba. This study will bring together over 200 scientists from 15 countries (Russia, USA, France, Denmark, Germany, Poland, Japan, Spain, Norway, Belgium, Netherlands, UK, Sweden, China and Canada) for a multi-year Climate Change study in the high Arctic of Canada. The Circumpolar Flaw Lead (CFL) System Study will use the Canadian icebreaker *CCGS Amundsen*. This project has a climate change focus to examine the behaviour of the large flaw lead that forms off of Banks Island. Further information can be found at http://www.ipy-cfl.ca/index.html

5.9 Recent Government Offshore Research

Over the past several years, a handful of scientists and engineers have been conducting research relevant to ice engineering issues for offshore exploration and development. Much of this research was funded through the government department allocations with additional funds from the PERD program (see Section 4.5) and INAC (see Section 7.2.11). Some of their activities are briefly described below. It should be noted that this is not intended to be an exhaustive list; rather it is the starting point for anyone interested in this research to contact the appropriate research group. The following projects relate to engineering aspects and support for engineering decisions. Studies related to environmental issues have not been included here. The most current information on all northern studies sponsored by the PERD program can be obtained from Natalie Shea (nshea@NRCan.gc.ca) who is a Technology Advisor on frontier oil and gas for the PERD Program. PERD has four programs that have projects relevant to the north and the Beaufort Sea:

- Northern (contact Garry Sonnichsen Gary.Sonnichsen@nrcan-rncan.gc.ca)
- Offshore Environmental Factors (contact Peter Smith SmithPC@mar.dfo-mpo.gc.ca)

- Marine Transportation & Safety (contact Bob Frederking Robert.Frederking@nrc.ca)
- Pipelines (contact Winston Revie wrevie@NRCan.gc.ca)

For information on INAC-sponsored research, interested persons should contact Ruth Mckechnie at mckechnier@inac.gc.ca).

Anne Barker from the NRC-CHC has conducted two years of field measurements and satellite observations of grounded rubble fields in the Beaufort Sea. She has studied the ice rubbling at the Minuk and Tarsiut sites (Barker et al 2008). The research has relevance with respect to the possibility of using Ice Rubble Generators to reduce ice loads on offshore structures (Barker and Timco 2005; Spencer et al 2007a) and for emergency evacuation to Evacuation Shelters (Barker et al 2007; Spencer et al 2007b). It is interesting to note that the relic berms from past artificial islands (see Section 3.1) and caisson structures (see Section 3.4) create large rubble fields (see Figure 34).

Figure 34: Photograph showing the large grounded rubble field that forms on the submarine berm at the Minuk site.

Steve Blasco of the Bedford Institute of Oceanography has been profiling the seabed of the Beaufort Sea for many years. He, and his colleagues, have developed and maintain a database of the Beaufort Sea scours (see Section 7.2.9). Using multi-beam sonar, he has provided incredible insight into the Beaufort seabed. He has profiled a number of the previous drill sites to investigate the size, shape and movement of the submarine berms (e.g. at Minuk and Tarsiut) and he has participated in a team that has investigated the origin of pingos on the Beaufort Sea shelf (Paull et al. 2007).

Scott Dallimore of the Geological Survey of Canada has been investigating the implications of natural and man-induced discharges of natural gas from terrestrial, lacustrine and nearshore areas of the Mackenzie Delta and the southern Beaufort Sea.

Michelle Johnston of the NRC-CHC has been active in measuring the properties (mechanical, salinity, temperature, drift, etc) of multi-year sea ice (Johnston 2008; Johnston and Timco 2008). Her research will be applied to better predict ice loads from extreme ice features.

Humfrey Melling of the Institute of Ocean Science has been continuously measuring the draft profile of the sea ice in the Beaufort Sea for more than a dozen years. He has deployed upward-looking sonar and developed a long-term record for seasonal pack ice in the Beaufort Sea (Melling et al. 2005). This has proven to be an extremely valuable data set for the ice in the region. He and his colleagues at the IOS, including Eddie Carmack and Bill Williams have been active in applying this research and investigating the oceanography of this region (Williams et al. 2008; Carmack and Macdonald, 2008).

Simon Prinsenberg from the Bedford Institute of Oceanography has been extremely active in developing and applying technology to remotely measure the thickness of sea ice. He has applied this technology to the Beaufort Sea region (Prinsenberg et al 2008; Peterson et al. 2008) and has collected important information on the ice in this region. His results are presented on the DFO website: http://www.mar.dfo-mpo.gc.ca/science/ocean/seaice/public.html

Steve Solomon and Don Forbes of the Bedford Institute of Oceanography have been actively engaged in investigating the near shore region of the Beaufort Sea. They have studied the waves and sediment mobility, as well as the subsidence, flooding, and erosion hazards in Mackenzie-Beaufort region (Solomon et al 2008; Stevens et al. 2009).

Val Swail of Environment Canada has been actively involved in researching the wave climate in the Beaufort Sea. He has recently completed an updated hind-forecast for this region (Swail et al. 2007).

Garry Timco of the NRC-CHC and his colleagues have been studying the ice forces on the structures in the Beaufort Sea (Timco and Johnston 2003; 2004; Frederking and Sudom 2006). They have developed predictive equations for ice loads on wide caisson structures. These results are being used in the new ISO Arctic Offshore Structures Standards.

5.10 Marine Transportation Update

Transport Canada is in the process of updating the Arctic Shipping Pollution Prevention Regulations (ASPPR 1989; AIRSS 1996). This will have a major impact on the regulations for shipping in the Beaufort Sea. The NRC-CHC has been working with Transport Canada to develop new regulations that have a solid scientific basis (Timco et al. 2004; Timco and Kubat 2007). Over the next year or so, Transport Canada will be holding a series of consultation meetings with interested stakeholders of these new regulations. Anyone with an interest in these new regulations should contact Victor SantosPedro at Transport Canada (SANTOSV@tc.gc.ca). People who are interested in being involved with the consultation meetings should contact Garry Timco at garry.timco@nrc.gc.ca.

6.0 OTHER RELEVANT STUDIES

There were a number of large-scale projects that were carried out in the Canadian Arctic. Although they were not done specifically in or for the Beaufort Sea, their results are applicable for this region. Some of the major ones are described in this section.

6.1 Pond Inlet Tests

A series of tests were carried out in an iceberg in May 1984 in Pond Inlet (Masterson et al., 1992). Tunnels were excavated in the iceberg and a hydraulic loading system forced a spherical shaped indenter into the face of the tunnel wall. The test system was servo controlled to follow a pre-determined velocity program to simulate an iceberg impacting a structure. Contact areas up to about 3 m^2 were attained and average pressures on this area were about 3 MPa. The primary purpose for the tests was to determine iceberg impact pressures for the design of the Hibernia GBS structure.

Data from these tests are not generally available in the public domain. The reports reside within oil companies and this information may be difficult to obtain.

6.2 Byam Martin (Rae Point) Indentation Tests

In the spring of 1984 the test apparatus which had been used at Pond Inlet was moved to Rae Point for testing in multi-year ice. A suitable floe in Byam Channel near Byam Martin Island was the selected site. The purpose of the testing was to simulate multi-year ice floe impacts on an offshore structure. Flat and spherical indentors with a maximum area of 2.5 m^2 loaded the ice at a range of velocities. At low velocities ductile behaviour was observed and at high rates brittle failure occurred. It was concluded that velocity has an important effect on ice pressures (Masterson et al. 1999).

Similar to the Pond Inlet tests, these data are not generally available in the public domain. The reports reside within oil companies and this information may be difficult to obtain.

6.3 Hans Island

Hans Island is a small rocky island, about 1 km in diameter, that is located in the centre of the Kennedy Channel (81ºN, 67ºW, see Figure 35) between Ellesmere Island and Greenland. Dome Petroleum/Canmar carried out three joint industry research projects at Hans Island. The test programs were carried out during a two-week period in the summer months (July/August) of 1980, 1981 (Danielewicz and Metge 1980, 1981 and 1982) and 1983 (Danielewicz and Cornett 1984). Metge (1994) summarized the results from all three seasons at Hans Island.

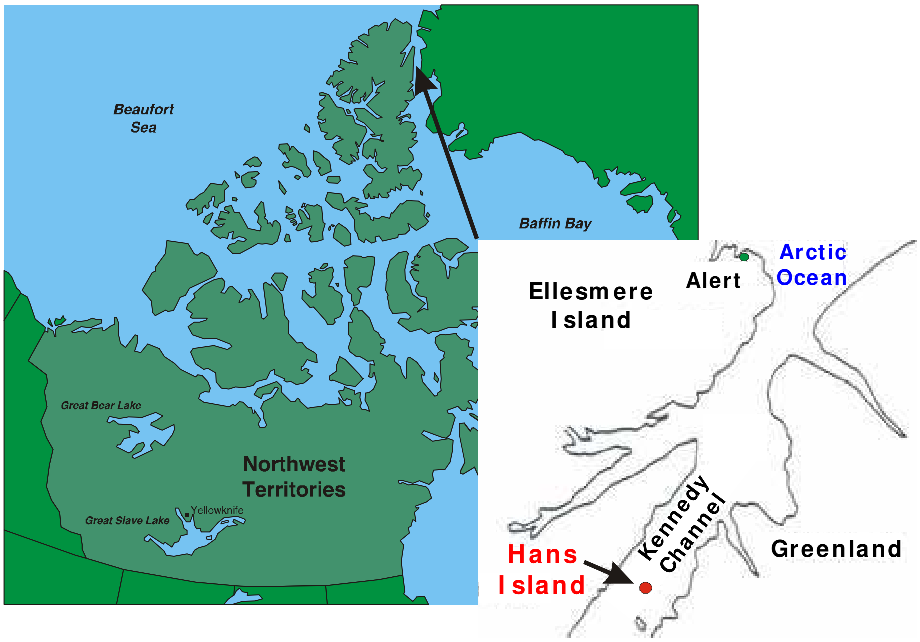

Figure 35: Map showing the location of Hans Island

In July and August the island is usually in open water. During these months, multi-year ice floes that originate from the Arctic polar pack can travel down Kennedy Channel and impact Hans Island. The interaction of isolated floes with the island was the focus of the Hans Island experiments. During the collision process, the ice floes gradually slowed down and often stopped in front of the island. In some cases the floes also split (see Figure 36). Ice loads were interpreted knowing the mass of the floe (areal extent and thickness) and rate of slowing down (deceleration).

The main focus of the measurements at Hans Island centered on determining the decelerations of the ice floe as it collided with the island. Various types of instrumentation were used including accelerometers, theodolites, electro-optical distance measurements and photogrammetry. Danielewicz et al. (1983) derived the equations that were used to determine the impact force. They examined the forces on the floe, including the ice load (F_i), air drag (F_a), water drag (F_w) and Coriolis force (F_c) and equated this to the mass (M) and acceleration (a) of the floe. By examining the individual terms, they found that they could disregard the environmental terms. Floes of mass up to 100 Mtonnes (about 6 km diameter and 6 m average thickness) impacted producing forces as high as 600 MN. The results of the Hans Island measurements were very significant in establishing the magnitude of loads that could be expected due to multi-year ice floe impacts on structures in the Beaufort. They led to confidence that exploration structures could be safely placed in areas of the Beaufort Sea subject to multi-year floe impacts.

Figure 36: Photograph showing a multi-year ice floe splitting after contact with Hans Island.

6.4 Arctic Pilot Project

The Arctic Pilot Project was developed to examine the feasibility of exporting natural gas from the High Arctic Islands to markets in Europe and North America. The proposed project would involve piping natural gas from the northern part of Melville Island to a Liquid Natural Gas facility (liquefaction, storage and loading) on the southern tip of the island. It would be transported by large very highly ice-strengthened LNG tankers with a capacity of about 140,000 cubic meters.

A considerable amount of research was carried out in this project. Unfortunately the reports are not generally available. The ASTIS database (Section 7.2.3) lists a number of the reports. It should be noted that there is renewed interest in the feasibility of this approach for exporting Arctic gas to southern markets.

6.5 Pack Ice Driving Force Experiments

Pack ice driving forces are a component in the limit-force scenario for determining ice forces on an offshore structure. A number of field projects were carried out in the Beaufort Sea in 1986, 1989 and 1991 to measure these forces during ridge building events. In the field projects, stresses were measured near the centre of multi-year ice floes within the ice pack for a 1 to 2 month period for each of the years noted. The drift of the floes was also measured. During periods of convergence the measured stresses increased and ridge building occurred around the floes. Periodic visits were made to the floes to recover data and note changes in the ridging around the floes. From these measurements and observations, loading on the edge of the multi-year floes was determined. Analysed results have been reported in Croasdale et al. (1992), Wright et al. (1992) and Comfort et al. (1998).

6.6 Exxon Large Beam Strength Tests

In the winter of 1979/80, five petroleum companies participated in an Exxon program in which thirteen large-scale ice strength tests were conducted offshore near Prudhoe Bay in Alaska (Chen and Lee, 1986; Lee et al., 1986; Petrie and Poplin, 1986; Wang and Poplin, 1986). The purpose of the program was to determine the uniaxial compressive strength of annual sea ice as a function of strain rate and direction of loading with respect to the preferred crystal alignment. Full ice sheet thickness test blocks with dimensions of 6 × 3 × 1.5 m thick were measured. A hydraulic loading system with a two million pound of force capacity was used to compress the ice blocks at constant strain rates from 10^{-7} s^{-1} to 5 X 10^{-5} s^{-1}. In the same test program, the strength of a number of smaller test specimens of sea ice was also measured. The test condition for each of the smaller specimens was set to be the same as if it was in-situ; i.e. at the same temperature and salinity that it would be in the ice sheet. The strength of a large beam was compared to the average of a number of smaller (laboratory size) specimens which represented the appropriate profile in the ice sheet. Exxon found that for ice from the same site and at the same environmental conditions, there was no difference in the strength of the ice. Thus, in compression, there does not appear to be a "size effect" in ice. They concluded that the equivalent full-thickness strengths of ice sheets can be directly inferred from small-scale laboratory tests. In spite of these test results, this finding is still controversial.

6.7 Adams Island

A 3-year joint project, beginning in 1982, observed and measured the ice interaction process and environmental driving forces around Adams Island (Frederking et al. 1983, 1984, 1986). The project was lead by the National Research Council of Canada (NRC), with participation from the Hamburg Ship Model Basin in Germany, Environment Canada (EC), and the Bedford Institute of Oceanography (BIO). Figure 37 shows the location of the project area. First year ice, with a maximum thickness of 1.8 m, interacted with Adams Island. The ice in Navy Board Inlet moves northward past Adams Island towards Lancaster Sound at an average rate of 0.1 m/day (maximum daily ice motion reached 0.3 to 0.4 m/day). Ice in the immediate vicinity of Adams Island also responds to 1.9 m tides.

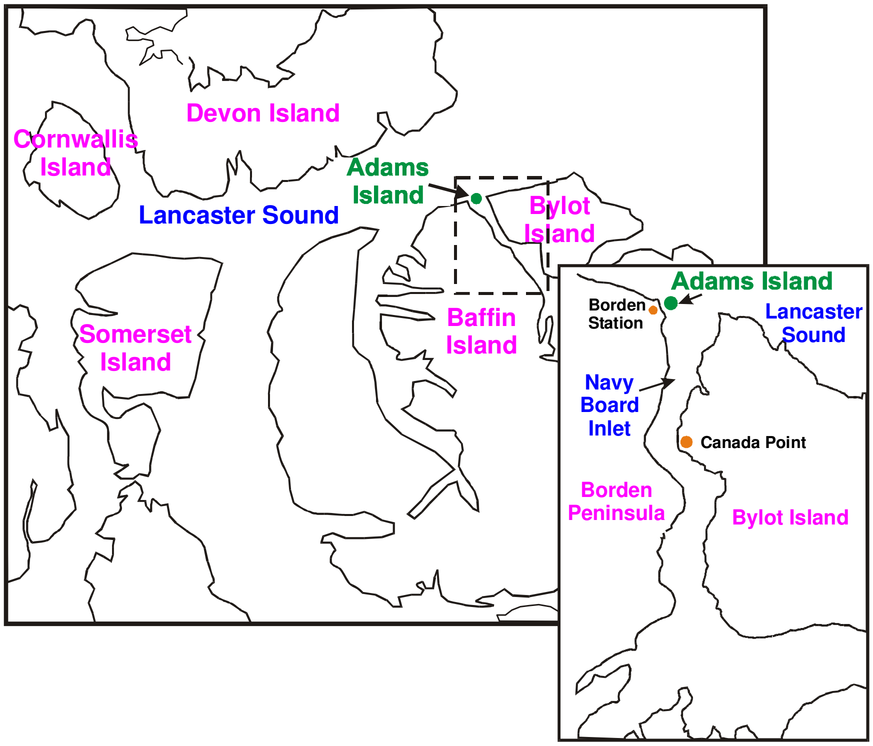

Figure 37: Map showing the location of Adams Island

Environmental parameters such as the air temperature, current, tide and wind were measured at Adams Island over three winters from 1982 to 1985. Horizontal ice movements around the Island were measured with an electronic distance measuring (EDM) instrument coupled to a theodolite. Ice stresses were measured using strain meters, bi-axial stress sensors and IDEAL panels installed in the level ice around the island. Ice stresses around the island were determined using measurements from these instruments. Global load on Adams Island was obtained by multiplying the average line load by the 200-m diameter of the island. Peak load levels on the island were estimated to be about 250 kN/m. The results were useful in establishing ice loads for slow movement of the ice cover combined with tidal actions.

7.0 RESOURCES

7.1 Books

There have been a number of books written on the exploration of the Beaufort Sea and the engineering issues associated with its development. Some of these are briefly described below:

In 1997, the Arctic Institute of North America (AINA) published a book that summarized the oil and gas exploration in the Beaufort Sea (Clark et al. 1997). *Breaking Ice with Finesse* is an easy-to-read and quite informative explanation of this exciting time in the north.

DOME - The Rise and Fall of the House that Jack Built is an historical novel that describes the operations of Dome Petroleum under Jack Gallagher (Lyon, 1983). The title of the book explains it all.

There have also been several books that relate more to ice engineering issues including Sanderson (1988), and Cammaert and Muggeridge (1988). Other ice-related books that are extremely informative include Pounder (1965), Hobbs (1974), Michel (1978) and more recently Loset et al. (2006) and Vershinin et al. (2006).

7.2 Libraries and Databases

There are a number of resources available that contain very useful information on past Beaufort activities. Some of these are described below:

7.2.1 Canada Institute for Scientific and Technical Information (CISTI)

The Canada Institute for Scientific and Technical Information (CISTI) is Canada's national science library and leading scientific publisher. It is part of the National Research Council of Canada in Ottawa. It maintains a large collection of scientific, technical and medical information. It has two on-line search engines – one for the CISTI Catalogue and the other for Discover, which is a journal-based database. CISTI has collected a considerable amount of the information on the Beaufort Sea activities. For example, it holds over 270 reports and appendices related to APOA studies. The library can usually supply a copy through interlibrary loan. However some reports are not circulated outside of the CISTI library. Further information can be found at: http://cisti-icist.nrc-cnrc.gc.ca/cisti_e.html

7.2.2 Arctic Institute of North America (AINA)

The Arctic Institute of North America (http://www.arctic.ucalgary.ca/) was created by an Act of Parliament in 1945. It is a non-profit membership organization and a multi-disciplinary research institute of the University of Calgary. The institute's mandate is to advance the study of the North American and circumpolar Arctic through the natural and social sciences, the arts and humanities and to acquire, preserve and disseminate information on physical, environmental and social conditions in the North. They have a large number of reports related to the Arctic catalogued at the University of Calgary. They are a very valuable source of information on the Beaufort Sea. They have been involved with data preservations projects and Arctic database development as discussed in the following two sections. AINA also publishes the journal “Arctic”.

7.2.3 AINA Arctic Science and Technology Information System (ASTIS)

As part of their activities, the AINA has developed the Arctic Science and Technology Information System (ASTIS) database. This is a comprehensive database that contains over 64,000 records describing publications and research projects about northern Canada. It is available to search online at: http://www.aina.ucalgary.ca/astis/

7.2.4 AINA Arctic Technology Preservation Project (ATPP).

A large number of contributions to ASTIS came from the AINA Arctic Technology Preservation Project (ATPP). This was a multi-year project that was funded by both industry and government. The purpose of this project was to preserve and make accessible the knowledge accumulated by the petroleum and pipeline companies that operated in northern Canada between 1960 and 1990. The project involved both abstracting the information into a database as well as cataloguing the reports in the library at the University of Calgary. This was a very important initiative that has successfully preserved this valuable information.

7.2.5 Canadian Offshore Oil and Gas Environmental Database

The National Energy Board (NEB) compiled all of the available environmental data that were collected and provided to the NEB and the Marine Environmental Data Services (MEDS) during offshore drilling operations. The data were released on a CD-ROM in March 1997. The disc was configured for a Windows 95 platform and it includes a software product called Interleaf Worldview for viewing and searching the meteorological data. Copies should be available from the National Energy Board (see Section 7.2.10)

7.2.6 NRC Ice Load Catalogue

The Canadian Hydraulics Centre of the National Research Council of Canada (NRC-CHC) in Ottawa has developed an "Ice Load Catalogue" (Timco et al., 1999a). This catalogue was funded through a large Joint Industry Project with eight participants. The following companies joined the JIP: Exxon Production Research, Conoco Inc., Marathon Oil, Japan National Oil Corporation, the Japanese JOIA project, NKK Corporation, Amoco Corporation, and the Canadian Program on Energy Research and Development. The Catalogue contains over 300 Events of ice loading on offshore and coastal structures. The catalogue contains information on the time-based behaviour of the load as well as details of the ice conditions during each loading event. There is a complete range of structures that are included in the Catalogue including bridge piers, light piers, wharves, dams, offshore structures and natural islands. There are a large number of load events from the Beaufort Sea structures. A copy of the three volume set of the NRC Ice Load Catalogue (Timco et al., 1999b) is available at CISTI (see Section 7.2.1). The analysis of the ice load events from this research has furthered the understanding of ice loads on wide caisson structures (Timco and Johnston, 2003, 2004; Johnston and Timco, 2003).

7.2.7 Dynamac

Data from the large ice loading events on the offshore structure Molikpaq were put onto a CD ROM by Klohn-Crippen, under contract from the Canadian Government (Klohn-Crippen 1998). This CD-ROM, titled DynaMAC, is distributed through the NRC Centre of Ice-Structure Interaction (see Section 4.10). It also contains information on the structure and several photographs.

7.2.8 NRC Catalogue of Local Ice Pressures

A Joint Industry Project has been carried out to develop a "Catalogue of Local Ice Pressures" (Frederking and Collins, 2005). The focus of the project was to determine average local ice pressures on various sizes and shapes of design areas, and to present the data in a form to facilitate probabilistic estimation of local ice pressures. The data are organized in a database to assist extraction of local ice pressures as a function of operational factors and ice conditions. The database includes four digital data sets on ship trials (1994 CCGS Louis S. St. Laurent, 1991 and 1996 Oden, and 2001 CCGS Terry Fox), two offshore structures (1985-86 Molikpaq caisson and 1990 JZ-20-2-1 jacket structure) and one field test (1995 Grappling Island). The information resides in the NRC Centre of Ice-Structure Interaction (Section 4.10).

7.2.9 The Beaufort Sea Ice Scour Database

The Geological Survey of Canada (GSC) at the Bedford Institute of Oceanography (BIO) in Dartmouth, NS has been actively involved in surveying the Beaufort Sea seabed for many years. They have collected detailed scour statistics for many regions of the

Beaufort Sea and have re-sampled several regions to investigate the rate of scouring in this region. Canadian Seabed Research works with the GSC at BIO and has produced a database of these scours. The database is available for purchase through them at http://www.csr-marine.com/

7.2.10 National Energy Board (NEB)

The National Energy Board (NEB) located in Calgary, AB has an extensive library related to the exploration phase of the Beaufort Sea. The NEB is an independent federal agency established in 1959 by the Parliament of Canada to regulate international and interprovincial aspects of the oil, gas and electric utility industries. The purpose of the NEB is to promote safety, environmental protection and economic efficiency in the Canadian public interest within the mandate set by Parliament in the regulation of pipelines, energy development and trade. These principles guide NEB staff to carry out and interpret the organization's regulatory responsibilities. The NEB is accountable to Parliament through the Minister of Natural Resources Canada. The NEB is the federal regulatory agency for the Beaufort Sea. During the 1980s, the regulatory process for the north was done through the Canada Oil and Gas Lands Administration (COGLA) which was based in Ottawa. This organization was integrated into the NEB and transferred to Calgary. Over the years, the NEB has collected a considerable amount of information from the Beaufort region. Although some of their more recent reports are on-line, many of the older Beaufort reports have been archived. Further information can be found at http://www.neb.gc.ca/

7.2.11 Indian and Northern Affairs Canada (INAC)

Indian and Northern Affairs Canada (INAC) is a federal department responsible for two mandates: Indian and Inuit Affairs, and Northern Development. These mandates are intended to support Canada’s Aboriginal and northern peoples in the pursuit of healthy and sustainable communities and broader economic and social development objectives. INAC has supported research in northern regions, mainly with regard to the Mackenzie Valley Pipeline and onshore and offshore drilling in the Mackenzie delta region. INAC has led the Northern Oil and Gas Science Research Initiative in cooperation with Environment Canada, Fisheries and Oceans Canada, and Natural Resources Canada, from 2002 to 2009. This initiative has supported research in northern regions to address information gaps for the environmental assessment and regulatory processes for the Mackenzie Gas Project and associated oil and gas activity related to onshore and offshore drilling. Further information regarding INAC’s role in the north can be found at http://www.ainc-inac.gc.ca/ .

7.2.12 Transport Canada (TC)

Transport Canada (TC) has had a very active interest in the Arctic for many years. They are responsible for the Arctic Waters Pollution Prevention Act (see http://www.tc.gc.ca/acts-regulations/GENERAL/A/awppa/menu.htm). This includes the Arctic Shipping Pollution Prevention regulations (ASPPR). These regulations are currently being revised (Timco and Kubat 2007). Transport Canada has been active in promoting the harmonization of the ice-strengthened vessels. This has now been accomplished through the International Association of Classification Societies (IACS) through the Unified Requirements of polar class vessels (http://www.iacs.org.uk/document/public/Publications/Unified_requirements/PDF/UR_I_pdf410.pdf). They have also supported the development of the International Maritime Organization (IMO) Guidelines for Ships Operating in Arctic Ice-Covered Waters http://www.tc.gc.ca/marinesafety/CES/Arctic/contacts.htm . More recently, they have been actively involved in the Arctic Marine Shipping Assessment.

7.2.13 Regulatory Roadmap

The Regulatory Roadmaps Project is a jointly sponsored initiative of Government Regulatory Agencies and the Canadian Association of Petroleum Producers. The Project prepares comprehensive Guides to regulatory approval processes for oil and natural gas exploration and production in selected jurisdictions. Useful information can be found at: http://www.oilandgasguides.com/

7.2.14 Beaufort Sea Strategic Regional Plan of Action (BSStRPA)

The Beaufort Sea Strategic Regional Plan of Action (BSStRPA) was recently initiated. It originated following correspondence between the Inuvialuit Game Council and the Minister of Environment, in June 2004 relating to their concerns regarding the environmental assessment of offshore oil and gas development in the Beaufort Sea. Based on discussions and a workshop held in Inuvik in 2005, the Beaufort Sea Strategic Regional Plan of Action was initiated. BSStRPA takes a community-based approach to the identification of regional needs with respect to planning for future offshore oil and gas development (including the coastal transition zone), and the actions needed to address them. The BSStRPA Steering Committee involves Inuvialuit Settlement Region organizations, federal and territorial governments, and industry. The Inuvialuit Game Council and the Inuvialuit Regional Corporation represent the Inuvialuit Settlement Region; the Government of Canada includes Indian and Northern Affairs Canada, Fisheries and Oceans Canada, Environment Canada, Canadian Environmental Assessment Agency, Natural Resources Canada, and the National Energy Board. Further information can be found on their website http://www.bsstrpa.ca/ .

7.2.15 US Cold Regions Research and Engineering Laboratory (CRREL)

The US Army Cold Regions Research and Engineering Laboratory (CRREL) was very active in the Beaufort Sea in the 1970s to 1990s, as well as many other cold regions areas of the world. The laboratory is located in Hanover, New Hampshire, USA. The lab has a long and proud tradition of research excellence. They have an extensive library collection that focuses on cold regions papers and reports. Further information can be found at: http://www.crrel.usace.army.mil/

7.2.16 USA Minerals Management Service (MMS)

The Minerals Management Service (MMS) is a resource management agency for United States public lands. The MMS is national in scope and headquartered in Washington, D.C. It includes two major programs - Offshore Energy and Minerals Management, and Minerals Revenue Management. The Offshore program, which manages the mineral resources on the Outer Continental Shelf, comprises three regions: Alaska, Gulf of Mexico, and the Pacific. It funds research and is a valuable source of information about public lands of the USA. Information on the MMS can be found at http://www.mms.gov/. The MMS has an extensive on-line library of research that it has sponsored. This can be located at http://www.mms.gov/library/ .

7.3 Research and Support Organizations

There are a number of research and support organizations that were active during the Beaufort exploration phase in the 1970s and 1980s and they remain active today. A number of the key ones are briefly described below:

7.3.1 Department of Fisheries and Oceans (DFO)

The Department of Fisheries and Oceans (DFO) was very active in Arctic research and they still maintain this strong interest today. They have conducted a significant amount of research related to the wildlife in this region. Sea ice research is carried out at a number of locations including the Institute of Ocean Science (IOS) in Sidney B.C. and at the Bedford Institute of Oceanography (BIO) in Dartmouth, N.S. At BIO, Simon Prinsenberg has developed innovative technology to measure the thickness of sea ice from air-borne sensors. Humfrey Melling of IOS has continuously measured the ice thickness in the Beaufort Sea region for many years. His research has provided an invaluable data set of the ice conditions in this region. DFO also maintains a very extensive on-line library. The library has collections in the areas of oceanography, hydrography, ocean research, environmental science, as well as geology, geophysics, seismology and earthquake studies. Some useful links are:

DFO National	http://www.dfo-mpo.gc.ca/
IOS	http://www.pac.dfo-mpo.gc.ca/sci/sci/facilities/ios_e.htm
BIO	http://www.bio.gc.ca/
BIO sea ice studies	http://www.mar.dfo-mpo.gc.ca/science/ocean/seaice/intro_e.html

7.3.2 Centre for Offshore Oil and Gas Environmental Research (COOGER)

Fisheries and Oceans Canada has established the Centre for Offshore Oil and Gas Environmental Research (COOGER) to coordinate the department's nation-wide research into the environmental and oceanographic impacts of offshore petroleum exploration, production and transportation. Further information can be obtained from the DFO website.

7.3.3 Natural Resources Canada (NRCan)

Natural Resources Canada has been active in research in the Beaufort Sea, largely through the Geological Survey of Canada office located at the Bedford Institute of Oceanography. Steve Blasco at BIO has maintained and updated a catalogue of the scours in the Beaufort Sea. This is a very unique dataset that has important implications for pipeline engineering in this region (see Section 7.2.9). They have also studied subsea permafrost in the Beaufort Sea and the changes in the coastline. NRCan also includes the Office of Energy Research and Development which oversees the PERD program (see Section 4.5). Further information can be found from their website http://www.nrcan-rncan.gc.ca/com/ .

7.3.4 Canadian Ice Service (CIS)

The Canadian Ice Service (CIS), a branch of Environment Canada, is the leading authority for information about ice in Canada's navigable waters. They have collected ice information for many years and have records of ice conditions in the Beaufort Sea. Information has been collected through aircraft over flights, ground observations, and satellite imagery. They maintain a detailed catalogue of ice conditions on their website: http://ice-glaces.ec.gc.ca/ . They are the best source of information on overall ice conditions in the Arctic regions.

7.3.5 Canadian Coast Guard (CCG)

The Canadian Coast Guard (CCG) operates vessels in the Arctic during the summer months. The CCG's Icebreaking program, in partnership with Environment Canada's Canadian Ice Service (see Section 7.3.4), helps maritime traffic move safely and quickly through, or around, ice-covered Canadian waters. They have a wealth of knowledge regarding shipping operations in the Arctic. Further information on their icebreaking fleet and their operations can be found at http://www.ccg-gcc.gc.ca/ .

7.3.6 NRC Canadian Hydraulics Centre (NRC-CHC)

The NRC Canadian Hydraulics Centre (NRC-CHC) has been very active in ice engineering issues since the 1970s. Today, they are the largest group of people in Canada working on Arctic ice engineering issues. They are a Technology Centre of the National

Research Council of Canada based in Ottawa. Their ice activities include development of codes for structures in ice-covered waters, expertise in global and local ice loads, ice forecasting, emergency evacuation from structures in ice-covered waters, ice properties, ice rubble generators, field measurements of the properties of multi-year ice, and seabed scour by ice ridges. They have an ice tank for physical model tests, cold rooms, and they have sophisticated numerical models for studying ice-structure interaction scenarios. They are also working with Transport Canada to revise the Arctic Shipping Pollution Prevention Regulations. Further information can be found at: http://chc.nrc-cnrc.gc.ca/

7.3.7 NRC Institute for Ocean Technology (NRC-IOT)

The NRC Institute for Ocean Technology (NRC-IOT) is located in St. John's NL. It opened in 1985 as the Institute for Marine Dynamics and recently changed its name to more accurately reflect the range of its activities. It has a world-class ice tank, wave tank and open water basin. Over the years, they have conducted numerous physical model tests of icebreakers in ice-covered waters. Their library is linked to the CISTI library, and it contains a large number of papers and reports related to ice activities. It also houses a database related to evacuation from offshore structures. Further information on IOT can be found at: http://iot-ito.nrc-cnrc.gc.ca/ .

7.3.8 Aurora Research Institute

In 1984, the Science Institute of the Northwest Territories was created by the NWT Legislative Assembly. The following year, the Science Institute of the Northwest Territories divided and was merged with Arctic College in Nunavut and Aurora College in the Northwest Territories. Licensing under the Scientists Act in the Northwest Territories is handled by the Aurora Research Institute in Inuvik. Licensing in Nunavut is handled through the Nunavut Research Institute in Iqaluit. The Aurora Research Institute is responsible for licensing and coordinating research in accordance with the NWT Scientists Act. They also promote communication between researchers and the people of the land, in which they work. They hold open forums to increase public awareness of the importance of science, technology and indigenous knowledge. Further information can be found at http://www.nwtresearch.com/ .

7.3.9 C-CORE

C-CORE was formed in 1975 through the financial support of the Devonian Foundation. It is located on the campus of Memorial University in St. John's, NL, Canada.
Since its inception, C-CORE has focused its research in two areas related to the ocean environment – ice, and remote sensing. Because of this, they have collected a large library of reports and conference proceedings related to ice issues. Although their business has expanded beyond ice and remote sensing, they still maintain a very active participation in these disciplines. Further information can be found at http://www.c-core.ca/ .

7.3.10 C-FER

C-FER, originally the Centre for Frontier Engineering Research Institute, was established November 7, 1983 with a mandate to address problems related to material, fabrication, design, regulations, transportation and construction of structures required for arctic and offshore development in Canada. In 1997, it incorporated as a private, not-for-profit company and formed a wholly owned subsidiary, C-FER Technologies (1999) Inc. Today, C-FER Technologies operates as a not-for-profit, wholly-owned subsidiary of the Alberta Research Council (ARC) with income earned entirely by performing fee-for-service work, mostly for private industry. Further information can be found at http://www.cfertech.com/ .

7.3.11 Sandwell

Sandwell is a private company that was very active in many of the direct engineering applications of the Beaufort Sea. These activities included the detailed design of the Molikpaq structure, designing and building ice roads and grounded ice pads, and many research projects. Most of the Arctic work came from the Calgary office. Further information on Sandwell can be found at: http://www.sandwell.com/en/index.shtml .

7.3.12 Canatec

Canatec is a Canadian consulting company that was formed largely by ice experts that left the oil industry during the downturn in interest in the Beaufort Sea in 1990. Although they have undergone a number of personnel changes over the years, they remain very active in providing environmental information on ice in many regions of the world. They also have an extensive library of reports related to the exploration phase of the Beaufort Sea. They also maintain a number of reports related to shipping in ice-covered waters. Further information can be obtained from their website http://www.canatec.ca/ .

7.3.13 BMT Fleet Technology

BMT Fleet Technology is another company that has a long history of research and knowledge regarding ice engineering and marine transportation. They have an extensive library related to these issues. Further information can be found from: http://www.fleetech.com/ .

7.3.14 Private Consultants

There are a small handful of private consultants who have been very active in ice related activities for many years. These consultants include Ken Croasdale (K.R. Croasdale and Associates), Brian Wright (B. Wright and Associates), Ian Jordaan (I. Jordaan and Assoc.) and Dave Dickins (D.F. Dickins and Associates). Also, Bob Gorman of Enfotec (http://www.enfotec.com/) has unique data and reports related to shipping in the Arctic.

7.4 Scientific Journals

There are a number of journals that have preserved important information related to the scientific and engineering research in Beaufort region of the Arctic. The major journals are listed below:

Cold Regions Science and Technology – http://ees.elsevier.com/crst/
Journal of Glaciology - http://www.igsoc.org/journal/
Annals of Glaciology - http://www.igsoc.org/annals/
Journal of Geophysical Research - http://www.agu.org/journals/jc/
ASCE Cold Regions Engineering - http://scitation.aip.org/cro/
Canadian Journal of Civil Engineering – http://pubs.nrc-cnrc.gc.ca/
Arctic Journal - www.arctic.ucalgary.ca

7.5 Conferences

There have been a number of conferences that focus on Arctic issues. These conferences usually have a very loyal following and they provide a good venue for the exchange of research results and ideas. The proceedings from the conferences often contain very useful information. However, it is often difficult to obtain them since only a limited number were published and distributed. Some of the more important conferences are briefly described below.

7.5.1 Port and Ocean Engineering under Arctic Conditions (POAC)

The POAC conference addresses the issues related to coastal and offshore engineering in ice-covered waters. POAC began in 1971 in Trondheim, Norway, and since then, it has been held on a regular basis every two years at different international venues. Over the years, this conference has been the mainstay of Arctic engineering conferences and typically attracts over 150 participants. The conference has been held in Norway, Canada, USA, Finland, Sweden, Japan, Russia, China, Germany, Greenland and Iceland. POAC maintains an active website at www.poac.com . Information on past and upcoming conferences can be found on this site. A full Table of Contents of all POAC papers and several years of POAC papers are now available on this website.

7.5.2 IAHR Symposium on Ice

The International Association for Hydraulics Research (IAHR) Symposium on Ice is the “sister” conference to POAC. It began about the same time as POAC and over the years, it has developed a loyal following. Both the IAHR and POAC cover topics such as ice mechanics and ice properties, but the IAHR also focuses on river ice problems. It also has been held in several countries world wide. This conference tends to be more science focused than POAC (which is more engineering based). This conference is also held every two years on alternate years from the POAC conference.

7.5.3 Offshore Mechanics and Arctic Engineering (OMAE)

The Offshore Mechanics and Arctic Engineering (OMAE) conference is sponsored by the American Society of Mechanical Engineers (ASME). It is held annually in different venues. It is a much larger conference than POAC or the IAHR, and covers many other topics in addition to ice. Typically 500 people attend. The number of ice-related papers varies depending upon the location of the conference. The proceedings from the 1980s were full of very good papers on ice issues, but lately, there have been very few ice papers at the conference. Further information can be found at http://www.ooae.org/

7.5.4 International Society of Offshore and Polar Engineers (ISOPE)

The International Society of Offshore and Polar Engineers (ISOPE) conference is also a very large conference that is held annually in different countries around the world. It attracts about 500 papers, and typically about 25 of these relate to ice issues. The conference began in 1989 and it has a loyal following. Further information can be found at http://www.isope.org/ .

7.5.5 ICETECH

The ICETECH conference has been held sporadically over the past many years. It is sponsored by the Society of Naval Architects and Marine Engineers (SNAME) as well as local sponsors. Historically it focused on shipping in ice-covered waters, but the more recent conferences have greatly expanded their scope. Further information can be found at http://www.sname-arctic.org/

7.5.6 Miscellaneous

There have been a large number of miscellaneous conferences and workshops held over the years. There was a flurry of such conferences in the 1980s but the pace then slowed. Lately, there has been a renewed interest and conferences on the Arctic are abundant. However, obtaining their proceedings after-the-fact is often difficult.

8.0 FINAL COMMENTS

This report has presented a very brief overview of the activities that took place in the Canadian Beaufort Sea during the 1970s through to the 1990s. Information was provided on the environment in this region, the types of drilling platforms used for exploratory and delineation drilling, the support agencies that funded research, the large-scale field measurement programs, as well as other relevant Arctic field programs. Information was also given on the numerous resources including libraries, databases and organizations that have expertise to provide more complete information. It is hoped that this report will be a useful guide to understanding the history of the Beaufort Sea development.

Comments, feedback or omissions are welcomed and should be addressed to the first author at garry.timco@nrc.gc.ca

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