Paper #6-2

HISTORICAL BACKGROUND ON ARCTIC EXPLORATION AND PRODUCTION TECHNOLOGY DEVELOPMENT

Prepared for the

Technology & Operations Subgroup

On March 27, 2015, the National Petroleum Council (NPC) in approving its report, *Arctic Potential: Realizing the Promise of U.S. Arctic Oil and Gas Resources*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Technology & Operations Subgroup. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached paper is one of 46 such working documents used in the study analyses. Appendix D of the final NPC report provides a complete list of the 46 Topic Papers. The full papers can be viewed and downloaded from the report section of the NPC website (www.npc.org).

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Topic Paper (Prepared for the National Petroleum Council Study on Research to Facilitate Prudent Arctic Development)		
6-2	**Historical Background on Arctic Exploration and Production Technology Development**	
Author(s)	**Peter Noble (Noble & Associates, LLC)** **Bill Maddock (BP)**	
Reviewers	**Doug Hoyt (ExxonMobil)** **Jed Hamilton (ExxonMobil)** **Randall Shafer (ConocoPhillips)** **Mitch Winkler (Shell)** **Geir Utskot (Schlumberger)**	
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SUMMARY

This paper describes the historical development of Arctic explorations and production technology. The historical period summarized in this paper is based on the years from the early1960s to the end of the twentieth century. In terms of the arctic offshore, it was a period of investment and innovation with respect to the arctic sciences, arctic design and construction and other field activities. These can be briefly summarized as follows:

- Major investment in the ice sciences through a large number of industry and government sponsored projects;
- Large scale ice imagery using Synthetic Aperture Radar (SAR) from fixed wing aircraft - prior to the widespread commercial access to satellite instruments;
- The use of ice as an engineering material for floating roads, airstrips, drilling pads and other structures;
- Knowledge of ice loads on bottom founded and floating structures through full scale field measurements. The observations and data acquisition from the Molikpaq and the Kulluk, in particular, remain the foundation for today's engineering parameters for offshore arctic operations;
- Ice management to protect station-keeping vessels and operations in ice during different seasons and ice conditions;
- Innovation in icebreaker design and construction. All of the vessels constructed for the Beaufort Sea are working today and have provided direction for today's ongoing technology developments for ice class vessels;
- The design and construction of bottom founded structures for year round deployment in a range of ice conditions from polar ice, seasonal first year ice and regions with iceberg incursions.

HISTORICAL BACKGROUND

Offshore arctic oil & gas exploration began in Alaska and the Canadian Beaufort Sea almost fifty years ago beginning with the construction of artificial gravel islands in shallow Alaskan State waters during the late 1960s. Similar activity took place in the shallow waters of the MacKenzie river delta in the Canadian Beaufort Sea in the early 1970s. Both the US and Canadian arctic regions are considered for this paper due to the geographical proximity and the close similarity in the arctic environments and the commonality of the operating companies.

In addition to the early exploration activities, the acquisition of environmental data, including ice data, was almost entirely supported by the oil & gas industry. This has been only recently supplemented by new research through other organizations.

This early exploration activity is also responsible for significant advances in icebreaker design and ice management and other operations in ice. It should be noted that all of the icebreaking supply vessels design and constructed for the Beaufort Sea in the 1980s are still in active service.

The historical development of exploration and production technologies is summarized under the following headings:

- Exploration Data Acquisition
- Exploration Drilling
- Production Facilities
- Pipelines
- Offloading and Tankering
- Logistics

EXPLORATION DATA ACQUISITION

Environmental data collected by industry was typically conducted under two umbrella organizations:

Alaska: Alaska Oil and Gas Association (AOGA)
Canada: Arctic Petroleum Operators Association (APOA)

Environmental data collected by government agencies includes:

Alaska: National Ice Center (NIC)
National Oceanic and Atmospheric Administration (NOAA)

Canada: Environment Canada - Canadian Ice Service (CIS)
Oceanography and Scientific Data (OSD), Fisheries and Oceans Canada

Over 400 AOGA reports on ice and other environmental have been collected summarizing the data collected primarily in the 1970s and 1980s. However, these reports have not archived in a central location and effort is required to locate individual documents.

APOA reports, collected over a similar time period to those in Alaska, are now archived in the Glenbow collections in Calgary, Alberta.

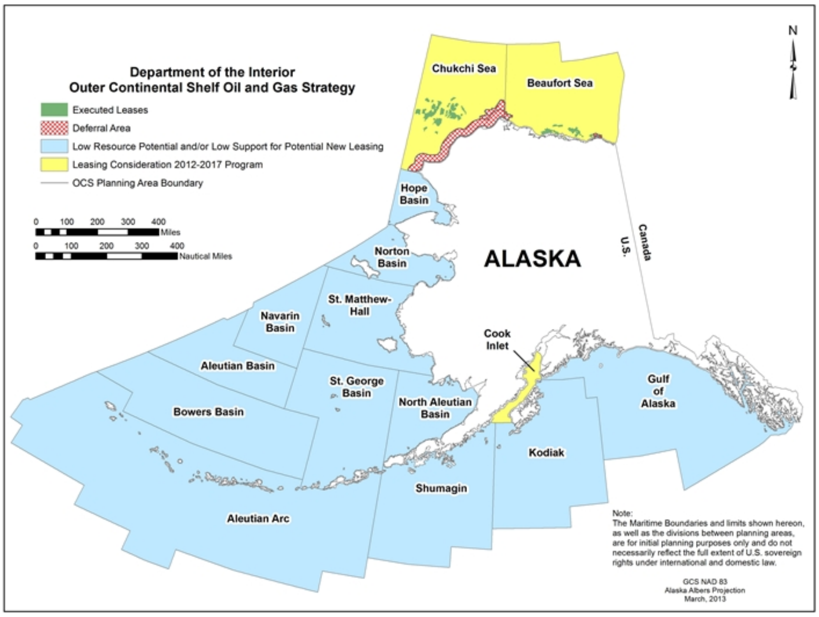
The National Ice Center is a multi-agency operational center operated by the US Navy, NOAA and the US Coast Guard. Their mission is to provide the highest quality, timely, accurate, and relevant snow and ice products and services to meet the strategic, operations, and tactical requirements of the United States interests across the global area of responsibility. Metocean and other types of environmental data are also available through other NOAA organizations.

In Canada, Oceanography and Scientific Data operating within the Department of Fisheries and Oceans is responsible for archived ocean data.

EXPLORATION DRILLING

Exploration activity in Alaska began in the late 1960s with the construction of artificial gravel islands in the shallow state water zones of the Beaufort Sea. Similar activity also took place in the MacKenzie delta region of the Canadian Beaufort Sea in the early 1970s.

Exploration activity in the more offshore areas of the Alaskan Outer Continental Shelf regions began in the 1980s and continues to the present. The diagram below describes the Alaskan OCS areas together with the number of exploration wells that have been drilled.



Area	Wells Drilled
Beaufort Sea	30
Chukchi Sea	5
Norton Sound	6
Navarin Basin	8
St. George Basin	10
Cook Inlet	13
Gulf of Alaska	12
Total	84

Figure 1: Alaska OCS - Wells Drilled

The technologies used for drilling exploration wells have moved from shallow water to increasing water depths using both fixed and floating structures as described in Figure 2 below.

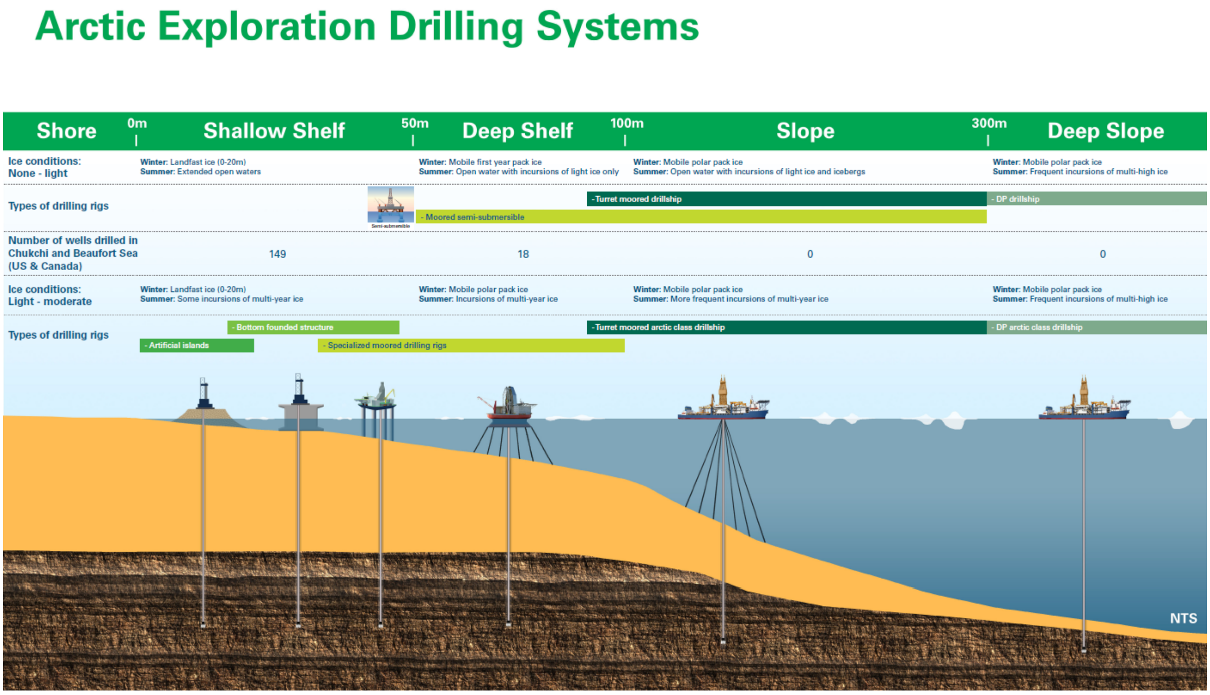


Figure 2: Drilling Technology - Chukchi and Beaufort Sea (Courtesy: British Petroleum)

BOTTOM FOUNDED STRUCTURES

Gravel island construction was used extensively in the 1980s for exploration in the Beaufort Sea to provide the foundations for a drilling rig and supporting facilities, with seventeen wells drilled out to water depths of close to 50ft using this technique. In Alaska, gravel islands were typically constructed by hauling gravel over ice roads to the island site during late winter months from onshore gravel sources. In Canada, dredged sand was typically used using a dredge fleet that was mobilized for island construction in the summer months, and over wintered in the Beaufort Sea to permit early deployment the following season.

Ice as an engineering material was also used to construct temporary islands to support drilling operations as shown for the Mars Spray Ice Island offshore Alaska and the Tarsiut Relief Spray Ice Island offshore Canada on Figures 3 & 4

Figure 3a: Spraying MARS Island 1986 (Photos: BP – Amoco)

Figure 3b: MARS Island

Figure 4: Tarsiut Caisson Retained Island and Ice Relief Well Pad (Photo: G. Timco)

The need to move exploration drilling into deeper waters led to the development of different substructure forms using caisson retained islands and then bottom founded Gravity Base Structures (GBS). Five different types of caisson retained islands and GBS exploration platforms have been deployed in the Beaufort Sea:

- Tarsiut Caisson Retained Island (the first man made offshore structure in the Beaufort Sea)
- Molikpaq Mobile Arctic Caisson (steel GBS type Mobile Offshore Drilling Unit)
- Caisson Retained Island (steel caissons)
- Single Steel Drilling Caisson (steel GBS MODU with later addition of steel substructure)
- Concrete Island Drilling System (CIDS)

The Tarsiut concrete caisson retained island was the first man made structure deployed offshore in the Beaufort Sea. This type of artificial island construction provided an economic extension of island construction into deeper waters. But the same limitations of artificial island construction still apply to this type of construction:

sand/gravel volumes increase rapidly with increasing water depth and limited resistance to open water storm wave conditions and multiyear ice interaction.

The Molikpaq steel GBS MODU was first deployed in the Canadian Beaufort Sea and was subsequently redeployed offshore Sakhalin Island as an early production facility and it continues to be in operation today. The Molikpaq is the most important of these early exploration structures:

- The structure was designed to resist interactions with both first year and multiyear ice;
- The structure experienced several encounters with major multiyear ice features in 1986;
- A significant level of instrumentation was installed on the platform to measure ice loads.

The Molikpaq currently remains as the most significant source of measured full scale multiyear ice loads on a structure and the results from these events form the basis of the design ice load requirements contained in both API and ISO Arctic Standards.

The steel caissons for the Caisson Retained Island are similar caisson structures as the Tarsiut Island except that the caissons were connected together to improve their stability when subjected to ice loads. These caissons are currently laid up in Tuktoyaktuk.

The SSDC is also a large GBS type MODU which was constructed from the mid section of a VLCC tanker. The hull perimeter was strengthened to resist direct contact with ice loads. The water depth range and the seabed stability requirements of the SSDC were subsequently enhanced with the addition of a new steel substructure called the MAT. The combined structures are now referred to as the Steel Drilling Caisson (SDC). The structure currently remains in storage in the Canadian Beaufort Sea but it may be redeployed outside of the Beaufort Sea in 2014.

The CIDS exploration structure is a concrete/steel hybrid GBS platform that was constructed in Japan for exploration offshore Alaska. The CIDS drilled three prospects offshore Alaska before activity in the Beaufort Sea slowed and the CIDS structure was laid up in Alaska before it was redeployed as a production facility offshore Sakhalin Island as part of the Sakhalin l project. It remains in operation today as a production facility.

FLOATING STRUCTURES

Offshore drilling in the North American Arctic using floating drilling units began in 1976, when Canadian Marine Drilling Ltd., a subsidiary of Dome Petroleum brought a fleet of vessels into the Canadian Beaufort Sea by way of the Bering Straits and Point Barrow.

This fleet included three ice-reinforced spread-moored drillships and a support fleet of four supply boats, along with a number of work and supply barges and a tugboat.

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Figure 5: Canmar Explorer Sea trials off Galveston Bay

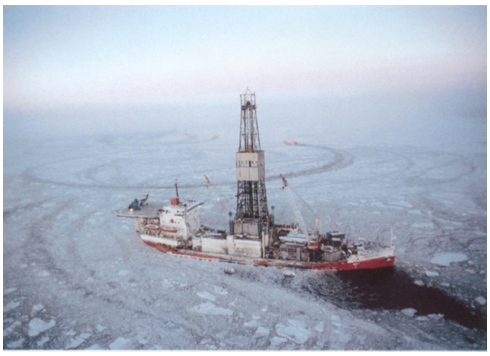

Figure 6: Canmar Drillship operating in the Beaufort Sea (Photo: R. Pilkington)

Figure 7: Canmar ice-worthy offshore supply vessels (Photo: BP – Dome Petroleum/Canmar)

These vessels were designed to be over-wintered in the Beaufort Sea which allowed an early start in the following season as the drilling areas often had open water conditions several weeks before the approaches to the Beaufort Sea around Point Barrow Alaska opened up.

Figure 8: Drillships over-wintering (Photo: BP – Dome Petroleum)

This equipment extended the ability to carry out exploratory drilling in water-depths beyond the range of artificial islands and bottom founded structures. However, spread moored drillships had their limitations for Beaufort Sea work as they were not able to resist significant interaction with ice while drilling.

This was not a significant impediment during the open water season but as freeze-up approached this limitation was addressed by using ice-worthy support craft in ice-management roles so that ice loads on the moored vessels could be maintained within acceptable limits.

A fourth drillship was added to the Canmar fleet and in 1979 a unique icebreaking offshore vessel the *Kigoriak* was added. The *Kigoriak* incorporated many novel features which were designed to enhance the offshore operations and ice management capabilities in support of arctic offshore drilling.

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Figure 9: *Kigoriak* ramming heavy ice

Figure 10: *Kigoriak* - special icebreaking features

A second major player in the development and use of floating drilling units in Arctic waters was Gulf Oil Canada. The company, through its subsidiary Beaudril, invested in a number of innovative purpose-designed and built units including four icebreaking ships and a conical, ice-worthy drilling unit, the *Kulluk.*

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Figure 11: Gulf Oil Canada- Beaudril icebreaking support vessels

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Figure 12: Beaudril drilling unit *Kulluk* in heavy ice (Photo: Gulf Canada Resources)

Figure 13: *Kulluk* showing icebreaking hull shape

The *Kulluk* was design to operate in early winter ice up to approximately 1.5m thickness and did so successfully in the early 1980s. However, with the down-turn in Arctic drilling that followed the depression of oil prices in the 1980s, the unit was laid up in the Arctic for many years with only brief operational periods, until she was acquired by Shell and reactivated to support the Beaufort Sea-Chukchi Sea exploration program in the late 2000s.

The unit met an unfortunate end when she was seriously damaged on a tow out of the Arctic and was subsequently scrapped in China in 2014.

PRODUCTION FACILITIES

The earliest structures installed for hydrocarbon production in Alaska are the platforms installed in Cook Inlet between 1964 and 1986 as described I Table 1. Although the seasonal ice conditions in Cook Inlet are relatively light, the high tidal currents and other environmental factors make this a challenging environment. The engineering design and construction of these platforms represent some of the earliest ice resistant platforms in the world.

Summary of Cook Inlet Platforms													
Platform Name	Type	Design Ice Thick, ft (m)	Wave		Wind Velocity, MPH (km/h)	Earth-quake (g)	Current, ft/s (m/s)	Leg Dia., ft (m)	Water Depth, ft (m)	Year	Designer	Jacket Wt, tons (tonnes)	Deck Wt, tons (tonnes)
			Height, ft (m)	Period (Sec)									
Anna	Quadpod	2.8 (0.9)	30 (9)	9	80 (129)	0.1	10 (3)	14 (4.3)	77 (23.5)	1966	Earl & Wright	1515 (1374)	1200 (1089)
A	Quadpod	6 (1.8)	41.5 (12.6)	10.8	65 (105)	0.15	10 (3)	14.6 (4.5)	83 (25)	1964	Earl & Wright	N/A	N/A
Baker	Quadpod	2.8 (0.9)	30 (9)	9	80 (129)	0.1	10 (3)	14 (4.3)	102 (31)	1965	Earl & Wright	2533 (2298)	N/A
Bruce	Quadpod	2.8 (0.9)	30 (9)	9	80 (129)	0.1	10 (3)	14 (4.3)	62 (19)	1966	Earl & Wright	1415 (1284)	1200 (1089)
C	Quadpod	3.5 (1.1)	28 (8.5)	8.5	65 (105)	0.06	12 (3.7)	15.5 (4.7)	73 (22)	1967	Earl & Wright	N/A	N/A
Granite Point	Quadpod	5 (1.5)	28 (8.5)	N/A	N/A	N/A	13.5 (4.1)	17 (5.2)	75 (23)	1966	Brown & Root	3400 (3084)	N/A
Grayling	Quadpod	6 (1.8)	28 (8.5)	8.5	100 (161)	0.1	10 (3)	17 (5.2)	125 (38)	1967	Brown & Root	3550 (3221)	N/A
King Salmon	Quadpod	3.5 (1.1)	28 (8.5)	8.5	65 (105)	0.06	12 (3.7)	15.5 (4.7)	73 (22)	1967	Earl & Wright	1585 (1438)	1200 (1089)
Monopod	Monopod	6 (1.8)	28 (8.5)	8.5	100 (161)	0.06	10 (3)	28.5 (8.7)	66 (20)	1966	Brown & Root	6000 (5443)	N/A
Spark	Tripod	3.5 (1.1)	28 (8.5)	8.5	60 (97)	N/A	10 (3)	13 (4.0)	62 (19)	1968	McDermott	N/A	N/A
Spurr	Tripod	3.5 (1.1)	28 (8.5)	8.5	60 (97)	N/A	10 (3)	13 (4.0)	67 (20)	1968	McDermott	N/A	N/A
Steelhead	Quadpod	4.2 (1.3)	28 (8.5)	8.5	80 (129)	N/A	12.6 (3.8)	18 (5.5)	183 (56)	1986	McDermott	N/A	N/A
Tyonek	Quadpod	2.8 (0.9)	27.5 (8.4)	8.5	80 (129)	0.1	10.1 (3.1)	14 (4.3)	100 (30)	1968	McDermott	N/A	N/A
Dillion	Quadpod	2.8 (0.9)	30 (9)	9	80 (129)	0.1	10 (3)	14 (4.3)	92 (28)	1967	Earl & Wright	1585 (1438)	1200 (1089)
Dolly Varden	Quadpod	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Osprey	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N/A Not Available													

Table 1: Cook Inlet Platforms

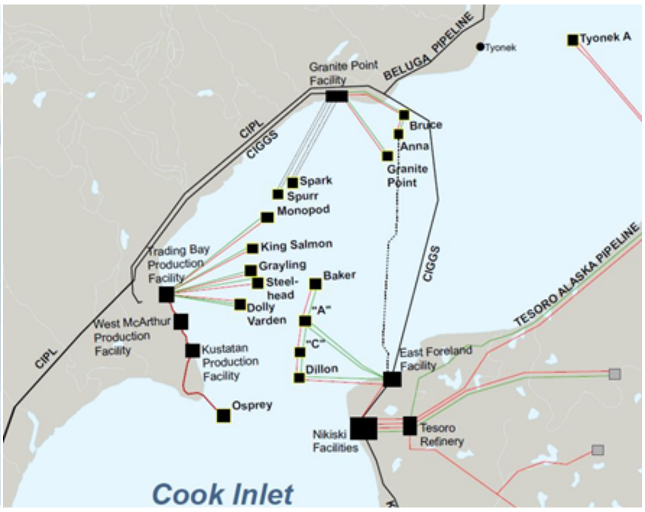

Figure 14a: Cook Inlet Platform (Photo: ExxonMobil) Figure 14b: Location of Cook Inlet Platforms (from http://dog.dnr.alaska.gov/AboutUs/Documents/PublicNotices/CI_Platforms_Infrastructure _DRR.pdf)

PIPELINES

Starting in 1968, Panarctic Oils Ltd drilled over 150 wells in the Canadian Arctic islands including 38 offshore wells in water depths ranging from 55 - 550m. Included in this was the Drake F-76 gas discovery 1200m offshore the Sabine peninsula on Melville Island in 55m water depth. In 1978 one of the earliest arctic pipelines was installed when two 6” (152mm) flowlines in a heat traced bundle were installed from the floating ice to the shoreline. Production tests were performed to determine hydrate formation, the performance of insulated and uninsulated lines and experimentation with alcohol injection rates. Thereafter, the well was placed on continuous low production rate for fuel for the test facility and camp. The well was plugged and abandoned in 1995.

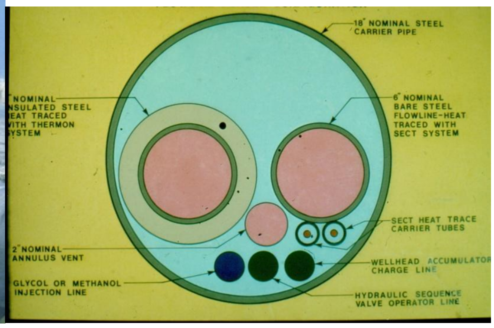

Figure 15a: Laying pipe through ice trench (Photo: D. Masterson)

Figure 15b: Pipe bundle (Courtesy: D. Masterson)

LOGISTICS AND RESUPPLY

The majority of arctic regions have significant access constraints for marine, air and land transportation. Deep water port facilities are limited and are typically at remote distances from operational areas. Similarly for airports capable of receiving large aircraft, these facilities are typically at remote distances from operations and there may be limited marine or road access for onward transport of heavy equipment.

Ports and airports serve as important bases for emergency response. They also act as a gateway to support SAR, pollution prevention and environmental safety as well as community health and security issues.

Figure 16 shows the survey results for both international Arctic airports and large/medium port facilities (http://www.arcticinfrastructure.org).

Figure 16a: International Arctic Airports (Courtesy: Institute of the North)

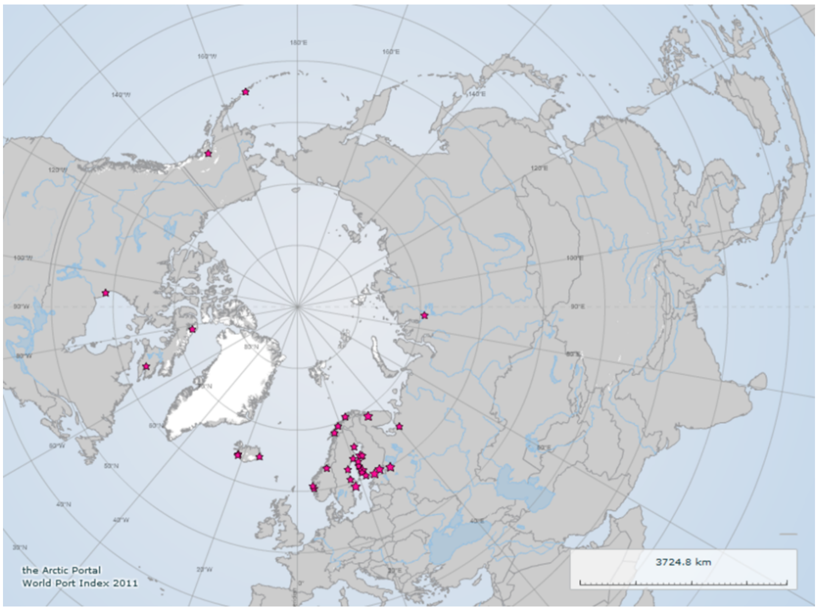

Figure 16b: Large / Medium Arctic Ports (Courtesy: Institute of the North)

Marine re-supply activities for E&P projects in Alaska and Canada have evolved over the past several decades and can be described as relatively mature. These activities are based on tug and barge operations and parallel the resupply chain used for northern communities. For Alaska, the southern depot is Seattle/Tacoma, while in Canada there are alternative routes, either by barge from Vancouver/Victoria, or by rail to Hay River on the southern shore of Great Slave Lake and thence by shallow draft barge down the MacKenzie River to the Beaufort Sea. There has been some use of Dutch Harbor as an intermediate staging point for Alaska resupply as it is the last deep-water port on the route north, but all supplies in Dutch have to be brought from elsewhere, so it has been of limited use.

Figure 17: Western Arctic Resupply Routes

Major sealift activities have taken place in years when significant capital equipment has been moved north, for example the Tarsiut concrete caissons to Canadian Beaufort Sea, while in other years large module loads have been carried to the North Slope of Alaska.

Figure 18a: Typical barge load for Alaska Sealift (Photo: Crowley Maritime)

Figure 18b: Tarsiut Caissons deploying from Vancouver to Beaufort Sea (Photo: B. Maddock)

While seaborne logistics have a long successful history of success, it should be noted that in some years ice has stayed close to the coast in the region of Point Barrow, AK and this has restricted access to the US and Canadian Beaufort Seas.

Technology Achievements

The historical period summarized in this paper is based on the years from the early1960s to the end of the twentieth century. In terms of the arctic offshore, it was a period of investment and innovation with respect to the arctic sciences, arctic design and construction and other field activities. These can be briefly summarized as follows:

- Major investment in the ice sciences through a large number of industry and government sponsored projects;
- Large scale ice imagery using Synthetic Aperture Radar (SAR) from fixed wing aircraft - prior to the widespread commercial access to satellite instruments;

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