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Forty Years of Northern Non-Renewable Natural Resource Development

W.W. NASSICHUK[1]

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ABSTRACT. Northern Canada is endowed with abundant non-renewable natural resources, and exploration and development of those resources have increased steadily since World War II. Particularly during the past 20 years new regulatory controls have been emplaced in response to elevated concerns about the possible impact of resource development on the environment. During the past 40 years gold, silver, copper, lead, zinc, nickel, asbestos, tungsten, uranium, coal and other minor commodities have been produced from more than 30 mines in the northern mainland, but at the present time only 6 mines are producing gold, silver, lead and zinc in that area: Con, Giant Yellowknife, Echo Bay, Mount Skukum, United Keno Hill and Faro mines. Lead and zinc are being produced at the world's most northerly mine, Polaris, on Little Cornwallis Island, and lead, zinc and silver are mined at Nanisivik on Baffin Island. At least 375 oil and gas wells have been drilled north of the Arctic Circle in the northern mainland since 1947, and 42 oil and gas fields have been discovered in the Beaufort Sea-Mackenzie Delta area alone. Total discovered and undiscovered resources in the latter area approximate 2131 billion m^3 gas and 1.35 billion m^3 oil. From 1961 to 1986, 176 wells were drilled in the Arctic Islands and 17 oil and gas fields were discovered. Discovered and undiscovered resources approximate 2257 billion m^3 gas and 686 million m^3 oil.

Key words: minerals, oil, gas, coal, Beaufort Sea, Mackenzie Delta, Arctic Islands, weather stations, transportation

RÉSUMÉ. Le nord du Canada a l'avantage de contenir des quantités abondantes de ressources naturelles non renouvelables, et la recherche ainsi que la mise en valeur de ces ressources ont augmenté continuellement depuis la Deuxième Guerre mondiale. Lors des dernières vingt années en particulier, de nouvelles réglementations de contrôle ont été mises en place pour répondre aux inquiétudes grandissantes concernant les retombées possibles de la mise en valeur des ressources naturelles sur l'environnement. Au cours des 40 dernières années, plus de 30 mines situées sur le continent nordique, ont produit de l'or, de l'argent, du cuivre, du plomb, du zinc, du nickel, de l'amiante, du tungstène, de l'uranium, du charbon et d'autres marchandises de moindre importance. À l'heure actuelle cependant, 6 mines seulement produisent de l'or, de l'argent, du plomb et du zinc dans cette région. Ce sont les mines de Con, Giant Yellowknife, Echo Bay, Mount Skukum, United Keno Hill et Faro. La mine Polaris, la plus septentrionale au monde, dans l'île Little Cornwallis, produit du plomb et du zinc, tandis que la mine de Nanisivik dans la Terre de Baffin produit du plomb, du zinc et de l'argent. Au moins 375 puits de gaz et de pétrole ont été forés au nord du cercle arctique sur le continent depuis 1947, et 42 champs pétroliers et gaziers ont été découverts dans la seule région de la mer de Beaufort et du delta du Mackenzie. Le total des ressources découvertes et non découvertes est proche de 2131 milliards de m^3 de gaz et 1,35 milliard de m^3 de pétrole. De 1961 à 1986, 175 puits ont été forés dans l'archipel Arctique, et 17 champs pétroliers et gaziers y ont été découverts. Les ressources découvertes et non découvertes y atteignent près de 2257 milliards de m^3 de gaz et 686 millions de m^3 de pétrole.

Mots clés: minéraux, pétrole, gaz, charbon, mer de Beaufort, delta du Mackenzie, archipel Arctique, stations météorologiques, transport

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INTRODUCTION

The arctic regions of the globe are now, more than ever, important both economically and strategically, and their importance to international relationships will continue to grow. The Soviet Arctic, in particular, is well endowed with non-renewable resources such as nickel, cobalt, platinum, copper, gold, tin, iron and diamonds, in addition to which oil, gas and coal are being exploited. In Spitsbergen coal is currently being mined and petroleum exploration is under way. A variety of metals and oil and gas are abundant and being exploited in Alaska. In arctic Canada, exploration for and development of resources have increased steadily since World War II, and it seems clear that the importance of northern mineral and energy resources will continue to increase in the future.

The purpose of this report is to provide a chronological summary of the exploration and development of non-renewable resources (minerals, oil, gas, coal) in northern Canada during the past 40 years, with emphasis north of the Arctic Circle. Equally important is the development of renewable resources in northern Canada, including wildlife, fisheries, forest products and hydro-electric power, but a review of those is beyond the scope of this study.

Heightened concerns for northern Canada's communities and renewable resources during the past 20-30 years have led to the development of policies and procedures that have necessarily had a direct impact on non-renewable resource exploration and development. Regulatory procedures have been developed to monitor land use and to assess the environmental and social impact of resource development. Happily, northern residents have become increasingly able to influence the regulatory process by participating in public hearings and, indeed, by serving as members on various review panels or boards.

In 1974 Thomas R. Berger was appointed by the Government of Canada to conduct an inquiry into the social, economic and environmental impact of a gas pipeline possibly followed by an oil pipeline in the Northwest Territories and Yukon. One year earlier a Pipeline Application Group under the leadership of J.G. Fyles was assembled to review the massive data presented by Arctic Gas, the consortium seeking to build the pipeline, and the Fyles report was a basis for formulation of the Berger inquiry. The National Energy Board was also reviewing the Arctic Gas proposal independently and was assisted indirectly by the Fyles report. The Berger inquiry was unique in that previously a major frontier project had never been reviewed through public participation before construction was begun.

The introduction of a new National Energy Program (NEP) for Canada in 1980 resulted in significant changes in oil and gas exploration in arctic regions. This policy was designed principally to ensure security of supply, increase Canadian ownership of the domestic petroleum industry and establish a pricing and revenue regime of benefit to both the nation and industry. Key elements of the policy included establishment of a Petroleum Incentive Program, which provided about 80% of the cost of exploration; requirements of 50% Canadian ownership of production; government ownership of 25% of any discovery; and a new system of land administration under the Canada Oil and Gas Lands Administration (COGLA). Under the land adminis-

[1]Institute of Sedimentary and Petroleum Geology, 3303 33 Street N.W., Calgary, Alberta, Canada T2L 2A7

tration system, the petroleum industry entered into a number of exploration agreements. The exploration agreement confers upon the interest-owner the right to explore and the exclusive right to drill in specific areas, and, as well, it describes the conditions of tenure and the work program to be undertaken. Most of the current agreements require the relinquishment of a portion of the lands initially held. The purpose of relinquishment is to focus exploratory activity and to maintain a bank of Crown reserve lands available for disposition. Although geology is the major consideration in the Crown's selection process, any special environmental considerations or other sensitivities that may be identified in a locality are also taken into account.

HISTORICAL BACKGROUND

The Inuit, the aboriginal people of arctic Canada, arrived from Siberia more than 8000 years ago. They were followed by the Vikings, the first Europeans to visit arctic Canada, by about 1000 A.D. The Vikings arrived by way of Iceland and Greenland and probably introduced iron implements to the region. As recently as 300 years ago the Inuit utilized native copper in the Coppermine River area.

Martin Frobisher visited Baffin Island in 1576 and raised the first hopes for mineral wealth in the Arctic of the New World. Frobisher's "blacke stone," amphibolite that he thought contained gold, was collected from Kodlunarn Island on the south side of Baffin Island. Several loads of "ore" from Canada's first "mine" were shipped to England by Frobisher, but the rock proved to be barren of gold.

British and Danish explorers searched for a sea route to the Orient through Hudson Bay and the Arctic Islands during the following 200 years. Many hardships, and even disasters, were suffered due to the frailty of ships and the inadequacies of equipment, but gradually maps were improved and the nature of the region that contained the "Northwest Passage" became better known. Samuel Hearne in 1771 proved that no passage lay west of Hudson Bay by travelling overland from the mouth of the Churchill River to the Coppermine River and the Arctic Coast. Hearne recovered a single two kilogram piece of native copper, a material used by the Inuit of the Coppermine area and now known to be associated with Proterozoic volcanic rocks from the northern mainland and Victoria Island. Alexander Mackenzie in 1789 travelled the river now named after him and reached the Beaufort Sea. Mackenzie observed yellow, waxy bitumen and coal during his travels.

In 1818 the search for the Northwest Passage was directed to the Arctic Islands, and by 1830 the central islands had been explored as far west as Melville Island. The mainland coast had been mapped from Bering Strait to Boothia Peninsula. In 1845 Sir John Franklin, Royal Navy, set out with two ships to complete the few miles of passage remaining to be discovered. The ships and their entire crews vanished. Naval searches, some on a large scale, were organized, but only in 1859 was evidence at last found to account for the tragic loss of Franklin's party. A great deal of the archipelago was mapped, however, by the "Franklin search" expeditions, and important fossil and mineral collections were signposts to future discovery.

Coal has been used sporadically in northern Canada for more than 100 years. The Nares expedition to northern Ellesmere Island (1875-76) mined some Tertiary coal for general use, and in the same period whalers used locally mined coal in northwestern Baffin Island. Coal has been known in the Yukon Territory, particularly near Carmacks, where it was used for mine power generation, and Dawson City, where it fueled river steamboats, since the early part of the twentieth century.

During World War I small quantities of mica, graphite and garnet were mined on Baffin Island and shipped to England for use in manufacturing. In 1919-20 Canada's first significant oil discovery was made at Norman Wells on the Mackenzie River. During 1928 and 1929 the lead-zinc deposits near Pine Point and the silver-pitchblend deposit near Great Bear Lake were delineated. A short time later, in 1930, the Great Bear Lake deposit was developed into the Eldorado silver mine.

The Great Depression resulted in a serious retrenchment in the mineral industry. Silver and gold were not affected as much as other metals because of their high value per unit weight. Exploration on a modest scale was supported by government and industry throughout the early thirties, and in 1935 the Yellowknife mining district was discovered.

The advent of World War II caused a shift in the emphasis of mineral exploration. Labour and material shortages and the demand for strategic minerals resulted in a decline in gold and silver mining. Silver production ceased at the Eldorado mine in 1940, but the mine reopened to produce uranium in 1942. By late 1944 no gold was being mined in the Northwest Territories.

During the war, the search for strategic minerals resulted in the discovery of tungsten-, tantalum- and lithium-bearing pegmatites. In 1944 and 1945 the delineation of new ore in the Giant Yellowknife Gold Mine led to a resurgence of interest in precious metals in the North. The end of the war alleviated shortages of men and materials, and gold production was re-established at the Negus, Con and Thompson-Lundmark mines near Yellowknife between 1945 and 1947.

EXPLORATION FOR MINERALS IN THE ARCTIC MAINLAND

Areal geological mapping in the northern Canadian Shield prior to 1950 had been carried out by traditional means, usually canoe and foot traverses. In 1952 an experimental light helicopter-supported mapping project by the Geological Survey of Canada, Operation Keewatin, attained dramatic success in increasing the pace of 1:250 000 scale mapping in remote areas. Operation Keewatin, and other similar projects that followed, resulted in the virtual completion of reconnaissance mapping of the Canadian Shield.

The mapping operations in the districts of Keewatin and Mackenzie resulted in the discovery of occurrences of gold, silver, nickel, copper, lead, zinc, molybdenum and asbestos. Pegmatites were found to contain lithium, beryllium, niobium and tantalum (Wright, 1967). The North Rankin Nickel Mine, established as a nickel-copper mine on the northwest coast of Hudson Bay (Fig. 1) during the 1950s, had by 1962, when it closed, extracted about 8.7 million kg of nickel and 2.3 million kg of copper with a total value of over $8 million.

Several mines in the Yellowknife area in the Northwest Territories, including the Giant Yellowknife Mine and the Con Mine, have been producing gold since the early fifties. The Negus mine closed down in 1951 but some of its shafts were incorporated into the Con Mine. South of Great Slave Lake, the Pine Point lead-zinc mine was brought into production in 1964. After 23 years of production the Pine Point Mine was closed in 1987.

During the 1960s the main emphasis in mineral exploration shifted to base metals and mining activity in the northern

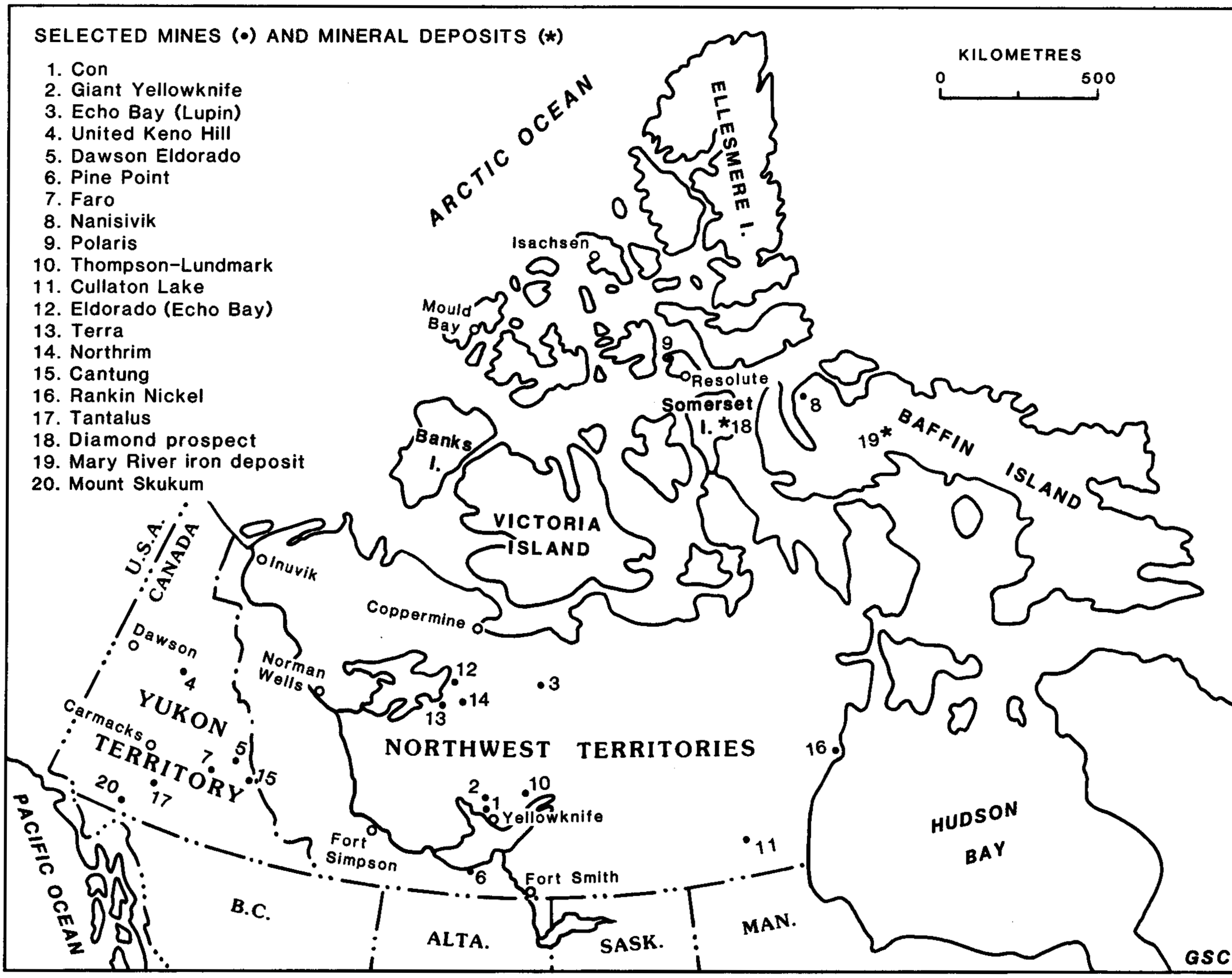

FIG. 1. Location of selected mines and mineral deposits, northern Canada.

mainland centred around the eastern end of Great Bear Lake. Copper, silver, bismuth, lead and other associated metals were recovered from the Echo Bay, Northrim and Terra mines (Fig. 1) and also from the nearby Norex mine. The Echo Bay Mine produced copper and silver from 1964 until 1976, when the old Eldorado silver-radium workings were reopened. From 1976 to 1981, when the mine closed, silver was produced only from the Eldorado property.

Exploration for gold has continued in the northern Barren Lands to the present time. In October 1981, Selco Inc. brought the Cullaton Lake gold mine into production. In April 1982 Echo Bay Mines Limited began production near Contwoyto Lake, at the Lupin gold deposit, which was discovered by Canadian Nickel Limited in 1961 (Fig. 1).

In the eastern District of Mackenzie, over 40 million t of massive sulphides containing copper, lead, zinc, silver and in some instances gold have been discovered in approximately 30 deposits. The deposits range in size from 11 million t to less than 39 000 t. None of these has yet been brought into production, mainly because of their remoteness.

In the District of Keewatin, uranium deposits are common in Proterozoic meta-sediments, within fracture zones and in various extrusive rocks, gneisses and pegmatites, but none has been developed to the mining stage.

Two large iron deposits containing 23-38 percent iron are located on the east and west coasts of Melville Peninsula. The western deposit may contain over 3 billion t of ore and the eastern deposit more than 1 billion t. A similar large deposit occurs near Mary River in northern Baffin Island (Fig. 1).

Metallic minerals have been produced in the Northern Cordillera since 1898, when the gold rush in the Dawson area initiated mining operations in the Yukon Territory. Silver, lead and zinc have been mined continuously at Keno Hill since 1946. Production of the same metals from the Faro (Curragh) Mine at Ross River began in 1969 and continues to the present time. Tungsten was mined at Cantung Mines from the early sixties until 1986. Other interesting deposits of tungsten, stratabound cupriferous redbeds, stratiform and replacement silver-lead-zinc, iron taconite and diamond-bearing diatremes also have been discovered. Gold and silver have been known from the vicinity of Mount

Skukum in the southern Yukon since the early 1930s, and production from Total Erikson's Mount Skukum Mine began in 1986.

PETROLEUM EXPLORATION IN THE NORTHERN MAINLAND-BEAUFORT SEA REGION

Only 8 wells were drilled in arctic Canada between 1920, when the Norman Wells field was discovered, and 1941. Five were exploration wells in the vicinity of Norman Wells and 3 were follow-up discovery wells. In 1941 and later, during World War II, numerous development wells were drilled in the Norman Wells field and some 20 exploratory wells were drilled in the surrounding area. Up until mid-1945, 31 800 m^3 of oil had been transported through the Canol pipeline to a refinery in Whitehorse. The strategic importance of the pipeline and refinery ended with the war, and Norman Wells production thereafter supplied only local demand along the Mackenzie River; up until 1955 total production from Norman Wells was 1 million m^3.

In reviewing petroleum exploration in the Mackenzie Delta-Beaufort Sea region, Young and Lyatsky (1986) suggested that the availability of vertical air photographs and new topographic maps, improved helicopters and newly published geological research had markedly positive effects on petroleum exploration in northern regions of Canada in the early 1950s. Peel Plateau Exploration Limited initiated exploration in arctic regions in 1953, and petroleum exploration north of the Arctic Circle advanced quickly in following years. In 1956, while four development wells were being drilled in the Norman Wells field, enthusiasm for expanded exploration in the northern Yukon and adjacent areas was growing.

In 1958, exploration drilling was initiated a considerable distance from the Norman Wells area and the Peel Plateau Eagle Plains Y.T. No. 1 well was drilled in the Eagle Plains Basin. A follow-up well, Western Minerals Chance Y.T. No. 1, drilled in 1959 discovered gas in the basin. The discovery of hydrocarbons after only two wells were drilled in a previously unexplored sedimentary basin can be considered partly good luck but also certainly a *coup* in terms of geological exploration. The next well was spudded in 1962; it was completed as a discovery in 1965. The high level of industrial interest in the oil and gas in northern mainland caused the Geological Survey of Canada to mobilize a large-scale mapping project, Operation Porcupine, to cover the northern Cordillera and much of the Mackenzie Delta in 1962.

Geophysical surveys were begun by private operators in the arctic mainland in 1958, and in 1959 seismic surveys were being conducted in both the onshore and offshore areas of the Beaufort Sea-Mackenzie Delta region. During the same period Shell Canada Ltd. and Gulf Canada Corporation Ltd. filed on large tracts of land onshore in the Mackenzie Delta. From the early seismic surveys a working hypothesis was developed of a seaward-thickening wedge of Mesozoic sediments up to 10 km thick under the Mackenzie Delta.

Although 16 wells had been drilled throughout the northern mainland by the early sixties to reach Paleozoic reservoir targets, none of these wells produced significant evidence for hydrocarbon accumulation. In 1962 the Texcan C. & E. Nicholson G-56 and N-45 wells were drilled on Nicholson Peninsula between Liverpool Bay and Wood Bay to bring petroleum exploration to the shores of the Beaufort Sea. Both of these wells reached Lower Cretaceous beds but were declared dry and abandoned. The Reindeer D-27 well, spudded in Richards Island in the Mackenzie Delta in 1965, confirmed that a thick Tertiary and Mesozoic section existed in the outer part of the Mackenzie Delta.

Exploration continued throughout the arctic mainland between 1962 and 1968, but of the 38 wells drilled none encountered significant hydrocarbons.

The 1968 discovery of the Prudhoe Bay field in northern Alaska inspired a dramatic increase in the number of seismic surveys and land applications in the Beaufort Sea-Mackenzie Delta region. Six wells were drilled in the delta in 1969 and exploration continued unabated until 1986, when sharply reduced oil prices resulted in a dramatic curtailment of exploration activity.

The first significant discovery of oil in Mesozoic-Tertiary strata in the Beaufort Sea-Mackenzie Delta area came in 1970 after 11 wells had been drilled. Oil from Lower Cretaceous strata flowed from the IOE Atkinson Point H-25 well (Fig. 2). During 1970 and 1971, 13 more wells were drilled onshore, and hydrocarbons were discovered in the Myogiak J-17 well on Tuktoyaktuk Peninsula.

In 1971 Candel and its partners drilled the East Mackay B-45 well, approximately 45 km south of Norman Wells. Although classified as a suspended well, it may now be of commercial significance because it is close to the newly built Norman Wells pipeline that transports oil to northern Alberta. In the same year Aquitaine and its partners ventured into the Foxe Basin in the Eastern Arctic to drill the Rowley N-14 well. A Paleozoic stratigraphic section of about 500 m thick was found and the well was abandoned as a dry hole.

The giant Taglu gas field was discovered in the Richards Island area of the Mackenzie Delta in 1971. The following year, the slightly smaller Parsons field was found. The Taglu field contains 68 billion m^3 of recoverable gas and 3.6 million m^3 recoverable condensate. With the completion of the Niglingtak H-30 well in the spring of 1973, 43 wells had been drilled in the area. The Niglingtak field contains 23 billion m^3 of recoverable gas and 3.7 million m^3 of recoverable oil (Procter *et al.*, 1984). In 1973 the Kugpik well encountered oil in Cretaceous sandstones of the Parsons Group and the YaYa South, Reindeer and Titalik wells discovered gas in the Tertiary Reindeer Formation, each well establishing a new field. That year, also, exploration moved into the shallow offshore areas when artificial islands were built from materials dredged from the seabed in water 2-3 m deep to serve as platforms for drilling and support services.

Between 1968 and 1974 approximately 95 wells were drilled in the northern mainland without success. A glimmer of hope appeared in 1974 when the Ashland Tedji Lake K-24 recovered gas from Cambrian sandstones 1136 m beneath the Anderson Plains. Production from Cambrian beds, it must be noted, is unusual in most of North America.

In 1975, 21 wells were drilled in the Beaufort-Mackenzie area. Although no new fields were discovered, several of the wells delineated previously encountered oil and gas accumulations.

The introduction of reinforced drill ships to the Beaufort Sea in 1976 marked a new era of arctic exploration. These drill ships allow wells to be drilled in water depths greater than 25 m during the ice-free summer and autumn seasons. The Kopanoar D-14 and Nektoralik K-59 wells discovered new pools in the deeper, offshore area (Fig. 2). During the same year gas was discovered in the Netserk F-40 well, which was drilled from a nearshore artificial island, and oil and gas pools were discov-

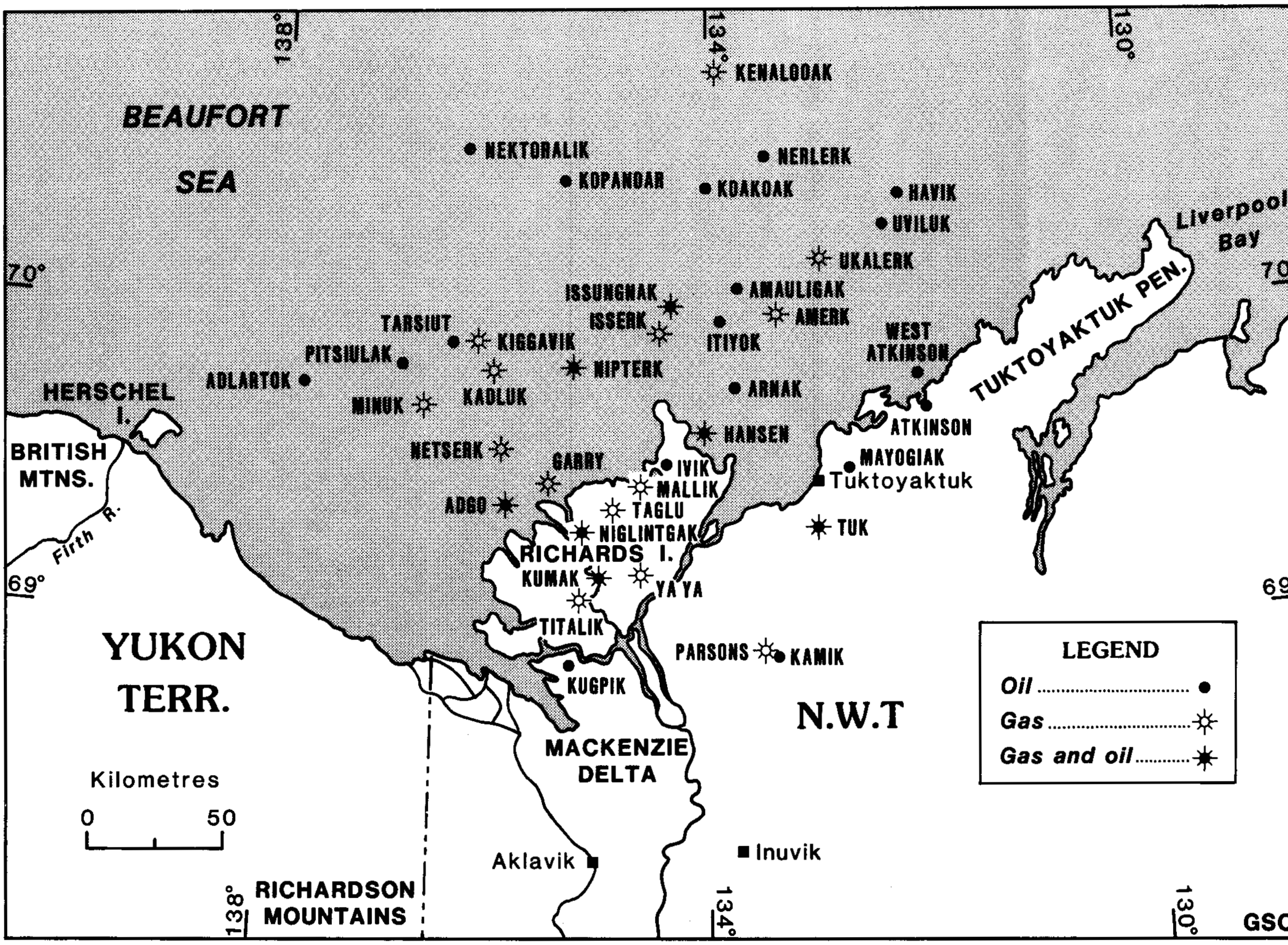

FIG. 2. Main oil and gas discoveries in the Mackenzie Delta-Beaufort Sea area; after Young and Lyatsky (1986).

ered in the onshore Kamik D-40 and Garry P-04 wells; the latter was drilled on a small island adjacent to Richards Island (Fig. 2). In 1977 the deeper offshore areas were probed from reinforced drill ships and the Ukalerk C-50 well discovered an accumulation of gas.

During the period 1978-81 the Kopanoar M-13 well in the Kopanoar field tested the greatest combined oil flow to that date in the Beaufort-Mackenzie area at 1545 $m^3 \cdot d^{-1}$. The Issungnak O-62 well and the follow-up 20-61 well discovered another giant gas field containing 71 billion m^3 of recoverable gas and 16 million m^3 of recoverable oil. The Tarsiut A-25 well and a follow-up well discovered the Tarsiut field, in which 2.4 billion m^3 of recoverable gas and 24 million m^3 of recoverable oil are estimated as reserves (Procter *et al.*, 1984). An additional well, the Koakoak O-22, also discovered oil (Fig. 2).

Another exploration era was initiated in the Beaufort Sea in 1982 when the Tarsiut N-44 well was drilled from an artificial, caissoned island. Such a structure allows year-round drilling in up to 22 m of water. The following year a conical reinforced floating platform, the *Kulluk*, was introduced into the area. Moored by cables to numerous heavy anchors, the platform is designed to withstand pack-ice approaching from any quarter.

In 1982, the West Atkinson L-17 well discovered modest amounts of oil in the nearshore area of the Tuktoyaktuk Peninsula, and the Kenalooak J-94 well in the offshore discovered gas. The giant Nerlerk structure yielded minor amounts of oil from several separate zones.

During 1984 several important discoveries were made in the Beaufort Sea. The Amauligak J-44 well oil and gas discovery is still being delineated, but it now appears to be an oil reservoir with perhaps the largest reserves in the area. The Tuk L-09 well was thought to have discovered one of the largest wet gas reservoirs onshore from the Lower Cretaceous Kamik Formation; in a follow-up well oil was also recovered from Tertiary clastic strata.

Several important discoveries were made in the Beaufort Sea during 1985 and 1986. These included gas and oil in the Nipterk L-19 well, oil in the Adlartok P-09 well, and oil and gas in both the Havik B-41 and Arnak K-06 wells (Fig. 2).

Oil and Gas Reserves

Approximately 375 wells have been drilled in the arctic portion of the mainland since 1947. The geological setting and resource potential of this area have recently been summarized by Nassichuk (1983) and by Procter *et al.* (1984). Reserves in the earlier discovered Norman Wells field have been increased to approximately 95 million m^3, and oil is currently being shipped through a 25 cm pipeline to northern Alberta at rates up to 4700 $m^3 \cdot d^{-1}$.

More than 200 wells have been drilled in the Beaufort Sea-Mackenzie Delta region. Of these, 36 were drilled from artificial islands, 34 from drill ships or floating platforms and the remainder lie in onshore areas. More than 40 hydrocarbon accumulations have been discovered, and according to Procter *et al.* (1984), these accumulations contain more than 286 billion m^3 of recoverable gas and more than 117 million m^3 of recoverable oil and condensate. The 1984 Amauligak discovery may increase the recoverable oil reserves by about 112 million m^3. The total discovered and undiscovered resources in the Mackenzie Delta-Beaufort Sea area may amount to 2131 billion m^3 of gas and 1.35 billion m^3 of oil (Procter *et al.*, 1984).

The first shipment of Beaufort Sea oil reached the market in 1986, when approximately 50 400 m^3 of oil from the Amauligak field was delivered by tanker to Japan.

Coal Resources

Coal is widely distributed through the Yukon and District of Mackenzie and ranges in rank from lignite to anthracite. Low rank coal was used to generate steam in river boats at Dawson near the turn of the century. A short time later, in 1923, the Tantalus Butte Mine near Carmacks opened and for the next 55 years supplied bituminous coal to a variety of base metal mines, the most recent being the lead-zinc mine at Faro. Minor amounts of coal were also delivered to the Faro Mine from deposits near Ross River.

Recent exploration has delineated large reserves in four principal areas, most of which could be used for power generation in the future. The reserves include: about 200 million t of Cretaceous and Tertiary lignite to bituminous coal in the Bonnet Plume Basin; at least 300 million t of subbituminous and bituminous coal of Upper Cretaceous and Carboniferous age in the Fort Liard area; 50 million t of Tertiary subbituminous and lignite coal at Rock River, southeast Yukon; and more than 1 billion t of Tertiary lignite and subbituminous coal in the Brackett Basin, near Fort Norman and near the Mackenzie River, a potential transportation route.

EXPLORATION IN THE ARCTIC ISLANDS

1947-50: Establishment of Weather Stations

A most important step in the development and opening of the High Arctic islands was the establishment between 1947 and 1950 of high-latitude weather stations by the United States Air Force and Navy under an international agreement between Canada and the United States. The stations were known as the Joint Arctic Weather Stations. Resolute was established by sea from Boston in 1947 and Eureka the same year by airlift from Thule Air Base in Greenland. Isachsen and Mould Bay were established by airlift from Resolute in the spring of 1948. Alert was established by airlift from Thule in 1950. The stations were operated jointly by the Canadian and U.S. weather services between 1947 and 1972, when they were taken over by Canada. The stations provided a radio communication network, weather information and all-season airstrips, all of which provided improved access for geological work in this remote part of Canada.

The U.S. Air Force, following shortly on the close of World War II, played a significant role in the advance of our knowledge of the Arctic Islands; during 1946 and 1947 the U.S. Air Force flew 17 long-range photographic flights from Fairbanks, Alaska, and from Edmonton to cover virtually the entire archipelago. The aircraft carried Canadian observers. During the flights, which covered distances of 4000-7500 km, some of the last major geographic discoveries of the Arctic Islands were made. Borden and Cornwallis islands were found to be, in each case, two islands, and Stefansson Island was discovered. The U.S. aeronautical charts that were made following the exercise were the first to succeed the British Admiralty charts of the nineteenth century. Strangely, these historic flights have never been documented in an official Canadian publication.

Trimetrogen Aerial Photography: Topographic Maps

An important function of the Royal Canadian Air Force (RCAF) since the establishment of this service in 1924 was survey photography. By 1931 this had reached the arctic mainland. By 1948, using converted Lancaster bombers, the RCAF reached the archipelago, and between 1948 and 1953 trimetrogen photography of the islands was completed. The photographs were used in the production of air navigation charts at a scale of 1:506 880. In 1948, the RCAF was able to add two new large islands to the map of Canada: Prince Charles Island and Air Force Island. This was the last major discovery of new land in Canada — and perhaps in the world. Between 1948 and 1957, the RCAF, using DC-3 aircraft and Lancaster bombers, completed the shoran net of the whole of the archipelago, starting from a fixed point south of Winnipeg.

In 1947 the Canadian government entered into contracts with civilian aircraft companies to obtain vertical aerial photographs of the whole of Canada. Photographic coverage of much of the archipelago was completed during the late fifties (the entire program took 19 years). The Surveys and Mapping Branch (Department of Energy, Mines and Resources) then used the photography and geodetic and other positional surveys to produce topographic maps at 1:250 000 scale.

Advances in Transportation

Early exploration of the Arctic Islands and northern mainland of Canada was carried out by sailing ship and by man-hauled sledge. Dog teams, canoes and other means of travel were used later, and eventually, as now, field exploration became dependent upon aircraft (see Christie and Kerr, 1981).

The aircraft era in geological exploration of the islands began in 1947, when Y.O. Fortier carried out a geological reconnaissance using an RCAF flying boat. Among the early activities by civilian aircraft in the archipelago was the use of helicopters for close support of field parties of the Geological Survey of Canada. In the summer of 1955, Operation Franklin, which initiated a modern era of scientific study in the High Arctic, was supported by two Sikorsky S-55 helicopters. Eleven geologists and ten assistants of this project successfully studied about 260 000 km^2 of previously little-known terrain in the Queen Elizabeth Islands.

In 1958 the Survey assisted in pioneering the use of light aircraft on oversized, low-pressure tires for landings on unprepared terrain. R. Thorsteinsson and E.T. Tozer, cooperating with W.W. Phipps, the well-known pilot and developer of "big wheels" for aircraft, mapped Melville, Brock, Borden, Mackenzie King and Prince Patrick islands in one season using a Piper Super Cub (PA-18). The revolutionary wheels with oversized tires were inspired by earlier experiments by the U.S. military on the tundra of northern Alaska. The De Havilland Beaver, Otter and Twin Otter eventually were fitted with oversized tires and the special wheels and brakes needed and are still operated in this mode.

The Polar Continental Shelf Project (PCSP) was created by the Government of Canada in 1958 to conduct scientific research over Canada's polar continental shelf and contiguous ocean areas. For 30 years the PCSP has provided logistical support, communications, navigational aids and air, ground and sea transport to innumerable government, university and industrial research activities and has been an important force in asserting Canada's sovereignty in the High Arctic.

The problems of transporting marketable products (e.g., coal, oil, natural gas, metallic minerals) from arctic regions to more populated areas have been subjects of considerable research for a decade at least. The development of improved, strengthened and ice-breaking steel ships has enabled seasonal maritime transport to be extended to many parts of the Canadian Archipelago (Franklin, 1983; Haglund, 1983). Designs for pipelines, liquefied natural gas (LNG) carriers and other specialized surface ships, and even submarine cargo carriers, are undergoing research and development (Bailey, 1983; Jacobsen and Murphy, 1983; Wilckens and Freitas, 1983; Kaustinen, 1983). Clearly, any implementation of these modes of transporting arctic commodities must await improved economic conditions.

Mineral Exploration

Mineral exploration in the High Arctic has been extremely limited compared with that on mainland Canada; a summary of that exploration up until 1980 was prepared by Findlay *et al.* (1981). In contrast to oil and gas exploration in the Arctic Islands, where expenditures since 1957 approximate $1.5 billion, total expenditures for mineral exploration and mine developments in the same period were less than $500 million. The predominance of Phanerozoic sedimentary strata over igneous rocks of all ages in the archipelago naturally favours oil and gas exploration, and the potential value of oil and gas discovered thus far exceeds the value of discovered minerals by a considerable margin. An extremely important result of mineral exploration in the High Arctic has been the development of new communities in support of successful mines. Inuit families work and live at Polaris and Nanisivik, lead-zinc mines on Little Cornwallis and Baffin islands.

Nanisivik Lead-Zinc Mine, Baffin Island

Sulphide-bearing carbonate rocks containing lead and zinc near Strathcona Sound on the northwest corner of Baffin Island were first noted by members of Captain Bernier's 1910-11 expedition. Reports of mineralization by Blackadar (1956) aroused the curiosity of Texas Gulf Sulfur Company Ltd. geologists. A visit to the area in 1957 confirmed the worth of the occurrences, and claims were staked to cover surface showings about 80 km northeast of the Inuit settlement of Arctic Bay.

Texas Gulf Sulfur conveyed ownership of these claims to a group headed by Frank Agar, and Nanisivik Mines was created to explore the claims. Guided by Graham Farquason and Strathcona Mineral Services Limited, a group was put together under the control of Mineral Resources International, the Government of Canada, Metallgesellschatt Canada and Biliton B.V., and the mine was brought into production by 1976 (Fig. 1).

Olson (1984) postulated that ore-bearing fluids derived from the Arctic Bay Formation reacted with hydrocarbon-bearing fluids and that the sulphides were deposited in already existing cavities. The ore body has a sinuous, flat, lenticular shape more than 3048 m long with a narrow keel-like ore shoot extending vertically below the main body. The pyrite-rich, galena-sphalerite deposit at Nanisivik is enriched in silver (up to 60 $g \cdot t^{-1}$), and the silver "sweetener" has made the Nanisivik Mine viable. With European smelters committed to long-term contracts, the Nanisivik mine has been one of Canada's highly successful base metal producers. From October 1976 to March 1986, Nanisivik treated 5.5 million t of ore with grades of 9.0-11.0% zinc, 0.80-1.7% lead and 42-60 $g \cdot t^{-1}$ silver. Total metal production was 600 000 t of zinc, 70 000 t of lead and 250 t of silver. Annual production is currently 700 000 t of ore at a grade of 9% zinc, 0.8% lead and 42 $g \cdot t^{-1}$ of silver.

The Polaris Lead-Zinc Mine, Little Cornwallis Island

The Polaris lead-zinc mine, located at latitude 75°30'N and longitude 96°20'W, is the most northerly mining operation in the world (Fig. 1). The discovery of the deposit had a strong element of luck tied to exploration that was not directly related to mineral prospecting. In the late 1950s, when enthusiasm was growing for the energy potential of the High Arctic, the North American oil industry looked north in search for untapped hydrocarbon wealth. In 1959, Bankeno Mines Limited of Toronto, in conjunction with Talent Oil and Gas Limited of Calgary, acquired more than 1.2 million ha of oil and natural gas priority applications in the Arctic and placed mapping crews in the field to conduct geological studies. These applications were granted in anticipation of the government issuing exploration permits once proposed regulations governing prospecting in the Arctic were released.

In 1960 Lionel Singleton and George Wilson of J.C. Sproule and Associates discovered mineralized gossans on the west coast of Little Cornwallis Island. The widespread nature of sulphide alteration in the area and the presence of galena and sphalerite caused a diversion from oil and gas exploration to base metals exploration.

Under extremely arduous conditions, Bankeno Mines drilled nine holes totalling 206 m in the fall of 1960. The results indicated the presence of widespread lead-zinc mineralization in dolomitic rocks of Paleozoic age. Bankeno Mines turned to Canada's principal lead-zinc producer, Consolidated Mining and Smelting Limited (Cominco), for assistance in evaluating and possibly developing the deposit. In spite of early misgivings, Cominco came to an accord with Bankeno Mines and agreed to develop the Little Cornwallis deposit. Cominco undertook a gravity survey over the surface showing and discovered one of the biggest gravity anomalies recorded in the history of Canadian mineral exploration. A several milligal anomaly was delineated, which, upon drilling, turned out to be a massive body of high-grade galena-sphalerite ore.

During the 1970s the main ore body was further delineated by drilling, and 13 other smaller deposits and showings were identified in the immediate area. Unique to the mining industry, the mill and concentrator were constructed as a unit at Trois

Rivières, Quebec, and in 1981 were floated on a barge about 5600 km by way of Davis Strait and Lancaster Sound to the mine site. Production commenced in 1982, and within months the mine achieved its rated milling capacity of 2300 $t \cdot d^{-1}$ at grades of 17% zinc and 6% lead.

Since it opened in 1982, the Polaris mine has produced an average of 200 000 t of zinc concentrates and 45 000 t of lead concentrates annually. The entire output of the mine is transported directly to smelters in Europe during a shipping season that extends from August to late October. The Polaris Mine contains over 4 million t of lead-zinc in a single ore-body (nearly twice the amount delineated in the whole Pine Point district).

Diamonds and Other Minerals in the Arctic Islands

Between 1973 and 1975, Diapros Limited, and later Cominco, investigated some diatremes reported by Blackadar and Christie (1963). Using geological and geochemical techniques special to diamond exploration, Diapros successfully located diamond-bearing kimberlite pipes on Somerset Island. Inspired by the Diapros activity, Cominco also acquired prospecting permits on Somerset Island and conducted a rather extensive exploration program for diamonds.

The program resulted in the discovery of a few small diamonds on Somerset Island; however, the character of the host rock and the limited diamond content did not indicate economic viability. Diapros and Cominco terminated diamond exploration in the High Arctic in the late seventies.

One of the most comprehensive mineral exploration programs undertaken in the Arctic Islands was conducted by Petro-Canada from 1981 to 1985. The program involved prospecting and geological mapping of about 200 000 km^2 throughout the archipelago from Victoria Island to northern Ellesmere Island. The company also completed a systematic collection of heavy-mineral samples from stream sediments on a density of about one sample per 50 km^2. An inventory of all coal deposits was also completed.

The program resulted in the discovery of several geochemical anomalies indicating elevated levels of lead, zinc and cobalt, none of which proved to be economically significant. At several localities, especially on Ellesmere Island, diamond-indicator minerals, including pyrope, ilmenite, chromite and diopside, were discovered, but no kimberlites, the probable source of the minerals, were found.

From 1984 to 1986 Panarctic Oils Limited conducted a modest search for copper-silver deposits in the Victoria Island region, where the association of native copper with the Proterozoic basalts had been known for many years. The sedimentary rocks adjoining the basalts were also studied, and numerous copper-silver occurrences were found. None, however, was of apparent economic significance.

PETROLEUM EXPLORATION IN THE ARCTIC ISLANDS

The first study dealing with the oil and gas possibilities of the Canadian Arctic Archipelago was completed by Fortier *et al.* (1954). This was a comprehensive account of all the exploratory and reconnaissance geological information available at that time. The study included a review of the rock and fossil collections and the observations made by the early explorers, and the results, mainly by the Geological Survey of Canada, of geological investigations carried out during the few years following the opening of the Joint Arctic Weather Stations.

The season of 1958, in which Thorsteinsson and Tozer (1959a) mapped the western Queen Elizabeth Islands by Super-Cub aircraft, has already been noted. A map and descriptive notes (Thorsteinsson and Tozer, 1959b) were published the year following this extraordinary mapping project, and these undoubtedly contributed to the decision by Dome Petroleum and partners to drill the first well of the Arctic Islands: Dome *et al.* Winter Harbour No. 1 on southern Melville Island. The well was spudded on September 1961 in Devonian rocks of an anticlinal structure in the Parry Islands Fold Belt. Gas was recovered from below the permafrost, but in non-commercial quantities. Two additional wells, both dry, were drilled in the fold belt in 1963 and 1964.

In 1962, Triassic tar sands were discovered on northwestern Melville Island. The discovery was made independently by Alan Spector, of the Earth Physics Branch (Department of Mines and Technical Surveys, now Energy, Mines and Resources), and by a party of J.C. Sproule and Associates Ltd. The deposits were evaluated by Trettin and Hills (1966), who noted that approximately 16 million m^3 of oil may be contained therein.

Douglas *et al.* (1963) elucidated the regional geology of northern Canada with special emphasis on the petroleum prospects of the region. The stratigraphic and tectonic features of the archipelago were shown to be similar to those of proven petroleum provinces in other parts of the world.

Results of Operation Franklin in 1955 were published by Fortier *et al.* (1963) in a compilation that became a standard reference for oil and gas exploration in the Arctic Islands. The interpretation of Tozer and Thorsteinsson (1964) of the geology of the western Queen Elizabeth Islands was even more important for hydrocarbon exploration. These authors provided a perceptive analysis of the petroleum prospects on Melville Island and correctly identified Sabine Peninsula on Melville Island as having the best prospects for petroleum discovery in the region. Many of the targets suggested by the authors were subsequently drilled and some resulted in gas discoveries.

Commercial companies began geological exploration in the Arctic Islands in 1959. In that year, teams of geologists of Dominion Explorers Ltd. and Round Valley Ltd., under the direction of consultants A.H. McNair and W.W. Gallup respectively, were active.

Field parties of J.C. Sproule and Associates commenced working in the archipelago in 1960 and were active during the sixties and early seventies. Sproule's greatest contribution to oil and gas development in the islands was his role in the formation of Panarctic Oils Ltd. Discussion on development of the company proceeded from 1964 until December 1967, when 19 companies, several individual investors and the Government of Canada formed the Panarctic consortium and pledged millions of dollars to exploration in the Arctic Islands.

In 1969, exploration moved from the Parry Islands Fold Belt to the southern edge of the Sverdrup Basin, a rift basin that contains at least 15 km of sedimentary strata ranging in age from Carboniferous to Tertiary (Fig. 3). Most of the oil and gas discovered in the Arctic Islands lies in the Sverdrup Basin. One of the three wells drilled in 1969, the Drake N-67, is the discovery well for the Drake Gas field, the largest gas field in the Arctic Islands (Fig. 3).

Between 1970 and 1973, 47 wildcat and delineation wells were drilled in the islands. A gas field was found in 1970 on King Christian Island, near the centre of the Sverdrup Basin.

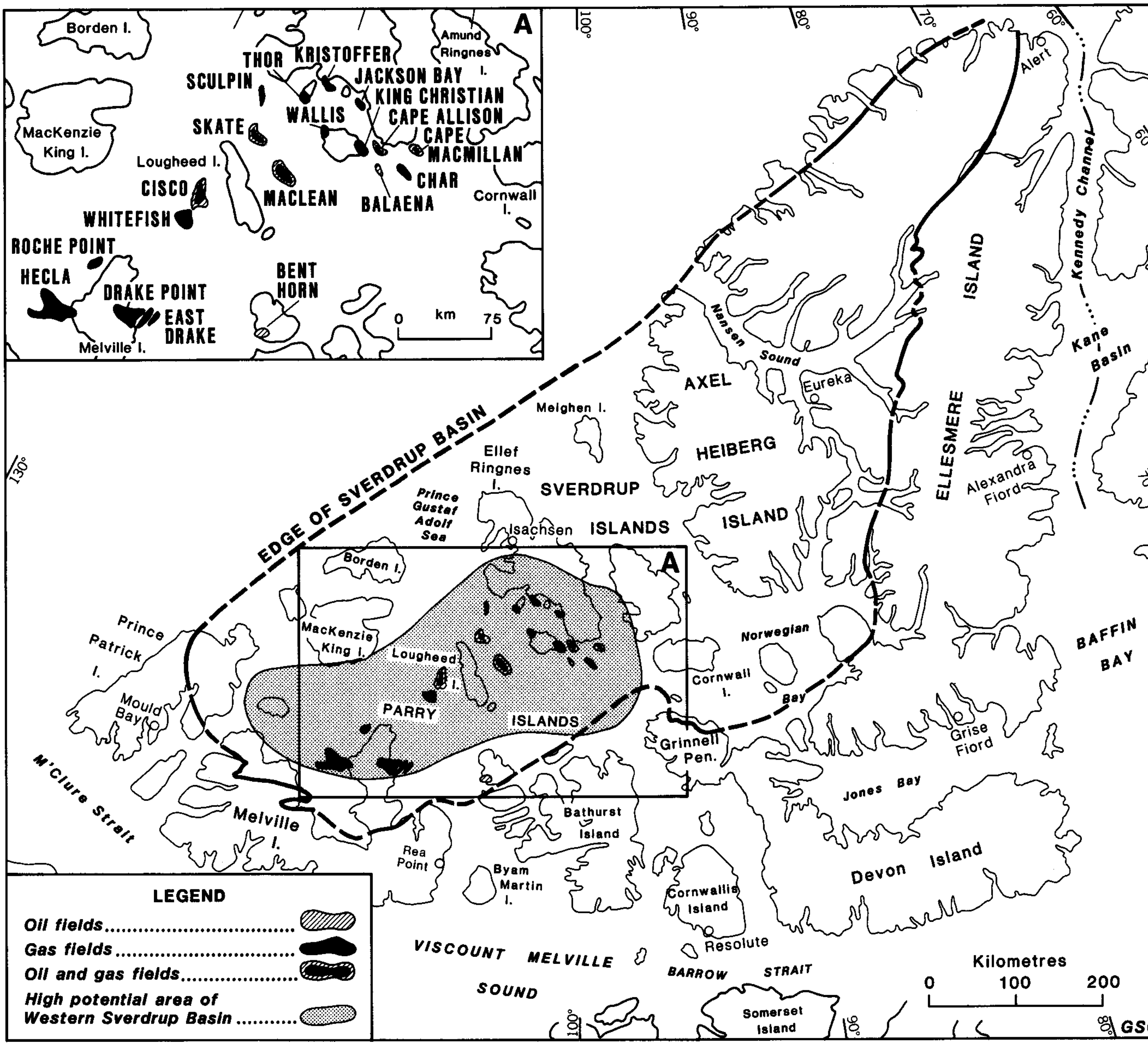

FIG. 3. Main oil and gas discoveries in the Canadian Arctic Archipelago (courtesy N.J. McMillan, 1987).

Twenty-one wells were drilled in 1972, from Banks Island to Brock Island in the west and from Russell Island to northern Ellesmere Island in the east. Four discoveries resulted: oil and gas in Romulus C-42 on Fosheim Peninsula; gas in Kristoffer Bay B-06 and Hecla F-62; and oil in Thor P-38. Similar results were attained in 1973 when two gas discoveries, Wallis K-62 and Thor H-28, resulted from 20 wildcat wells.

An innovative engineering scheme was unveiled in the Arctic Islands in 1974 when the Hecla N-52 well was drilled from artificially thickened ice more than 130 m above the sea floor. After two months of flooding and freezing, an ice platform was formed that was 122 m in diameter and 4.5 m thick in the centre. A well drilled from this ice "island," a delineation well for the Hecla field, recovered gas. Two other wells were drilled as delineation wells for the Drake field.

Important progress was made on Cameron Island in 1974 when the Bent Horn oil field was discovered. A test of Devonian reefoid carbonate rocks flowed oil and water to the surface from an interval below 3200 m in the Bent Horn N-72 well.

An extremely active period of oil exploration took place in the Arctic Islands between 1975 and 1985, when 77 wildcat and delineation wells were drilled. Gas was discovered in the East Drake I-55, Jackson G-16A, Roche Point J-43, Whitefish H-63 and Sculpin K-08 wells, and non-commercial oil was found in the Balaena D-58 well. Both oil and gas were found in the Char G-07, Skate B-80, Maclean I-72, Cisco B-66, MacMillan 2K-15 and Allison C-47 wells.

Instability in the world petroleum market began to influence exploration in the Arctic Islands in 1984. By 1986, drilling had ceased due to plummeting petroleum prices. The main base of field operations of Panarctic Oils Ltd. at Rea Point, Melville Island, was shut down.

One hundred and seventy-six wells were drilled in the Arctic Islands during the course of 25 years of petroleum exploration from 1961 to 1986. Jones (1981) provided a succinct review of the economic significance of discoveries up to 1980. Panarctic Oils, a participant in at least 80% of the wells, showed extraordinary success and uncovered important oil and gas resources for future exploitation. Moreover, important new data on subsurface geology were incorporated into the scientific literature to assist in future exploration for oil and gas. Waylett (1979) and Rayer (1981), both of Panarctic Oils Ltd., synthesized the numerous subsurface and surface data to provide up-to-date summaries of the oil and gas potential of the area. Complementing these reports are new summaries of Arctic Islands geology and potential for oil and gas resources by Nassichuk (1983) and Procter *et al.* (1984).

Oil and Gas Resources

Petroleum exploration in the Arctic Islands has resulted in the discovery of 18 hydrocarbon accumulations accounting for at least 361 billion m^3 of marketable proved and probable gas reserves and at least 76 million m^3 of recoverable oil reserves. Estimates by Procter *et al.* (1984) place the total discovered and undiscovered oil resources in the Arctic Islands at 686 million m^3, and the total discovered and undiscovered gas resources are estimated to be 2257 billion m^3.

Recoverable oil reserves of approximately 49 million m^3 in the Cisco field make it the largest in the Arctic Islands. Bent Horn, Balaena, Skate, Maclean, Cape Allison and Cape MacMillan add approximately 28 million m^3 of recoverable oil to the reserves.

The Drake field is the largest gas accumulation, with at least 99 billion m^3 of proved and probable reserves. The Hecla field has 86-100 billion m^3 of proved and probable gas reserves and Whitefish contains at least 57 billion m^3 of proved and probable gas reserves (Procter *et al.*, 1984). Gas also occurs in the Cisco, Jackson Bay, King Christian, Kristoffer, Maclean, Thor, Cape MacMillan, Char, Roche Point, Romulus, Sculpin, Skate and Wallis fields (Fig. 3).

In 1985 the ice-breaking tanker MV *Arctic* transported a single shipment of approximately 16 000 m^3 of oil from the Bent Horn field on Cameron Island to Montreal. A year later another shipment of the same amount of Bent Horn oil was delivered to Montreal. About 800 m^3 of oil in the latter shipment was off-loaded at Resolute to allow the Northern Canada Power Commission to test the suitability of Bent Horn crude oil as a replacement for diesel fuel.

Coal Resources

Lignitic to bituminous coals occur in the Canadian Arctic in strata ranging in age from Tertiary to Devonian. Coal has been exploited for short periods by small communities, for example by Pond Inlet up until 1959, but none has been mined on a large scale. Given the abundance of coal elsewhere in Canada, it is extremely unlikely that coal in the High Arctic will be required for other than local use. Nevertheless, three major companies, Petro-Canada, Gulf Canada Resources and Utah Mines, were granted exploration licences in 1981. Petro-Canada conducted an extensive evaluation of the thickest and most widely distributed coals in the archipelago, those in the Tertiary Eureka Sound Formation, and concluded that the deposits were not of immediate economic significance.

CONCLUSIONS

During the past 40 years exploration for and exploitation of mineral and hydrocarbon resources in northern Canada have increased steadily. During that interval, about 40 mines have produced gold, silver, lead, zinc, tungsten, uranium, asbestos, nickel, copper and coal in the Yukon and Northwest Territories. At the present time 8 mines are producing gold, silver, zinc and lead in the area. Included are two lead-zinc-silver producers in the Arctic Islands, Polaris, the world's most northerly mine on Little Cornwallis Island, and the Nanisivik mine on Baffin Island.

With the exception of exploration and discovery in the Norman Wells area in the early 1920s, the search for oil and gas in northern Canada was rather modest up until the late fifties, when exploration activity began to accelerate in the Mackenzie Delta. A dramatic increase in arctic exploration was inspired by discovery of the Prudhoe Bay oil field in northern Alaska in 1968, and since then nearly 400 wells have been drilled and abundant oil and gas resources have been identified in the Mackenzie Delta-Beaufort Sea areas and in the Arctic Islands.

Even though significant conventional oil and gas resources remain to be discovered in western Canada, where most of Canada's reserves occur, it is clear that those resources are finite and must, in the foreseeable future, be augmented by supplies from Canada's frontier regions. Accordingly, the substantial oil and gas discoveries that have been made in northern Canada during the past 40 years, and especially during the past 20 years, have shown that northern Canada will continue to be important as a frontier for oil and gas exploration.

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