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Last Ice Area Greenland and Canada

Geoscience Resource Development Report

Peter Adams, Consultant
Prepared for WWF – Canada
January, 2014

Melting sea ice near Axel Heiberg Island, Nunavut, July 2012. Source: Dr. Schroder-Adams, Carleton University.

Report
Last Ice Area Greenland and Canada – Geoscience Resource Development Report
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Last Ice Area

This is one of a series of research resources commissioned by WWF to help inform future management of the Area we call the Last Ice Area. We call it that because the title refers to the area of summer sea ice in the Arctic that is projected to last. As climate change eats away at the rest of the Arctic's summer sea ice, climate and ice modellers believe that the ice will remain above Canada's High Arctic Islands and above Northern Greenland for many more decades.

Much life has evolved together with the ice. Creatures from tiny single celled organisms to seals and walrus, polar bears and whales, depend to some extent on the presence of ice. This means the areas where sea ice remains may become very important for ice-adapted life in future. One of my colleagues suggested we should have called the project the Lasting Ice Area. I agree, although it's a bit late to change the name now, that name better conveys what we want to talk about. While much is changing, and is likely to change around the Arctic, this is the place that is likely to change the least. That is also meaningful for the people who live around the fringes of this area – while people in other parts of the Arctic may be forced to change and adapt as summer sea ice shrinks, the people around the LIA may not have to change as much.

As a conservation organization, WWF is not opposed to change. Our goal is to help maintain important parts of the natural world, parts that are intrinsically and extrinsically important to the wellbeing of humans and animals. WWF does not hold the power and authority to impose its vision on people. Instead, we try to present evidence through research and options for action. It is then up to the relevant authorities as to whether they will take action or not; the communities, the Inuit organizations and the governments of the Last Ice Area will decide its future fate. We hope you will find the information in these reports useful, and that it will help you in making wise decisions about the future of the Last Ice Area.

Clive Tesar, WWF Global Arctic Programme, Last Ice Area Project Lead.

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Introduction

The purpose of this report is to produce an accurate, unbiased geoscience report on the value and likelihood of geological resource development in the Last Ice Area (LIA). Current and future development of resources will have a significant impact on economic and environmental issues in the Arctic.

The WWF (World Wildlife Fund) Global Arctic Programme (GAP) works with world leaders, industry, academics and indigenous peoples around the world to develop innovative solutions to the current and future issues facing the Arctic. Development is increasing, and the circumpolar states of Canada, Denmark, Russia, US and Norway are assessing potential resources in their Arctic territories.

With climate change and global warming a reality, Arctic sea ice is receding, and the area of remaining ice is getting smaller. The remaining ice area, including Canada's Arctic Islands and Northern Greenland, is projected to retain its summer sea ice longer than any other area in the entire Arctic (WWF LIA Factsheet 2011). This is the core of the Last Ice Area, the area where critical Arctic summer sea ice is predicted to be most resilient (Figure 1).

The Last Ice Area (LIA) is a project that examines the future of the summer sea ice, and its importance, both locally and internationally. WWF started the project 2 years ago and has progressively involved partners, including Inuit representatives, governments, researchers, and funders. A NASA report concludes that the Arctic is losing its summer sea ice at a rate of approximately 12% every ten years (NASA 2013). Scientists are projecting that the last area in which summer sea ice will persist is in Canada's Arctic Islands and Northern Greenland. Sea ice models predict that by 2040 a fringe of sea ice will remain in this region when all other large areas of summer sea ice have disappeared. This is the core of an area that will be important ecologically because of the life that is associated with sea ice, and will also be culturally important to Inuit. The persistent summer sea ice habitat of the LIA will provide the High Arctic with an area that is expected to experience less change than other parts of the Arctic.

Studies predict that the Arctic contains 10% oil and 25% gas of the earth's known remaining petroleum reserves (PRB 08-07E 2008). There is an increased interest in areas of potential economic mineral occurrences such as gold, diamonds, copper zinc, platinum group, rare earth minerals, uranium, base metals, coal, and iron ore throughout the Arctic. Industry exploration and production activity is expected to intensify as the area becomes more accessible.

The goal of this report is to enhance the expertise and credibility of the WWF's geoscientific information by introducing a balanced, third party assessment of the current and future development of geological resources in the Arctic Islands and Northern Greenland. Reliable and accurate science is the foundation for discussions on sound environmental stewardship, resource evaluation and policy programs. This report provides an unbiased assessment of not only the value of the geological resources, but also an analysis of if and when potential reserves could become economically viable.

Any judgements of potential economic viability are solely those of the author based on an estimate of current costs of developing any given resource, and the current and likely future price of that resource based on global supply and demand. The determination of potential development of a resource does not attempt to project future political or other factors that might affect the likelihood of resource development.

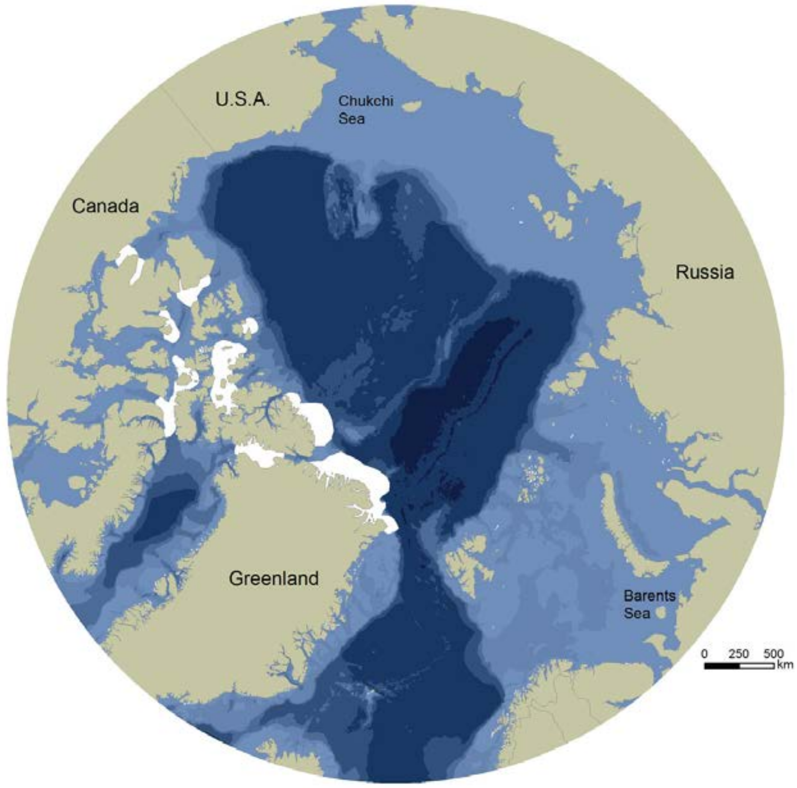


Figure 1 Last Ice Area Extent projected to 2040.
Map Produced by WWF - Canada, March 29 2010.
Projection: North Pole stereographic.

1. Arctic Islands LIA Hydrocarbon Potential

The most northerly of Canada's resource exploration regions, the Arctic Islands, comprises some of Canada's largest hydrocarbon basins. Although there have been numerous geological studies in the islands exploration activity has been spread out over a large area. The few wells drilled to date have discovered gas resources equal to 20% of the remaining reserves in western Canada, and two of the largest undeveloped gas fields in Canada are in the Arctic Islands. The Geological Survey of Canada estimates the potential of the Arctic Islands at 4.3 billion barrels of oil (686 x $10^6 m^3$) and 79.7 tcf of gas (2,257 x $10^9 m^3$) (Chen et al. 2000). For comparison the Prudhoe Bay Field in Alaska has 25 billion barrels of oil and the Ghawar Field in Saudi Arabia, the largest oil field in the world, has more than 75 billion barrels of oil. It should be noted resource estimates vary from study to study depending on factors used in the calculations.

The Mesozoic and late Paleozoic rock sequences in the Sverdrup Basin have the greatest petroleum potential (Figure 2). The deeper parts of the Mesozoic succession and a number of relatively untested late Paleozoic plays in the sedimentary basins of the Arctic Islands may prove to be future exploration targets. These are estimated to have at least as much potential as those already tested (Embry 2011).

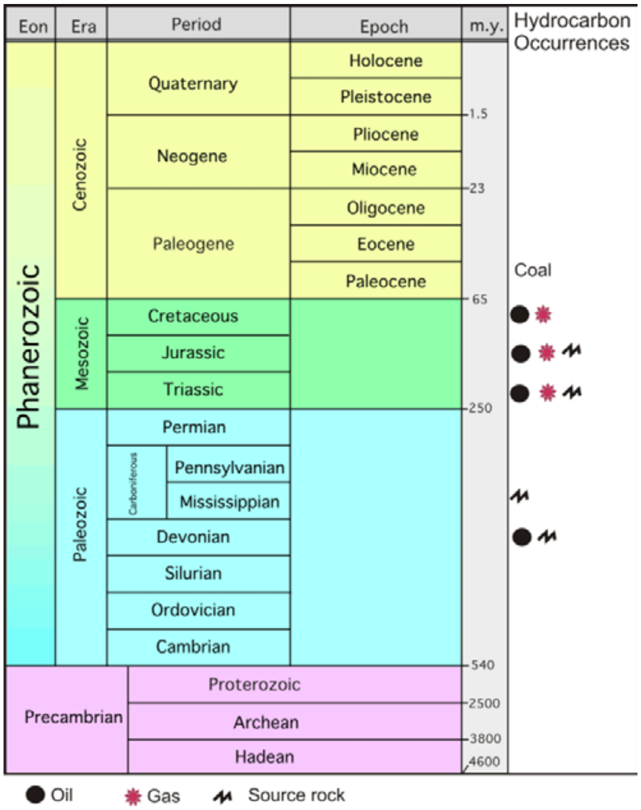


Figure 2. Geological time scale and hydrocarbon occurrences of the Canadian Arctic Islands. The Mesozoic Sverdrup Basin and the Paleozoic Bent Horn Field in the Franklinian Basin are the only known fields in the Arctic Islands.

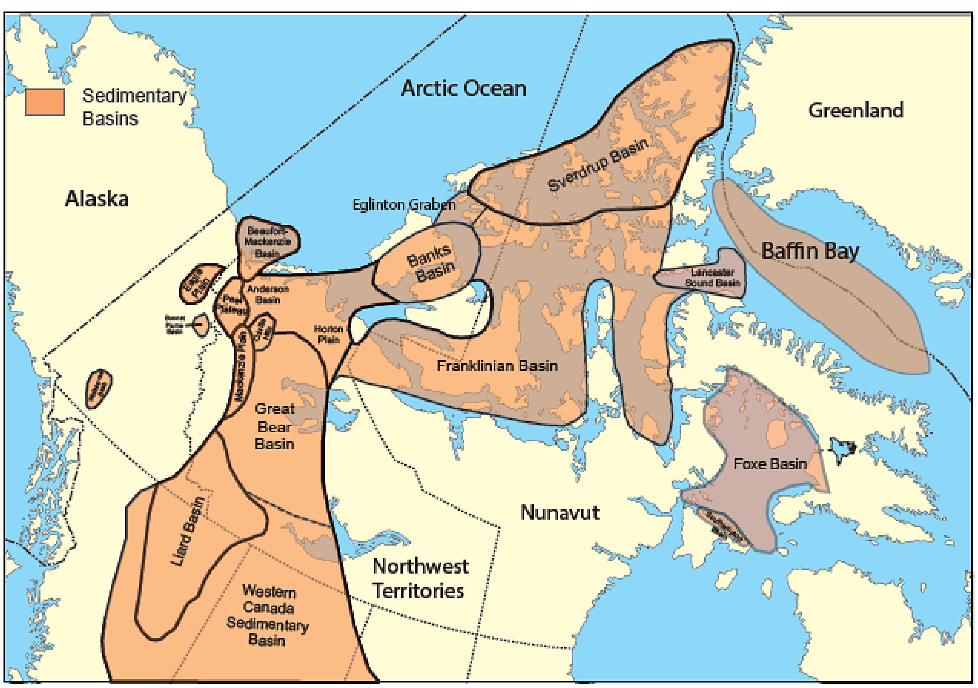


Figure 3. Sedimentary Basins of Northern Canada. Source: modified after Schroder-Adams 2014.

Most of the past exploration efforts (and discoveries) has been in the central Sverdrup Basin, however, the southern rim of the basin and the Arctic Fold Belt may be areas of future exploration (Figure 4). The structural complexity of the Arctic Fold Belt creates significant potential along this trend (Embry and Beauchamp 2008). More importantly, relative proximity to shipping lanes through the Northwest Passage make exploitation of discoveries along the southern rim of the Sverdrup Basin a more economically attractive proposition.

Throughout the Arctic Islands there are many untested plays, most of which would be under intense exploration if they were located in southern Canada (INAC 1995). Transportation, infrastructure and other costs, not petroleum potential, are clearly limiting the development of this remote region.

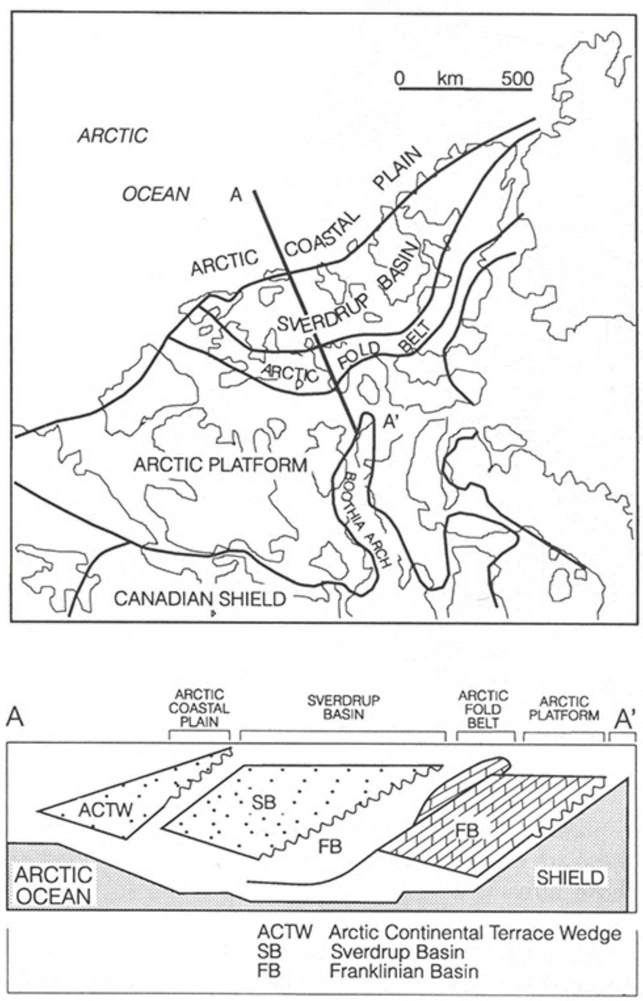


Figure 4. Structural elements of the geology of the Arctic Islands. Source: INAC 1995.

1.1 Sverdrup Basin

Introduction

The surface and subsurface geology and petroleum potential of the Sverdrup has been studied over the last 50 years. In the 1970s and early 1980s 120 wells were drilled and tens of thousands of seismic lines were shot in the basin. One oil field and fifteen gas fields were discovered in the Sverdrup Basin (Meneley 2008). Despite favorable geology and several major

finds, there was a decline of interest by the oil and gas industry in the mid-eighties. The region's remoteness and unfavorable economics continue to present numerous operational logistics and regulatory challenges that work against a possible revival of exploration in the basin.
It is estimated the discovered resource in the Sverdrup Basin to be 17 trillion cubic feet of gas and 2.5 billion barrels of oil (Chen et al. 2000).

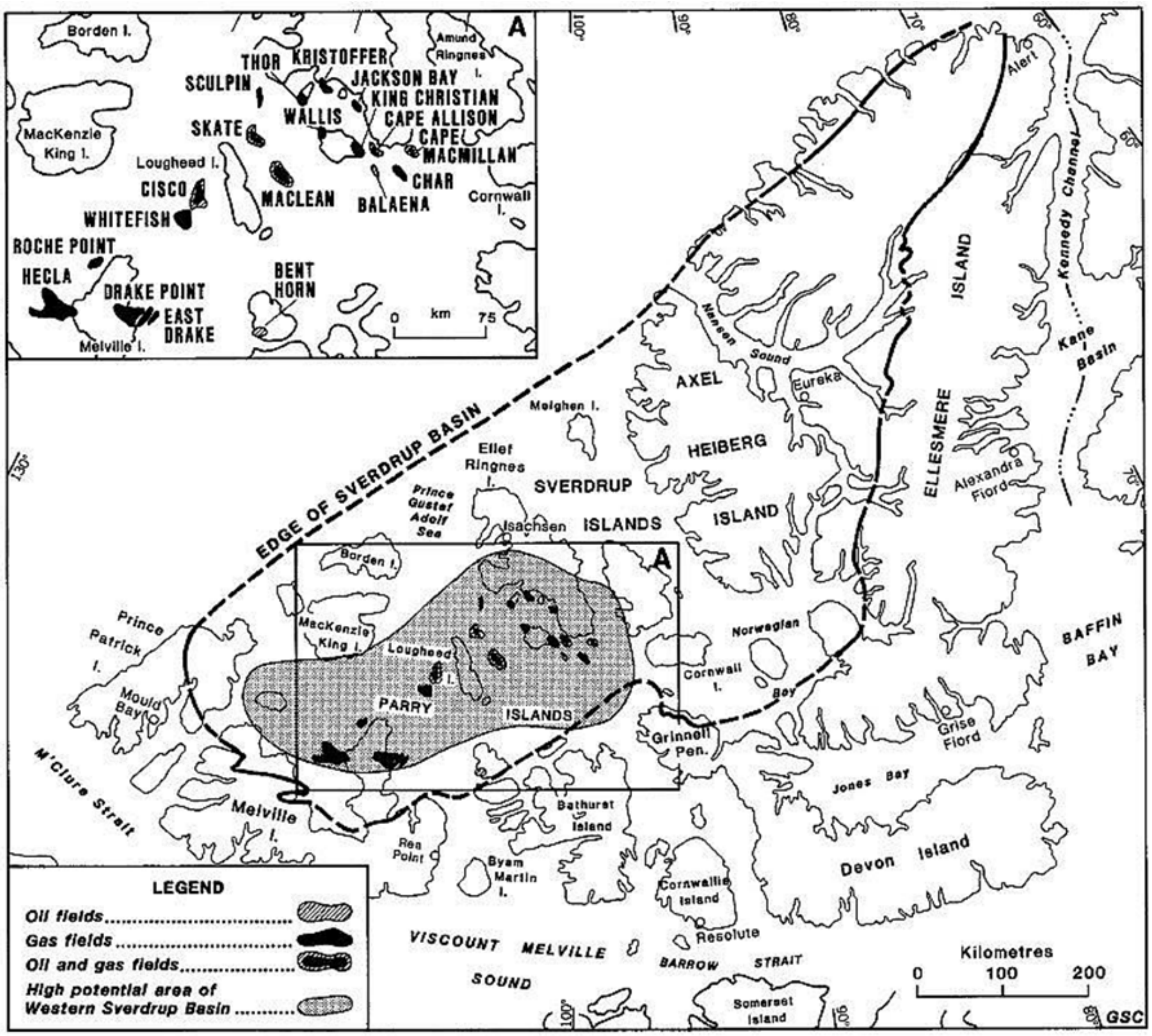


Figure.5 Map of Sverdrup Basin with locations of oil and gas fields. Source: Nassichuk 1987.

Basin Summary

Approximately 330 million years ago, the Sverdrup Basin developed as a regional depression that extends in a northeast-southwest direction for approximately 1,000 km and is up to 350 km wide. Successive rock formations were built up over 270 million years to as much as 14 km in thickness. The basin fill has up to 5 km of Carboniferous and mixed Permian sediments (carbonates, evaporites and siliciclastics) and up to 9 km of Mesozoic to Paleogene siliciclastics (Embry and Beauchamp 2008).

The considerable amount of surface and subsurface data enables an understanding of the regional depositional and tectonic history of the basin. The basin has a unique combination of tectonic, depositional and climatic factors. The rocks are generally younger to the northwest and are divided into three major units: 1.) Precambrian basement rocks; 2.) the Franklinian sedimentary succession; and 3.) the Sverdrup Basin sedimentary succession. The Paleozoic Franklinian sedimentary succession overlies the Precambrian basement rocks and consists of limestone, evaporites, and sandstones. Overlying the Franklinian sedimentary succession is the Sverdrup Basin sequence. The Early Carboniferous to Early Tertiary Sverdrup Basin contains the Eureka Sound Formation which consists of mainly sandstone and siltstone (Embry and Beauchamp 2008).

In the 1970s, the petroleum potential of Sverdrup Basin was rated as good due to the presence of structures, reservoirs and source rocks as well as several gas discoveries (Drummond 1973). Since that time, extensive structural, stratigraphic, sedimentological and geochemical studies have been carried out in the Sverdrup Basin and a clearer picture of the petroleum potential has emerged.

Hydrocarbon Production

After the formation of Panarctic Oils in 1968 exploration in the Sverdrup Basin was initiated. From 1969 to 1985 120 wells were drilled in the Sverdrup basin and fifteen gas fields and one oil field were discovered. Numerous oil and gas shows were encountered at several Carboniferous to Cretaceous stratigraphic levels (Chen et al, 2000). The current discovered resource in the Sverdrup Basin stands at 17 trillion cubic feet (500 x 10^9 m^3) of natural gas and 2.5 billion barrels (294 x 10^6 m^3) of oil. The ultimate potential resources (discovered plus undiscovered but predicted) calculated are in the order of 44 to 47 trillion cubic feet (1,242 to 1,343 x 10^9 m^3) of gas and 3.3 to 5.4 billion barrels (540 to 882 x 10^6 m^3) of oil, not including the potential of a number of significant unconventional resources such as oil sands and gas hydrates (Hogg and Enachescu 2013).

Drake Point Gas Field, Sabine Peninsula, Melville Island: In 1969 a well drilled at Drake Point, was the first major discovery in the Arctic Islands. The Drake Point Gas Field is the largest in the Arctic Islands, with at least 6 tcf of initial gas-in-place and 4.9 tcf of initial marketable gas. However there has been no production from the field. This large gas field has been delineated by 14 wells, including the 1969 discovery well and two relief wells drilled to control a blowout of the discovery well. There were two significant blowouts due to high gas pressure during the drilling program. A well drilled in 1970 on King Christian Island resulted in a blowout of spectacular proportions. King Christian D-18 blew wild for 91 days, and, after catching fire, was the source of an 80 metre column of flame. The well may have discharged as much as 200 million cubic feet of gas per day. The Drake Point gas field is ranked as the 150th largest gas fields in the world (Wikipedia Oil and Gas Fields).

Cisco Gas Field, west of Lougheed Island: The first well in the Cisco Field was drilled in 1981. The field contains 306 MMB of oil and 0.16 bcf of proved and probable gas reserves. The large proportion of oil to gas found in this structure holds promise for other oil accumulations in the large and major categories (INAC 1995).

Hecla Gas Field, Sabine Peninsula, Melville Island: The first well in the Hecla Gas Field was drilled in 1972. The gas field contains 4.2 tcf of gas and 3.5 tcf gas-in-place, respectively of proven and probable gas reserves. The Hecla gas field is ranked as the 131st largest gas field in the world (Wikipedia Oil and Gas Fields).

Reservoir Potential

All petroleum discoveries in the Sverdrup Basin are associated with Mesozoic sandstone in Tertiary structural reservoirs. Numerous Mesozoic sandstone units occupy the basin margins with a few extending across the entire basin. The porosity and permeability present in these rocks create excellent potential reservoir rocks. Porosity is also present in Upper Paleozoic siliciclastics and thick carbonate successions (INAC 1995).

The preponderance of natural gas in the Sverdrup Basin is considered to be a result of a major gas release during early Tertiary mountain building. These events resulted in extensive structural deformation of Triassic and possibly Upper Paleozoic source rocks. Fracturing due to Mesozoic magmatism and Tertiary deformation breached the most prospective reservoir strata in many structures and gas released from older source rocks flushed previously trapped oil updip and out of the basin (Chen et. al. 2000).

The main hydrocarbon source rocks are Middle to Late Triassic shales, which were formed on ancient, deep-water seafloor deposits. The bituminous shales are widespread across the basin and are the established source for most, if not all, discovered hydrocarbons. Highly bituminous Early Carboniferous shales with 40% Total Organic Carbon (TOC)are thought to be present in the central portion of the basin and in isolated low lying areas along the flanks of the basin. Triassic source strata are in the oil window in the western and southeastern portions of the basin but are overmature in the central area. Additional potential source rocks may be present in Upper Paleozoic strata. The Upper Paleozoic source strata are all overmature and may well have started generating hydrocarbons as early as the Triassic (Chen et. al. 2000).

Conventional Reservoir Potential

All current petroleum discoveries in the Sverdrup Basin are in Mesozoic sandstone sequences in Tertiary structural reservoirs (Chen et. al. 2000). Given the widespread and prolific Triassic source strata and the numerous and diverse potential traps, large conventional oil and gas resources may yet be undiscovered. Stratigraphic plays in Late Paleozoic carbonates and siliciclastics are also likely but with the overmaturity of the source strata, gas would be expected in most cases (Embry, 2011)

Unconventional Reservoir Potential

An oil sand deposit in Early Triassic sandstones was discovered on the basin margin on Sproule Peninsula, Melville Island in 1962 with in-place reserves estimated at up to 2.8 million barrels of oil. This may represent the only sign of a large volume of oil flushed from the basin in the early Tertiary (Trettin and Hills 1966).

Unconventional oil in the form of liquids associated with shale gas may well occur in the thick Middle-Late Triassic bituminous shales in the western Sverdrup. The Triassic shales also have potential for large shale gas reserves given their extent, thickness and organic carbon content. Early Carboniferous bituminous shales along the southern basin margin also have potential for liquids. Finally, very large resources of gas hydrates are also present in the Sverdrup Basin (Majorowicz and Osadetz 2001).

Conclusions

The Sverdrup Basin likely harbours large natural gas resources in both conventional (structural and stratigraphic traps) and unconventional (shale gas, gas hydrates) reservoirs. Much of the oil generated by the Triassic source rocks was flushed from the basin by an early Tertiary gas migration related to fracturing and uplift of overmature Triassic source rocks in the eastern and central portions of the basin. Large oil fields in the western Sverdrup Basin may be present in stratigraphic traps related to marginal unconformities, basin ward facies changes, and narrowing of reservoir rock on the flanks of salt domes.

Major hydrocarbon resources are undoubtedly present in structural and stratigraphic traps in Upper Paleozoic and Mesozoic reservoirs, in widespread and thick bituminous shales, and in large gas hydrate deposits. Conventional oil prospects are interpreted to be present in Mesozoic sandstones in stratigraphic traps which escaped the major gas flush. Unconventional oil resources are established in the Sproule Peninsula oil sands and may possibly occur in subsurface Carboniferous and Triassic bituminous shales.

Numerous unexplored fault-bounded structures probably exist offshore in addition to structural/stratigraphic traps associated with salt deformation and fault blocks that form structural traps around the basin margins. The risk of source rock overmaturity, breakdown of trap integrity and biodegradation of oils increases towards the eastern margin of the basin and large economic plays are less likely in these areas (Embry 2011).

1.2 Franklinian Basin

Introduction

During the 1960s and early 1980s fifty wells were drilled and several thousand kilometers of seismic lines were shot in the Franklinian Basin without significant success except for the Bent Horn field. Although only minor amounts of petroleum were encountered, several wells did have reservoir quality porous rock. Primary drill targets were Paleozoic carbonates and sandstones. Despite favorable geology in the Franklinian Basin petroleum industry interest in the area declined from the 1980s and 1990s (Drummond 1973).

Basin Summary

The Franklinian Basin is a north south trending feature that extends from Banks Basin in the southwest to Baffin Island in the southeast and from Ellesmere Island to Greenland in the north (Figure 3). The basin is approximately 2,400 km long and 1,200 km wide to the south tapering to 300 km wide in the north. The 10 km thick basin fill is predominately Paleozoic carbonates and sandstones. Regional structure consists of the Arctic Platform to the east and southwest and the deformed Arctic Fold Belt to the east (INAC 1995).

Hydrocarbon Production

The Bent Horn oil field was discovered by the Bent Horn N-72 well in 1973. The field is small and is estimated to contain 12 million barrels of oil. The field has been delineated by six wells (including the discovery well). Two of these wells contained oil, one is rated as an oil show only and three were dry holes (INAC 1995).

The Bent Horn oil field (Figure 5) occurs more than 3 km below the surface on Cameron Island. The basin is made up of Devonian and older shelf reef rocks that define an exploration fairway with reservoir potential rated as good. Various surveys confirmed the presence of thick layers of sediment containing a variety of possible hydrocarbon traps. Drilling has demonstrated that the limestone is generally tight with only local porosity, but limited and localised fracturing improved permeability.

From 1985 to 1996, Panarctic Oils shipped 2.8 million barrels of oil from the Bent Horn field to Montreal refineries during summer seasons. However, production and transportation of oil ceased in 1996 due to the high cost of single season production. The porosity type and the complex structural setting in the Bent Horn field make reserve determination difficult and the current estimations are subject to considerable uncertainty (Chen et. al. 2000).

Reservoir Potential

The Franklinian Basin has first-rate structural traps, excellent reservoir rocks and several defined source areas that delineate possible onshore and offshore drilling targets in the Arctic Islands. A large number of structural and especially stratigraphic traps remain undrilled. No new seismic lines have been completed since the early 1980s and any existing 3D is not publicly available. The large amplitude folds and faults of the Arctic Fold Belt provide structural traps in the basin. Stratigraphic traps include reef development on the rim of the carbonate shelf with shale and salt horizons providing seals for the traps.

Although uncommon within the thick carbonate succession of the lower Paleozoic, potential source rocks have been identified. Black shales have 3 to 5 % Total Organic Carbon and high gas yields. The Bent Horn oil source rock is unknown at this point but circumstantial evidence points to the encasing shales. To the west, organic matter within these horizons becomes overmature due to deep burial beneath a thick Devonian clastic wedge which was later eroded. The remnants of the clastic wedge are also prospective for gas generation (INAC 1995).

Conclusions

Several under-explored petroleum systems with distinct plays may exist in the Franklinian Basin. Although the Bent Horn discovery is the only play that has yet been proven, areas of fair to good hydrocarbon potential occur in other parts of the Franklinian Basin. Supported by evidence of hydrocarbon shows and favourable geology the remaining plays can only be considered as conceptual.

Many large structures identified by seismic exploration have been drilled. Less attention has been paid to peripheral areas and older rocks of the surrounding Arctic Platform. With the evolution of both exploration concepts and exploration technology since the end of the last phase of exploration, the full potential of the Franklinian Basin remains to be established.

Future exploration is likely to focus on oil prospects in reef complexes along the basin rim, particularly those close to the structural interface of the Arctic Fold Belt and the Sverdrup Basin. The structures of the Arctic Fold Belt have major potential for both gas and oil. Both plays are rated as good for hydrocarbon potential (Embry et. al. 2012).

1.3 Banks Basin

Introduction

In the 1970s and early 1980s 11 wells were drilled and more than 9,200 km of seismic lines were shot in the Banks Basin (Figure 2) without significant success. The first well in the Banks Basin, Elf Storkerson Bay A-1S, was drilled in 1971, and tested the Tertiary and Upper Mesozoic sections of the Arctic Continental Margin without success (INAC 1995). However, a number of exploration plays with moderate potential were defined, mostly for gas. Although no hydrocarbons were encountered, several wells did contain reservoir quality porous rock. Primary drill targets were Paleozoic carbonates, with Mesozoic sandstones in the overlying section as a secondary objective (Miall 1979). The last well was drilled in 1982 and despite favorable geology interest in the area by the petroleum industry declined through the mid-1980s.

Basin Summary

Banks Basin, to the southwest of the Sverdrup Basin, is a north-south trending structure approximately 350 km long by 100 km wide. The basin is mostly onshore Banks Island, but also extends northwards across the McClure Strait. Banks Basin is a north-south series of highs with intervening subbasins, extension faulting and minor folding. The basin fill consists of a 2 to 3 km thick succession of lower Paleozoic carbonates and Mesozoic siliciclastics. Deeper burial of Mesozoic source rocks may improve oil potential (INAC 1995).

Reservoir Potential

Banks Island contains Devonian and older shelf carbonates that define an exploration play fairway with good reservoir potential. Mesozoic and Tertiary clastic strata are also potential reservoir rocks. Thick sections of porous, permeable rock occur in the basin and recovery of formation water from several intervals is evidence of reservoir quality rocks (Miall 1976). Changes in rock types and carbonate build-ups form the petroleum traps in Banks Basin with seals created by overlying shales.

1.4 Baffin Bay

Introduction

The only well drilled in the Canadian part of the Baffin Bay basin is Ocean Drilling Project (ODP) Site 645, drilled for scientific purposes. In Davis Strait five dry and abandoned wells were drilled during 1976 to1977, however, these wells are in territories on the west Greenland Shelf. The Geological Survey of Denmark and Greenland proposes that seismic failed to test potential pre-Tertiary sequences (INAC 1995). Oil surfacing at several areas halfway along the coast of Baffin Island indicates subsurface oil seeps (Klose et. al.1982). There have been few seismic programs on the northeastern Baffin shelf and the reconnaissance lines shot were not enough to define drilling targets. In 2010 Parks Canada committed to establishing a marine conservation park in Lancaster Sound which will prohibit any resource exploration in the area.

Basin Summary

Most of the northeastern Baffin shelf is relatively narrow but thickens and broadens opposite the mouth of Lancaster Sound (Figure 3). The basin has a maximum thickness of 14 km with an average of 8 km. The thick Mesozoic sandstone layers in Baffin Bay have reservoir rock potential and outcrop samples all show good porosity and permeability. Promising reservoir characteristics have been preserved in age comparable sections in the subsurface on the southeastern Baffin and Labrador shelves (Klose et. al.1982).

Reservoir Potential

Numerous structural elements in the northeastern Baffin shelf and the deeper parts of the basin are potential structural hydrocarbon traps. Thick Mesozoic sequences are prospective for gas and oil with evidence of active oil seeps and petroleum source rocks. Good reservoir porosity occurs in Cretaceous to Lower Tertiary formations. Upper Cretaceous shale draped over earlier Cretaceous structures forms a regional top seal (INAC 1995).

Upper Cretaceous marine strata are widespread in the Baffin Bay basin and the West Greenland shelf. Upper Cretaceous shale is rich in organic material indicating the existence of oil-prone source rock. The potential for both oil and gas source rocks also occur in younger, Paleocene marine shale. Other Cretaceous formations contain terrestrially derived organic material and are possible gas source rocks (Drummond 1973).

1.5 Summary

Potential for oil and gas resources in the thick, extensive layers of Paleozoic and Mesozoic strata in the Arctic Islands has been demonstrated by oil and gas exploration activities in the 1970s to 1980s. The lower Mesozoic strata and a number of untested upper Paleozoic plays may be future exploration targets.

Although much of the past exploration focus (and success) has been in the central Sverdrup Basin future activities may test the southern rim of the basin and the Arctic Fold Belt. There is significant hydrocarbon potential along this exploration fairway of structural complexity (INAC 1995). Proximity to potential Northwest Passage shipping lanes makes exploitation of geological resources along the southern rim of the Sverdrup Basin more economically feasible.

Tables 1 and 2 show the distribution of gas and oil resources in Canada and the northern Canadian territories. The ultimate risked recoverable resources for Northern Canada are 11.88 billion barrels of oil and 147.0 trillion cubic feet of natural gas. This represents 21% of the oil and 23% of the gas, estimated for all of Canada. The remaining recoverable resources for Northern Canada are 11.6 billion barrels of oil and 146.3 trillion cubic feet of gas, 35% and 33%, respectively of the Canada total. For the remaining risked (see Chapter 2) recoverable resources 23% of the oil and 40% of the gas is in Nunavut. Note that all the resources for Nunavut are onshore and offshore the Arctic Islands (Drummond 2009).

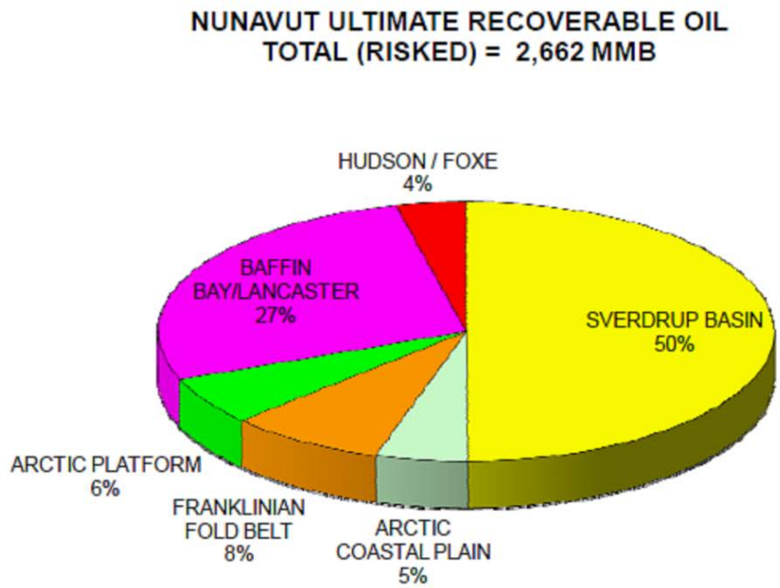
Table 1 Recoverable Gas (Risked) - BCF (billion cubic feet)

	Discovered	Undiscovered	Ultimate	Remaining Resource	% Canada Remaining
Canada	303,638	332,483	636,120	442,718	
Northern Canada					
NWT	16,242	54,740	70,982	70,474	15.90%
Nunavut	15,963	42,304	58,267	58,267	13.20%
Yukon	522	17,271	17,794	17,555	4.00%
Total	32,727	114,315	147,042	146,296	33.00%
% Canada	10.80%	34.40%	23.10%	33.00%	

Table 2 Recoverable Oil (Risked) - MMB (million barrels)

	Discovered	Undiscovered	Ultimate	Remaining Resource	% Canada Remaining
Canada	29,032	26,614	55,647	32,994	
Northern Canada					
NWT	1,182	5,032.59	6,215	5,962	18.10%
Nunavut	323	2,339.47	2,662	2,660	8.10%
Yukon	406	2,596.80	3,002	3,002	9.10%
Total	1,911	9,969	11,880	11,624	35.20%
% Canada	6.60%	37.50%	21.30%	35.20%	

Source: Drummond 2009.



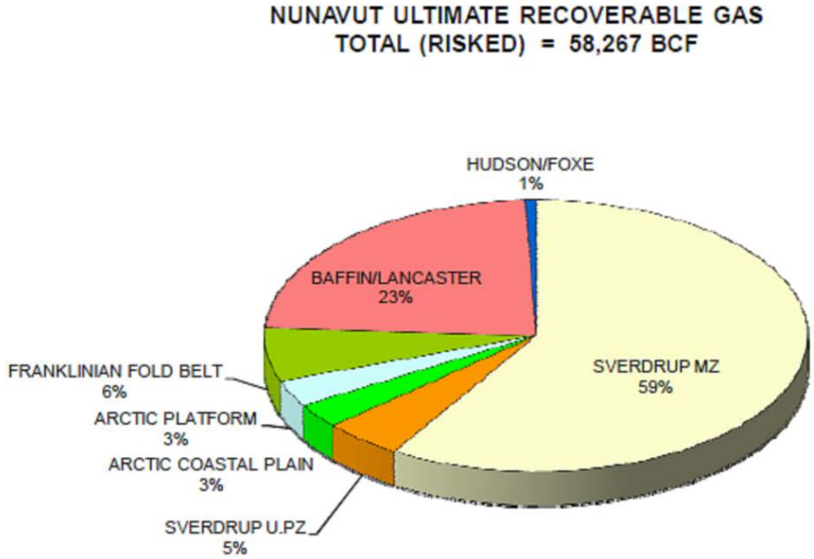


Figure 6. Pie charts showing ultimate recoverable resources for the Arctic Islands and the Last Ice Area. Source: Drummond 2009.

2. Economics and Risked Potential Resources

2.1 Risk Analysis

Evaluation of the economic potential of geological resources is a complex process. In this section some simplified calculations on how to assess exploration factors are reviewed. The most important single variable in the evaluation of exploratory investment is risk. A simple formula to describe the economics of geological exploration can be summarized by:

Resource Potential + Economics + Risk = Decision

Risk is a matter of perception: risk perception represents the assessment of the probability of a specified type of incident happening, and how important such an incident is. The search for geological resources is by its nature a function of complex probabilities (Megill 1988).

Each risk assessment unit is assigned a probability of occurring based on a confidence scale where 1.0 is absolutely sure to occur and 0 is absolutely sure not to occur. In exploration, such conditions often relate to the crucial geological factors required for a successful petroleum resource system. Confidence is measured by actual data quantity and quality, although it can also be founded on confidence in theoretical models and analogues. As more geological data is attained the level of confidence assigned to a risk factor increases (Megill 1988).

This study of resource potential is based on the concept of the hydrocarbon play. A play is a collection of known oil pools and/or prospects (accumulations and/or potential accumulations) that have common geological features and history of hydrocarbon generation, migration, and entrapment. The established play is given a higher potential ranking due to association with known hydrocarbon occurrences and the attendant increase of information. Conceptual plays are geologically possible but have a number of uncertainties although some have known hydrocarbon occurrences. Conceptual plays are ranked lower than established plays (Gal and Jones 2003).

In its simplest form risk in hydrocarbon exploration can be summarized by three factors or risk assessment units (AU):

1. Source Rocks: Hydrocarbons are generated in source rocks that are typically rich in organic matter. The type of organic matter, and depth and time of burial of potential source sediments are the major factors that determine whether gas or oil is generated. Hydrocarbons migrate from source rocks into reservoir rocks where they may be trapped. Many source rocks have been identified in the LIA study area.

2. Reservoir: The reservoir rocks must be porous and permeable enough to hold and permit movement of oil and gas. There are many potential reservoir rocks in the subsurface of the LIA study area; chiefly sandstones, dolostones, and limestones. As well, many possible stratigraphic and structural traps can occur; these can be related to basement features, stratigraphic facies, subcrop limits, and fault and fold belts. A reservoir must have a seal to contain the fluids within the hydrocarbon reservoir.

3. Environment: The factors here include timing of geological processes, size of prospect, revenue generation, costs and others. The timing of trap formation with respect to hydrocarbon generation and migration is a crucial aspect to forming hydrocarbon accumulations, and is not always well constrained. Many types of traps have been identified in the LIA.

Play fairway analysis is essentially an assessment of exploration risk at a basin scale. Applying risk analysis to a play fairway in frontier basins allows exploration activities to be concentrated in the most prospective parts of a basin. Furthermore, basins themselves can be ranked by combining the risks for individual plays within a basin, allowing exploration investment to be committed to the most prospective basins (Fraser and Gawthorpe 2003).

Estimated ultimate recovery is an approximation of the quantity of oil or gas that is potentially recoverable or has already been recovered from a reserve or well. Recoverable gas or oil is calculated by multiplying volume in place by a recovery factor. Marketable natural gas refers to gas volumes that are technically recoverable under current market conditions (Drummond 2009). The marketable volume is calculated by multiplying recoverable volume by a marketable factor. Marketable hydrocarbon volumes are almost always lower than in-place or recoverable volumes. The final figures for ultimate risked resources will provide a hydrocarbon quantity that can be multiplied by economic factors to arrive at an approximation of a monetary value.

2.2 Canadian LIA Risk Analysis

Tables 3 and 4 are the risked analysis of oil and gas resources for the Arctic islands (Drummond 2009). Recoverable resources are those that are technologically or economically feasible to extract. If a new resource is found, but it cannot be extracted by current methods, then it would not be considered part of recoverable reserves (Drummond 2009). These calculations are highly valued by companies as they provide the information required to delineate plays and play fairways thus allowing companies to focus their activities and investments in areas with the greatest chance of success. The size and value of the resource can be calculated and compared with other exploration areas to allow better investment decisions. The ultimate resource numbers in the tables indicates that the LIA certainly merits further exploration depending on other factors such as extraction and transportation costs, and economic factors. For Greenland LIA risked resources see Chapter 5.6.

Table 3

ARCTIC ISLANDS ULTIMATE GAS RESOURCES
ESTABLISHED PLUS CONCEPTUAL RISKED (billion cubic feet)

AREA	DISCOVERED GAS RESOURCES			UNDISCOVERED GAS RESOURCES			ULTIMATE GAS RESOURCES		
	IN-PLACE	RECOVERABLE	MARKETABLE	IN-PLACE	RECOVERABLE	MARKETABLE	IN-PLACE	RECOVERABLE	MARKETABLE
SVERDRUP BASIN NWT	4,199.0	3,720.0	3,496.8	7,836.0	5,829.3	5,539.5	12,035.0	9,549.3	9,036.3
SVERDRUP MZ Nunavut	16,313.2	13,663.0	12,843.3	27,656.5	20,574.1	19,551.3	43,969.7	34,237.1	32,394.6
SVERDRUP U.PZ Nunavut	0	0	0	3,687.5	2,743.2	2,606.8	3,687.5	2,743.2	2,606.8
ARCTIC COASTAL PLAIN	0	0	0	2,310.6	1,720.1	1,634.3	2,310.6	1,720.1	1,634.3
ARCTIC PLATFORM	0	0	0	2,526.9	1,831.0	1,740.3	2,526.9	1,831.0	1,740.3
FRANKLINIAN FOLD BELT	0	0	0	4,978.7	3,691.4	3,509.2	4,978.7	3,691.4	3,509.2
LANCASTER BASIN	0	0	0	4,870.2	3,616.0	3,436.2	4,870.2	3,616.0	3,436.2
BAFFIN BAY/DAVIS STRAIT	2,875.0	2,300.0	2,139.0	10,427.3	7,737.2	7,354.6	13,302.3	10,037.2	9,493.6
HUDSON/FOXE	0	0	0	630.6	391.0	367.5	630.6	391.0	367.5
Total	**23,387.2**	**19,683.0**	**18,479.1**	**64,924.3**	**48,133.3**	**45,739.7**	**88,311.5**	**67,816.3**	**64,218.8**

Table 4

ARCTIC ISLANDS ULTIMATE OIL RESOURCES
ESTABLISHED PLUS CONCEPTUAL RISKED (million barrels)

AREA	DISCOVERED OIL		UNDISCOVERED OIL		ULTIMATE OIL		UNDISCOVERED RISKED		ULTIMATE RISKED	
	IN-PLACE	RECOVERABLE	IN-PLACE	RECOVERABLE	IN-PLACE	RECOVERABLE	IN-PLACE	RECOVERABLE	IN-PLACE	RECOVERABLE
SVERDRUP BASIN	1,600.4	320.1	5,129.3	1,199.3	6,729.7	1,519.4	4,315.1	1,008.5	5,915.5	1,328.6
ARCTIC COASTAL PLAIN	0	0	1,561.9	367.1	1,561.9	367.1	546.7	128.5	546.7	128.5
ARCTIC PLATFORM	0	0	1,706.7	399.3	1,706.7	399.3	682.7	159.7	682.7	159.7
FRANKLINIAN FOLD BELT	14.2	2.8	1,822.8	431.8	1,837.0	434.6	911.4	215.9	925.6	218.7
LANCASTER BASIN	0	0	1,318.2	306.7	1,318.2	306.7	949.1	220.8	949.1	220.8
BAFFIN BAY/DAVIS STRAIT	0	0	2,199.5	508.1	2,199.5	508.1	2,199.5	508.1	2,199.5	508.1
HUDSON / FOXE	0	0	2,836.1	652.3	2,836.1	652.3	425.4	97.8	425.4	97.8
Total	**1,614.6**	**322.9**	**16,574.5**	**3,864.6**	**18,189.1**	**4,187.5**	**10,029.9**	**2,339.3**	**11,644.5**	**2,662.2**

Figure 7A illustrates play fairways for ultimate risked hydrocarbon potential in the Arctic Islands based on the information in Tables 3 and 4. Archean rocks have no potential while the Sverdrup Basin has the highest hydrocarbon potential. The higher potential regions define fairways where hydrocarbon resources are most likely to be found. These are the areas that would be the focus of future exploration activities and would have the greatest impact on the LIA.

Figure 7B shows the Last Ice Areas for the Arctic Islands and Greenland. Many regions with the highest hydrocarbon potential (Sverdrup Basin) overlap some of the larger predicted last ice cover areas.

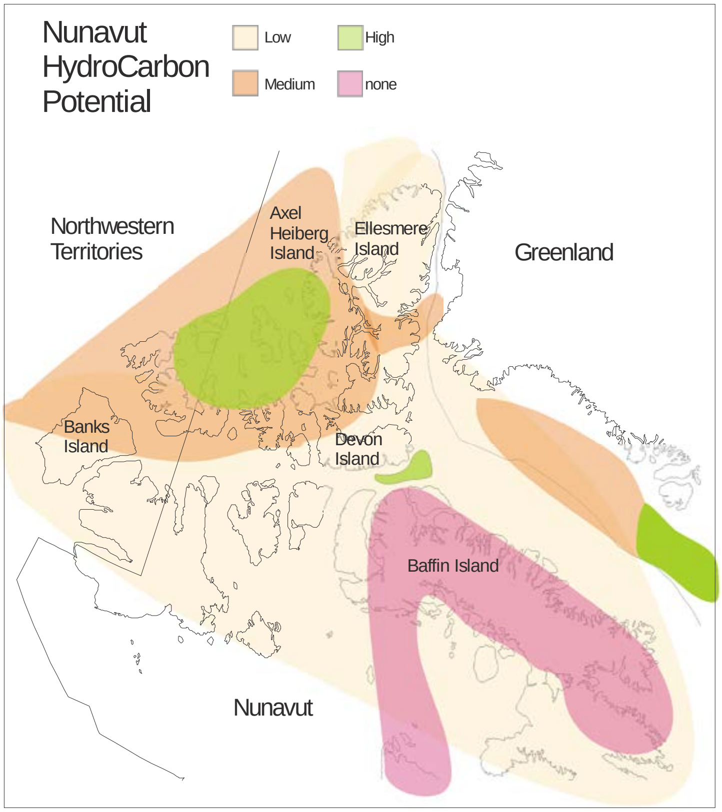


Figure 7A. Exploration fairways based on ultimate risked hydrocarbon potential in the LIA.

Figure 7B. Map of the LIA in the study area. Light blue areas are the projected last ice areas in the Arctic Islands. Source: modified after Last Ice Area Google Earth - 2040 sea ice description.

3. Coal Resources

The presence of Tertiary coal measures in the Canadian Arctic Islands has been known for over 150 years. The site of Fort Conger on southern Ellesmere Island, which was a base for early explorers Nares (1875-76), Greely (1881-83) and Peary (1898-1912), was in part located to take advantage of adjacent mineable coal. Historical exploration in the area has identified several areas with significant coal accumulation: including Fosheim Peninsula, Vesle Fiord, Strathcona Fiord and Stenkul Fiord (Bustin 1980).

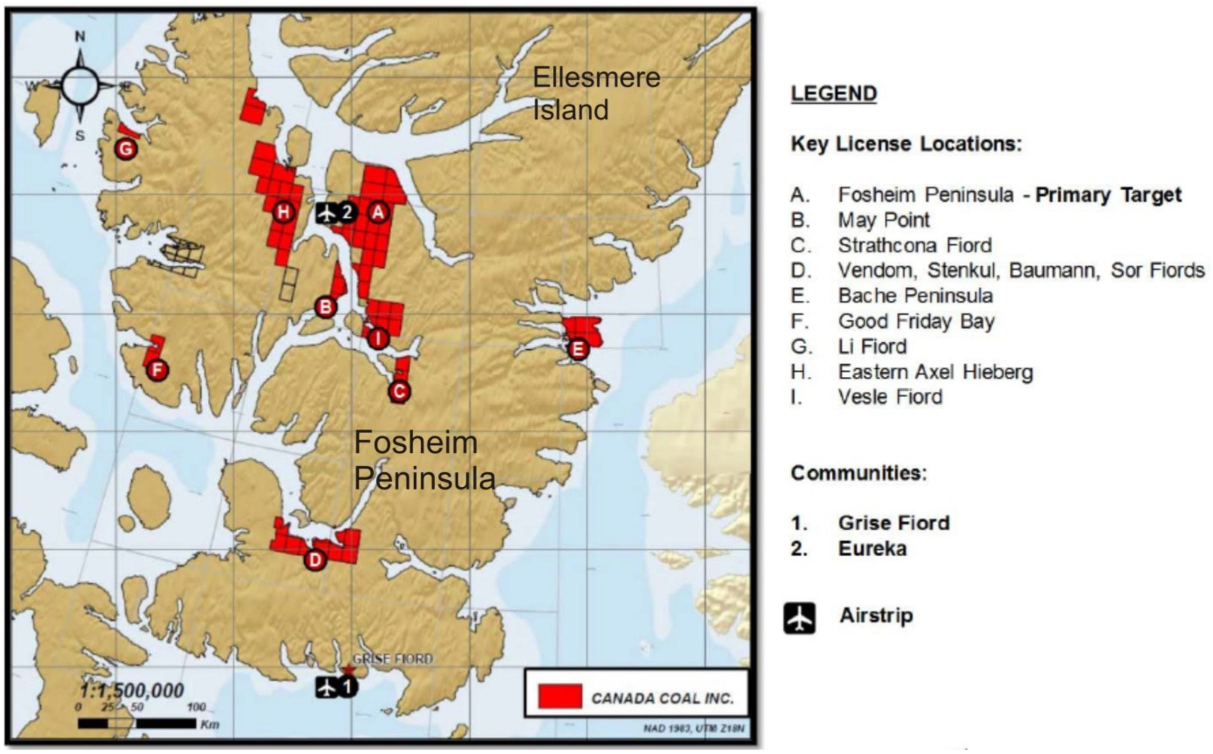


Figure 8. Canada Coal Inc. exploration areas on the southern Fosheim Peninsula of Ellesmere Island. Source: Canada Coal 2013.

3.1 Geology

The Eureka Sound Formation is the main coal bearing unit and is widely distributed, extending from Banks Island in the southwest to Ellesmere Island in the northeast with a maximum thickness of 3,300 m on the Fosheim Peninsula. The formation contains numerous coal seams that range in thickness from 1 to 2 m on central Axel Heiberg (Bustin 1980).

When originally deposited, the Eureka Sound Formation probably enveloped most of the Arctic Islands, and is also likely present offshore of the islands, in interisland seaways and off the northern margin of the Arctic Islands. The Eureka Sound Formation has excellent potential for coal particularly on Ellesmere Island (Embry and Beauchamp 2008).

3.2 Potential Coal Resources

The main operator in the area is Canada Coal which holds 75 licences totaling 2,442,627 acres on Ellesmere and Axel Heiberg Islands. In 2013, they acquired 11 additional licenses pending that will add an extra 281,667 acres to the project area. Exploration will initially focus on coal deposits within Late Cretaceous and Tertiary sediments along the southwestern coast of Ellesmere Island (Associated Geosciences Inc. 2011).

Coal resources within the area of study are calculated as 43.8 billion tonnes (Total non NI-43-101 Compliant) with 15,000 million tonnes of lignite, 11,000 million tonnes of sub-bituminous and 4,000 million tonnes of high-volatile bituminous. The area encompasses only a small portion of the known outcrop area of Late Cretaceous and Tertiary coal measures in the Arctic Islands which suggests that considerable further resources may be present (APEX 2009).

No current coal resources can be officially assigned to the Canada Coal project due to a lack of empirical data. Coal resources are usually classified into measured, indicated and inferred categories in accordance with GSC 88-21 and Canadian Institute of Mining, Metallurgy and Petroleum (CIMM) guidelines. These are incorporated in NI 43-101 which is a codified set of rules and guidelines for reporting on information related to mineral properties owned by, or explored by, companies which report these results on stock exchanges within Canada (CIM 2013). In order to be classified as a resource, potential coal must exist in such form and quantity that there are reasonable prospects for economic feasibility. In the Canada Coal project area there has been insufficient exploration to define a coal resource and it is uncertain if further exploration will result in delineation of the project as a resource (Associated Geosciences Inc. 2011).

3.3 Coal Exploitation

Canada Coal was originally considering an open pit mine that would operate 6 to 9 months of the year. However, in December 2013 Canada Coal Inc. announced that it has withdrawn all project applications submitted to the Nunavut Impact Review Board and will delay exploration activities on Ellesmere Island for at least one year while it works on a new project proposal. The company said it’s taking these actions because it needs time to do more consultation with the people of Grise Fiord (Nunatsiaq Online 2013). The company has relinquished licenses for coal that it held for locations on Axel Heiberg Island, due to a site of a famous fossil forest. At this point in the project no coal production or development has occurred in this area. The next level of coal exploration will include a more detailed shipping hazard study, hydrographic surveying, port infrastructure analysis and other logistical concerns.

3.4 Conclusions

Although coal resources located in such remote areas as the LIA are not currently economically significant, recent advances in coal mining, processing and transportation technology may enable future exploitation of the coal potential if sizable resources are determined. In order to advance the exploitation of coal resources further exploration data is required to gain confidence in the geological interpretations and seam thicknesses already identified. Additional work is required to enhance historic understandings and geological interpretations and advance the project to a stage where coal resources can be estimated in accordance to NI 43-101.The logistics of bulk shipping of coal from the LIA remain challenging; however, the large potential target size of coal in the Canada Coal project area warrants further exploration.

4. Mineral Deposits

Based on 2012 statistics, approximately 112,657 km^2 of Crown land in Nunavut is covered by prospecting permits, mineral claims, or mineral leases. This is approximately 5.7% of Nunavut’s land area. According to statistics released by Natural Resources Canada in November 2012, it is estimated that more than $420 million has been spent on exploration and development. In terms of overall investment Nunavut is ranked fourth in Canada after Ontario, Quebec, and British Columbia (AANDC 2012).

When discussing mineral occurrences or deposits one must differentiate between a resource and a reserve. A resource is a geological term whereas a reserve is the economically mineable part of a mineral resource. Geological exploration activities establish the grade (quality), the size (tonnes) and other features of the resource. Investment in a license area by a company is driven by an interest to explore for resources that can be developed into an economic reserve. Generally the transformation of a resource to a reserve requires the application of a range of scientific and economic factors. Mining companies will have a strong interest in announcing large resources to attract new investors; therefore one must be critical of company reports and evaluations of resources.

4.1 Geological Setting

Mineral exploration in the Arctic Islands has been limited compared with that on mainland Nunavut because mineral deposits are mainly associated with Archean basement rocks. The prevalence of Phanerozoic sedimentary strata over igneous rocks of all ages in the Arctic Islands naturally promotes hydrocarbon exploration over mineral exploration. The potential value of know petroleum resources discovered exceeds the value of discovered minerals by a substantial margin (AANDC 2012).

The Arctic Islands are underlain by rocks of the Archean and Proterozoic-aged Churchill, Arctic Platform, Franklinian and younger geological provinces. Paleozoic sedimentary rocks mainly occur in the central and western Arctic Islands. The latest known period of widespread mineralization in the area predates these sedimentary rocks, therefore rocks of this age (Paleozoic) or younger may be discounted as favourable sources of metalliferous deposits. Most of the Arctic Islands fall in this category (Nassichuk 1987).

The east coast of Ellesmere and Devon islands and large portions of Baffin and Somerset islands are geologically favourable to mineralization. The geology of these areas is a continuation of the Rae Domain which contains extensive mineralization on the mainland to the south. The region hosts diverse mineral deposits and occurrences including iron ore, base metals such as lead and zinc, gold, platinum group elements (PGE), diamonds and sapphires (AANDC 2012).

At the present time, parts of eastern Ellesmere and Devon Islands are covered by permanent ice caps that make geological exploration activities difficult. There are minor exposures of Rae Domain Archean and Proterozoic rocks without sedimentary cover in these areas. Recent aeromagnetic surveys have recorded anomalies to the north that warrant further study (AANDC 2012). This may result in exploration fairways that are favourable for mineralization in the Arctic Islands LIA. However, current exploration efforts are mainly concentrated in the more southerly islands and on the mainland.

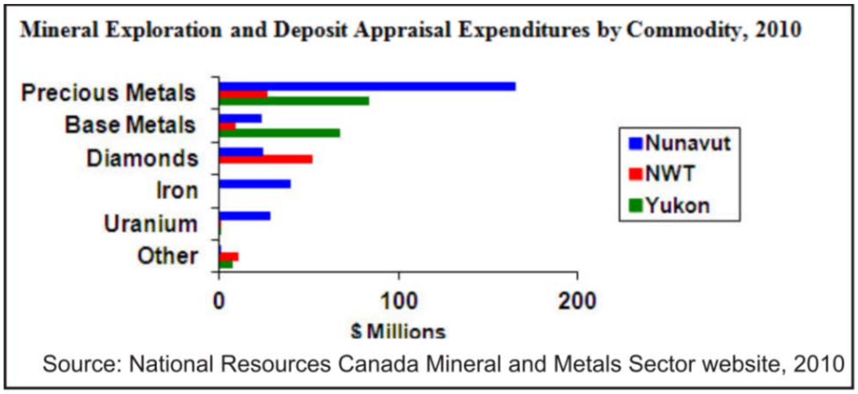


Figure 9. Mineral exploration expenditures for various minerals in the north. Source: Natural Resources 2010.

4.2 Mineral Resources

Base Metal - Polaris Mine: The Polaris ore body was discovered in 1971 on Little Cornwallis Island, northwest of Resolute (Figure 10). Analysis indicated a massive concentration of galena and sphalerite in limestone, 60 to 300 metres below the surface. Exploration continued throughout the 1970s resulting in discovery of widespread lead-zinc mineralization in Paleozoic dolomitic rocks (Nassichuk 1987).

Figure 10. The map shows the location of current mineral exploration in the Arctic Islands for 2013.

By 1973 surface drilling and underground development had outlined the Polaris ore body and defined reserves of approximately 25 million tonnes grading 14% zinc and 4% lead. Mine construction began in 1979, and the first ore was produced in late 1982. The Polaris mine produced over 21 million tonnes of lead-zinc ore during the life of the mine, with a market value of over $15 billion. The mine closed in July, 2002 after more than twenty years of lead-zinc production (AANDC 2012).

Other Base Metal Activity: The decommissioned Nanisivik Roche River zinc-lead-silver mine is located east of the community of Arctic Bay on northwestern Baffin Island. Environmental monitoring and testing continues at the decommissioned Nanisivik and Polaris mines. The Storm copper-zinc-silver property, located on the northwest coast of Somerset Island, has ongoing exploration (AANDC 2012).

Iron Ore - Mary River: In December 2012, the Minister of Aboriginal Affairs and Northern Development and other federal departments with jurisdictional responsibility approved the Baffinland Iron Mines Corporation's Mary River project on Baffin Island.

The Mary River Group consists of structurally complex Archean mixed metasedimentary – metavolcanic successions. The deposit has an inferred resource of 237 million tonnes of ore with 65% iron. Further exploration work is expected to increase the resources on the property. Iron ore will be extracted from the ground using conventional open pit mining and then transported via rail and ship to customers to the south (Nunavut Geoscience Exploration Overview 2012).

The Mary River iron ore project was projected to enter development in 2013 and requires an estimated $4.1 billion of direct investment up to 2040 for the construction of a road, railway, deep-water port and mine site infrastructure. The project will employ an estimated 1,500 people for construction and a further 900 people during mining operations (Nunavut Geoscience Exploration Overview 2012).

The operator, Baffinland Iron Mines Corp., scaled back the project in 2013. The original plan was to produce 18 million tonnes of iron ore per year. The scaled back plan will produce just 3.5 million tonnes per year. Transportation of iron ore to the coast by railway will be postponed, and the ore will be trucked to an existing small port on Baffin Island instead of building a new one (Globe and Mail 2013).

Other Iron Ore Activity: Roche Bay and Tuktu properties are located on the east coast of Melville Peninsula. The properties hold four mineral leases and 45 claims at Roche Bay, and 16 mineral claims at Tuktu that are undergoing advanced exploration activities (AANDC 2011).

Diamonds - Chidliak: Peregrine Diamonds Ltd.'s Chidliak diamond project is located northeast of Iqaluit, on the Hall Peninsula of Baffin Island. The project's land base covers 807,200 hectares of Crown land and Inuit Owned land (surface rights) and contains a number of known kimberlites. Continued exploration work on the Chidliak diamond project resulted in the discovery of two new kimberlites, bringing the total in this diamond district to 64. There are 61 kimberlites on the Chidliak property and three on Peregrine's Qilaq property (AANDC 2012). There is no active mining on these properties.

Gold – Baffin Island: The Baffin Island Gold project led by Commander Resources has two properties: Bravo Lake and Qimmiq, south of Clyde River (Figure 10). The properties contain a number of prospects, and recent exploration has focused on the Bravo Lake property. The

Kanosak prospect consists of two sedimentary units that contain gold mineralization. This mineralization, including several gold showings at surface, trends over a distance of more than three kilometres. At the Malrok prospect, the mineralization is hosted in structurally thickened silicate iron formation units (AANDC 2011).

4.3 Mineral Exploration Strategy - Parnautit

In 2007 the Mineral Exploration and Mining Strategy (Parnautit) was released to provide a basis of policies and actions to support mineral exploration in Nunavut. The Government of Nunavut (GN) provides core funding to the Canada-Nunavut Geoscience Office (CNGO) in Iqaluit, and direct program support of the CNGO's territorial mapping and research projects (Nunavut Government 2007).

Key aspects of the strategy are:

- Provide long term social and economic benefits to Nunavut
- Contribute to Nunavut's economic goals
- Work to protect the environment and minimize impacts
- Is attractive to investors

Operating mines throughout the territory would provide prospects for both employment and business. This will require growth for exploration activity and potentially result in new mineral discoveries and development in the region (Nunavut Government 2007).

4.4 Conclusions

The prevalence of Phanerozoic and Mesozoic rocks in the Arctic Islands naturally favours hydrocarbon exploration over mineral exploration, and the potential value of known hydrocarbon discoveries significantly exceeds the value of discovered minerals. All of the mineral exploration activities occur in the southern part of the Arctic Islands particularly on Baffin Island where the geology is favourable for mineralization. However, outcrop occurrences and geophysical surveys may define an exploration fairway extending from the mainland across Baffin Island and along the eastern side of Ellesmere and Devon Islands.

There are no currently operating mines in the Arctic Islands. However, the Mary River project is expected to produce 3.5 million tonnes of iron ore in 2013 to 2014. There are several prospective economic mineral projects that are in various stages of exploration.

One result of mineral exploration in the Arctic Islands has been the development of new communities to support resource projects. Inuit families worked and lived for years at the now closed Polaris and Nanisivik lead-zinc mines on Little Cornwallis and Baffin Islands.

5. Greenland LIA Resource Development

Introduction

The purpose of this section is to establish an overview of mineral and hydrocarbon georesources within the Greenland Last Ice Area (Greenland LIA). WWF has prepared a separate report on the geology and georesources of the Greenland LIA. Therefore, this report will only give an overview of the geology of the Greenland LIA and focus on assessing the potential for mineral and hydrocarbon georesources.

5.1 Geological Setting

Greenland's geology is an extension of North America and Northern Europe Archean cratons and Paleozoic sedimentary basins. Greenland is dominated by crystalline rocks of the

Precambrian shield, formed during a succession of Archean and early Proterozoic orogenic events which stabilized as a part of the Laurentian Shield approximately 1,600 million years ago.

Major sedimentary basins formed during late Proterozoic time and throughout the Phanerozoic in north and north eastern Greenland, and accumulated sedimentary successions 10 to 15 km thick. Palaeozoic orogenic belts, the Ellesmerian fold belt of North Greenland, and the East Greenland Caledonides disturbed parts of these successions.

Onshore and offshore Upper Palaeozoic and Mesozoic sedimentary basins formed along the continent–ocean margins in North, East and West Greenland and were closely related to continental break-up and the formation of rift basins. Initial rifting in East Greenland in latest Devonian to earliest Carboniferous time and succeeding phases culminated with the opening of the North Atlantic in the late Paleocene. In both central West and central East Greenland sea-floor spreading was accompanied by extrusion of Tertiary plateau basalts.

During Quaternary time Greenland was almost completely encompassed by ice sheets, and the current inland ice is a result of the Pleistocene ice ages. Vast amounts of glacially eroded detritus were deposited on the coastal shelves offshore Greenland (Frost 2013).

5.2 Greenland Mineral Geology

The east coast of Ellesmere and Devon islands and large portions of Baffin and Somerset islands have geology favourable to mineralization. The geology of these areas is a continuation of the Rae Domain from the Canadian Arctic Islands which contains extensive mineralization on the Canadian mainland to the south (AANDC 2012).

The youngest known period of widespread mineralization in the area predates the Upper Palaeozoic and Mesozoic sedimentary rocks, therefore rocks of Phanerozoic age (Figure 2) may be discounted as favourable sources for metalliferous deposits. Most of the eastern Arctic Islands and the west coast of Greenland are in this category (Nassichuk 1987).

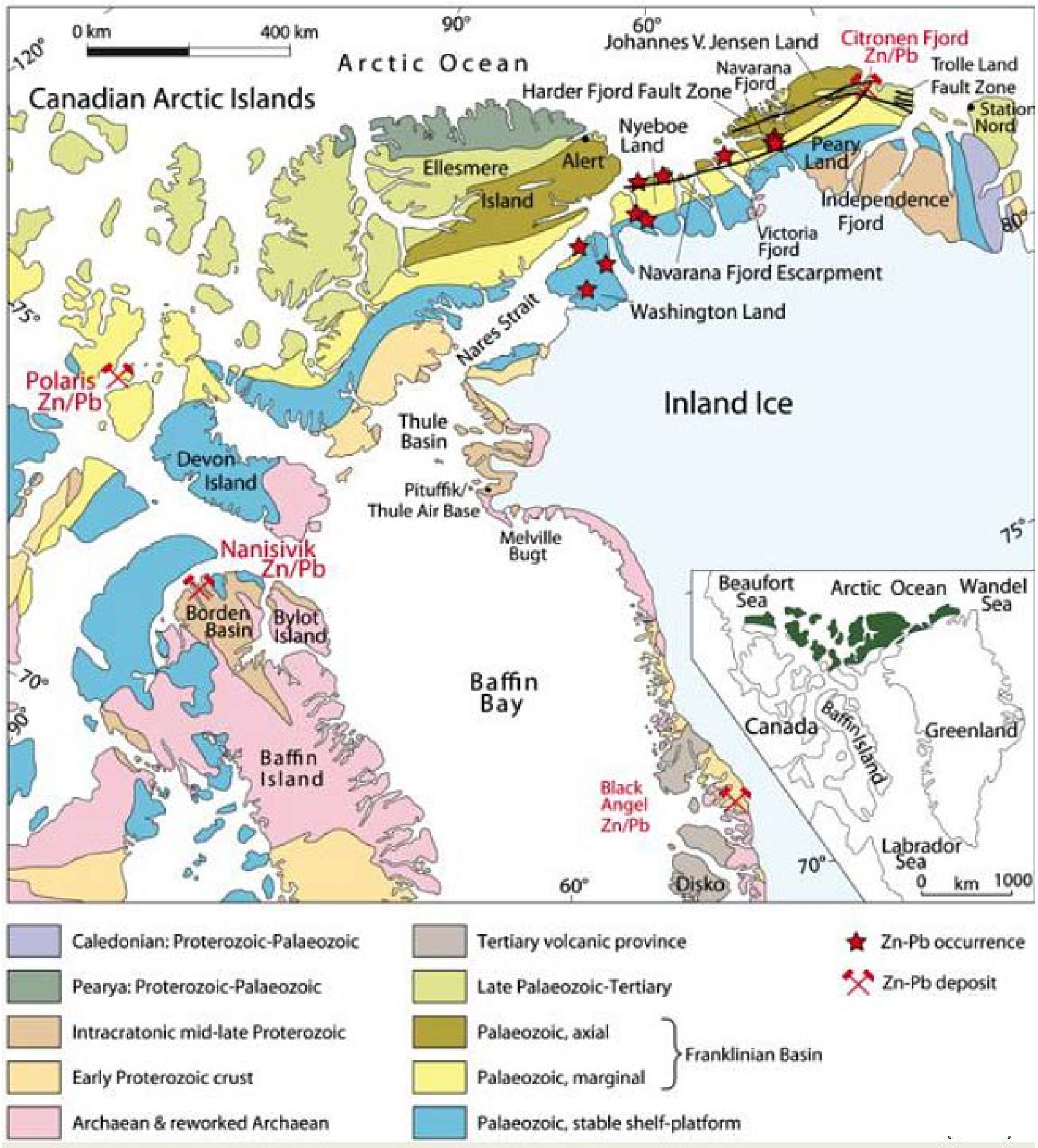


Figure 11. Detailed geology and zinc- lead mineralization in the Arctic Islands and northern Greenland. Zn-Pb occurrences are where there is a significant mineralization that requires further investigation before becoming commercially viable. Note that the Polaris and Nanisivik zinc- lead mines in the Arctic Islands have been closed and are now in a remediation phase. Source: Knudsen 2012.

5.3 Greenland LIA Mineral Resources

In the Greenland LIA, mineral occurrences include iron, copper, zinc, lead, gold, titanium as well as wolfram and barite (Figure 12). This is not an inclusive list of mineral occurrences in the Greenland LIA, but an overview representing the most important occurrences and the resources where exploration activities are either ongoing or most likely to develop within the next years.

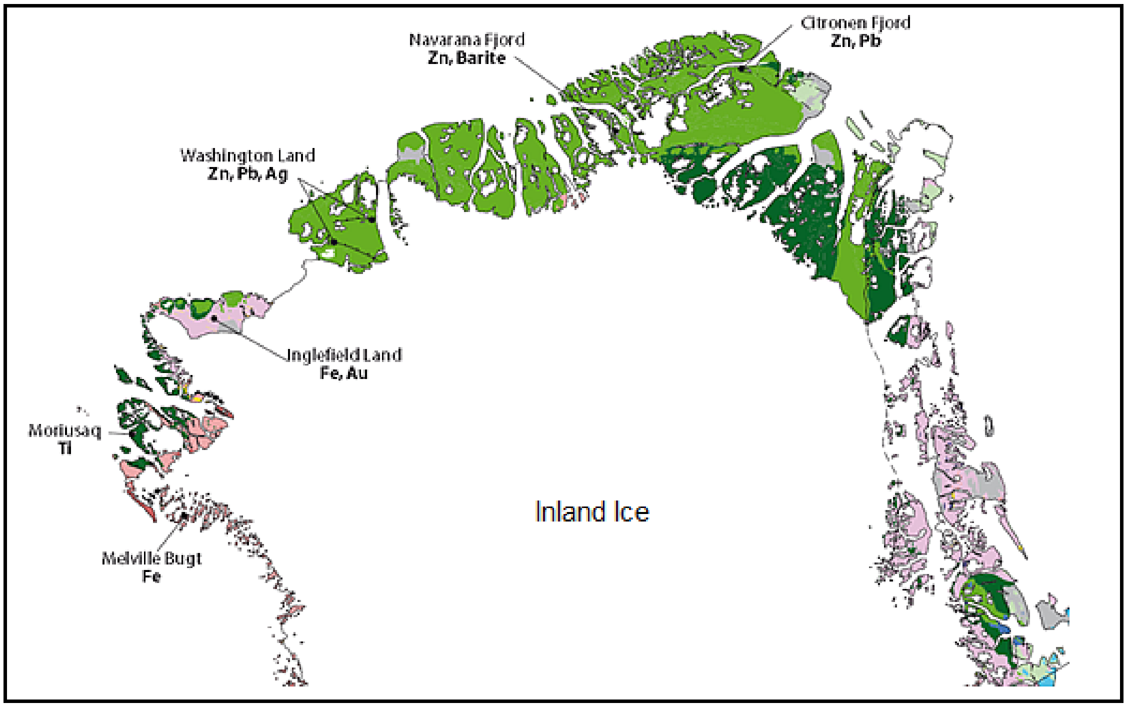


Figure 12. Map of geological environments and selected mineral occurrences in the northern Greenland LIA. Citronen Fjord is the most active area for zinc- lead mineral exploration and development. Source: Frost 2013.

5.4 Greenland Mineral Strategy

The Greenland Bureau of Minerals and Petroleum's Mineral Strategy was established in 2004 to evaluate exploration activity in the country. From 2004 to 2009 the number of granted exploration licences increased significantly and several prospective occurrences were discovered.

The Bureau of Minerals and Petroleum (BMP) published a later mineral strategy effective from 2009 (Greenland Mineral Strategy 2009).The objectives of Mineral Strategy 2009 are:

- Greenland will be recognised as potential exploration area.
- A practical proportion of any profits generated should be shared with the country.
- Licence terms must be reasonable for both small and large companies, robust enough to handle economic trends and simple to administer for companies and authorities.
- It must be possible to implement the strategy within the framework of a new mineral agreement between Greenland and Denmark.

For many years, there has been broad political agreement in Greenland that efforts should be made to develop the mineral sector into an industry that contributes to economic development and creation of new jobs. The development of the mineral resource sector must take place in a manner that will benefit Greenland as a whole and should secure a fair proportion of the value gained from extraction. Local insight and knowledge of the activities must be acquired to ensure that local labour and local enterprises are used to the greatest possible extent.

5.5 Greenland Hydrocarbon Resources

In contrast to other regions of the Arctic, Greenland has received little oil and gas exploration interest. The Greenlandic government has been actively promoting hydrocarbon exploration in Greenland since prices increased through the 1970s and a United States Geological Survey (USGS) study estimated large deposits of oil and gas in the waters around southern Greenland (Gautier et. al. 2007). The aim was to attract companies that could provide NUNAOIL, the national oil company of Greenland, with capital and experience. Initially these efforts were met with little interest from multinational energy companies, who perceived the investment to be too high of a risk. However, this changed with the licensing rounds in 2006 when large companies such as Statoil, Dong, Husky, Shell, Chevron, ExxonMobil and Cairn Energy began actively researching the area (Østhagen 2012).

There are numerous oil seeps and shows west of Greenland and extensive bitumen occurrences in the Franklinian Basin of northern Greenland. However, no significant oil or gas fields have been discovered either onshore or offshore (NPC 2011). The total area of sedimentary basins with petroleum potential in Greenland exceeds 350,000 km² (GEUS 2002). The total seismic data base is 110,000 km, but coverage is uneven, with most of the surveys concentrated in southern Greenland. Only 13 offshore wells and 1 onshore well have been drilled, all in West Greenland and all were dry. Large areas still remain untested (Greenland Bureau of Minerals and Petroleum 2012).

For resource analysis the USGS divides Greenland into the West Greenland-East Canada Province (Canadian Baffin Bay), North Greenland Sheared Margin Province and the East Greenland Rift Basin Province (Figure 13). All of the historic and modern drilling and seismic activity has occurred on the south western margin and southern tip of the Greenland continental margin.

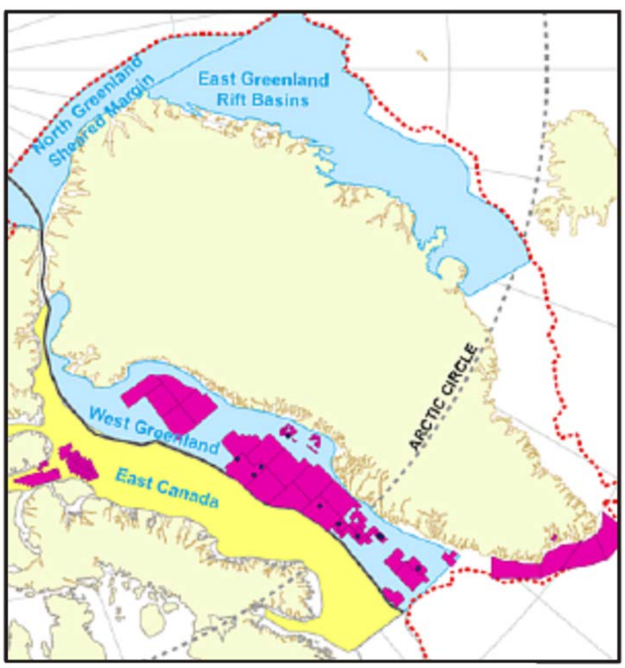


Figure 13. Key Greenland offshore basins (including the Canadian portion of the Baffin Bay area in yellow). Active exploration licenses are shown as pink. Note that all wells drilled so far are in the southern part of the West Greenland-East Canada Province. Source: USGS Circum-Arctic Resource 2008.

The nature of the rift basins flanking Greenland are such that the East Greenland Basin mirrors the geology of the Norwegian Shelf and North Sea margin where giant oil fields occur.
The same is true on the western flank of Greenland where the West Greenland Basin mirrors the geology of the East Canada Basin. This means that similar hydrocarbon potential occurs in Greenland waters (Figure 14).

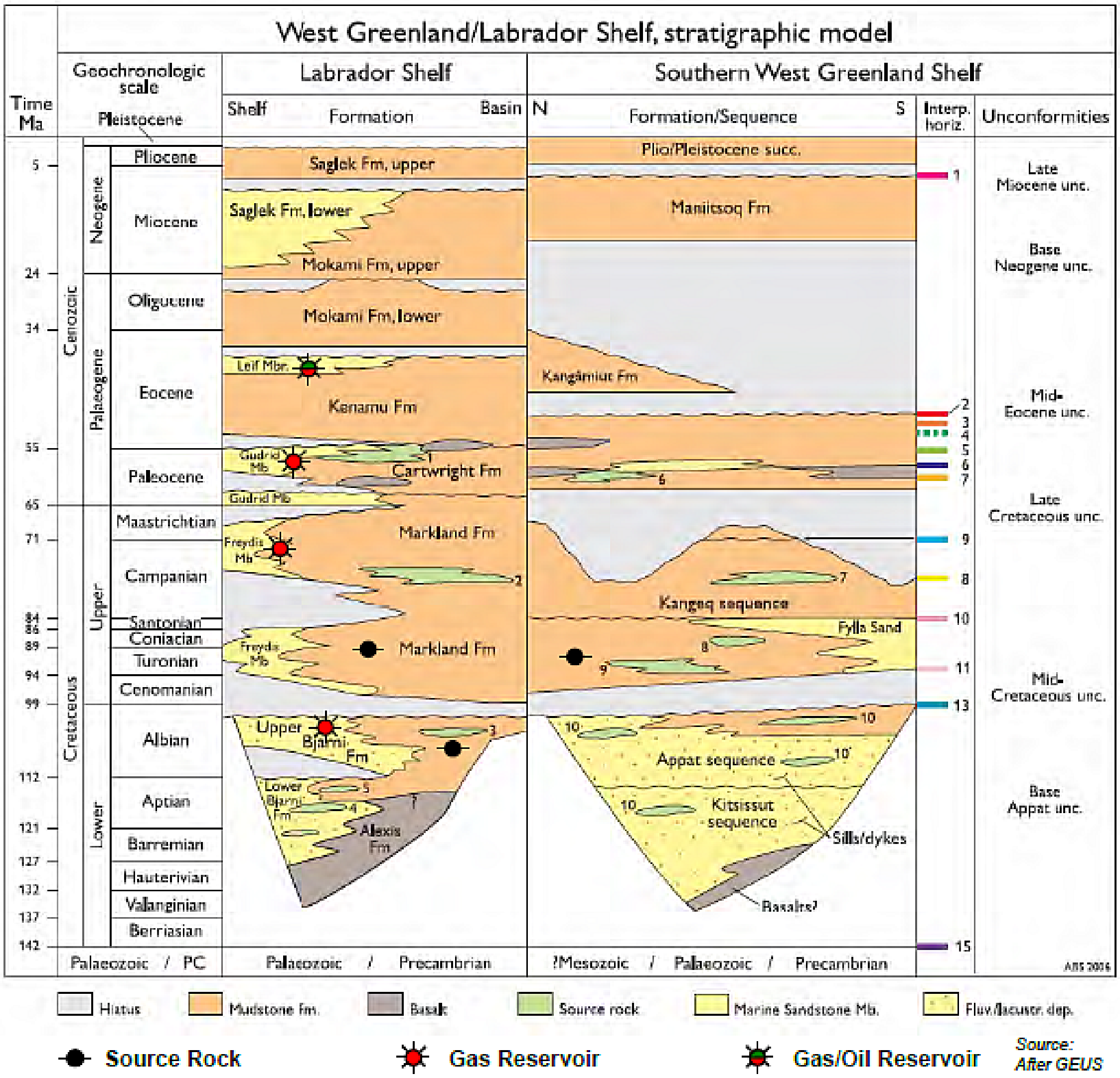


Figure 14. Stratigraphic chart shows how the geology of south western Greenland mirrors that of the Labrador Shelf, Eastern Canada. Reservoir rock characteristics and hydrocarbon shows are the same on either side of the rift zone in the central part of the basin. Source: Frost 2013.

Field work onshore and limited exploration wells offshore west Greenland have demonstrated elements of a working hydrocarbon system. Recent drilling by Cairn Energy LLC in 2010 has validated the occurrence of oil and gas trapped in structures offshore West Greenland. Gautier et al 2008 remarked that analysis by the USGS proposes that the offshore basins flanking Greenland offer the greatest potential for encountering large resources.

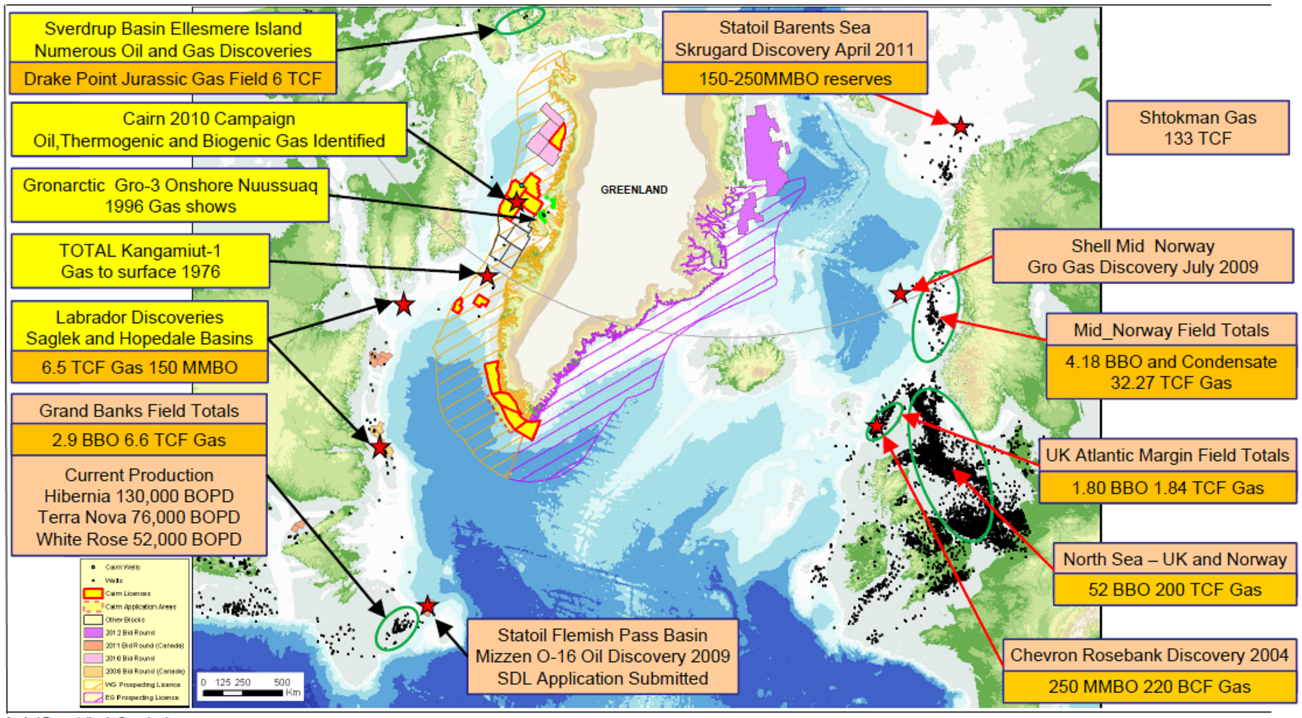


Figure 15. The geology and hydrocarbon occurrences of Greenland reflect those of the Labrador Shelf to the west and the huge oil fields of the Norwegian Shelf and North Sea to the east. Due to the nature of rift basins it is possible that the same large deposits may be present offshore Greenland. Source: Cairn Energy 2011.

There have been no fields discovered to date, and no commercial development on the Greenland Continental Margin. The only hydrocarbon activity in the Greenland LIA is offshore Melville Bay (Figure 12) where a number of companies lead by ConocoPhillips have licenses covering approx. 70,000 km^2 in the North Greenland Sheared Margin Province. TGS Inc. is planning seismic, magnetic and gravimetric surveys on the north eastern part of Greenland that may impinge on the Greenland LIA (Figure 16).

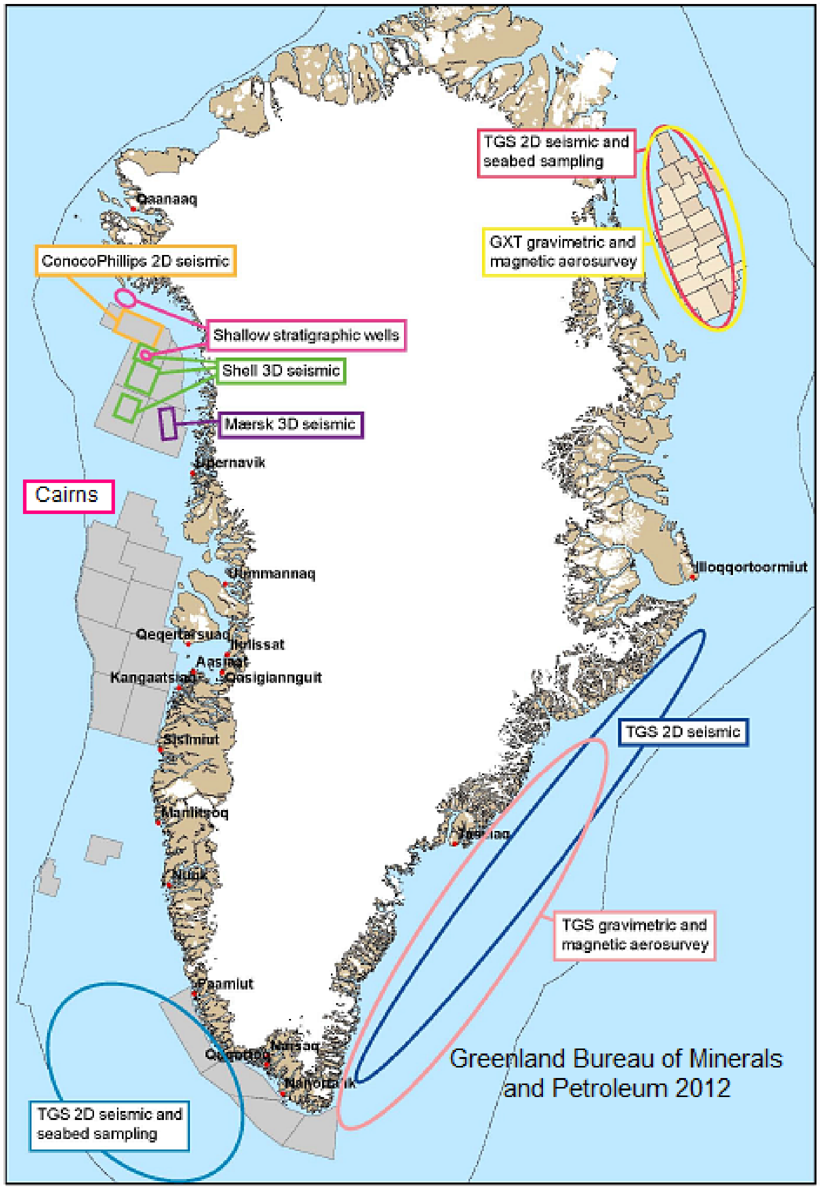


Figure 16. Hydrocarbon exploration activities and license blocks for 2012. Most of the proposed projects are offshore geophysical surveys which are a crucial initial step leading to exploration drilling. Source: Greenland Bureau of Minerals and Petroleum 2012.

5.6 Greenland Hydrocarbon Economics

As stated by Gautier et. al. 2007 the USGS assessed fully risked, undiscovered, technically recoverable conventional oil and gas resources in the West Greenland–East Canada Province (Figure 17). For conventional resources, the USGS estimates that the West Greenland–East Canada Province contains approximately 17,000 MMBOE of oil, natural gas, and natural gas liquids (Gautier et. al. 2008).The assessment indicates that about half of the undiscovered oil and gas resources in the province are estimated to be in the rifted margin. MMBOE is millions of barrels of oil equivalent, where one BOE is the amount of energy gained by burning one barrel of oil.

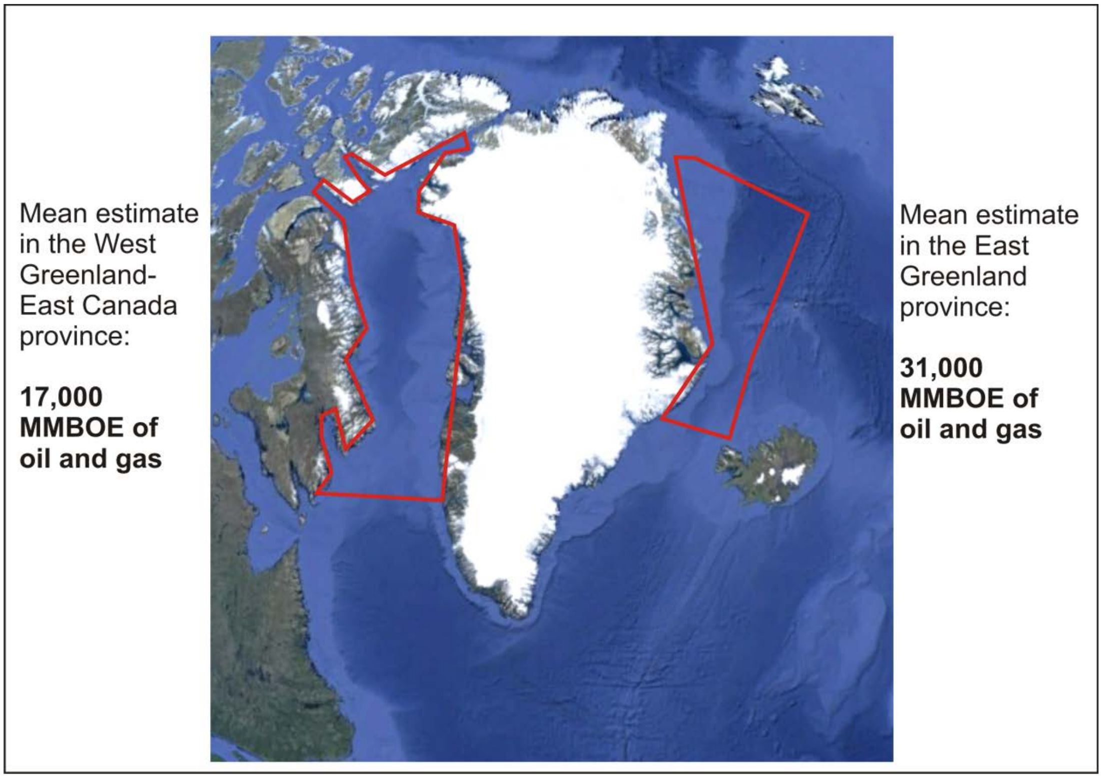


Figure 17. The map shows the mean USGS estimates for oil resources in west and east Greenland. Assessed areas and possible play fairways are outlined by red.

The USGS assessed fully risked, undiscovered, technically recoverable conventional oil and gas resources in the East Greenland Rift Basin Province. Most of the undiscovered oil, gas, and natural gas liquids are likely in the offshore parts of the East Greenland Rift Basins. The USGS estimates that the East Greenland Rift Basins Province contains approximately 31,000 MMBOE of oil, natural gas, and natural gas liquids (Gautier et. al. 2008).

Table 5 summarizes the "Yet to Find" or undiscovered hydrocarbon potential in a number of the known fields in the Arctic ranked by MMBOE. The Greenland provinces would be promising exploration play fairways given favourable economic conditions. As more data is collected the estimated hydrocarbon resources will change. Areas near the Greenland LIA will likely garner more interest from companies as exploration in the Arctic continues and further development may occur.

Table 5

Greenland Commercial Context

USGS "Yet to Find" Hydrocarbon Potential, North of the Arctic Circle

USGS (July 2008) risked mean estimate for Greenland potential is ~50 billion boe				
Hydrocarbon Province	Oil (mmbo)	Total Gas (bcfg)	NGL (mmbngl)	BOE (mmboe)
West Siberian Basin	3,660	651,499	20,329	132,572
Arctic Alaska Basin	29,961	221,398	5,905	72,766
East Barents Basin	7,406	317,558	1,422	61,755
East Greenland Rift Basin	8,902	86,180	8,122	31,387
Yenisey-Khatanga Basin	5,584	99,964	2,675	24,920
Amerasia Basin	9,724	56,891	542	19,747
West Greenland-East Canada	7,274	51,818	1,153	17,063
Laptev Sea Shelf	3,116	32,563	867	9,410
Norwegian Margin	1,437	32,281	505	7,322
Barents Platform	2,056	26,219	279	6,704

Source: USGS Circum-Arctic Resource: Estimates of Undiscovered Oil and Gas North of the Arctic Circle, 2008.

6. Arctic Operation Costs

Table 6 illustrates the total upstream cost of discovering and producing a barrel of oil equivalent. These costs include exploration costs, operating costs, capital costs, taxes, royalties and the rate of return on investment. The numbers do not include downstream costs such as transportation, refining or distribution.

	Lifting Costs	**Finding Costs**	**Total Upstream Costs**
Canada			
Canada conventional	$12.69	$12.07	$24.76
Canada off-shore	-	-	$43.00
Canada oil sands	-	-	$40.00
United States – Average	$12.18	$21.58	$33.76
On-shore	$12.73	$18.65	$31.38
Off-shore	$10.09	$41.51	$51.60
Africa	$10.31	$35.01	$45.32
Middle East	$9.89	$6.99	$16.88
Central & South America	$6.21	$20.43	$26.64
All Other Countries – Average	$9.95	$15.13	$25.08

Table 6. Costs for producing crude oil and natural gas in US$ per Barrel of Oil Equivalent. Costs are for barrel of oil equivalent. Source: EIA 2014.

6.1 Drilling Costs

Exploration in the Arctic LIA involves sophisticated machinery, complex logistical support systems, and large volumes of capital. For example, offshore wells in the Canadian sector of the Beaufort Sea, where most active Arctic exploration takes place, cost more than $100 million and offshore wells in the Arctic Islands often cost more than $200 million due to greater water and target horizon depths. In July 2007, Imperial Oil and ExxonMobil Canada bid $585-million to acquire exploration rights for a 205,000-hectare parcel in the Beaufort Sea. More recently, in June 2008, BP Exploration alone has committed $1.18 billion for exploration of a 202,380-hectare parcel in the Beaufort Sea (Parliament of Canada PRB 08-07E 2008).

In the US sector of the Beaufort Sea a well drilled in 1984 (Shell Mukluk) – cost $1.5 billion, and came up dry (EIA 2013). At the time this was the most expensive failure in oil industry history. In 2012 Shell began drilling the offshore Burger-A well in the Chukchi Sea, beginning an important stage in a programme that has already cost $4.5 billion and taken more than seven years to implement. The investment has not yet discovered any hydrocarbons, or delivered any financial returns. It's also not likely to provide anything in the near future as Shell has halted its Arctic exploration program due to several equipment problems. In fact, neither Shell nor any other company has any plans for exploring offshore Alaska in the near future (Oil and Gas Journal 2013).

In 2011 Cairn Energy invested $573 million to drill 4 offshore wells in the southern part of the West Greenland-East Canada Province for an average of $143 million per well. In 2010 Cairn spent $212 million to drill 2 more offshore wells in the area for an average of $106 million per well. Although there were several showings all wells were dry (BBC 2011).

The daily rates of offshore drilling rigs vary depending on the drilling environment and rig availability. Rig rates reported by industry web services show that a deepwater floating rig is more than twice that of a shallow water rig, and rates for a jackup rig can vary by a factor of three depending upon capability. With deepwater drilling rig rates in 2010 of around $420,000 per day, and adding similar additional operational costs, a deepwater well drilling for 100 days will cost US$100 million or more (see Rig Zone rigzone.com). With the added expense for drilling in frontier regions investors must have sufficient capital to regenerate exploration in the LIA.

It is estimated that the Sverdrup Basin alone could hold up to approximately 11 percent of Canada's total crude oil resources and 20 percent of Canada's natural gas resources (Embry and Beauchamp 2008). No exploration work has occurred in the region since the mid-1980s despite significant potential. The inactivity is a result of the extensive technical and logistical challenges that occur in drilling and transporting oil and gas in such a challenging frontier environment. Most of these georesources will remain “orphaned” until the environmental, technical and economic landscape becomes more favourable.

In 1979 a consortium of government and private companies put in place a plan to develop the large Drake Point Gas Field. The plan was to develop the Drake field first and then tie the nearby Hecla field into the project at a later date. To bring both fields online, it was assumed that 20 wells would be necessary. The field would be serviced by a pipeline to a port and transportation to markets by icebreaking LNG carriers. The numbers below outline some of the costs to bring the project online. Note that costs are in $CDN for 1979, these costs would be significantly higher using current $US.

Estimated Drake Field Development Costs

Estimated drilling capital costs: 20 wells at $CDN17.5 million per well for $CDN350 million total
Flowlines: $CDN18 million
Pipelines: 22 km at 20 inch diameter for $CDN15.9 million, 8 km at 8 inch diameter for CDN$2.8 million
Dehydration plant (1,000 MMcf/d throughput): $CDN90 million
Total field capital cost: $CDN458 million
Annual field operating costs: $CDN33 million
(Source: Milne 1979)

With such exorbitant costs, drilling in the LIA is a high-risk high-cost proposition. The return must be very high to merit investment in what still remains a geologically high-risk scenario. To alleviate this, industry is developing a number of technologies that will significantly lower drilling costs including ice roads and ice drilling pads, directional and horizontal drilling to limit the surface area of well site locations, coiled tubing drilling, and grind and inject techniques. Other technical infrastructure advances would include airstrips built of thickened ice, new icebreaker designs, ice-breaking supply boats, and floating dry docks for servicing ships on site (EIA 2013). However, arctic exploration costs far outstrip costs in more favourable conditions elsewhere in the world.

Average Capital Costs per Well in Western Canada
Excluding Oil Sands Expenditures

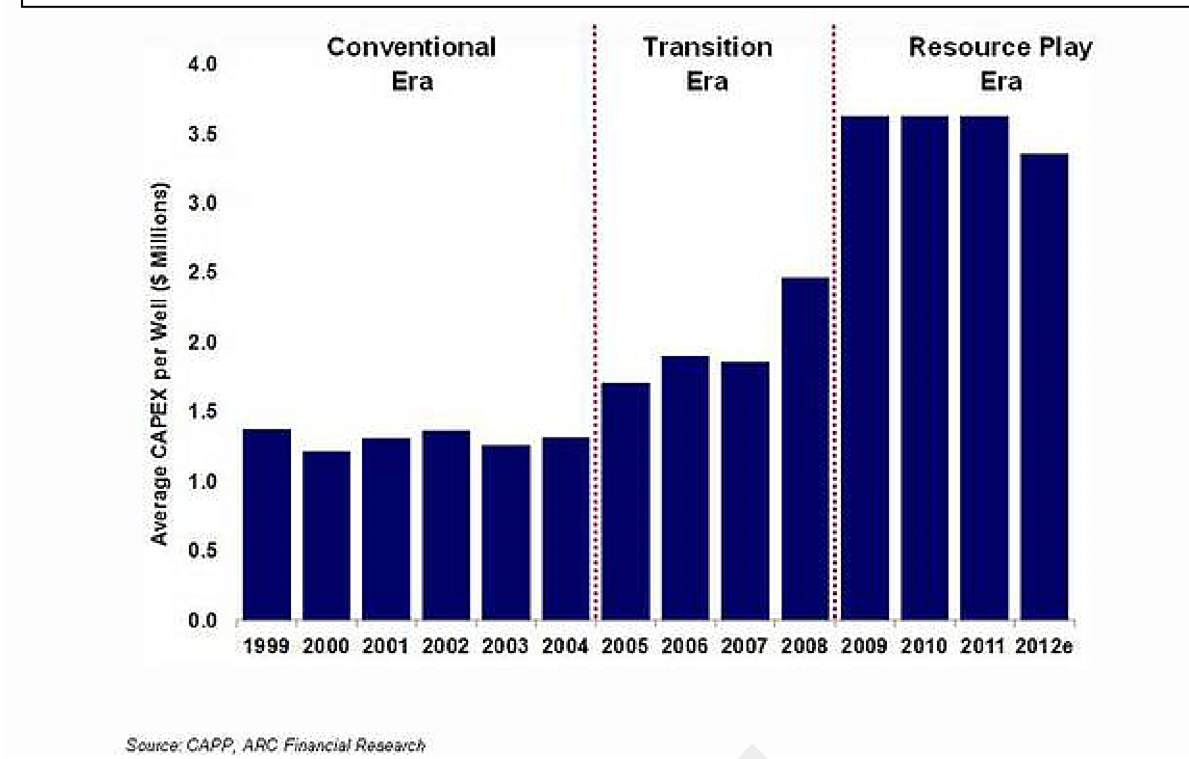


Figure 18. The average cost per well in western Canada as compared with drilling costs in the Arctic which range from $100 to $200 million per well. Source: CAPP, ARC Financial Research 2011.

6.2 Canada Royalty Costs
After submitting a winning bid on a property there are still additional costs to the operator. A royalty is a payment to the owner (in this case the Crown) of the subsurface mineral rights for the extraction of mineral ores or petroleum by private parties. Tables 7 and 8 illustrate the royalty system used for Crown lands in Nunavut. Royalties are a key factor for the calculation of exploration and production costs and have a direct impact on the likelihood of future resource activity in the LIA.

Petroleum Royalty
Royalty rates for frontier lands are specified in the Frontier Lands Petroleum Royalty Regulations of Canada. Payout status is key for determining royalty rates. Payout is a measure of when a holder has recovered the cost of their initial investment in a project, including a specified return allowance. Prior to "project payout", royalties of 1% of gross revenues are payable for the first 18 months of production, increasing by 1% every 18 months to a maximum of five percent. After recovery of initial investment (i.e. payout) the royalty is the greater of 5% of gross revenues or 30% of net revenues. The 1% to 5% royalty rate is charged in the pre-payout phase of a project (AANDC 2010).

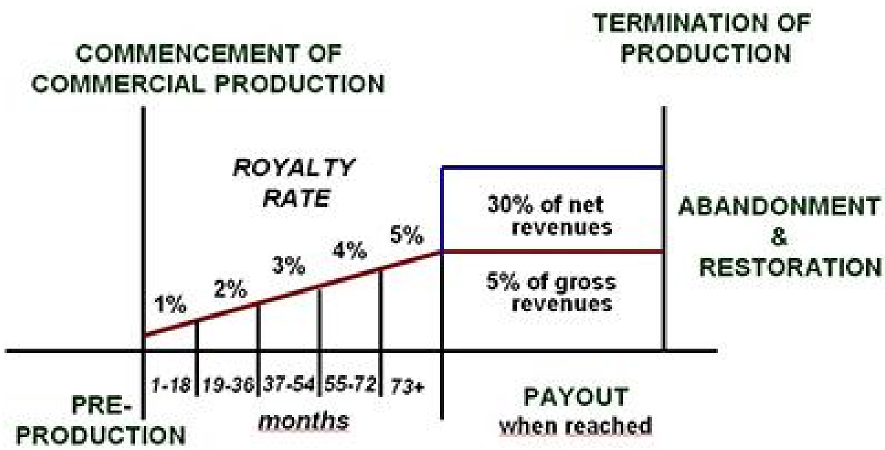


Table 7 Petroleum Royalties calculations and royalty life cycle of a Petroleum project. Source: AANDC 2010.

Mining Royalty
The royalty is a percentage of the mine's annual profit. In the regulations the profit is called the value of the mine's output. At this point the royalty corresponds to a portion of the net value of the ore being extracted, and not a portion of any additional value created by the mine owner from further processing of the ore. The profit is calculated as the mine's total revenue less the cost of mining and processing and other deductions and allowances. The royalty is directed at the value of the ore extracted and not at the value created when the ore is upgraded.

The royalty rate applied to the annual mine profit is the lesser of 13% of the total profit and the sum of the marginal royalty rates given in the table below (AANDC 2012).

Bracket	n = Value of the Mine's Output (Mine Profit)	Marginal Royalty Rate
1.	≤ $10,000	0
2.	$10,000 < n ≤ $5 million	5%
3.	$5 million < n ≤ $10 million	6%
4.	$10 million < n ≤ $15 million	7%
5.	$15 million < n ≤ $20 million	8%
6.	$20 million < n ≤ $25 million	9%
7.	$25 million < n ≤ $30 million	10%
8.	$30 million < n ≤ $35 million	11%
9.	$35 million < n ≤ $40 million	12%
10.	$40 million < n ≤ $45 million	13%
11.	$45 million < n	14%

Table 8. Mineral Royalties calculations.
Source: AANDC 2012.

6.3 Canada Regulatory Costs

A number of regulations must be followed to acquire exploration rights in Nunavut. Indian and Northern Affairs Canada (INAC) manages the regulatory process for exploration activities in Nunavut. These are added costs that are included in the expenditures for mineral development in the LIA.

Mineral Regulations

Indian and Northern Affairs Canada (INAC) reviews, records, and administers mineral claims, and issues leases and prospecting permits on Crown land (AANDC 2010).

<u>Representation Work</u>

A mineral claim only remains active if a certain amount of representation work is completed on the claim. Once recorded, a mineral claim is valid for a period of two years. The claim can be renewed to its third year if the holder does representation work valued at $4 per acre during the first two year period. A claim can be held up to 10 years if the holder does representation work for at least $2 per acre per year for each year after the first two year period.

Representation work can include:

- Stripping, drilling, trenching, sinking shafts and driving adits or drifts
- Geological, geochemical, geophysical work or other exploratory work approved by a District Geologist
- A survey of the claim approved by the Surveyor General
- Work done in constructing roads or airstrips to provide access to the claim

To file the work a holder must complete a Statement of Representation Work, pay fees of 10 cents per acre, and report to the Mining Recorder in accordance with Canada Mining Regulations.

Mining Leases
A holder can apply to lease a mineral claim if representation work of at least $10 per acre has been completed on the claim and if a legal survey of the claim has been recorded with the Mining Recorder. There are fees of $25 per claim plus the first year rental of $1 per acre contained in the surveyed claim. The holder must have a lease if they intend to sell or otherwise dispose of minerals or ore with a gross value of more than $100,000 in one year.

Prospecting Permits
A prospecting permit will allow a company to prospect in a large area without competition for a period of three or five years, and give the holder the exclusive rights to stake a mineral claim within that area. An application for a prospecting permit costs $25 plus 10 cents per acre deposit for the first work period. Then 20 cents per acre deposit for the second work period and 40 cents per acre deposit for the third work period.

Petroleum Regulations
Managing the development of oil and gas resources for Canada's federal lands in Nunavut and northern offshore areas is a federal responsibility of the Northern Oil and Gas Branch of the Department of Indian Affairs and Northern Development. These are added costs that are included in the expenditures for petroleum development in the LIA.

In Table 9 Period means a segment or portion of the term described in the license. Rental is the fee paid to the federal government for obtaining licenses for petroleum activity. The term shall be comprised of two consecutive periods of six and three years. The drilling of one exploratory or delineation well (with a Drilling Deposit of $1million) prior to the end of Period 1 of the term is a condition precedent to obtaining tenure to Period 2. Failure to drill a well on the lands by the end of Period 1 will result in the termination of the Exploration License. There is no charge for Period 1 (AANDC 2013).

Exploration License	Rental per hectare	Significant Discovery License	Rental
1st year of Period 2	$5.50	Year 1 to 5	$0.00
2nd year of Period 2	$8.00	Year 6 to 10	$50,000
3rd year of Period 2	$8.00	Year 11 to 15	$250,000
4th year of Period 2	N/A	Year 16 to 20	$1,000,000
N/A	N/A	Beyond year 20	Annual increase of $100,000

Table 9. Calculations of the rental charges for petroleum exploration and significant discovery regulatory costs. Source: AANDC 2013.

6.4 Greenland Royalty Costs

A royalty is a payment to the owner (in this case the Government of Greenland) of the subsurface mineral rights for the extraction of mineral ores or petroleum by private parties. Royalties are a key factor for the calculation of exploration and production costs and have a direct impact on the likelihood of future resource activity in the Greenland LIA. Greenland royalties include (Greenland BMP 2009):

- 7.5 % of the value of the sum total of the value of oil/condensate, or the value of natural gas determined by the price obtainable from sale in the free market of Europe
- 10 % of the value if the amount above is negative and has not been positive in any preceding year
- 12.5 % of the value shall only be calculated for an Exploitation Licence in years when the calculation basis is positive

6.5 Greenland Regulatory Costs

A number of regulations must be followed to acquire exploration rights in Greenland. The Bureau of Minerals and Petroleum manages the regulatory process for exploration activities. These are added costs that are included in the expenditures for mineral development in the LIA.

Mineral Regulations

The BMP reviews, records, and administers mineral claims, and issues leases and prospecting permits on Crown land (Greenland BMP 2013). The application procedures and standard terms have been approved by the Government of Greenland and the Danish Minister for Environment and Energy as the basis for the granting of exploration and prospecting licenses in Greenland.

At the submission of an application for an exploration license the applicant will pay a fee of $912 to BMP for each license applied for. These minimum exploration expenses are calculated for each particular exploration license as the sum of the following two components:

Period	amount per licence (US$)	amount per km2 (US$)	Total (US$)
Years 1-2	18,235	182	18,417
Years 3-5	36,471	912	37,383
Years 6-10	72,943	1,824	74,767

Table 10. Calculations of the cost charges for mineral exploration. Source: Greenland BMP 2013.

If the operator has delineated a commercially viable deposit it wants to exploit and provided the terms of the exploration licence has been complied with, the licensee is entitled to be granted an exploitation licence for a fee of US$18,235 at the granting of an exploitation licence. Other regulations and obligations must be satisfied if the license or the license areas are amended.

Petroleum Regulations

The BMP manages the regulations for development of oil and gas resources in Greenland.

<u>Prospecting Licences</u>

The Prospecting License covers hydrocarbon prospecting in the onshore and offshore license areas as indicated by the BMP. Prospecting activities include field mapping, geochemical surveys, hand samples and other low level prospecting work (BMP 2009).

The license fees are:

- A fee of US$2,734 at the granting of the licence
- A fee of US$1,367 on approval of transfer of the licence

Exploration License

If the operator has delineated commercially viable resources it wants to take to the next stage an exploration license may be applied for. Exploration work includes seismic studies and exploratory wells. Scheduled periods are agreed upon by the operator and the BMP. Fees and rentals paid to the BMP for the license are (Greenland BMP 2009):

- US$18,226 to the BMP for the issuance of the Exploration Licence
- US$36,452 to the BMP upon each extension of the Licence for the purpose of exploitation
- For each Exploitation Licence, the licensee shall pay an annual rental of US$8,229,712

The licensee is obligated to cooperate with the BMP to facilitate activities in Greenland, and to assist NUNAOIL with developing knowledge and experience for further exploration, development and production of hydrocarbons (Greenland BMP 2009).

7. Commodity Forecasting

Long-term georesource commodity price projections (Figures 19 and 20) are based on the assumption that resources will be increasingly more challenging and costly to find and develop thereby increasing the marginal cost of production. At the same time, global demand for georesources will continue to increase with the result of an overall increase of prices in real terms.

The rate of petroleum price increase is expected to ease slightly over time due to recent discoveries of new large sources elsewhere in the world (National Energy Board 2012). These include new plays in Brazil, and oil plays like the Bakken in North Dakota and Saskatchewan, and the Cardium and Viking gas plays in Alberta. The use of alternative fuel such as natural gas, oil sands and biofuels should also decrease demand.

7.1 Petroleum Forecast

Oil and natural gas price projections are based on a number of factors such as industry consultation, other industry forecasts, the increasing forward curve for prices, and the attributes of each case. The National Energy Board of Canada Energy Supply And Demand Projections to 2035 outline the calculations used for price projections. The Reference Case price projection is formulated first, and is a typical projection based on analysis of other industry price case factors (National Energy Board 2012). It reflects the current supply costs of new plays in North America such as low porosity sandstone and shale production in the Bakken play. Due to higher natural gas demand and increased production costs there will be a gradual real increase in petroleum prices over the projection period. The Reference Price projection is used to predict the other four cases' price projections based on estimated economic factors (National Energy Board 2012). The High and Low curves reflect price volatility. The Fast and Slow Cases reflect variations in hydrocarbon demand due to changes in economic factors.

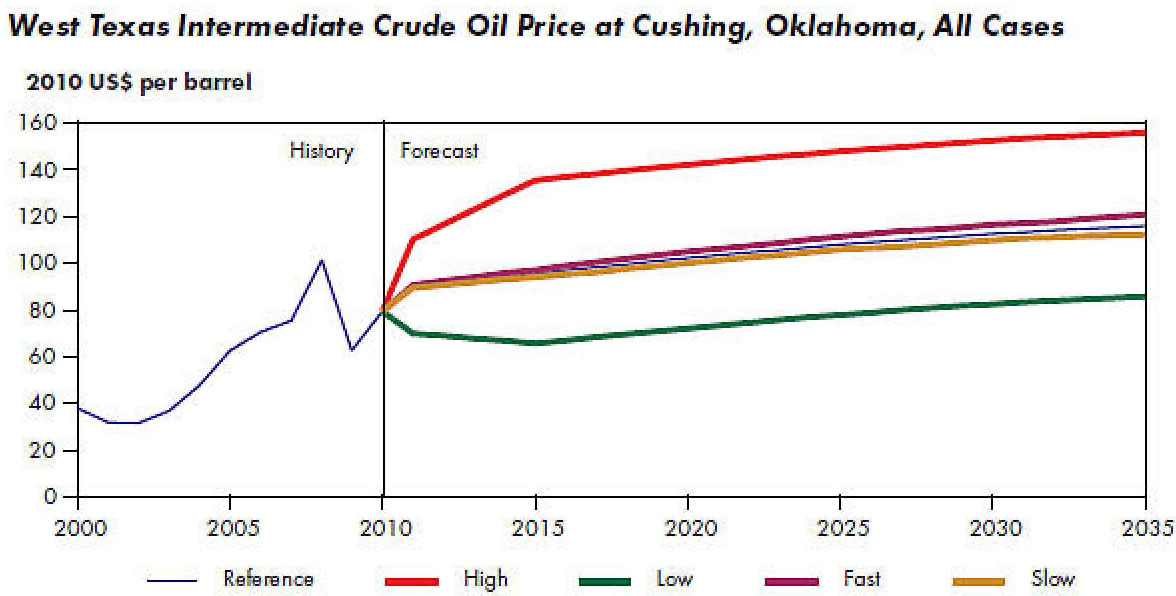


Figure 19. Predicted increase in oil prices over time to 2035. Note: West Texas Intermediate Crude Oil index is widely used as an international benchmark for crude oil prices. Source: National Energy Board 2012.

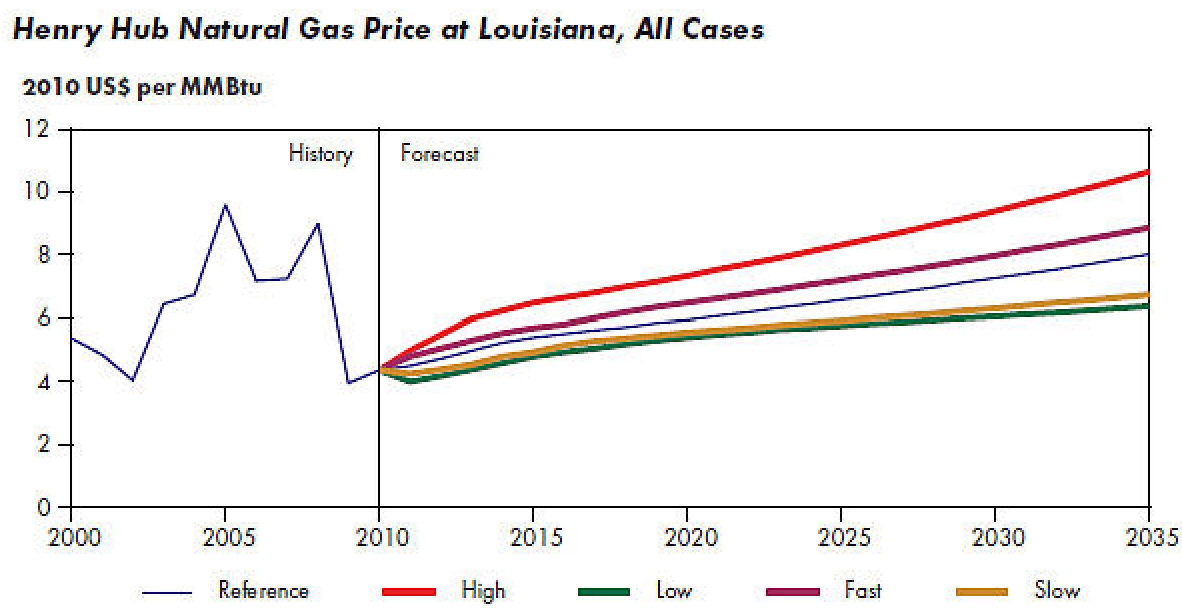


Figure 20. Predicted increase in gas prices over time to 2035. Note: The Henry Hub index is widely used as an international benchmark for natural gas prices. Source: National Energy Board 2012.

A key finding of the NEB Energy Futures report is that energy supply will grow to record levels over the projection period. The implications of oil and gas price trends on the LIA are crucial. By multiplying the projected price by the ultimate resource (Tables 3 and 4) the estimated value of the resource can be calculated. As the commodity price increases the resource will become more valuable, and the likelihood of renewed exploration in the LIA will also increase.

7.2 Zinc Forecast
Zinc demand is growing at an increased rate (Figure 21). Zinc price increases have a similar trend as petroleum prices. Corrosion-resistant plating of iron is the major application for zinc. Other uses are in batteries, alloys and dietary supplements. In the LIA there is a major zinc deposit under development at Citronen Fjord, Greenland. There a number of other zinc showings throughout the LIA and two closed zinc mines in the Canadian LIA which suggests that future exploration in the LIA will increase.

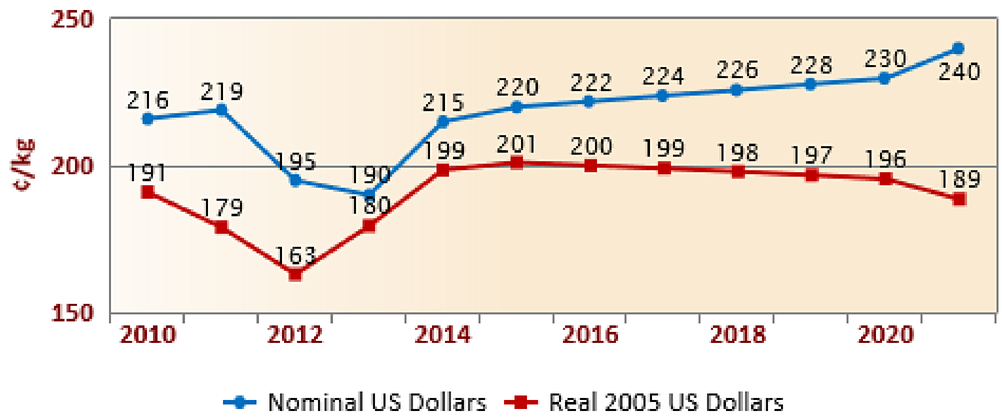


Figure 21. World Bank Zinc Price Forecast to 2025.
Source: World Bank Commodity Forecast Price data, October 2013.

8. Arctic Infrastructure

The Arctic is a harsh environment where temperatures can drop below −50°C and traditional engineering practices often fail. The extreme environment poses challenges for building and maintaining infrastructure, and the general scarceness of habitation has kept large-scale transportation networks to a minimum. The development of transportation routes and other infrastructure in the Arctic is closely linked with resource development. Development in the Arctic will require a multi-level domestic and international governance effort to construct efficient, secure, environmentally sensitive infrastructure systems that would facilitate offshore and onshore resources and local community development.

8.1 Gateway to the North
Under a national policy agenda, the Government of Canada has authorized three major trade and transportation gateways: Asia-Pacific region, Atlantic region, and the central Ontario/Quebec region (PPM 2010). The formation of a future Arctic Gateway under the current federal government policy framework requires meeting policy criteria such as growth potential and significance for contributing to national objectives (National Arctic Gateway 2012).

The Nunavut Transportation Strategy 2001 document makes reference to Nunavut's connections to transport corridors and new international trade opportunities. The Nunavut Government recommended several priority projects in the strategy that include provision of search and rescue response capability; environmental crisis response; major deep water ports at Iqaluit, Rankin Inlet, and Bathurst Inlet; major airport developments at Iqaluit, Rankin Inlet and Cambridge Bay; and connection with the National Highway System through Bathurst Inlet and Manitoba.

The establishment of the Arctic Gateway is critical for an emerging long-term northern development strategy of Canada. The investments in northern transportation infrastructure and the careful development of international Arctic shipping and economic activity now within the gateway framework will have significant payback for Canada in the immediate future and in decades to come by opening the north to economic development (Nunavut Transportation Strategy 2001).

8.2 Greenland Infrastructure

Greenland faces similar challenges for transportation and infrastructure. The Greenland government and private operators have established a consortium to address further economic growth and socio-economic development at Qaasuitsup, Northern Greenland. This will include expansion of the existing airport, construction of a new harbour and office buildings to support onshore and offshore services in 2014 to 2018 (Greenland Government 2013).

Ironbark Zinc Limited has delineated a major lead-zinc deposit at its Citronen Fjord site in northeastern Greenland. The company is constructing open pit and underground mine facilities including a processing plant, port, roads, tailings and water management and other infrastructure at the mine site (Ironbark 2011).

8.3 Arctic Resource Development and Environmental Change

The Arctic is a significant supplier of geological resources to the global market, and changing Arctic conditions will have both positive and negative financial impacts on the exploration, production, and transportation activities of this industry.

Climate change impacts on oil and gas development have been minor to this point, but may result in future financial costs and benefits. For example, offshore oil activities are likely to profit from thinner and less extensive sea ice because of cost reductions in the construction of platforms that must withstand ice forces. Conversely, ice roads used for access to onshore activities and facilities, are likely to be operational for shorter periods and be less safe than at present. The thawing of permafrost will adversely affect structures and increase the cost and maintenance of buildings, pipelines, airfields, and coastal installations which support petroleum activities (International Arctic Science Committee 2010).

The coal and mineral extraction industries in the Arctic are important to national economies, and the actual extraction process may be less affected by environmental conditions. However, changing ice conditions will possibly affect the transportation to market of coal and minerals. Mines that ship their ore via marine transport such as the Mary River iron ore project on Baffin Island are likely to incur lower costs due to reduced sea-ice extent and a longer shipping season. Conversely, mining services that have infrastructure on permafrost are likely to experience higher construction and maintenance expenses as the permafrost thaws.

Any future geological resource exploration and development activities in the LIA would require expansion of air, marine, and land transportation systems. As a result of a longer shipping season and transit through the Northern Sea Route and Northwest Passage cost reduction will be significant. Other changes may include deeper drafts in harbors and channels as sea level rises, a reduced need for icebreaker support and a lower requirement for strengthening of ship hulls and offshore oil and gas platforms. Conversely, coping with heightened storm activity associated with an increase of open waters, greater wave heights, and possible flooding and erosion threats to coastal facilities, are likely to result in increased costs (International Arctic Science Committee 2010).

8.4 International Standards Organization

ISO 19906:2010, adopted by the Arctic Council and Canada in 2002, specifies requirements and provides recommendations and guidance for the design, construction, transportation, installation and removal of offshore structures in the LIA and other cold regions. The objective of ISO 19906:2010 is to ensure that offshore structures in the north provide an elevated level of dependability with respect to personnel safety, environmental protection, and asset value to the owner, the industry and to society. The ISO 19906:2010 Arctic Offshore Structure standard is not mandatory for companies, unless made so by a regulator or by industry self-regulation. The ISO 19906:2010 endeavours to harmonise existing regional, national and international codes and standards and also update the provisions to include the latest agreed upon knowledge and technologies (ISO 2010).

ISO 19906:2010 focuses on important Arctic factors and on how the standard can be used in conjunction with other ISO offshore structural standards. Topics covered include features of Arctic and cold regions; when the standard should be implemented; types of ice actions and how they should be applied; ice actions in conjunction with other physical environmental conditions; manmade islands; subsea installations; ice data collection; monitoring; interpretation and analysis; ice management systems and operational aspects of Arctic structures; and low temperature materials and equipment (Blanchet et. al., 2011).

The harsh Arctic environment of the LIA creates a number of challenges. Marine icing on exposed surfaces, sea ice and icebergs hazards, structural vibrations as a result of ice actions, ice rubble encroachment, and ice build-up from icebreakers will adversely affect operations in the LIA. In many cases, special procedures are required for operations in extreme environmental conditions that need to be factored into design and cost estimates.

8.5 Transportation and Navigation

An increase in Arctic shipping through the LIA is expected by 2020, due to a surge of ecotourism voyages and the development of several large-scale mining projects such as Citronen Fjord in northeastern Greenland and the Mary River project on Baffin Island. By 2050, Arctic shipping in LIA waters could increase by a factor of six, if large-scale georesource production occurs (CIGI 2013). As maritime activities continue to increase, the levels of resupply to northern communities will also increase as populations grow. Problematically, only 10 percent of Canada's Arctic waters are charted to modern standards, according to the Canadian Hydrographic Service, and few navigational aids are available (Humbert and Raspotnik 2012).

New technology such as ice management systems provide more efficient ways to conduct operations by extending the operating season while mitigating ecological, environmental, and safety risks. Systems for ice management address the complex challenges associated with operating in the harsh but fragile Arctic environment and provide ice visualization, analysis, tracking and risk mitigation tools for offshore Arctic operations (Ion Geophysical 2013).

In 2007, the Canadian government said it would address the lack of deepwater port infrastructure in the Canadian LIA by committing $100 million dollars to turn the port at the old Nanisivik mine on Baffin Island into a deepwater facility. Due to budget constraints in March 2013 the government announced a major downsizing of northern development leading to a reassessment of infrastructure investment (CIGI 2013).

The increasing gap between service requirements and capabilities, such as equipment transportation and spill response measures, in the LIA highlights the concerns of resource operators. The lack of infrastructure including road and rail networks, deepwater ports, paved runways, geology and topographic maps —impedes safe transportation, and makes exploration and resource development extremely difficult, risky and more expensive.

One of the Arctic's most important contributions to the northern Canadian and Greenlandic economies will be the Trans-Arctic waterways. Arctic states have recognized that the new waterways will be an opportunity to re-define their national boundaries and expand commercial operations. Three potential Trans-Arctic routes are being considered for formerly inaccessible regions (Figure 22). The shortest comparable routes, for instance, through the Panama or Suez Canals, or around the Cape of Good Hope, are more than twice the distance of the longest Arctic route (Parliament of Canada Info Series PRB 08-07E, 2008). The Northwest Passage route transits the LIA and will be crucial for future georesource activities.

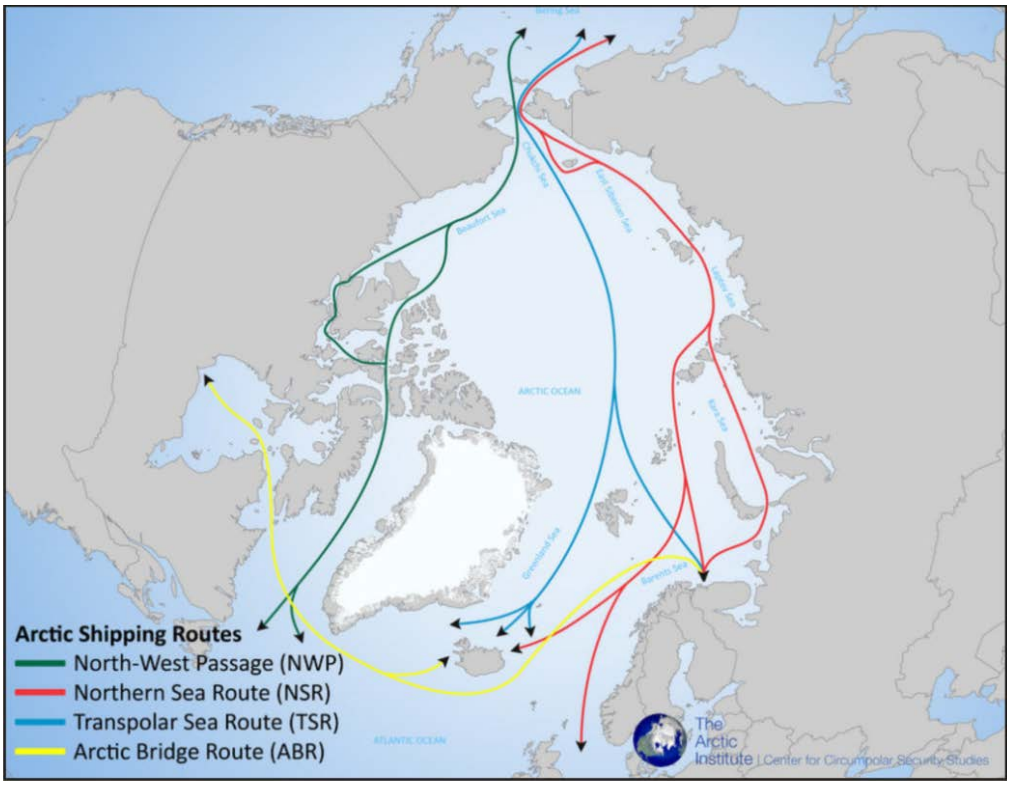


Figure 22. Polar view of the major trans-arctic shipping routes. The Bering Strait is a natural choke point for shipping. Source: Humbert and Raspotnik 2012.

As cited in the Ottawa Citizen, January 4, 2014 the future may be here now. Most studies suggested that commercial shipping through the Northwest Passage would not occur for many years yet. However, in September 2013 the Danish owned Nordic Orion bulk carrier made history when it hauled 15,000 tonnes of coal from Vancouver to Finland through the North West Passage. It took four days less than it would have by transiting the Panama Canal and the greater sea depths allowed the Orion to carry 25% more coal. Shipping through the passage saved the company $200,000.Talks are underway between Transport Canada and various shippers to increase such voyages. Unlike Russia, where shippers have more than 400 ice class carriers, Canada has not made upgrading Arctic infrastructure and shipping activities a priority. To take advantage of newly open Arctic shipping lanes Canada and Greenland must make significant investments in shipping facilities and define regulations required for safe transportation through the LIA.

9. Environmental Impact of Resource Development

Predicted decreases in sea-ice cover may result in increased exploration activity in the LIA due to easier access. Permafrost thaw and snow cover changes require lower impact vehicles and changes in the scheduling of exploration work (Muir 2012). Future continuation of development in the LIA requires discussions between businesses, governments, northern communities on climate impacts, adaptation and mitigation needs to assess and respond to environmental impacts and vulnerabilities.

Figure 23. Melting glaciers on Axel Heiberg Island, Nunavut.
Source: Dr. Schroder-Adams, Carleton University.

Potential Environmental Impacts
Georesource exploration activity requires power generation, transportation and infrastructure development, together with an attendant increase of workers. Environmental impacts may sometimes be far removed from the source, for example contamination of watercourses, or changes in land-use, as a result of construction of access routes. It is important to consider immediate, short-term impacts as well as long-term, indirect and cumulative results from separate, but linked operations (IUCN 1993). The impact of spills in the LIA will be discussed in Chapter 11.

1. Air Quality Impact

Due to atmospheric factors the Arctic may experience high local levels of air pollution as a result of temperature inversion. Sources of atmospheric emissions are:

- Flaring, venting and purging of gases
- Engine combustion such as diesel engines and gas turbines

- Fire protection systems
- Summer road transportation
- Gas losses during drilling or geological events

2. Hydrological Impacts

Groundwater and surface water protection are major issues in both Arctic and subarctic regions. Activities such as excavation and infill can alter watercourses and drainage patterns, which in turn, can change vegetation and wildlife patterns. Operational activities can also introduce contaminants to the hydrological environment. The main impacts on the hydrological system from LIA resource operations are:

- Introduction of industrial water to the environment
- Contamination of ground and surface water by drilling fluids and oil leaks
- Sewage and domestic waste water management

3. Impacts on Soil

Thermal stability of the permafrost layer in LIA and Arctic regions directly affects ecosystem sensitivity. Soil type and the quantity of ice in the soil will determine the extent of disturbance. Soils are particularly vulnerable to degradation and changes in temperature and human influence can reshape the landscape. Peat at the surface provides an insulating layer for underlying permafrost layers. Disruption, compression or clearing of the peat layer during exploration and production activities would decrease the insulating effect, thus altering the heat balance and resulting in permafrost degradation (Muir 2012). Major potential effects of geological resource development on soil include:

- Soil compaction
- Erosion caused by slope angle and water pooling during construction
- Changes in drainage patterns near infrastructure
- Contamination from operational emissions, leakage, site drainage and spills

4. Impacts on Biological Diversity

Consideration of impacts from georesource operations on biodiversity is important in the circumpolar region. With only a small amount of vegetation in the Arctic, further loss or alteration by infrastructure construction can be critical. The use of winter trails may result in submersion of peat, bog, moss and lichen communities. Extensive modifications of vegetation cover can disturb permafrost stability, since evapotranspiration from vegetation at ground level is one of the important factors for balancing the heat budget and maintaining permafrost (Arctic Environment Ministers 2013).

Damage to vegetation would adversely affect nutrient cycles, eliminate the organic litter layer, accelerate the rate of soil loss through erosion and disrupt the availability of wildlife habitat. Animal populations are influenced by changes in vegetation, soil, water and noise. Ecosystem alterations would affect, for example, animals' habitats, food supplies, breeding areas, migration routes, or grazing patterns (IUCN 1993).

Important factors for evaluating the effects of georesource activity on biodiversity include:

- Vegetation or soil destruction
- Erosion and modification of soils
- Local and regional extinction rates
- Changes in topography or hydrology

The Arctic Islands are critically important for migrations of whales, birds, and fish, yet there is little understanding of how industrial development and climate change will affect these. The effect of dwindling Arctic snow, sea ice, and glaciers on global sea levels, weather patterns, and fisheries are currently being studied. This deficiency of basic scientific knowledge and lack of data present a challenge for both resource and environmental interests.

10. Effects of Arctic Climate Change

A significant amount of georesources occur offshore in the LIAs shallow and biologically productive shelf seas. Any effects of resource development will have to take into account present and future climate impacts that may increase the vulnerability of Arctic ecosystems and species.

10.1 Snow, Water Ice and Permafrost in the Arctic

When added to the Arctic Climate Impact Assessment (ACIA 2008), the Arctic Council's report: Snow Water Ice and Permafrost in the Arctic (SWIPA), is the most comprehensive compilation of scientific knowledge on the impacts of climate change on the frozen parts of the Arctic (AMAP 2012). The observed recent changes in sea ice and in the mass of the Greenland ice sheet and Arctic ice caps and glaciers are dramatic. Some of the major SWIPA findings as detailed in AMAP 2012 are:

- Warming of the Arctic has been double that of the global average since 1980. Arctic summer temperatures are higher than at any time in the past 2,000 years.
- Virtually all frozen parts of the Arctic are affected by warming. Permafrost temperatures have increased by up to 2°C, and nearly all glaciers and ice caps in the Arctic have been declining faster since 2000 (Figure 25).
- There have been fundamental changes in Arctic ecosystems and in some cases loss of entire habitats.
- Transportation options and access to resources have been adversely affected. Arctic infrastructure faces increased risks of damage due to temperature fluctuations and permafrost reduction.
- The Arctic continued to break records in 2012. Some of the important results conclude that the minimum Arctic sea ice extent in September 2012 set a new record low. The nearly ice sheet-wide melt event on the Greenland ice sheet in July 2012, covered nearly 97% of the ice sheet on a single day (Figure 26).

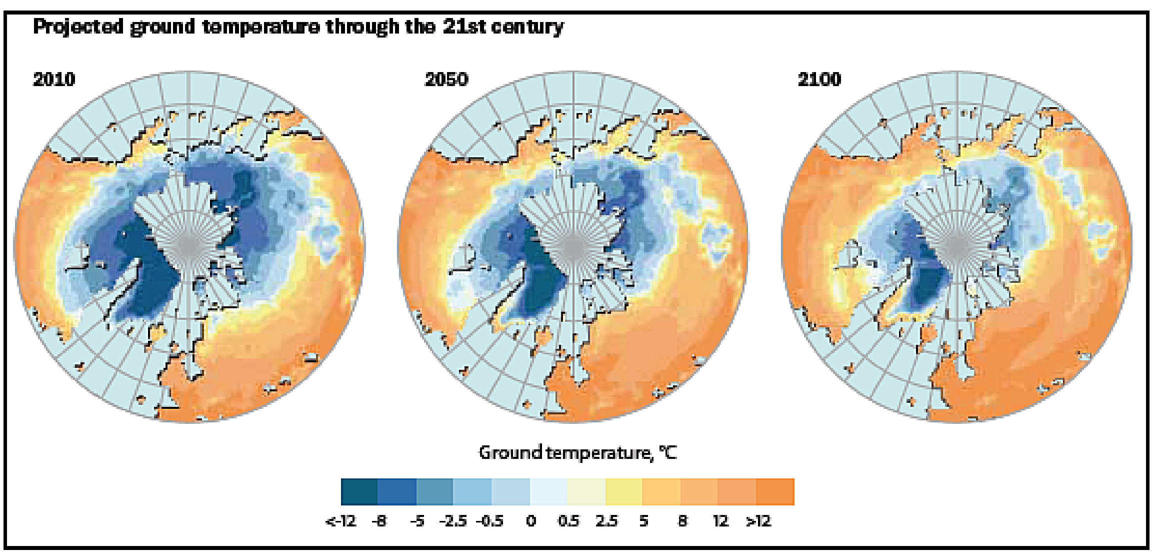


Figure 24. Projected increase in ground temperature through 2100. As the ground temperature increase permafrost, sea ice and glaciers begin to melt.
Source: AMAP 2012.

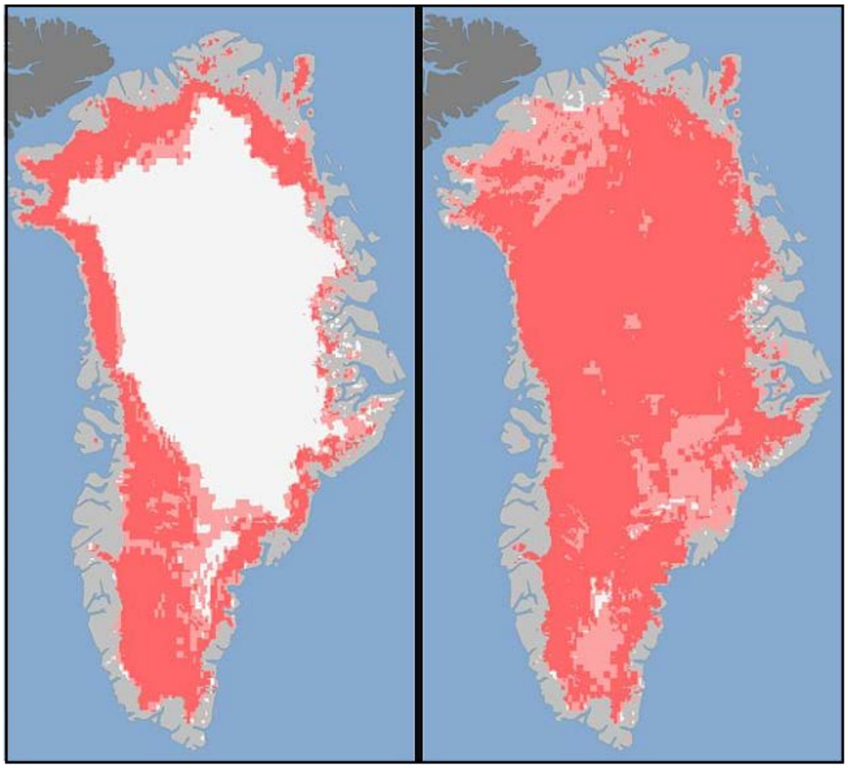


Figure 25. Shades of pink represent melted ice in satellite pictures of Greenland taken July 8, 2012 (left) and July 12, 2012 (right). After just a few days of intense melting nearly the entire surface of Greenland's massive ice sheet had turned to slush, NASA images show—the fastest thaw rate since satellites began tracking the ice sheet 30 years ago.
Source: National Geographic 2012.

Possible future developments are also described in the SWIPA assessment (ONS 2012). The autumn-winter average temperatures are projected to increase by between 3°C and 7°C by the late twenty-first century (AMAP 2012). Precipitation is estimated to increase throughout the year, but particularly in winter. However, mountain glaciers and ice caps are projected to lose between 10 and 30 percent of their total mass by 2100 despite increased precipitation. The Arctic Ocean, except the LIA, is predicted to be nearly ice free in the next 30 to 40 years (AMAP 2012).

There is now evidence of a number of potential Arctic feedback mechanisms and critical tipping points that affect the earth system. One example is the interaction of snow and sea ice with the climatic system. As highly reflective snow and ice surfaces are diminished, darker surfaces will absorb more of the sun's energy and increase the warming trend (AMAP 2012). Examples of other such potential tipping points due to the collapse of the Arctic summer sea-ice are increasing melt rate of the Greenland ice sheet, release of methane gas from melting permafrost and possibly alterations of the thermohaline circulation. SWIPA projects global sea level will rise by 0.9 to 1.6 m by 2100 (ONS 2012).

10.2 Arctic Ocean Acidification

As carbon dioxide in the atmosphere increases it dissolves into surface waters and creates carbonic acid which in turn increases ocean acidification. Other changes in the Arctic (melting permafrost and the decay of terrestrial organic matter) amplify acidification. As a result, the magnitude of ocean acidification is more pronounced in the Arctic than in other oceans. Expanding low oxygen areas, lower salinity, rising seawater temperatures are together shifting environmental domains in the ocean (AMAP 2012).

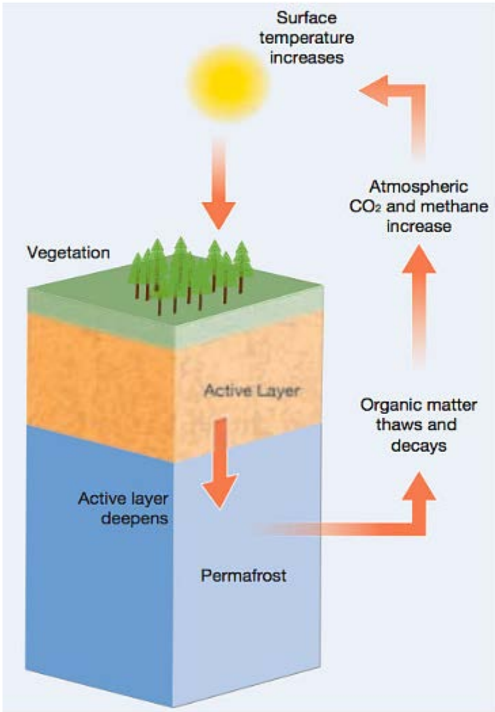
10.3 Climate Change Impacts for the Arctic

Climate change throughout the Arctic and the circumpolar region will affect energy and mining activities and associated terrestrial and marine infrastructure. Some significant climate impacts are:

Energy - Access to some offshore and onshore LIA regions may improve as a result of a retreat of the ice cap associated with warming Arctic environments. Sea ice mobility may improve access to some parts of the LIA but may also increase unpredictability of ice movement (Oceans North 2013). Pipelines will be affected by changes in ground thermal regime, drainage and terrain stability, all of which may be due to climate warming over the lifetime of a georesource project. In turn, there is the need to closely monitor the performance of the pipeline right-of-way to maintain pipeline integrity and minimize environmental problems (Muir 2012).

Mining - Mining projects and the associated integrated land and marine transportation networks may be more viable due to sea ice decline. Climate change will affect engineering design, operations, and closure and abandonment of mines. Re-supply of mining activity is generally limited to winter months in the LIA and the availability of ice roads, while field exploration is restricted to air access in the summer. If ice roads deteriorate substantially, construction of costly all season roads or marine transport will be necessary. The impact of warming on permafrost and ground conditions will affect the stability of waste-rock masses, tailings piles and tailings-containment impoundments that all depend on permafrost to ensure that contaminants and acid-rock drainage are not discharged to the environment (IUCN 1993). For facilities located on river channels or coasts, like the Mary River mine on Baffin Island, additional factors such as coastal erosion and sea-level rise, river-ice break-up and ice-jam flooding must be planned for.

Infrastructure - Permafrost presents challenges for the design, construction and operation of infrastructure throughout the circumpolar region. Thawing of the ground can lead to loss of structural strength and an increase of settlement and instability. The damage to insulating vegetation and other ground disturbances can increase the rate of warming and resultant degradation of permafrost. Additional warming may occur from heat inherent with mine operations such as building heat and water, sewage and hydrocarbon pipelines. Structural settlement and slope instability of runways, roads and pipelines, may also result from environmental modifications (Muir 2012).



Time taken for permafrost to reach depth

Time (yr)	Permafrost depth
1	4.44 m (14.6 ft)
350	79.9 m (262 ft)
3,500	219.3 m (719 ft)
35,000	461.4 m (1,514 ft)
100,000	567.8 m (1,863 ft)
225,000	626.5 m (2,055 ft)
775,000	687.7 m (2,256 ft)

Figure 26. Permafrost Cycle – As surface temperature increases the active permafrost layer deepens and the permafrost layer thaws. During the thaw part of the cycle entrained organic matter thaws and decays resulting in an increase of atmospheric CO_2, methane and temperature. As surface temperature rise the rates of thaw increases. The chart on the right demonstrates the amount of time required for permafrost to freeze to depth.
Source: modified after https://www.google.ca/search?q=permafrost+images

Climate warming presents future challenges for resource development and infrastructure design in the LIA. Global climate changes become significant over longer time scales while short term impacts from ground disturbance and construction will occur immediately. Failure to properly design exploration sites and infrastructure for changing environmental factors can have serious economic and environmental consequences.

11. Hydrocarbon Spills

The main environmental concern for petroleum exploration in the LIA would be the chance of a large scale oil spill. When an offshore accident occurs, weather conditions and the tremendous distances involved will delay response action and restoration efforts for weeks and even months. Oil masses persist in Arctic environments longer than anywhere else. The climate conditions that characterize the Arctic – sea ice, sub-zero temperatures, high winds and seas and poor visibility – will influence the effectiveness of clean up strategies and oil recovery (Potter et.al. 2012).

Oil spills in and under ice in the LIA constitute a distinct challenge. Operational discharges from offshore activities in Arctic waters are not expected to add significantly to the total load of hydrocarbons which are naturally carried into the region through oceanic circulation. Sea birds, some marine mammals, and fish larvae are particularly vulnerable to larger oil slicks, so the ecological severity of a spill in the environment will depend on its timing and location relative to patterns of breeding, spawning and species massing. Onshore petroleum activities may create physical disturbances such as habitat fragmentation associated with pipelines and roads (Potter et. al. 2012).

Large oil spills from Arctic shipping, including bunker fuel from cruise ship based tourism are major threats. Harsh weather conditions, pervasive ice, limited hydrographical and bathymetrical charting, as well as remoteness from emergency response centres are factors that will affect maritime transport (ONS 2012).

The current technologies and infrastructure for recovery of oil from the surface perform poorly in high waves and rough weather conditions, and ocean currents will spread the pollutants over extensive areas. In the Arctic, low temperatures and scarce sunlight over much of the year will slow evaporation rates as well as the physical, chemical and biological breakdown of pollutants (MMS 2007). Thus, hazardous compounds released during an emergency may remain in Arctic ecosystems for long periods of time, aggravating the risk of bioaccumulation.

But perhaps the most critical threat may come from a single-hulled, crude oil tanker operated by a company that wants to save time and money by taking a shortcut through the Northwest Passage. If that ship is grounded or is crushed by melting ice, it could make the two-year, $2 billion clean-up of the Exxon Valdez look insignificant.

Experts all agree that at the present time Canada and Greenland are not equipped to handle such a catastrophe. With no Arctic seaports or roads, a lack of Arctic naval presence, and few and small airports from which to stage recovery programs, all combine to create complications when mounting an effective response. Many critical issues must be addressed concerning the ability to effectively respond to an Exxon Valdez size disaster in the LIA, where enormous volumes of ice and water flow through dozens of channels (Struzik 2008).

In 2011 the WWF produced a comprehensive paper on spill response, mitigation policies and liability recommendations. The current design of Arctic offshore liability rules leaves governments, taxpayers, communities and the environment vulnerable in the event of a significant spill. These rules are important not only because of how they shape and limit any claims for compensation (post-spill), but also because of how they create incentives for offshore companies to avoid excessively risky activities.

11.1 Oil in Ice Covered Waters

Strategies and techniques for dealing with oil in ice have been studied intensively by industry and government groups in the polar states. These reports address the fate and behavior of fresh and emulsified crude oil and gas, in a variety of ice conditions. Figure 28 illustrates the effect of oil in ice covered waters in the LIA.

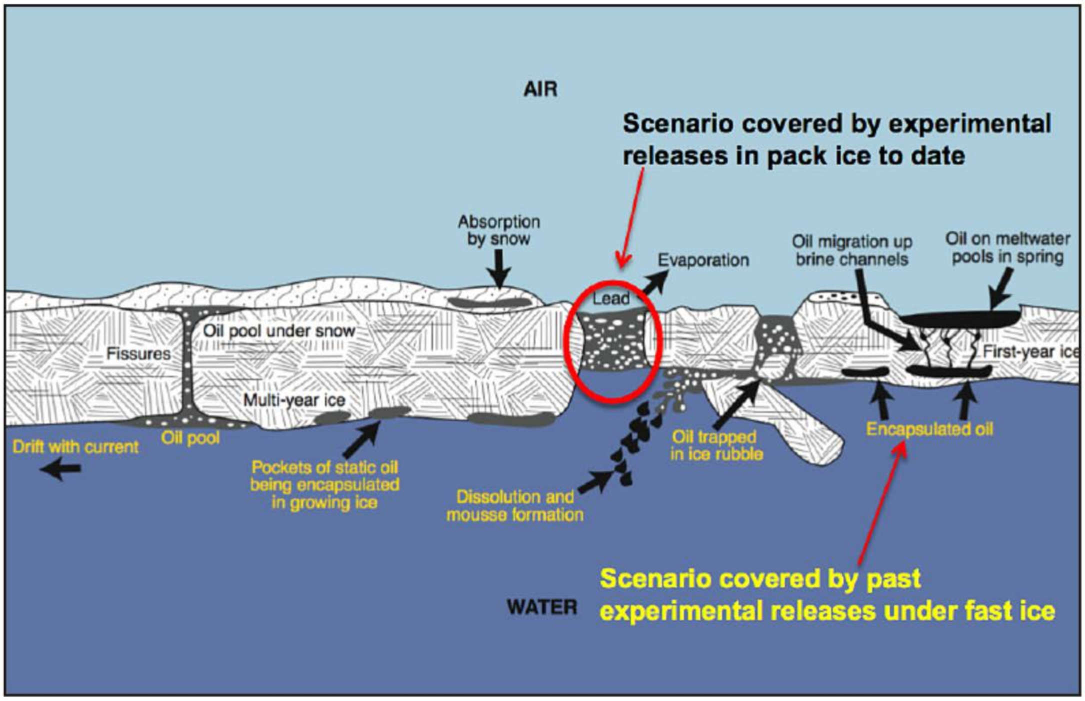


Figure 27.The diagram illustrates the relationship between oil and ice and snow. There are many complex interactions that affect the spread and recovery of oil spills in the Arctic that are absent in more temperate conditions. Source: Glover and Dickins 1999.

Spreading - In the cold Arctic waters of the LIA, oil spills tend to spread less and remain slightly more viscous than in more temperate waters such as the Gulf of Mexico. However, spreading of oil is dramatically reduced by the presence of ice and snow. In general, the spread of oil spilled under stable ice is based on currents and projected under-ice storage capacity as shown above. Currents in the LIA are strong and thus may spread oil over greater distances (Allen and Nelson, 1981).

Evaporation - Evaporation of the volatile components of oil occurs when the oil rests on the water or ice surface. Evaporation rates of oil slicks are influenced by winds, slick thickness and temperature. Laboratory testing of oils from the North Slope of Alaska show that the initial evaporation rate within the first 48 hours of a spill ranges from 16% to 30% depending on the type of oil tested (Arctic Response Technology 2012).

Dispersion - Dispersion is a process that occurs when small oil droplets are forced under the surface by waves and turbulence and remain suspended in the water column. Dispersion rates are affected by sea conditions, oil viscosity, interfacial tensions, and emulsification of the oil. The natural dispersion of a slick is generally decreased by the formation of stable water in oil emulsion.

Entrainment and rapid immobilization - Oil leaked beneath growing ice is rapidly immobilized and integrated into the ice structure and all weathering processes are essentially halted (Allen and Nelson 1981; Dickins and Buist 1981). Therefore, when response teams pump or burn oil from a trapped layer beneath or within the ice, they will be handling virtually fresh oil, even months after the spill occurred.

Ice storage - Variations in ice thickness provide natural basins that effectively contain oil beneath the ice within a small area. Surveys in late winter near Prudhoe Bay report that under-ice storage capacities are estimated to be as high as one million barrels per square mile (Glover and Dickins 1999). It is suggested that a mid-winter spill that may occur beneath the ice would be naturally contained within a relatively small area when compared to a similar size spill in open water.

Vertical migration - Oil encapsulated within or trapped beneath the ice will begin a vertical migration through the ice sheet in the spring months (Potter et. al. 2012). As conditions warm, and break up continues, oil will naturally rise to the surface. Response strategies can then be scheduled to handle a spill trapped within the ice during the previous winter months.

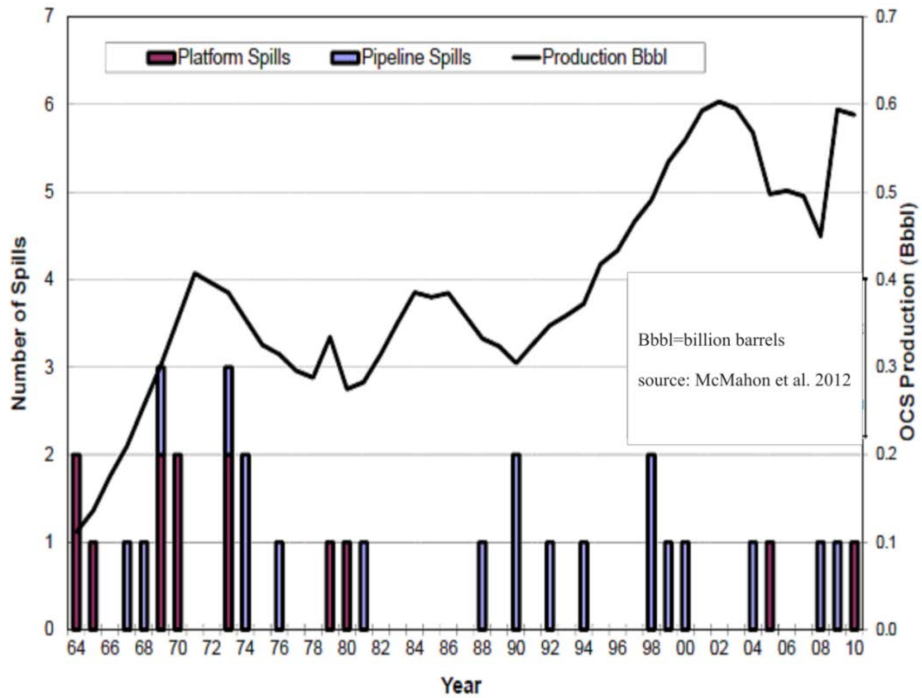
11.2 Oil and Ice Spill Response

The large body of knowledge gained from real spills, experimental field slicks, tank tests, and scientific studies has led to the development of a number of response strategies and options to handle the wide range of nearshore and offshore conditions if petroleum exploration resumes in the LIA (EPPR 2011). Arctic spill contingency plans emphasize multiple countermeasure options to manage a variety of spill situations. Proven techniques include in situ burning in ice and fire-resistant booms in open waters as well as mechanical recovery with modern containment and recovery equipment (Potter et. al. 2012).

Each Arctic season has distinctive challenges and advantages for responding to a spill. During freezeup and breakup, drifting ice and limited site access will restrict response options and may substantially reduce recovery effectiveness (EPPR 2011). Long periods of darkness and cold temperatures in mid-winter hampers spill response activities but create a stable ice cover that naturally contains oil within a relatively small area and provides a safe working platform for oil recovery and transport (Potter et. al. 2012). In the summer, ice free waters provide the advantage of proven response techniques but introduce the problems of wind and wave actions and the challenge of containing an extremely mobile target (Arctic Response Technology 2012).

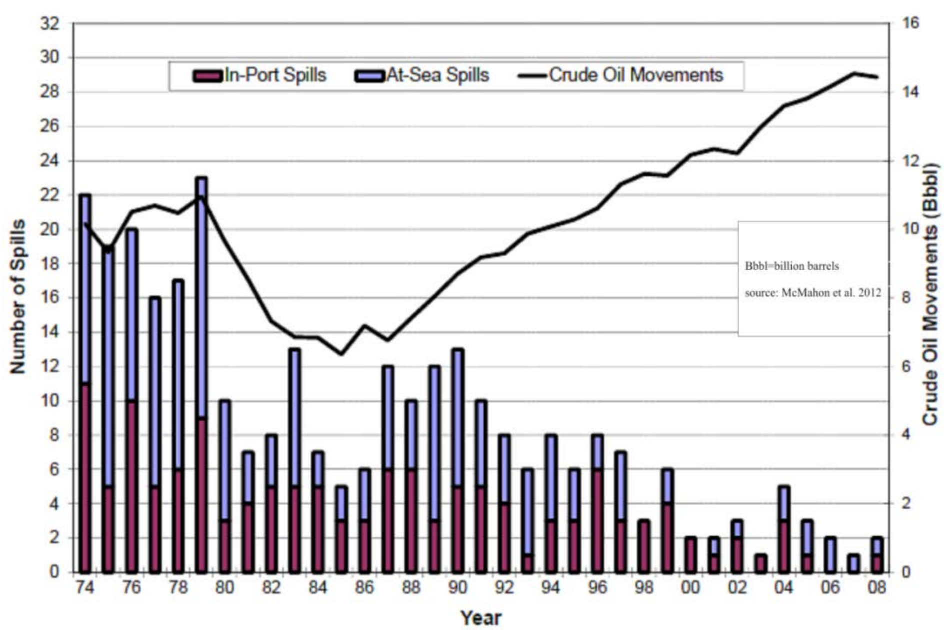
Spill response is demanding under any circumstances, and Arctic conditions impose additional environmental and logistical challenges. At the same time, unique aspects of the Arctic environment can in some instances be more to the responders' advantage than in many ice-free waters (Potter et. al. 2012). Solid ice naturally contains and immobilizes oil for up to 230 days per year giving response crews time to design and implement a plan for managing discharges (Arctic Response Technology 2012).

With advancement of spill containment and recovery technology, scientific knowledge, and social and brand awareness the actual spill occurrence rate has dramatically decreased over the last few decades (Figures 29 and 30). Oil spill cleanup in the Arctic environment will never be a simple operation and the rich and unspoiled ecosystems of the LIA will always be at risk from industrial activity.



OCS Oil Production vs. Petroleum Spills ≥ 1,000 Barrels from OCS Oil and Gas Operations, 1964 through 2010

Figure 28. The chart documents a significant decrease in platform and pipeline oil spill occurrences measured against US Outer Continental Shelf (OCS) hydrocarbon production. Source: McMahon et. al. 2012.



Crude Oil Spills ≥ 1,000 Barrels from Tankers Worldwide vs. Crude Oil Transported Worldwide, 1974 through 2008

Figure 29. The chart shows oil spill occurrence when measured against worldwide tanker movement. Since the 1970's there has been a remarkable drop in shipping spill rates. Source: McMahon et. al. 2012.

12. Discussion and Conclusions

As it assumed the chair of the Arctic Council in 2013, Canada stated its top priorities for Arctic development as: responsible Arctic georesource development; safe Arctic shipping; and sustainable circumpolar communities. These are common themes for all Arctic states. Canada's adaption of these priorities faces enormous cost and operational barriers. Development of this nature is increasingly discussed because the retreat of Arctic summer sea ice is making development on the fringes of the Arctic Ocean more feasible. By the same logic, the area where summer sea ice is projected to persist the longest, the Last Ice Area (LIA), is where development is likely least feasible. As part of its research to frame potential management options for this ecologically valuable area, WWF has commissioned an independent report on the geological resources of the area, and the likelihood of their development.

Large known and predicted hydrocarbons occur in the LIA although there is no current exploration or production except for some seismic surveys by Conoco south of the Greenland LIA. Most of the past exploration emphasis has been in the Paleozoic and Mesozoic strata in the central Sverdrup Basin. Future exploration may test the play fairways along the southern rim of the Sverdrup Basin and the Arctic Fold Belt where there is significant hydrocarbon potential.

In the Greenland LIA hydrocarbon potential occurs in major offshore sedimentary basins, notably the large basins offshore west Greenland and east Greenland. To date no fields have been discovered and no commercial development occurs on the Greenland continental margin. Assessment studies indicate that there is significant potential for large resources in the offshore basins particularly in the West Greenland-East Canada Province.

The geological setting of the LIA naturally favours hydrocarbon georesources over mineral resources. The latest known period of widespread mineralization in the area predates the Paleozoic sedimentary rocks, therefore rocks of this age or younger may be discounted as sources of metalliferous deposits. Most of the mineral exploration activities occur in Archean rocks in the southern part of the LIA particularly on Baffin Island where the geology is more conducive for mineralization. A number of zinc-lead deposits and occurrences have been delineated in the Greenland part of the LIA with the Citronen Fjord deposit being in an advanced stage of exploitation. The Mary River iron ore project on Baffin Island is scheduled to begin commercial production in 2014.

There are many technical and environmental obstacles which will complicate Arctic and LIA development. Technical challenges arise from extreme climatic conditions that necessitate specific requirements for equipment, materials and construction operations. Environmental concerns are particularly associated with accidents and pollution that may damage delicate Arctic ecosystems and local people's livelihoods. The main obstacle, however, is the lack of sufficient infrastructure to confirm viability, economy and safety of LIA operations.

Climate warming presents challenges for resource development and infrastructure design in the LIA. Georesource activity is likely to experience savings due to reduced sea-ice extent and a longer shipping season. However, continued warming will increase the rate of permafrost thawing which in turn will alter ground conditions. This will adversely affect structures and increase the cost and maintenance of tailings impoundments, buildings, pipelines, airfields, and other installations which support resource activity. Structures must be designed to ensure that contaminants and acid-rock drainage are not discharged to the environment.

Large scale pollution is the primary environmental concern for georesource activity in the LIA. In Arctic environments pollution both onshore and offshore persist longer than anywhere else. Responder's time and efforts will be hampered by harsh environmental conditions, a near total lack of infrastructure and long distances. The environmental and ecological impact of Arctic contamination would depend on its timing and location relative to patterns of breeding, spawning and species migration. Sea birds, marine mammals, and fish larvae are particularly vulnerable to larger oil spills and other industrial contaminants.

Oil spill prevention is the ultimate goal, but, in the event of a spill, operators must strive to ensure that the response is robust, efficient and well-adapted to local conditions. Ice in its various forms can make it more difficult to detect oil, and to encounter, contain and recover oil slicks with booms, skimmers, and other countermeasures (Glover and Dickins 1999). The current technologies and infrastructure for recovery of oil from the surface perform poorly in high waves and rough weather conditions, and ocean currents will spread the pollutants over extensive areas. In the Arctic, low temperatures and scarce sunlight over much of the year will slow evaporation rates as well as the physical, chemical and biological breakdown of pollutants. Thus, hazardous compounds released during an emergency may remain in Arctic ecosystems for long periods of time, aggravating the risk of bioaccumulation.

The natural containment provided by ice may offer some relief. In open water, slicks can spread and drift so quickly that shoreline impingement may occur before a response can be initiated. Ice, however, may confine oil spills and provide time to mount a response. Due to the cold temperatures and reduced wave energies in ice fields, spilled oil will weather more slowly, which may extend the window-of-opportunity for some countermeasures. Extreme Arctic conditions present a number of challenges to mounting safe and effective oil spill response actions. To overcome these challenges responders must develop action plans with an understanding not only of the physical environment but also with a basic understanding of the effect this environment will have on the fate and behavior of spilled oil (Potter et al. 2012).

Reports from both industry and government groups in the polar states have addressed strategies and techniques for handling pollutants in a variety of ice conditions. With very little infrastructure in the LIA from which to stage an effective recovery program it becomes obvious that Canada and Greenland are poorly equipped to handle such catastrophes. The rich and unspoiled ecosystems of the LIA will always be at risk from industrial activity. A comprehensive, international policy on clean-up response techniques, mitigation policies and liability recommendations is required.

Conclusions

The LIA is a frontier region for petroleum and mineral exploration. Commodity forecasts, for both petroleum and minerals, predict a steady increase of demand for georesources and subsequent increase of prices over the next 20 to 25 years. New technology and data will make parts of the LIA more prospective. Given the long lead times necessary to meet regulatory requirements, a lack of strategic infrastructure, economic factors and insufficient scientific data large scale production of resources in the LIA is unlikely to occur within the next 20 to 30 years. New large discoveries in more temperate environments are of more interest for industry investment.

The most probable targets for future georesource development in the LIA are:

1. Hydrocarbons – Development of West Greenland-East Canada Province is possible in 20 to 25 years if current seismic studies delineate large-scale offshore structures (Gautier 2008). All the recent surveys are south of the LIA. The Greenland continental margin may be more prospective than the Sverdrup Basin due to infrastructure factors.
2. Zinc – Citronen mine site production is possible in 10 to 15 years if current activity demonstrates significant reserves (Ironbark 2011).
3. Iron ore – Limited production at Mary River may begin in 2014 but large scale mining is probably 15 to 20 years away (Nunavut Geoscience Exploration Overview 2012).

These estimates are best judgments by the author based on the content of this report and other readings, approximation of resource development costs, long project lead times in the Arctic and the current and likely future price of a georesource based on global supply and demand. As more data becomes available the estimates will become more refined.

Natural resource development, economic growth, ecosystem protection, and impact of climate change in the Arctic all have one thing in common - a pressing need for science. Except for a few areas, LIA land masses, oceans, ecosystems and climate have received little attention or funding (Karlsson and Smith 2013). There is a crucial requirement for scientific observations, including long-term monitoring and mapping programs, modern computer modeling, and development of technologies ranging from simple field sampling to sophisticated satellite monitoring systems to enable informed decision making by both public and private actors in the LIA. This will require innovative, cooperative solutions to overcome the challenges of economic resource development in the LIA region.

Glossary

Archean rocks: Ancient rocks more than 2.5 billion years old. Minerals are altered by intense heat and pressure.

Arctic Fold Belt: Major structural fold and fault belt in the Arctic Islands.

Craton: An old and stable part of a continent.

Carbonates: A rock made up primarily of carbonate minerals. Limestone and dolostone are the most common examples.

Dip: The angle that a rock unit, fault or other rock structure makes with a horizontal plane. Expressed as the angular difference between the horizontal plane and the structure.

Directional and horizontal drilling: Drilling at an angle to the vertical up to 90º.

Emulsion: A mixture of two or more liquids which are normally not mixable.

Evapotranspiration: The sum of evaporation and plant transpiration from the earth's surface to the atmosphere.

Facies: A facies is a distinctive rock unit that forms under certain conditions of sedimentation, reflecting a particular process or environment.

Igneous Rocks: A rock formed by the crystallization of magma or lava.

Kimberlites: Many diamond deposits are found in kimberlite volcanic pipes.

Metasedimentary, metavolcanic: Alteration of the minerals, textures and composition of sedimentary and volcanic rock caused by exposure to heat, pressure and chemical actions.

NI 43 -101: A codified set of rules and guidelines for reporting on information related to mineral properties owned by, or explored by, companies which report these results on stock exchanges within Canada. The objective of the NI 43-101 technical report is to provide a summary of scientific and technical information concerning mineral exploration, development and production activities on a mineral property that is material to an investor (CIM 2013).

Oil field: A region with an abundance of oil wells extracting petroleum (crude oil) from below ground.

Orogeny, orogenic belts: The primary mechanism by which mountains are built on continents.

Permeability: A measure of how well a material can transmit fluids. Materials such as gravel, that transmit water quickly, have high values of permeability. Materials such as shale, that transmit water poorly, have low values. Any reservoir rock has to have permeability to accommodate hydrocarbon fill and transportation.

Play: A group of oil fields or prospects in the same region that are controlled by the same set of geological circumstances.

Plateau basalts: A type of volcanic rock.

Porosity: The volume of open pore space in a rock, sediment or soil, usually expressed as a percentage. This pore space can include openings between sand grains, fracture openings and caverns. Any reservoir rock has to have porosity to accommodate hydrocarbon fill.

Sedimentary Basin: A low and usually sinking region that is filled with sediments from adjacent positive areas.

Siliciclastics: They are sandstone and siltstone based rocks which hold for 50 - 60% of the world's oil and gas exploration.

Structures: Folded and faulted rock strata.

Subcrop: Places where it is impossible to determine for sure that the exposed rock is connected to bedrock.

Tectonics: Pertaining to the global forces that cause folding and faulting of the Earth's crust. Also used to classify or describe features or structures formed by the action of those forces.

Thermohaline: The large-scale ocean circulation that is driven by global density gradients created by surface heat and freshwater changes.

TOC (Total Organic Content): Used as an indicator of the amount of organic carbon in a geological formation, particularly the source rock of an oil play.

Ultimate potential resources: An estimate of the discovered volume plus undiscovered volume of hydrocarbon reserves that exist in an area. Undiscovered refers to volume of hydrocarbons yet to be discovered but considered likely when taking into account the geological prospects of that area and anticipated technology and economic conditions.

Unconformities: A buried erosional or non-depositional surface separating two rock masses or strata of different ages, indicating that sediment deposition was not continuous.

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