CHAPTER 5 – CANADIAN ARCTIC ISLANDS

BANKS BASIN

Age	Mesozoic over Paleozoic
Depth Target Zones	Maximum 3000 m to base Mesozoic; up to 2000 m Paleozoic
Hydrocarbon Shows	None
First Discovery	None
Basin Type	Unstable cratonic margin
Depositional Setting	Marine shelf to basin transitional (Paleozoic); fluvial, transitional and marine shelf (Mesozoic)
Potential Reservoirs	Mesozoic sandstones, Devonian Blue Fiord carbonates
Regional Structure	North-south series of highs with intervening subbasins, extension faulting, minor folding
Seals	Transgressive marine shales (Weatherall Formation), basinal shales (Eids Formation) and inter-tonguing marine shales in the Mesozoic section
Source Rocks	Eids shale and other basinal equivalents of lower Paleozoic shelf carbonates
Depth to Oil Window	Base of Mesozoic is transitional from immature into overmature Paleozoic sediments
Total Number of Wells	*11* (onshore Banks Island)
Seismic Coverage	9200 km^2 of reconnaissance seismic
Area	60,100 km^2 (Banks Island)
Area under Licence	None

(Bare tundra, low relief terrain. Population centre at Sachs Harbour on southwestern Banks Island. Extreme winter operating conditions.)

Banks Basin contains a moderately thick Mesozoic section overlying a thick sequence of lower Paleozoic carbonates and basinal equivalents. Eleven wells have been drilled without success, but a number of exploration plays have been defined that have moderate potential, principally for gas. The basin is mostly onshore, but extends northwards across McClure Strait into Eglinton Craben where deeper burial of Mesozoic source rocks may improve oil potential.

Geological Setting (Figs. 51, 52)

Banks Basin is a longitudinal trough of Jurassic to Tertiary clastic sediments confined on the western side by the Storkerson Uplift, a horst of Mesozoic age, which parallels the rifted margin of the Canada Basin, and by the Prince Albert Homocline, composed of westward-dipping Paleozoic strata on eastern Banks Island and neighbouring Victoria Island. The basin is overlain by a thin Tertiary cover, which thickens to the west across the Arctic Coastal Plain and the continental shelf of the Beaufort Sea.

Exploration History

The first well on Banks Island, Elf Storkerson Bay A-l 5, drilled in 1971, tested the Tertiary and upper Mesozoic succession of the Arctic Continental margin west of the Storkerson Uplift. Banks Basin (sensu Miall, 1979) lies east of the Storkerson Uplift and has been tested by seven of the 11 wells drilled on the island. The most recent well, Chevron Muskox D-87, was drilled in 1982. Although no wells discovered hydrocarbons, several did encounter reservoir quality porous rock. Primary targets have been Paleozoic carbonates, with

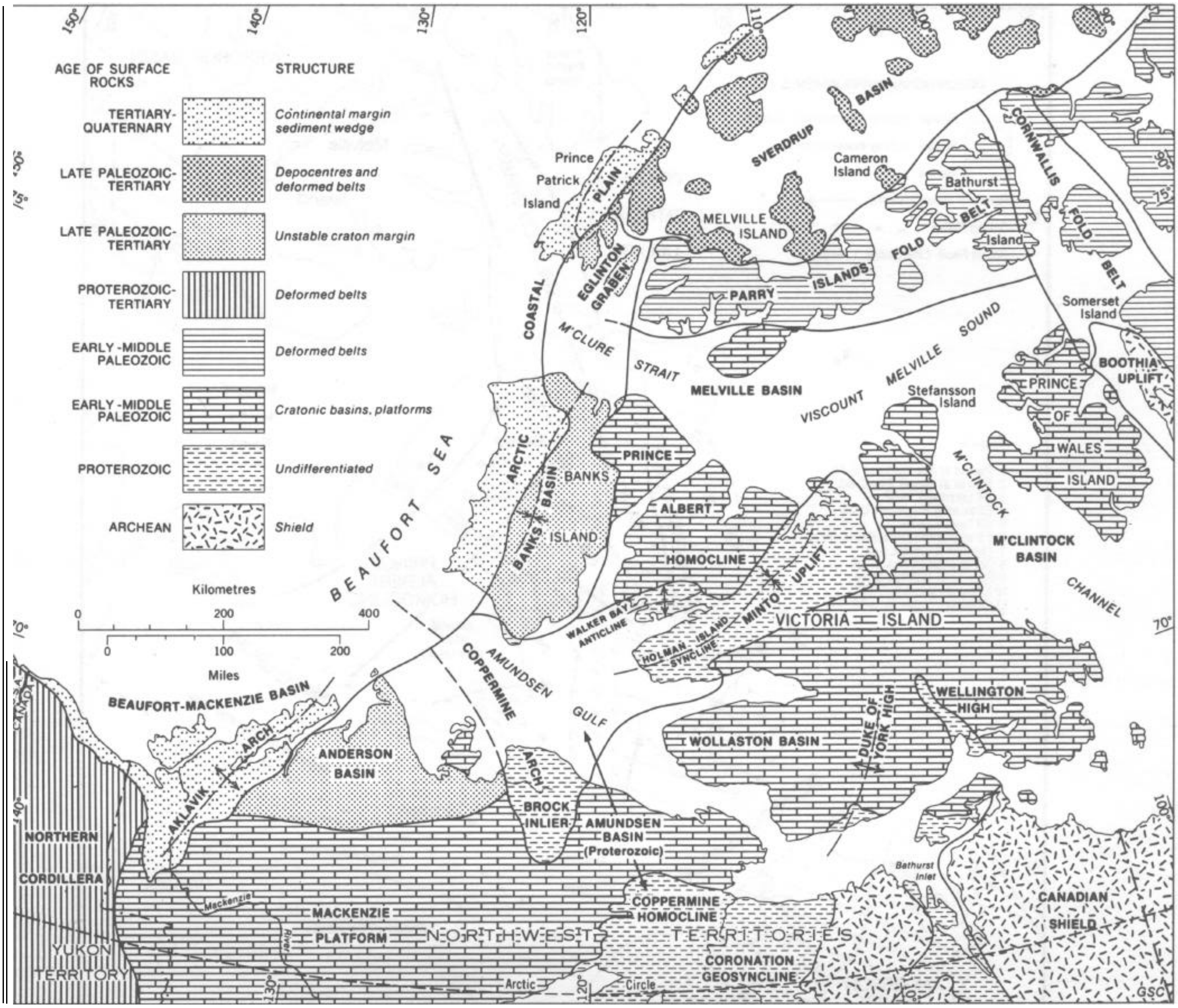

Figure 51. *Regional tectonic elements in the western Canadian Arctic (from Miall, 1979).*

sandstones in the overlying Mesozoic section a secondary objective.

Stratigraphy (Fig. 53)

For most of the early Paleozoic, the Banks Island region straddled a zone of major facies transition from carbonate shelf in the east to shale basin in the west. The older shelf facies are represented by dolomites of the Allen Bay-Read Bay formations, widely exposed on western Victoria Island (Late Ordovician to Late Silurian - approximately 1000 m in the Murphy et al. Victoria Island F-36 well), and by limestones of the Blue Fiord Formation (Early to Middle Devonian, 632 m in Deminex-CGDC-FOC-Amoco Orksut I-44). The carbonate shelf is fringed by a chain of bioherms culminating in Blue Fiord reefs, which shared a contiguous environment of deposition with the productive reef in the Bent Horn oilfield on Cameron Island to the northeast. Between shelf and basin a slope carbonate facies has been recognized.

Melville Island Group clastics from a northern and northwestern hinterland in the late Middle Devonian superseded carbonate deposition in the region. The bulk of the Melville Island Group sediments are of deltaic origin with associated shallow marine and fluvial facies. An easing of clastic input to the basin in the Frasnian enabled growth of reefs of the Mercy Bay

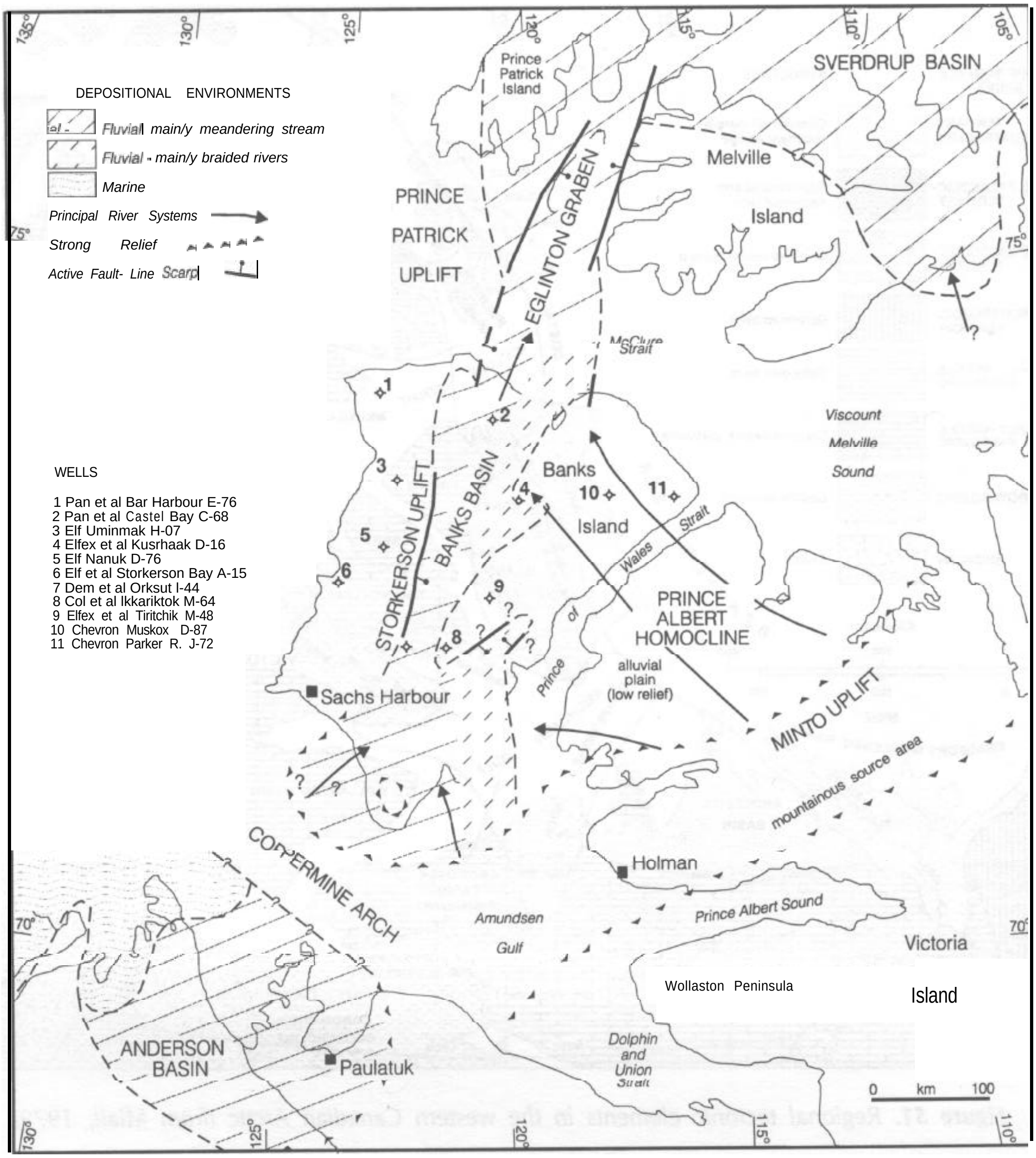

Figure 52. *Mid-Early Cretaceous paleogeography, Banks Island area (from Miall, 7979).*

Formation towards the end of Melville Group deposition.

Mesozoic strata overlie rocks of the Melville Island Group at a major stratigraphic break, which lasted from the Late Devonian to the Middle Jurassic. The oldest Jurassic formation is the Hiccles Cove Formation of the Wilkie Point Group, a thin shelf to shoreline sandstone preserved in the deepest parts of Banks Basin. Shales of the Mackenzie King Formation were deposited during the Early Cretaceous (356 m in Orksut I-44), later overstepped on the basin margins by thick fluvial sandstones of the Isachsen Formation (Hauterivian to Aptian, >200 m ?). The Isachsen Formation is variable in thickness and texture and was deposited during a period of active uplift and rifting. Marine shales with local shoreline sandstones of the Christopher Formation were deposited during a period of regional transgression that culminated in the Cenomanian with the development of barrier island sandstones of the Hassel Formation. The Kanguk Formation, a basinal bituminous shale, was deposited from the Turonian to the Maastrichtian.

The Paleogene Eureka Sound Formation is predominantly fluvio-deltaic. Deposited across the breadth of the Arctic Coastal Plain, this formation is preserved in the shallow subsurface in Banks Basin. The

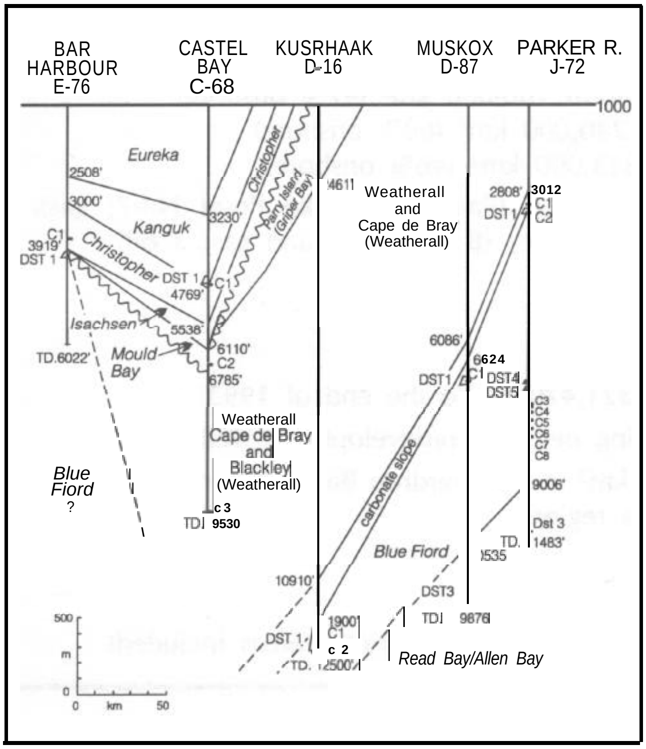

Figure 53. *East-to-west cross-section through some of the Banks Island Wells.*

younger Beaufort Formation is preserved as a thin veneer across the Arctic Coastal Plain, thickening progressively into the offshore.

Potential Reservoir

Devonian and older shelf carbonates and their associated bank edges define a fairway with good reservoir potential crossing Banks Island. Thick sections of porous rock have been encountered in the Blue Fiord Formation with pipe recoveries of formation water obtained from intervals in Panarctic Tenneco et al. Castel Bay C-68 and Chevron et al. Parker River J-62. The fluvial sandstones of the lsachsen Formation (and younger Mesozoic and Tertiary formations) are also potential reservoir rocks.

Structure, Traps and Seal

Early Paleozoic deposition occurred over a stable cratonic margin. Traps are related to facies transitions and carbonate build-ups with seal provided by overstepping basinal shales. The development of horst and graben topography in the mid-Mesozoic rifting episode created the possibility of structural traps in the Paleozoic and stuctural/stratigraphic traps in Mesozoic sandstone reservoirs. Seal is provided by marine shales within the Mesozoic succession.

Source Rocks

The overlying marine shales and downslope basinal equivalents of the Paleozoic carbonates have good potential as source rocks, given sufficient organic richness. However, based on spore coloration, the Paleozoic section is overmature (Miall, 1976). The Mesozoic section appears immature with the bituminous shales of the Upper Cretaceous never sufficiently buried to generate oil.

Potential

The major hiatus in the stratigraphic record represents an extended period of uplift and truncation, culminating in rifting in the Jurassic. Generation and migration of Paleozoic hydrocarbons is likely to have occurred prior to and during this period, lessening the possibility of preservation of accumulations in Paleozoic rocks.

Although several potential reservoirs are present, the distribution of porosity in the Paleozoic section remains uncertain. The majority of traps in the Paleozoic are stratigraphic and would require intensive seismic delineation. The overmaturity of the Paleozoic section, the absence of upper Paleozoic and Triassic source rocks known from the Sverdrup Basin, and the general lack of sufficient maturity in the Mesozoic section lessen the prospect of an oil play in this basin. However, the Paleozoic and the lower Mesozoic section retains a moderate potential for significant gas discoveries.

Acknowledgement

The above analysis of Banks Island potential has been taken, with some slight modification, from the report by Jefferson et al. (1988).

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ARCTIC ISLANDS: SVERDRUP AND FRANKLINIAN BASINS

Area	Arctic Stable Platform 780,000 km2 (47% onshore) Arctic Fold Belt 240,000 km^2 (60% onshore) Sverdrup Basin 313,000 km^2 (46% onshore)
Discoveries	First discovery in 1969 (Panarctic Drake Point N-67; gas): 18 subsequent discoveries (8 gas; 7 oil and gas; 3 oil)
Discovered Resources	Gas: 407 x E9 m^3 Oil: 66 x E6 m^3
Production	Gas: none Oil: Bent Horn 321,470 m^3 to the end of 1993
Total Number of Wells	177 (192 including delineation/development wells?)
Average Well Density	1 well per 1630 km^2 in the Sverdrup Basin, 1 per 7000 km^2 in the Arctic Islands region
Seismic Coverage	44,242 km
Pipelines	None
Area under Licence	13,000 km^2 (or 37,500 km^2 if restricted areas included)

Most northerly of Canada's exploration regions, the Arctic Islands overlie one of Canada's largest petroliferous basins. Exploration activity has been extensive, but sparsely distributed, across this huge region. Nevertheless, the 160 wells drilled to date have discovered gas resources (over 14 trillion cubic feet) equal to 20% of remaining reserves in western Canada, and two of the largest undeveloped gas fields in Canada are in the Arctic Islands. Exploitation of the oil resources of the region is already underway. Both gas and oil potential in this basin is very high and realizable given enhanced geological understanding and new exploration methods. It is likely that the vast resources of this region will become important to North America in the next century with the depletion of conventional resources in western Canada.

Geological Setting (Fig. 54)

Since the dawn of the Cambrian, deposition in the sedimentary basins of the Arctic Islands has extended the North American landmass some 1400 km seaward of the Canadian Shield and its skirt of Precambrian metasediments. The sedimentary column is divided into lower and upper sections characterized by more or less continuous subsidence and deposition, separated by major tectonic uplift – the Ellesmerian Orogeny – in the Late Devonian and Early Carboniferous. With this exception, the preserved strata span most of the Paleozoic, Mesozoic and early Tertiary.

The sedimentary strata, tectonic deformation and petroleum geology of the older pre-Ellesmerian section is discussed below under the title "Franklinian Basin". Post-Ellesmerian geology is discussed under the title of its successor, the largely superimposed "Sverdrup Basin". Finally, the geology underlying the Arctic Coastal Plain and extending under the waters of the Arctic Ocean is discussed under the heading "Arctic Continental Terrace Wedge".

Exploration History (Figs. 55, 56)

The presence of extensive sedimentary basins with thick successions of Paleozoic and Mesozoic strata in the Arctic Islands, potentially favourable for oil and gas, was demonstrated in the 1950s by geologists of the Geological Survey of Canada (examples of the work of these earlier researchers are described in Fortier et al., 1954, and Thorsteinsson, 1958).

Exploration by petroleum companies began in the early 1960s. Most seismic exploration and drilling has occurred north of latitude 75°N, that is, in the Arctic Fold Belt and Sverdrup Basin. South of this latitude, exploration of the mildly deformed Paleozoic sequences of the Arctic Platform has been very sparse, with only three wells drilled (on Prince of Wales and

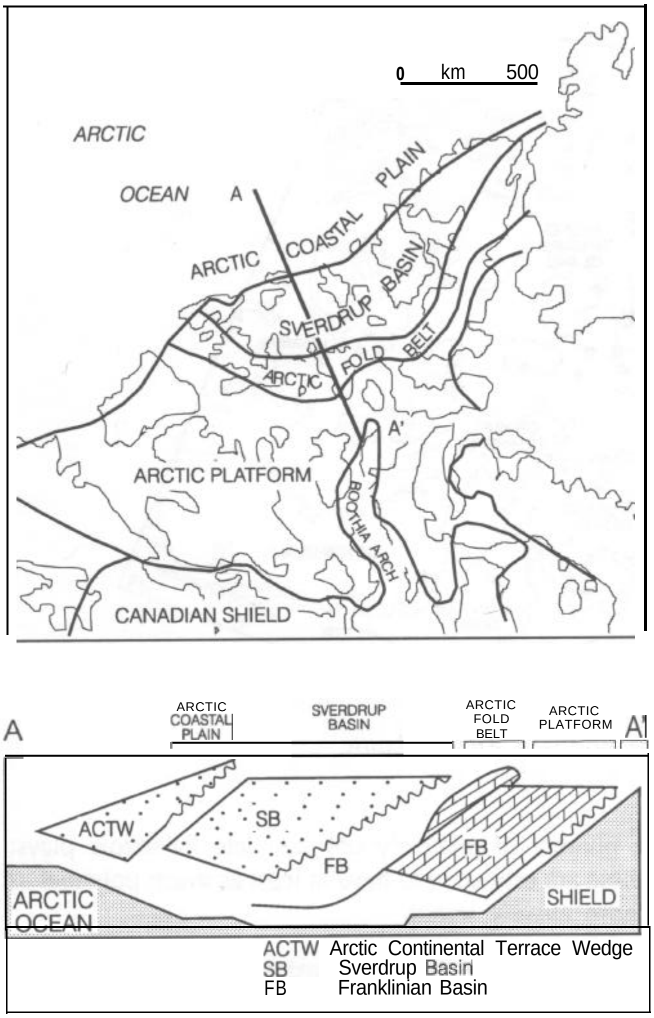

Figure 54. *Tectono-stratigraphic elements of the Arctic Islands.*

Somerset islands). The presence of the permanent ice cap and the extreme remoteness of the region have caused exploration of the Arctic continental terrace wedge to be equally limited.

The first Arctic Islands exploratory well was spudded in 1961 at Winter Harbour, Melville Island. Dome et al. Winter harbour No. 1 A-09 drilled Lower Paleozoic strata to a total depth of 3823 m. The well penetrated sandstones and siltstones of the Middle to Late Devonian clastic wedge in the up-hole section; these swabbed gas at low unsustained rates during a completion test. No hydrocarbons were tested from the thick carbonate section lower in the well and no significant porous zones were noted.

Since the drilling at Winter Harbour, a total of 19 discoveries have been made; three oil, 12 gas, and five oil and gas. Discoveries of oil alone have tended to be small with the larger accumulations containing gas, or gas with associated oil. The offshore discovery at Cisco is an exception: the large proportion of oil to gas found in this structure holds promise for other oil accumulations in the large and major categories. Discoveries are listed in Table 6 and the cumulative discovery curve (in barrels of oil equivalent) shows no diminution of discovery size with exploration to date (Fig. 57).

In the early 1970s, industry turned to the north coast of Melville Island where thick Mesozoic sequences were known to be present in the Sverdrup Basin. Panarctic Drake Point N-67 well, drilled in *1969* to 2577 m on the Sabine Peninsula of Melville Island, was the first major discovery in the Arctic Islands. This giant gas field has been delineated by 14 wells, (including the discovery well and two relief wells drilled to control blowout of the discovery well). The delineation program discovered a major offshore extension to the field at East Drake I-55. Combined resources in the main Drake Point pool and the East Drake extension are quoted by the Geological Survey at 98.5 x E9 m^3 (3.5 tcf). A second giant gas field was discovered soon afterwards at Hecla, 50 km along structural trend to the west of the Drake Point Field. In 1978, the smaller Roche Point gas discovery was drilled north of Hecla and just offshore of northwest Sabine Peninsula.

Early in their exploration program, Panarctic Oils Ltd. pioneered drilling offshore locations from artificially thickened sea ice. This proved an economic and efficient way of testing the numerous offshore structures in the central Sverdrup Basin, which lie in water depths of up to 500 m. A succession of discoveries followed near Lougheed Island, on the southwestern coast of Ellef Ringnes Island, on King Christian Island, and in the intervening waters. The first of these discoveries by Panarctic in the central Sverdrup Basin was King Christian in 1970, followed by Thor, Kristoffer, Jackson Bay, Whitefish, Char, Balaena, Cisco, Skate, Maclean, Sculpin, Cape Macmillan and finally Cape Allison in 1985. Dome and partners added Wallis to the tally in 1973.

Over this period, drilling also continued along the southern margin of the basin with success at Bent Horn on Cameron Island in 1974. This is the sole discovery in Paleozoic carbonates of the Franklinian Basin. It is also the only discovery in the Arctic Islands under production.

Drilling in the far northwest of the Sverdrup Basin on the Fosheim Peninsula also had limited success, recording a single discovery by Panarctic at Romulus.

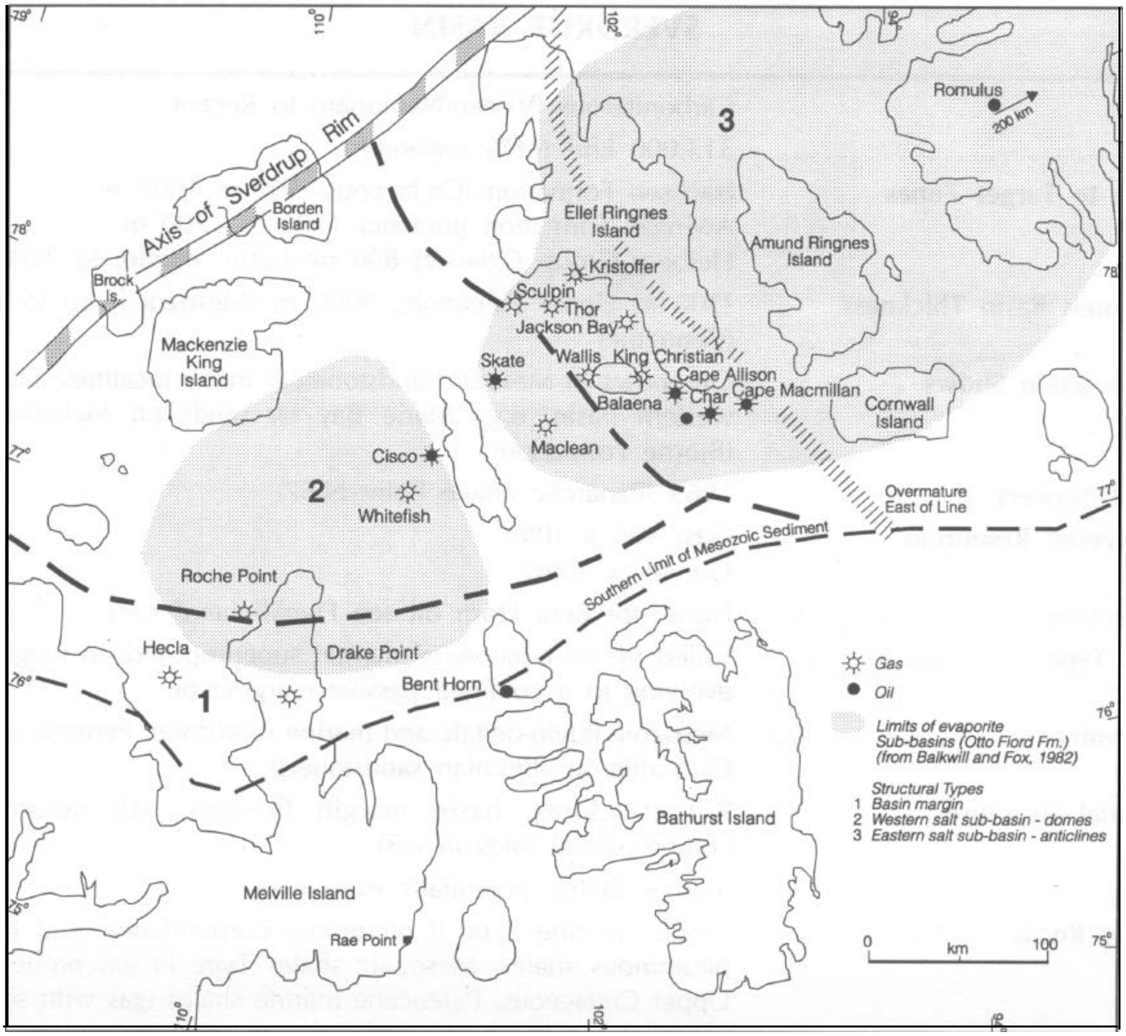

Figure 58. *Tectonic elements of the Sverdrup Basin.*

The northwestern margin of the developing basin was sub-parallel to the developing rift system. Horsts and grabens developed along this margin, but overall subsidence along this “Sverdrup Rim” was consistently less than in the basin depocentre. Since the inception of Mesozoic-Cenozoic spreading in the Canada Basin, the Sverdrup Rim has remained structurally high, more or less effectively separating the Sverdrup Basin from the Arctic Ocean.

The Sverdrup Basin was a major depocentre through much of the late Paleozoic and Mesozoic. Rapid subsidence, initiated by rifting in the Carboniferous and Early Permian, was followed by thermal subsidence at a more sedate rate, in passive margin fashion. From the Late Jurassic to the mid-Cretaceous, subsidence rates and deposition in the basin were influenced by events leading to the rifting and formation of new oceanic crust in the Canada Basin to the northwest. Widespread volcanism in the northern part of the Sverdrup Basin in the mid-Cretaceous coincides with the main rifting in the proto-Canada Basin, and occurs where the north-northeast-striking late Paleozoic rifts of the Sverdrup Basin intersect the northeasterly trending rifted margin of the Canada Basin.

The early Paleogene saw the growing influence of orogenic events in the east coupled to the widening of the northern North Atlantic, and, in particular, to accommodate sea-floor spreading in Baffin Bay. The Eurekan Orogeny folded the eastern half of the Sverdrup Basin, much of which is uplifted and exposed on Ellemere Island. The influence of this compression affected strata as far west as Lougheed Island. In the western Sverdrup Basin, subsidence continued as a result of differential loading of Carboniferous salt and the development of diapir fields. However, during the Tertiary, the focus of deposition shifted west to the Arctic Continental Terrace Wedge, beyond the confines of the Sverdrup Basin.

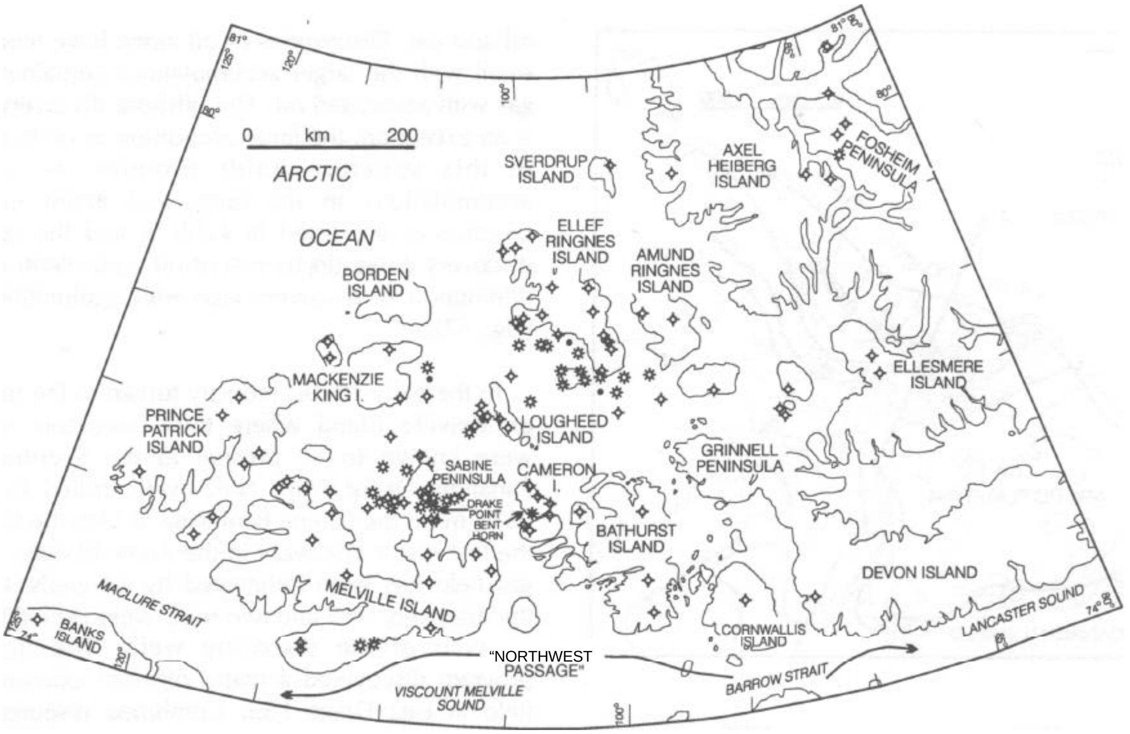

Figure 55. *Well locations in the northern Arctic Island*

Oil and condensate of various gravities and some gas were tested from Triassic and Jurassic sandstones. Although good to excellent permeability was inferred from several of the drillstem tests, pressure declines indicated reservoirs of limited extent and productive capability. The eight other wells drilled in this part of the basin were unsuccessful.

Following the peak drilling year of 1973 when 37 wells were drilled, drilling declined precipitously to a mere four wells in 1980. The early 1980s saw some recovery as companies worked new exploration licences across the basin. However, drilling continued to decline through the mid-eighties with the last exploratory well spudded in 1986. Panarctic unsuccessfully sidetracked an existing delineation well to further delineate the Bent Horn pool in 1987. Since that time, the basin has seen no exploration activity and has been ignored despite its potential for further major discoveries.

Outlook

The Geological Survey of Canada estimates the potential of the Arctic Islands at 686 x E6 m^3 oil and 2257 x E6 m^3 gas (average expectation). Both gas and oil potential are highest in the Sverdrup Basin, in both Mesozoic and late Paleozoic rocks. Future exploration may target deeper parts of the Mesozoic succession and a number of relatively untested late Paleozoic plays: these are estimated to have at least as much potential as those already tested.

Although much of the past exploration focus (and success) has been in the central Sverdrup Basin, future efforts may target the southern rim of the basin and the Arctic Fold Belt. The Bent Horn field lies within this latter region of structural complexity and there is considerable potential along this trend. 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 region there are many untested plays, most of which would be under intense exploration if they were located in southern Canada. Although development costs are high, resources discovered per metre drilled have been greater in the Arctic than in western Canada. Transportation cost, not petroleum potential, is clearly limiting the development of this remote region. In the late 1970s, various routes for a gas pipeline to southern Canada were studied and abandoned (Polar Gas Pipeline Project). Liquefaction and shipping of gas from Sabine Peninsula was also considered as an alternative to an extremely long and costly pipeline (Arctic Pilot Project). Tanker transport of oil, and possibly of liquefied natural gas certainly command greatly superior economics to any pipeline

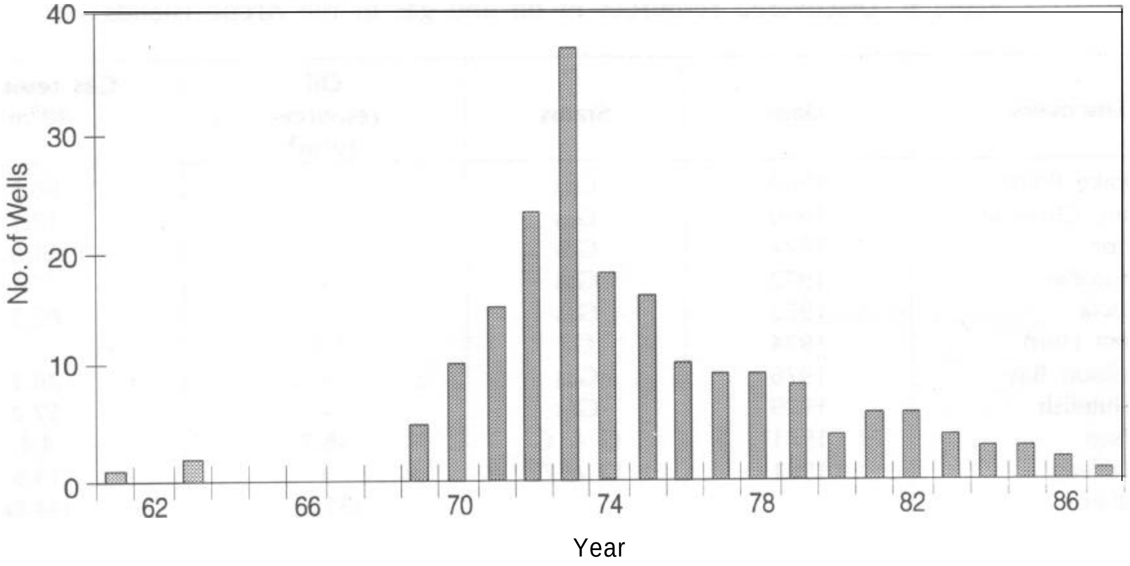

Figure 56. *Drilling history, Arctic Islands.*

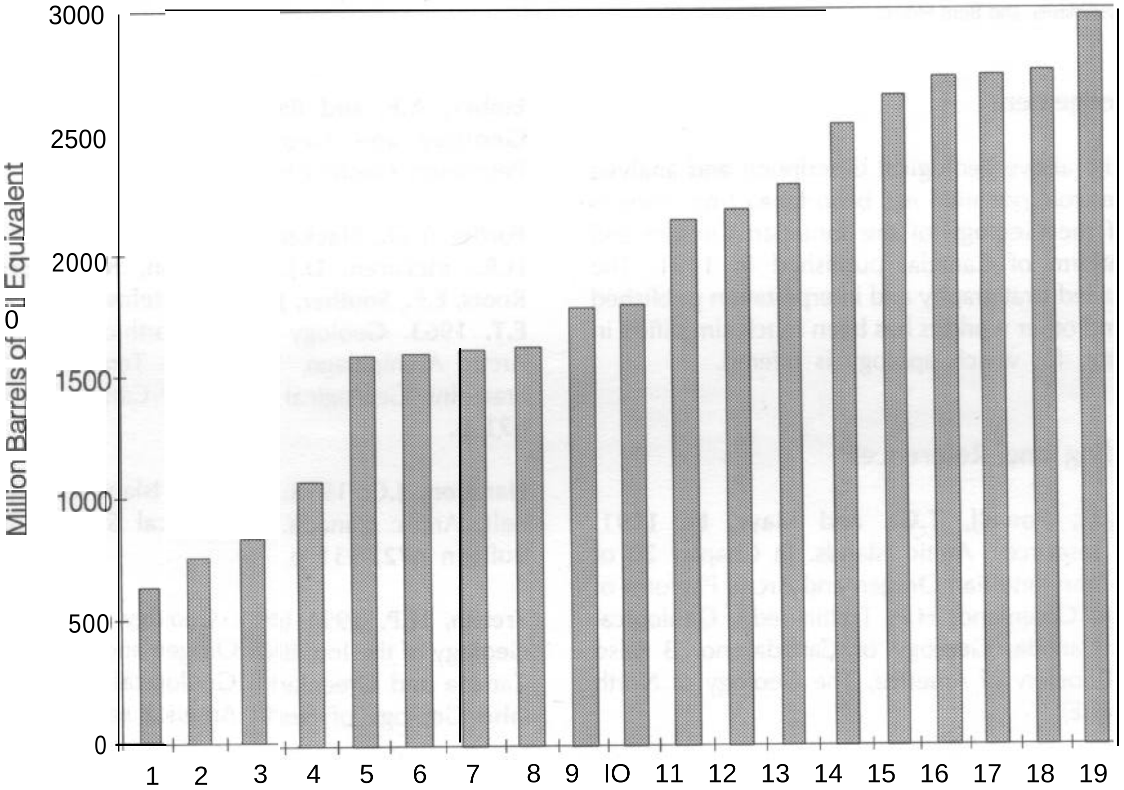

Figure 57. Cumulative discovered resources in the Arctic Islands by sequence of discovery.

project and allow for increments to supply without the major market perturbation inevitable with new supply from a large capacity pipeline. Further oil development awaits the discovery of new fields along the southern margin of the basin, and for gas exploitation, the capability of major gas consuming countries to greatly expand their ability to import LNG.

Table 6. Discovered resources of oil and gas in the Arctic Islands

Discovery	Date	Status	Oil resources E6 m^3	Gas resources E9 m^3
Drake Point	1969	Gas		98.5
King Christian	1970	Gas	-	17.3
Thor	1972	Gas		11.9
Kristoffer	1972	Gas	-	27.1
Hecla	1972	Gas		85.5
Bent Horn	1974	Oil	1.0	
Jackson Bay	1976	Gas		28.3
Whitefish	1979	Gas		57.2
Cisco	1981	O & G	48.7	4.4
Maclean	1981	O & G	3	13.6
Other			(31.5)	(44.6)
	TOTAL	=	66	406 (14.3 tcf)

Notes: Discoveries in the category “other” include Romulus (1972, oil), Wallis (1973, gas), Roche Point (1978, gas), Char (1980, oil and gas), Balaena (1980, heavy oil), Skate (1981, oil and gas), Sculpin (1982, gas), Cape MacMillan (1983, oil and gas), and Cape Allison (1985, oil and gas).

Source: GSC (1983) for individual fields; NEB (1994) for “other” and basin totals includes unpublished revisions to discovered resource estimates and Bent Horn.

Acknowledgement

Much of the above geological description and analysis of the Paleozoic potential has been taken from various authors of the Geology of the Innuitian Orogen and Arctic Platform of Canada, published in 1991. The highly detailed stratigraphy and interpretation published by these and other workers has been much simplified in this account, for which apology is offered.

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SVERDRUP BASIN

Age	Carboniferous (Viséan/Namurian) to Recent
Area	313,000 km^2 (46% onshore)
Depth to Target Zones	Isachsen Formation (Cretaceous) 500 to 1000 m Awingak Formation (Jurassic) 1100 to 1700 m Heiberg Group (Triassic) 800 m (basin margin) to 2200 m
Maximum Basin Thickness	1300 m Upper Paleozoic; 9000 m (Mesozoic); up to 300 m (Cenozoic)
Hydrocarbon Shows	Oil shows in Mesozic sandstones at many localities within the western basin, e.g., Marie Bay tar sands on Melville Island (Bjorne Formation)
First Discovery	1969 (Panarctic Drake Point N-67)
Discovered Resources	Gas: 406 x E9 m^3 Oil: 65 x E6 m^3
Production	None (for Bent Horn oil see Franklinian Basin)
Basin Type	Failed rift on continental margin superimposed on megasuture, evolving to a confined passive margin-type
Reservoirs	Mesozoic fluvio-deltaic and marine sandstone; Permian reefs (?); Carboniferous-Permian sandstone(?)
Regional Structure	Rift structures, basin margin flexures, salt deformation, compressional folds in east
Seals	Marine shales, potentially evaporites
Source Rocks	Triassic marine Type II oil prone; Carboniferous and Permian bituminous shales; Mesozoic shales Type III gas prone Upper Cretaceous, Paleocene marine shales (gas with some oil potential but barely mature)
Depth to Oil/Gas Window	Variable
Total Number of Wells	160 exploratory and delineation wells
Average Well Density	One well per 1630 km^2

Geological Setting (Fig. 58)

The Sverdrup Basin overlies the central and distal Franklinian Basin with angular unconformity. The basin depocentre is displaced northwest and outboard (relative to the North American craton) of its predecessor and may overlie a plate suture of Ellesmerian vintage now incorporated within the North American continental margin. Northwest of the basin axis, the basin shallows onto the Sverdrup Rim, a zone of thickened continental crust that borders the Arctic Ocean. The Sverdrup Basin is about 1300 km along a northeast-southwest axis, and up to 400 km wide. The axial region contains up to 3 km of upper Palaeozoic strata, up to 9 km of Mesozoic strata, and locally more than 3 km of uppermost Cretaceous and Tertiary strata.

Inception of the Sverdrup Basin followed the relaxation of Ellesmerian compression and uplift in the Arctic Islands in the early Carboniferous. An incipient rift system developed under extension, which struck north-northeast across the western Arctic Islands. The east-west striking Parry Island Fold Belt – the culminating feature of the Ellesmerian Orogeny – formed the southern terminus of this rift system. Normal faults, predominantly down-to-basin, parallel the earlier compressional structure along this margin.

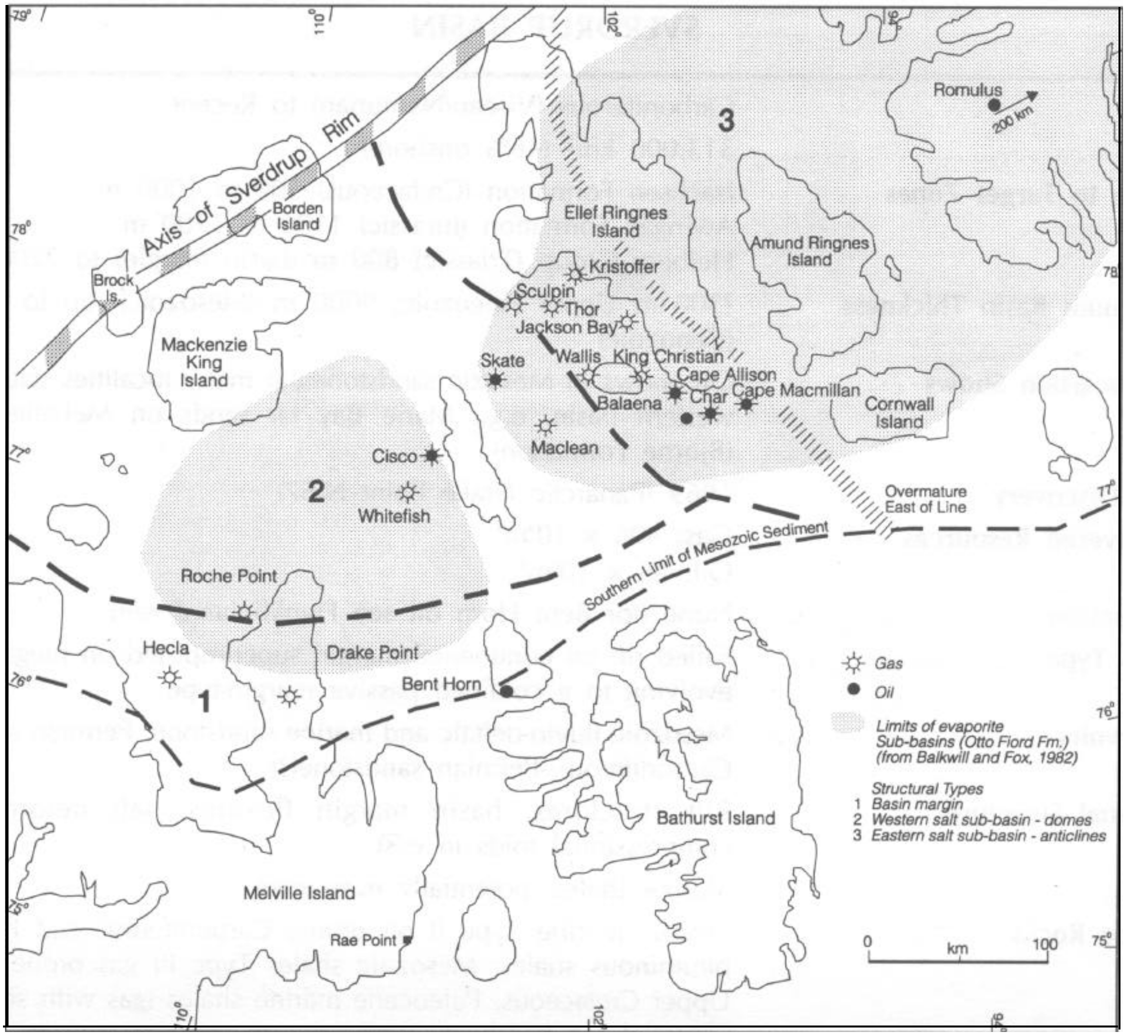

Figure 58. *Tectonic elements of the Sverdrup Basin.*

The northwestern margin of the developing basin was sub-parallel to the developing rift system. Horsts and grabens developed along this margin, but overall subsidence along this “Sverdrup Rim” was consistently less than in the basin depocentre. Since the inception of Mesozoic-Cenozoic spreading in the Canada Basin, the Sverdrup Rim has remained structurally high, more or less effectively separating the Sverdrup Basin from the Arctic Ocean.

The Sverdrup Basin was a major depocentre through much of the late Paleozoic and Mesozoic. Rapid subsidence, initiated by rifting in the Carboniferous and Early Permian, was followed by thermal subsidence at a more sedate rate, in passive margin fashion. From the Late Jurassic to the mid-Cretaceous, subsidence rates and deposition in the basin were influenced by events leading to the rifting and formation of new oceanic crust in the Canada Basin to the northwest. Widespread volcanism in the northern part of the Sverdrup Basin in the mid-Cretaceous coincides with the main rifting in the proto-Canada Basin, and occurs where the north-northeast-striking late Paleozoic rifts of the Sverdrup Basin intersect the northeasterly trending rifted margin of the Canada Basin.

The early Paleogene saw the growing influence of orogenic events in the east coupled to the widening of the northern North Atlantic, and, in particular, to accommodate sea-floor spreading in Baffin Bay. The Eurekan Orogeny folded the eastern half of the Sverdrup Basin, much of which is uplifted and exposed on Ellemere Island. The influence of this compression affected strata as far west as Lougheed Island. In the western Sverdrup Basin, subsidence continued as a result of differential loading of Carboniferous salt and the development of diapir fields. However, during the Tertiary, the focus of deposition shifted west to the Arctic Continental Terrace Wedge, beyond the confines of the Sverdrup Basin.

Stratigraphy (Fig. 59)

The earliest post-Ellesmerian strata in the Arctic islands belong to the Emma Fiord Formation of Early Carboniferous age. This formation of lacustrine shales, rich in alginite and characterized as "oil shale" at outcrop, may be of limited distribution in the subsurface. Much more widespread around the margins of the developing basin, and possibly within the deeply buried rifts of the basin are the red beds, sandstones and conglomerates of the Borup Fiord and Canyon Fiord formations. Of Late Carboniferous to Early Permian age, these formations mark an early phase of rapid subsidence in the basin. The sediments were derived from bevelling of the basin rims and the local erosion of horsts within the basin and were deposited in an arid continental setting. Coevally with clastic deposition around the basin margins, evaporites of the Otto Fiord Formation were being deposited in two main depocentres along the axis of the basin, roughly east and west of the modern Lougheed Island. These thick Upper Carboniferous salts - halite predominates - mark the first marine incursions into the developing rift.

As marine influence increased in the Late Carboniferous and Early Permian, thick marine limestones of the Nansen and Belcher Channel formations were deposited in the northern and eastern basin and (more thinly) across the Sverdrup Rim. Reef growth occurred along the rims of the carbonate shelf. Argillaceous limestones and shales (Hare Fiord Formation) replaced evaporites in the central basin.

In the Late Permian, the shales and siltstones of the van Hauen Formation were deposited across the basin, marking the end of carbonate deposition. Sandstones of the Sabine Bay, Assistance Bay and Trold Fiord formations are. proximal quivalents and suggest progradation from the northeast. Limestones of the Degerbols Formation are distal equivalents of the Trold Fiord sandstones. The retreat of carbonate deposition towards the east during the Permian and the growing predominance of sandstone/shale deposition across much of the western Sverdrup Basin may partly reflect the growing regional influence of uplands to the northwest and northeast of the Sverdrup Basin and partly the drift of the basin into more northerly paleolatitudes.

The Permo-Triassic boundary is marked by an unconformity at the basin margins, but was probably conformable across much of the basin as a shale-on-shale transition. Sandstones of the Bjorne Formation (Lower Triassic) were the first major incursion of coarse clastic deltaic systems in the basin. During this period sandstones of the Sadlerochit Formation were being shed into the Alaskan North Slope Basin, possibly sourced from the same hinterland as the Bjorne.

Subsequent deposition in the Triassic saw the advance and retreat of deltaic systems into the basin, in response to the interplay of fluctuating sea levels and basin tectonics. The Roche Point and Pat Bay formations of the Schei Point group represent modest regressions into the basin. The subsequent transgressive phase of these cycles is typified by the deposition of bioclastic shelf limestones. These deltaic advances in the Middle to Late Triassic were the harbinger of the major advance across the basin of the deltaic systems that deposited the sandstones of the Heiberg Group (split distally by tongues of marine shale and sequence boundary unconformities into the Skybattle, Maclean Strait and King Christian formations). The source hinterland for the rivers that deposited the sandstones of the Heiberg Group was to the east of the basin. Over 1500 m of stacked delta-front, and delta-plain sediments were deposited in the basin depocentre, which acted as a sediment trap, allowing marine shale deposition to the northwest.

Marine transgression in the Early Jurassic drowned the Heiberg deltas, depositing thick shales of the Jameson Bay Formation and subsequently the Mackenzie King Formation in the Middle and Late Jurassic. From the Early Jurassic onwards, deposition was increasingly affected by source areas to the northwest. By the mid-Jurassic, the basin was confined between the emergent Sverdrup Rim to the northwest and Ellesmere-Bathurst-Melville islands to the southwest. Shoreface sandstones were deposited on either side of this Sverdrup seaway. Significant regressions during this period deposited sandstones of the Sandy Point, Hiccles Cove and Awingak formations. Quite complex interleaving of marine/deltaic sandstones and shales developed as the relative dominante of river systems shifted to and fro across the basin, restricting the connectivity of the seaway.

A major transgression at the beginning of the Cretaceous deposited shales of the Deer Bay Formation around the basin margins. There followed uplift and truncation associated with the onset of rifting in the Canada Basin in the Early Cretaceous. The subsequent regression deposited fluvio-deltaic sandstones (Isachsen Formation) across the basin and onto the newly formed continental margin.

From the Aptian onwards, deposition in the Sverdrup Basin became increasingly subsidiary to the building continental margin. A Major unconformity associated with regression and deposition of the Albian-

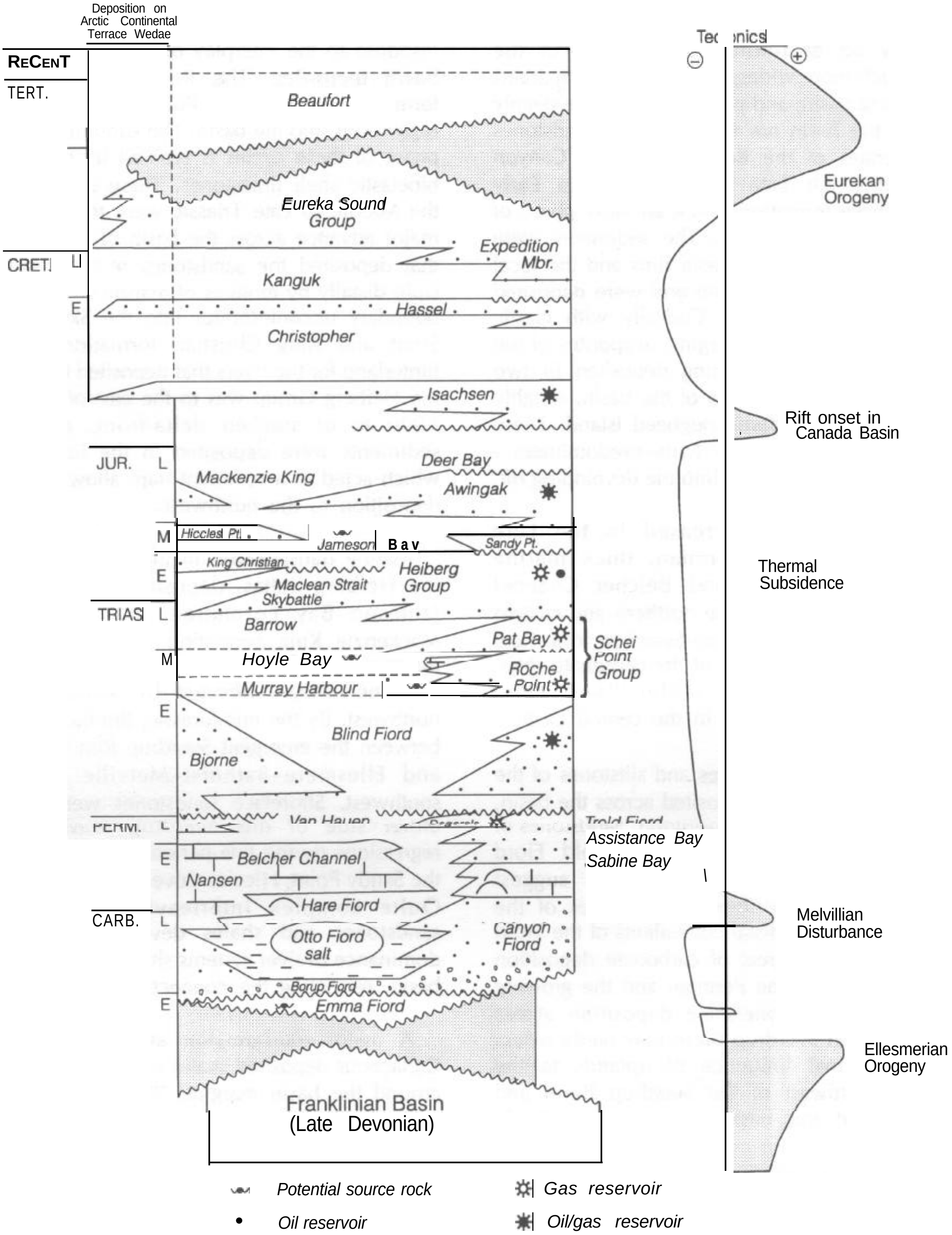

Figure 59. *Summary stratigraphy of the Sverdrup Basin.*

Cenomanian Hassel Formation correlates with break up in the Canada Basin. Deposition of thick Kanguk Formation shales in the Late Cretaceous reflects the flooding of continental margins worldwide during global highstand.

The basal member of the Eureka Sound Group (Expedition Member) represents the final pulse of continuous sedimentation in the Sverdrup Basin. The various units of the Eureka Sound Group range in age from Campanian or Maastrichtian to Late Eocene or earliest Oligocene. The group comprises alluvial, deltaic and estuarine members. The strata are rich in poorly consolidated, fine to very coarse grained sandstones, with abundant coal. The Eureka Sound Group is deeply truncated across the Sverdrup Basin by drainage systems developed during lowstands in the Paleogene and Holocene. Its marine/deltaic facies are more fully preserved on the Arctic Continental Terrace Wedge.

Reservoirs

The proven reservoirs of the Sverdrup Basin are shallow marine, delta-front and delta-plain sandstones of the Schei Point Group, Heiberg Group, Awingak and Isachsen formations. These have been the primary target for the bulk of exploratory drilling in the Arctic Islands and currently contain all the important discoveries.

(1) Schei Point Group. In the Roche point gas field, 24 m of pay were encountered in marine sandstones of the Roche Point Formation and 15 m in the shallower Pat Bay Formation. Porosity in the better, lower pay zone is 18%. Reservoir quality was inferior in the lower zone.

(2) Heiberg Group. Fourteen accumulations have been drilled in Heiberg Group sandstones, thirteen in the uppermost King Christian Formation. Average net pay in this formation is 30 m with maximum thicknesses of 60 m encountered in the Kristoffer discovery in stacked delta-plain sandstones. Porosity in Drake and Hecla is in the range of 18-20%. Reservoirs tend to be homogeneous and massive, with little variation in porosity about the mean. The sandstones are generally very clean and show excellent response on electric logs.

(3) Awingak Formation. Gas was discovered at Whitefish in 10 m thick, coarsening-upward delta-front sandstones. Pay thicknesses of 5 to 8 m in each cycle combined for 17 m net pay, *averaging 16% ‘porosity. Two hundred kilometres to the east, at Cape Macmillan, gas was tested from a 22 m thick sandstone. The basal 7 m of this unit is coarsening-upward and of poor reservoir quality. This is capped by 15 m of clean delta-plain, proximal delta-front sandstones with 18% porosity.

(4) Isachsen sandstones contain hydrocarbons in Balaena and Whitefish. Thirty metres of oil-bearing sandstone were encountered in Balaena in delta-front sandstones. Porosity in this youngest reservoir is 30%.

Although significant accumulations discovered to date have been in Middle Triassic and younger formations, Early Triassic Bjorne sandstones, and Permian Trold Fiord sandstones and associated Degerbols carbonate also are potential reservoirs. Shows of both oil and gas were encountered in the Bjorne Formation in certain wells drilled in the Drake and Hecla fields, respectively. In Drake L-67, gas shows were noted deep in the well from the Degerbols. Although no shows have been noted in Permian carbonates, reefs along the Nansen/Belcher Channel shelf edge and isolated buildups encased by van Hauen shales are potential reservoirs.

The oldest potential reservoirs within the Sverdrup succession are continental sandstones of the Canyon Fiord and Borup Fiord formations. The conglomeratic facies of alluvial fans - characteristic of both formations, at least around the basin margins - tend to have poor porosity and permeability. Much more attractive from the viewpoint of potential reservoirs are aeolian sandstones, also typical of arid environments, and associated with Permian redbeds in many basins of the world. This facies has yet to be identified in the Sverdrup.

Structure, Traps and Seal

Three styles of structural traps are associated with existing discoveries in the Sverdrup Basin. These occur in geographically separate areas as.shown in Figure 58.

(1) A broad low-relief flexure parallels the southern margin of the Sverdrup Basin. This hosts two giant gas fields, Drake Point and Hecla, which fill local closures along the flexure to spill point. The fields are crossed by the northeasterly trending system of normal faults, which may have formed due to reactivation of the initiating rifts of the basin. The eastern offshore area of the Drake Point field is elongate along this northeasterly trend where the faults have larger throws and provide the dominant structural grain. The Drake Point gas field is the

largest field in Canada's frontiers, and typifies the large low dip structures found along the southern margin of the basin.

(2) The second family of structures includes the Whitefish gas discovery and the Cisco oil and gas discovery west of Lougheed Island. Whitefish is typical of this class of structures: it is a dome, 25 km in diameter with relief of 175 m. Some extensional faulting is present but the frequency of faulting is low and throws are modest. Reservoir continuity across the fields appears good. These structures overlie the western Carboniferous salt subbasin and are formed over salt diapirs which, however, fail to pierce the stratigraphic level of the reservoirs. Two diapirs are exposed on northern Sabine Peninsula. The trend continues offshore in a northeasterly direction and parallels a second trend 30 km to the northwest. Trap fill in these structures is in excess of 50%.

(3) The third class of structures lies offshore of southwestern Ellef Ringnes Island and King Christian Island – an area of some 10,000 km². These are anticlines of early Tertiary age developed or accentuated during the Eureka Orogeny. The structures have high relief and their development was facilitated by the eastern Carboniferous salt subbasin that underlies this area. Salt walls coring the anticlines are orthogonal to the east-west direction of principal stress developed during the orogeny. Discoveries in this type of structure are Kristoffer, Sculpin, Thor, Jackson Bay, Wallis, King Christian, Cape Allison, Cape MacMillan, Char and Balaena. The King Christian gas discovery is typical: the structure is elongate (12 by 5 km) with in excess of 1000 m of relief. These structures are poorly filled, to about 10% of their closure. This is likely the consequence of late growth, restricted hydrocarbon catchment area, declining hydrocarbon generation with overmaturity of source rocks, and, possibly, to surface seepage through extensive crestal faulting typical of these structures.

The discoveries at Skate and Maclean – offshore of eastern Lougheed Island – are intermediate between the domal structures west of Lougheed Island and the anticlinal folds and salt walls just described. They probably represent salt-related swells of pre-Eurekan age, reactivated and faulted by Eurekan compression.

Closure on tilted rift blocks contributes to the trap at East Drake. With this exception, the rift trend is undrilled. Similar fault-bounded traps are likely to be common along the Sverdrup Rim. Other structural targets occur in the northeastern Sverdrup Basin, centred on the Fosheim Peninsula of Ellesmere Island. These lie within the Hazen Fold Belt where significant thicknesses of Mesozoic strata are preserved. Elsewhere on Ellesmere Island, uplift has removed much of the Mesozoic basin-fill.

Stratigraphic pinchout onto the southern flank of the basin appears to be a component of trapping in one of the gas pools in the Hecla field. This is likely to occur elsewhere along trend in many of the Mesozoic sandstones. Trapping also may occur down-dip from tar sands, for example, from those exposed at Marie Bay on western Melville Island. Depositional pinch-out onto the flanks of salt swells is also likely, as is trapping against salt intrusions.

Source Rocks

The oldest identified source rock in the Sverdrup Basin are the oil shales of the Carboniferous Emma Fiord Formation. Total organic carbon content, measured on outcrop samples, ranges up to 50%. The shales are rich in alginite and are thought to be have been deposited in a lacustrine environment. The Emma Fiord Formation is likely to be overmature (but possibly a rich source of gas) except at the extreme margins of the basin. Dark, organic-rich shales also have been noted in the Upper Carboniferous and Permian Hare Fiord and van Hauen formations.

The thickest and most widely distributed of the source rocks in the Sverdrup Basin are the distal marine facies of the Triassic Schei Point Group' (Murray Harbour and Hoyle Bay formations). Recurrent deposition of organic rich shales within the basin was favoured by low-energy stratified waters in areas remote from deltaic influx. Switching of sediment source direction ensured that these source rocks were widely distributed within the basin, albeit at slightly different times throughout the Triassic. Analysis of samples from Schei Point shales shows much variation about an average TOC of 4%. All samples contain marine Type II organic matter of algal origin with excellent potential as an oil source.

Extracts from Shei Point shales show close geochemical correlation with all discovered oils within the basin, suggesting a common source for oil. Indeed, the distribution of existing discoveries is well explained by the regional maturity map for the Schei Point shales alone. The presence of gas is explained by the flanking position of gas accumulations to areas of overmature Schei Point source rock, raised to maturity levels beyond the oil window by high heat flow associated with salt or volcanic intrusion and/or depth of burial. Mixed gas and oil discoveries can be explained by invoking more than one phase of hydrocarbon migration linked to successive tectonic events that affected the maturity of the source rock. As a general observation, Triassic source rocks become overmature east of a line running roughly down the axis of Ellef Ringnes Island and southeast to Ellesmere Island.

Jurassic shales of the Jameson Bay Formation also contain Type II kerogen and are oil-prone west of Lougheed Island, but this interval is only marginally mature. Maturity levels may increase locally near salt intrusions. Farther east, where Type III organic matter predominates in more proximal deltaic facies, this and most other Mesozoic shales can be expected to be more gas-prone.

Potential

The Sverdup Basin is a large and diverse petroliferous basin with an excellent discovery record. Proven plays in the Triassic sandstones contain accumulations of giant class and many smaller discoveries can be expected. No tail off in the cumulative discovery record is evident. Larger accumulations tend to be in the structures of subtler relief removed from the influence of the Eurekan Orogeny. Stratigraphic traps in these reservoirs are entirely unexplored and the potential for large closures is high, especially along the southern margin of the basin. Up-dip from the western salt subbasin (in and around Sabine Peninsula) the structures are likely to contain gas. Farther west, the Schei Point shales are likely to be less mature, and oil accumulations in similar traps are possible. One example of such a potential field are the tar sands at Marie Bay on western Melville Island, which are hosted in Lower Triassic Bjorne sandstones. The distribution of the Bjorne Formation in the southwestern basin makes this an interesting target below the Heiberg and Schei Point groups. The Awingak Formation is of interest throughout the western Sverdrup, particularly in view of its association with coeval source rocks west of Loughheed Island.

Numerous undrilled fault-bounded structures are likely to exist offshore in addition to structural/stratigraphic traps associated with salt deformation. Horst blocks are particularly attractive and are likely to be within drilling depth around the basin margins.

Generally speaking, the risk of source rock overmaturity, break down of trap integrity and biodegradation of oils increases towards the eastern margin of the basin: large economic prospects are less likely in these areas. Although the discovery rates have been high, these considerations weigh against pursuit of prospects in the zone of Eurekan structures.

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FRANKLINIAN BASIN

Age	Cambrian to Early Carboniferous
Area	Arctic Platform 780,000 km^2 (47% onshore) Arctic Fold Belt 240,000 km^2 (62% onshore) and extending at depth beneath the Sverdrup Basin
Depth to Target Zones	0.5 to 5 km
Maximum Basin Thicknes	10 km
Hydrocarbon Shows	Oil staining in Thumb Mountain (Upper Ordovician), Bird Fiord and Weatherall formations (Middle Devonian). Gas shows in first well drilled in basin – at Winter Harbour No. 1 A-09 in the Upper Devonian clastic wedge
Sole Discoveries	Bent Horn N-72 (1974: 43° API oil)
Discovered Resources	Oil: 1.0 x E6 m^3
Production	Oil: Bent Horn: 321,470 m^3 to the end of 1993
Basin Type	Carbonate-dominated continental margin (miogeocline) in lower Paleozoic. Foreland Basin in Late Devonian
Depositional Setting	Marine carbonate/shale basin; switching to siliciclastic marine/deltaic/fluvial in Late Devonian
Reservoirs	Early to Middle Devonian reefs; carbonate bank margins and shallow-water shelf carbonates and mounds; sandstones of the clastic wedge
Regional Structure	Highly structured Arctic Fold Belt outboard of the Arctic Platform
Seals	Marine shales (Cape de Bray Formation at Bent Horn)
Source Rocks	Ordovician and Lower Devonian shales (gas); shales of the clastic wedge (oil?); Middle Devonian carbonates and shales coeval with reefs (oil?); structurally juxtaposed source rocks of the overlying Carboniferous and Mesozoic (oil?)
Depth to Oil Window	At surface in the Arctic Fold Belt
Total Number of Wells	50

Geological Setting (Fig. 60)

The Early Cambrian to mid-Devonian Franklinian Basin was contiguous with the Hudson Platform to the southeast and the Interior Platform to the southwest, and part of an uninterrupted continental margin bordering the North American craton. Carbonate deposition predominated over this lengthy period, constructing a thick pericratonic wedge (miogeocline). Beginning in the Middle Devonian, siliciclastic sediments derived from eastern highlands thrown up by the Ellesmerian Orogeny spread across the region. The deposition of these thick foreland basin deposits – the 'clastic wedge' of Embry and Klovan (1976) – heralded the folding and uplift of much of the Franklinian Basin at the culmination of the Ellesmerian Orogeny.

The southern edge of the Arctic Fold Belt marks the limit of folding of Franklinian strata by Ellesmerian compression. The Arctic Fold Belt is the southern component of a broad region of past tectonic activity – the Innuitian Tectonic Province – which also includes distal parts of the Franklinian Basin, the Sverdrup Basin and the Arctic Continental Terrace Wedge.

South of the Arctic Fold Belt, the Arctic Platform is generally mildly deformed, except in the vicinity of the Boothia Arch. The axis of this major uplift of Silurian vintage strikes north from the Canadian Shield, exposing Archean rocks along its length. The structural influence of the arch extends north of Barrow Strait into Cornwallis Island and the Grinell Peninsula of Devon Island, where complex interference structures developed at its intersection with the Arctic Fold Belt.

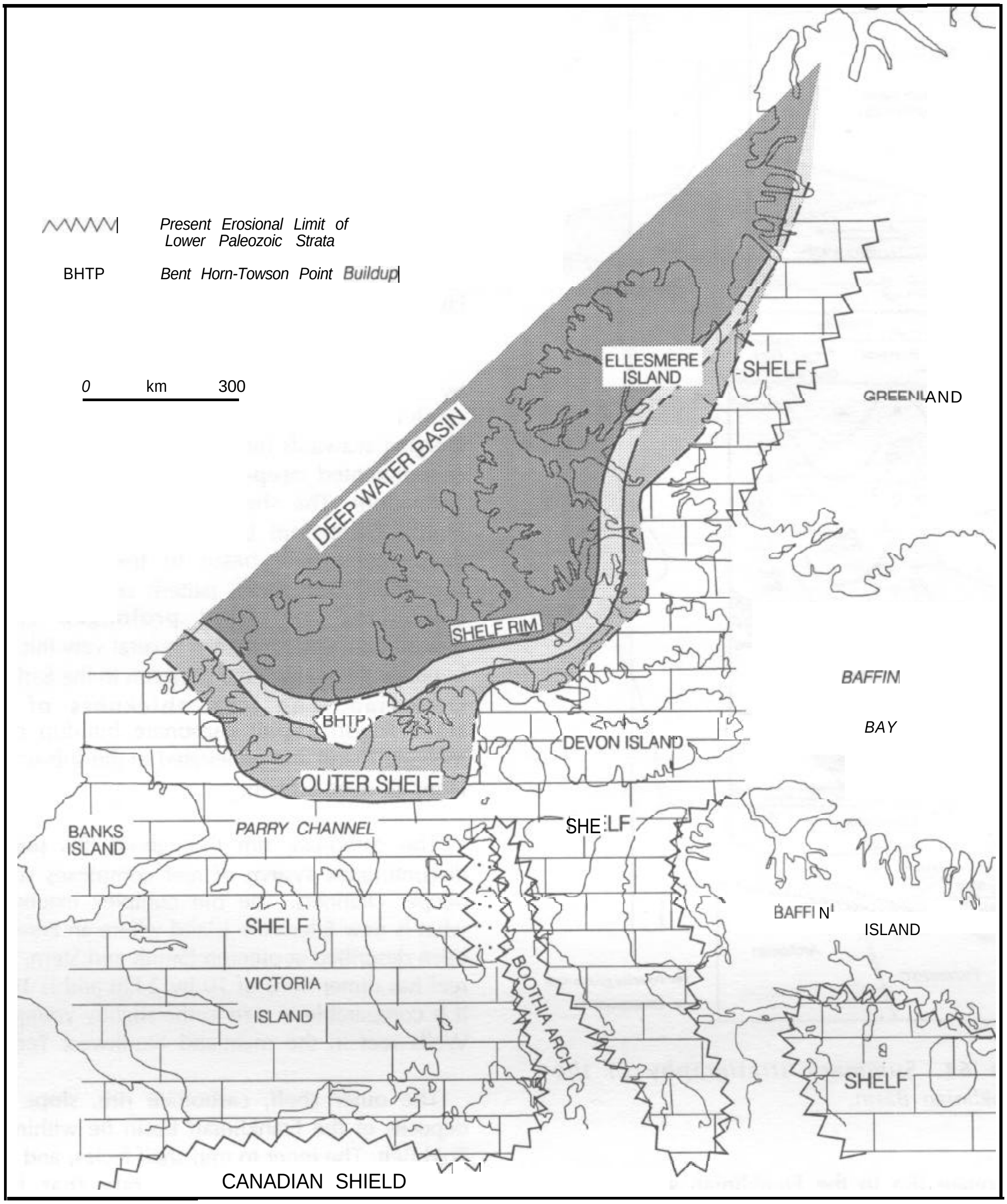

Figure 60. Generalized Cambrian to Middle Devonian paleogeography, Franklinian Basin.

Stratigraphy (Fig. 61)

The thickness of the Cambrian increases from the edge of the Canadian Shield to over six kilometres in northeastern Ellesmere Island. Within the Arctic Platform, sandstones of the Gallery and Turner Cliffs formations were widely deposited following a long period of peneplanation, which separates Cambrian rocks from the Precambrian. The succession on Ellesmere Island is much thicker and predominantly marine. It includes shelf carbonates (Ella Bay Formation), deltaic sandstones (Rawlings Bay Formation) and distal equivalent (Archer Fiord Formation), and shelf mudrocks of the Kane Basin Formation. Deep-water equivalents (Grantland Formation) are found in northeastern Ellesmere Island.

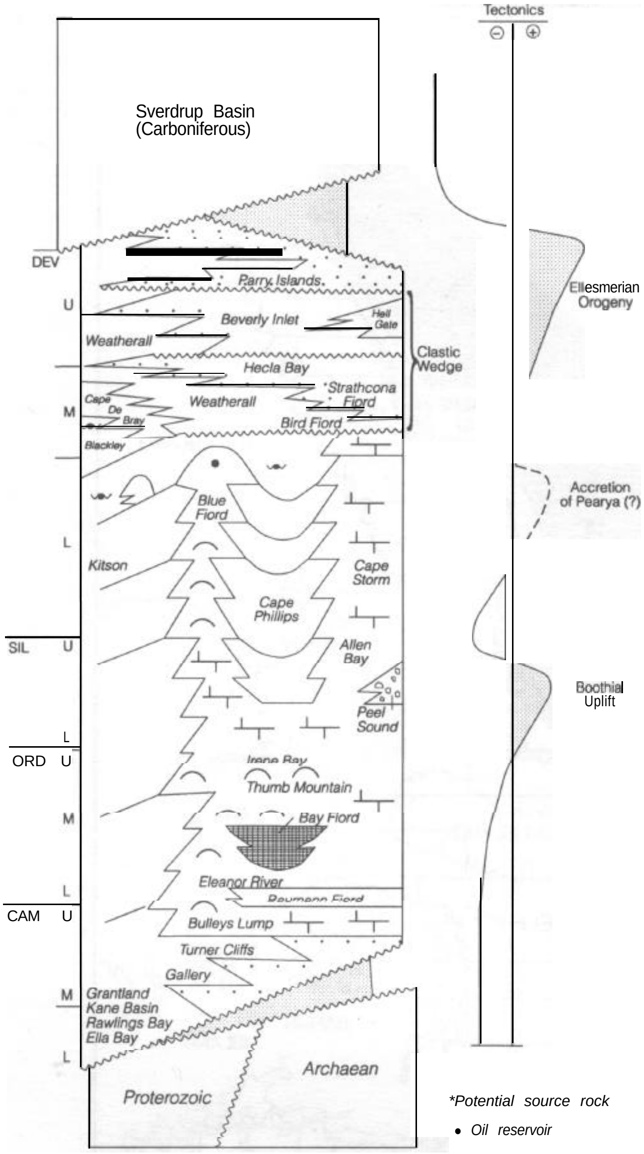

Figure 61. Summary stratigraphy of the *Franklinian Basin.*

A carbonate rim to the Franklinian shelf began to develop in the Early Ordovician (Bulleys Lump Formation), restricting marine circulation across the inner shelf. Laminated carbonates, anhydrite and gypsum of the early Middle Ordovician Baumann Fiord Formation were deposited, succeeded by marine limestones of the Eleanor River Formation. An evaporitic basin was re-established after deposition of the Eleanor River Formation. Thick halite of the Bay Fiord Formation occurs in the subsurface of Bathurst and Melville islands within a more extensive area of gypsum-anhydrite deposition.

Marine environments were established across most of the continental margin late in the Ordovician and persisted into the Late Devonian. This lengthy period saw rapid accretion of the carbonate-dominated continental margin. Ordovician units include marine limestones of the Thumb Mountain Formation (up to 400 m thick, overlying Bay Fiord evaporites across much of the Arctic Platform), Irene Bay and Allen Bay formations. Reef builders were active in the Middle and Late Ordovician in northeastern Melville Island where mounds up to 30 m high and 1500 m in diameter have been described. Similar mounds are known from the Hudson Platform.

Silurian to Devonian deposition was characterized by division into a shallow water carbonate shelf to the south and east (Allen Bay and Cape Storm formations), merging seawards into deeper shelf environments with re-sedimented deep-water carbonates (Cape Phillips Formation). The shelf was rimmed by reefs (“Blue Fiord” Formation) bordering a plunging slope and deep-water shale basin to the northwest (Kitson Formation). This facies pattern endured until the Late Devonian, conferring prolonged stability in depositional environments. Several very thick carbonate buildups grew along the shelf rim in the Early to Middle Devonian. The total thickness of the Bent Horn-Towson Point carbonate buildup exposed on Melville Island and penetrated in the subsurface at Bent Horn is over 600 m.

The carbonate rim throughout this period was a discontinuous system of reef complexes separated by deeper channels. The rim complex extended east to what is now Ellesmere Island where an Emsian reef has been described at outcrop (Smith and Stern, 1987). This reef has dimensions of 10 by 2 km and is 100 m thick. It is comparable in size to the slightly younger Norman Wells reef in the mainland Northwest Territories.

The outer shelf, carbonate rim, slope and basin deposits of the Franklinian Basin lie within the Arctic Fold Belt. The inner to mid shelf facies, and most of the Cambrian to Ordovician strata that have been penetrated lie within the Arctic Platform. Local complexity and an interruption in carbonate sedimentation is present in the vicinity of the Boothia Arch where conglomerates of the Peel Sound Formation were shed from the arch during its main phase of growth in the Silurian.

The Ellesmerian Orogeny saw the influx of siliciclastic sediments from east to west across the carbonate shelf starting in the earliest Middle Devonian. The Ellesmerian Orogeny may be linked to plate movements that also emplaced an exotic terrane, Pearya, on the northern edge of the region. Pearya may have been a supplementary source of quartzose sediments. These deposits form a massive wedge (maximum preserved thickness of 4 km), which originally thickened to the west (and distally) towards the modern coasts of the Beaufort Sea. Deposition of the clastic wedge ended as Ellesmerian uplift propagated westwards, resulting in the erosion of major thicknesses of the clastic wedge and their redeposition beyond the confines of the Arctic Islands.

The earliest strata assigned to the clastic wedge are fine grained clastics of the Blackley Formation, which overlie black shales of the Kitson Formation. Blackley strata were deposited at the toe of an advancing slope on which siltstones and shales of the Cape de Bray Formation were deposited. Diachronous upwards-coarsening characterizes the westward regression of the coarse-grained clastic depositional systems and the Cape de Bray is overlain and laterally equivalent to deltaic and marine shelf deposits of the Bird Fiord and Weatherall formations. The first incursion of fluvial deposits into the basin is recorded by sandstones of the Strathcona Fiord Formation on Ellesmere Island, followed by the much more widespread braided-stream deposits of the Hecla Bay Formation in the late Middle Devonian. An unconformity above the Hecla Bay Formation marks the end of the first of three main regressive pulses within the clastic wedge. The second advance of the deltaic systems into the basin in the Late Devonian deposited the Beverley Inlet Formation across most of the basin (the Fram, Hell Gate and Nordstrand Point formations are proximal equivalents on Ellesmere Island). The final pulse deposited the Parry Islands Formation, which again spread fluvial and coastal plain facies across the basin. There is a gap in the stratigraphic record above the Parry Islands Formation, extending from the latest Devonian to earliest Carboniferous. This hiatus marks the end of deposition within the Franklinian Basin.

Reservoirs

Bent Horn Field

The Bent Horn oil pool was discovered by the drilling of the Bent Horn N-72 well, spudded in 1973. The reservoir is in reefal limestones of the Blue Fiord Formation. The field produces 45° API oil from a single well (A-02). The discovery lies within the highly structured transition zone between the Arctic Fold Belt and the Sverdrup Basin, in the upper of two northward-directed backthrusts, truncated and sealed on the southern side by a normal fault of 300 m throw. The pool is confined on the eastern side by a facies transition from reefal carbonate to shale.

The Bent Horn pool has been delineated by six wells (including the discovery well). Two wells recovered oil, one is rated as an oil show and three were dry holes. Only the A-02 well penetrated an oil zone in the overthrust sheet, and has proved to be the only well able to sustain production. This well is capable of 5300 bbls/day with minimal water production. The F-72 and N-72 wells missed the nose of the upper thrust sheet but encountered oil in the footwall of the thrust. The extent of the N-72 pool appears limited on the basis of production tests. Subsequent sidetracking of the F-72 well to intersect the upper thrust sheet failed to encounter any porous zones.

Drilling has demonstrated that the Blue Fiord limestones are generally tight with local porosity in vugs and caverns. Permeability is improved by fracturing, but this appears to be highly localized. The field has an active water drive. The field is limited to the upper thrust sheet and its extent along strike is uncertain. On production since 1985, the well has produced 321,469 m^3 of oil to the end 1993. The porosity type and the complex structural setting makes reserve determination difficult and the estimate of 1.0 x E6 m^3 is subject to considerable uncertainty.

Other Potential Reservoirs

Basal Cambrian sandstones are poorly consolidated and usually have good porosity in outcrop. These sandstones are diachronous, and older equivalents may be present at depth in the more distal parts of the Franklinian Basin. Although good porosity has been noted at outcrop, porosity in the subsurface is unlikely to be better than fair. Cambrian reservoirs in the Colville Hills of mainland Northwest Territories average 12% porosity.

Upper Cambrian and Ordovician precursors of the carbonate rim reefs of the Blue Fiord Formation have modest potential as reservoirs. Porosity development in these carbonates and the much more extensive mounds and patch reefs and shallow-water carbonates of the shallow Franklinian Shelf are potentially porous, but porosity development is probably rare.

Sandstones of the clastic wedge are potential reservoirs with reservoir quality depending on depositional facies. Porosity seldom exceeds 10% in the deltaic/marine sandstones of the Bird Fiord and Weatherall formations on Melville Island, but more proximal fluvio-deltaic sandstones may exhibit superior reservoir characteristics.

Structure, Traps and Seals

Large regular folds are evident at outcrop in the Parry Islands section of the Arctic Fold belt. Seismic and field studies reveal more complex structure at depth, of which this is the surface expression in younger horizons. Multiple detachments and ramping of thrust sheets are present within the Ordovician salt and weaker shale intervals in the predominantly carbonate sequence. These show a progression in structural complexity that can seldom be deduced from outcrop studies alone, and which greatly increases the permutations of potential reservoir, seal and source to be found within the fold belt. Drilling on structural targets within the Franklinian sequence has not been based on modern interpretations of the target structures. Recent recognition of the effects of the Melvillian Disturbance in the Canrobert Fold Belt on northwestern Melville Island – distinct in age and style of deformation from the Parry Islands Fold Belt – underlines the recent advances in our understanding of the structural complexity of this region (see Harrison, 1991).

The larger amplitude structures of the Arctic Fold Belt are found within the shelf carbonate areas of the Franklinian Basin. Basinward (i.e., to the north) the structuring of the predominantly shale succession has resulted in chevron folding of much greater frequency.

Structural traps within the fold belt include simple anticlines, thrust anticlines, sub-thrusted sheets and sub-salt traps, and basement fault blocks. Shale horizons and salt provide seals. West of 105°W, there has been little tectonic influence since the end of the Ellesmerian Orogeny, and the risk of seal failure as a result of late reactivation of the structures is slight. This is not the case close to the margin of the Sverdrup Basin, where active extensional tectonics and possibly strike-slip movement along the many thrust sheets risked the integrity of pre-existing traps.

Anticlinal structures, so evident in the Arctic Fold Belt, are absent from the Arctic Platform. Potential traps are related to faulting of the basement and especially to faulting associated with arches. Archean rocks are exposed along the crest of the Boothia Arch. This major structure is thought to be a westward-verging thrust and most of the associated surface structures have been mapped along its western flank. The Cambrian to late Silurian succession on both flanks probably does not exceed 2000 m in total thickness. The three wells drilled on Prince of Wales and Somerset islands tested structures on the flanks of the Boothia Arch.

Stratigraphic traps include reef development on the rim of the carbonate shelf. This depositional transition from shelf to slope resulted in a transition in gross geotechnical properties, and hence of focus for structural discontinuity. In this sense it is hardly surprising that discoveries along the trend of the main barrier may have the added structural complexity of faulting. Large reefs also develop on the slope seaward of the main reef trend. Reefs of this type are more likely to be encased in shale and are removed from the main zone of structural discontinuity at the shelf edge. Patch reefs and oolitic shoals within the shallow waters of the shelf are likely to be common in Ordovician through Middle Devonian strata of the Arctic Platform.

Source Rocks

Although uncommon within the thick carbonate succession of the lower Paleozoic, some potential source rocks have been identified. Black shales of the Upper Ordovician Cape Phillips Formation and Lower Devonian Kitson Formation have 3 to 5 % TOC and high gas yields. The source of the oil at Bent Horn is unknown but circumstantial evidence suggests that it is derived from encasing shales of the Cape Phillips Formation.

Within the Middle to Upper Devonian clastic wedge, shales of the Weatherall, Bird Fiord, Blackley and Cape de Bray formations are potential oil sources. Maturity levels within these horizons increase to the point of overmaturity towards the west, the result of deep burial beneath sediments of the clastic wedge, subsequently eroded. Potential for gas generation also exists within the clastic wedge.

Potential

Three petroleum systems may exist in the Franklinian Basin: all are under-explored and incorporate many distinct plays. Potential ranges from fair (Cambrian to Silurian), to good (Lower to Middle Devonian carbonates and Middle to Upper Devonian clastics). Only one play can be considered proven – the Bent Horn discovery: the remainder are conceptual, although supported by hydrocarbon shows and promising geology.

Petroleum System 1. Basal Cambrian to Lower Ordovician (sandstone and carbonate reservoir facies and associated source rock facies).

Lower Ordovician carbonates in structures beneath the Bay Fiord salt are a potential gas play due to the high level of maturity of any communicating source rock. Top seal in the form of halites of the Bay Fiord Formation is confined to Melville and Bathurst islands. Lack of porosity and absence or over-maturity of source rock are the chief risks of these plays, although prospects for sealing and preservation of accumulations beneath the salt are favourable.

Cambrian sandstones form an important reservoir rock on the Interior Platform in the Colville Hills and are likely to exhibit similar reservoir character across the Arctic Platform. However, the absence of any extensive salt-basin of Cambrian age on the Arctic Platform reduces the likelihood of effective top seals for Cambrian sandstones. Traps are most likely to be stratigraphic onlap and pinchout onto the basal Cambrian unconformity. Such traps are well\ positioned to intercept hydrocarbons migrating up-dip from deeper parts of the basin.

Petroleum System 2. *Upper Ordovician to Middle Devonian (carbonate buildups and associated source rock facies).*

Upper Ordovician carbonates (e.g., Thumb Mountain Formation) in Ellesmerian anticlines and thrust plates are tight or yielded water, but the presence of porosity, oil staining, and gas shows, combined with the close proximity to source rocks, indicate that undrilled closures still have some potential, probably for gas.

The Silurian to Middle Devonian shelf rim and isolated carbonate buildups on the upper slope have the best potential for hydrocarbon discoveries in lower Paleozoic strata. Reefal buildups appear to be relatively frequent within this trend. Porosity is present, although locally plugged with bitumen. The Bent Horn pool lends confidence that active oil source rocks occur in coeval off-reef facies. There is potential for major oil fields within this play.

Petroleum System 3. *Upper Devonian clastic wedge (sandstones and associated source rocks).*

Gas shows in the Winter Harbour well, and oil staining in surface and some subsurface samples are recorded from Upper Devonian sandstones of the clastic wedge. Potential reservoir rocks are in close stratigraphic proximity to source rocks both within the clastic wedge and to source rocks near the base of the overlying Sverdrup succession. Maturation levels are generally favourable. Structural targets include anticlines, and fault-bounded thrust sheets within the Arctic Fold Belt and along the margin of the Sverdrup Basin.

Future exploration is likely to focus on oil prospects in reef complexes along the carbonate rim, particularly close to the structural interface of the Arctic Fold Belt and the Sverdrup Basin. The major structures of the Arctic Fold Belt involve clastic wedge sandstones, which form a major play for both gas and oil. Potential for both plays to host major pools of oil and gas is good.

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ARCTIC CONTINENTAL TERRACE WEDGE

Age	Cretaceous to Recent
Depth to Target Zones	?
Maximum Basin Thickness	12 km
Hydrocarbon Shows	?
Discovered Resources	None
Basin Type	Passive margin
Depositional Setting	Transitional to marine shelf and oceanic basin
Reservoirs	Fluvio-deltaic/marine sandstones, turbidites(?)
Regional Structure	Extensional faulting; rotated fault blocks
Seals	Marine shales (?)
Source Rocks	Unknown
Depth to Oil Window	>3000 m (?)
Total Number of Wells	10 wells have tested the proximal edge from onshore locations along the Sverdrup rim

The Arctic Continental Terrace Wedge is known to contain thick accumulations of sediments. Seismic refraction studies on the Arctic continental shelf north of Axel Heiberg Island reveal the presence of a thick (10 km) deformed sedimentary succession on the outer shelf. Seismic reflection profiles obtained along the path of the Ice Island show the presence of a wedge of faulted sedimentary strata (2 km) on the inner shelf, west of Axel Heiberg Island.

The wedge comprises Upper Cretaceous and Paleogene sequences that correlate with oil and gas bearing sequences in the southern Beaufort Sea and Mackenzie Delta. The Eureka Sound Formation, while predominantly fluvial at outcrop in the Arctic Islands, is likely to have deltaic and marine equivalents offshore, which may include potential reservoir and source rocks. These may have been sufficiently buried to reach maturity beneath a thick wedge of poorly consolidated Beaufort Formation sandstones deposited above the circum-Beaufort unconformity in the Early Miocene.

However, the geographic remoteness, and the large proportion of the basin that lies beneath the shifting Arctic Ocean ice pack removes the region from possible economic exploitation in the foreseeable future.