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Mineral Potential of Arctic Canada

R. G. McCrossan

R. M. Procter

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R. G. McCrossan and R. M. Procter
Geological Survey of Canada
Calgary, Alberta

ABSTRACT

Canada is on the threshold of a major new phase in the development of its Arctic resources. The Prudhoe Bay discovery triggered a boom in northern petroleum exploration that is just getting into high gear this year. Mining activity also has greatly expanded in the last few years with some 73 active exploration programs underway and several large new mines just coming into production. The size of these ventures is indicated by ore reserves of two lead-zinc mines to the value of 900 million dollars at Pine Point in southern Northwest Territories, and 1.2 billion dollars at the Anvil property in the southern Yukon Territory. Other properties with very large reserves are currently under development.

Approximately 465,000 sq. miles of the 1.5 million square miles of Canada north of the 60th parallel are underlain by sedimentary rocks. A volumetric estimate of petroleum potential on the basis of rather scanty evidence is made at 54 billion barrels. With the current activity in the area it should be possible to improve this estimate considerably in the next 2 or 3 years. The two most promising areas are the Arctic Coastal Plains containing large volumes of young sedimentary rock and large structures, and the Mesozoic Sverdrup Basin also with many potential hydrocarbon traps. The Interior Plains of the mainland and the Arctic lowlands, as well as the fold belts of the Franklinian miogeosyncline indicate lesser potential.

INTRODUCTION

We would first like to acknowledge the help of several of our colleagues in the Geological Survey in selecting a few highlights from a vast amount of information available on this subject, especially W.W. Heywood for the data on metallic minerals.

It would be an understatement to say that the mineral potential of Arctic Canada is untapped. Observations on both petroleum and metallic mineral resources were made by early explorers. Indeed Indians made use of oil from seeps, were aware of many of the larger ore deposits, and Eskimos used native copper deposits at Coppermine river in prehistoric times.

The first commercial exploitation of petroleum was at Norman Wells, which was discovered in 1920 but not developed until World War II. Since the discovery at Prudhoe Bay there has been an enormous increase in petroleum exploration in northern Canada. Placer mining in the Yukon Territory of course goes back to the Gold Rush in the 1890's and this led to the finding of lode deposits soon after. The remoteness of the area made exploitation of anything but the precious metals unattractive until very recently.

There are some 13 producing mines in the Territories as well as 73 active exploration and development programs in progress, some of which will soon achieve production.

I will first comment briefly on the metallic deposits and then will devote somewhat more attention to petroleum, since Prudhoe Bay is probably why we are here.

METALLIC MINERALS

The Yukon and Northwest Territories comprise about 40 per cent of the land area of Canada (1.5 million sq. mi.) but, at present these regions contribute less than 5 per cent of the metallic and non-metallic mineral production. The small number of producing mines compared to the total area suggests a promising future for mineral exploration.

Gold was the first mineral to be mined in the north and has been the mainstay for development in the Territories. Discoveries have been made in most greenstone belts and occurrences in metasediments are of considerable interest.

Large deposits of metamorphosed iron formation are associated with Archean volvanic rocks on Eastern Arctic Islands. Extensive studies have indicated several billion tons of high grade ore. Cherty magnetite-hematite iron formations are present in Proterozoic rocks of the eastern Yukon where an estimated 40 billion tons of ore are present in one deposit.

Concentrations of lead and zinc commonly occur in veins in Proterozoic and Cambrian sediments or as stratiform replacement deposits.

Native copper and various copper minerals occur widely in the Coppermine lavas and associated sediments. Recent exploration has indicated a possible 4 million tons of 3 per cent copper in one deposit and one million tons of 2.5 per cent copper ore in another.

Copper and molybdenum are common associates in porphyry type deposits such as a deposit near Whitehorse with more than one billion tons grading 0.38 per cent copper.

Extensive exploration programs for the above mentioned minerals as well as uranium, nickel, molybdenum, silver, rare earths, asbestos, coal and others are being carried out also and commercial deposits of some of these already are known to exist.

From what we know now it is reasonably certain that many large mines will be found like the Pine Point lead-zinc deposit with 32 million tons reserves of Pb-Zn ore valued at $900,000,000 and 8,000 tons per day production or the Anvil Pb-Zn deposit in the southern Yukon of 50 million tons valued at 1.2 billion dollars. Gigantic reserves of iron ore are indicated already and only await favourable economics for exploitation.

PETROLEUM

Activity

One of the clearest indications of the favourable potential of Arctic Canada for petroleum has been given by the oil industry itself. The land rush that has developed since the Prudhoe Bay discovery is almost unprecedented. Subsequent to the announcement of the discovery the number of permits jumped from around 4,000 to almost 7,000 and increased the coverage by 132 million acres to a total of 322 million before the end of the year. Now almost every acre of the sedimentary basins of Arctic Canada is under permit for exploration. Perhaps the change in activity can best be shown by a graph of drilling activity (Fig. 1). There is an obvious jump after Prudhoe Bay from an almost static footage of around 125,000 feet to about 175,000 the following year and by the end of 1970 it may well be off the graph. There is also a clear trend towards deeper holes. Only about 80 of the 432 wells to the end of 1969 are in excess of 5,000 feet in depth and most of these were drilled in the Great Slave Plains near the Alberta border. Some concept of the degree to which the area has been tested can be obtained by comparing numbers of exploratory wells drilled per cubic mile of sediments. For Continental U.S.A. it is 1 well per 7 cubic miles, for northern Canada it is 1 well for 2,000 cubic miles.

The Middle Devonian Norman Wells reef oil pool (Fig. 2), discovered in 1920 through the evidence of an oil seep, remains the only commercial producing field in the Territories. It seems likely that there would be a good deal more oil found in this area.

Industry estimates of activity over the next five years indicate 360 wells for the area south of Norman Wells, 220 wells for the area north of Norman Wells to the Arctic Coast, and 75 wells for the Arctic Islands.

A major strike in any one of these areas would of course require significant upward revision of these estimates.

Oil and Gas Shows

Some of the more important indications of hydrocarbon potential in Arctic Canada are shown on figure 2. Starting in the southwestern part of the Northwest Territories, the Pointed Mountain and Beaver River gas fields have already proved up important gas reservoirs in Middle Devonian limestones. One of the most significant indications is the occurrence of the oil sands in the Bjorne Formation in the lower Triassic on Melville Island in the west-central Canadian Arctic Archipelago. Though the deposit is not commercial it is on the updip southern edge of the Sverdrup basin and, therefore, must be considered an extremely significant indicator of potential. Perhaps the most exciting recent discovery was Imperial's Atkinson Point well located on the Arctic Coast, east of the Mackenzie delta. This well flowed a medium gravity sweet crude to the surface from a drill stem test at about 5,700 feet. Production is from a lower Cretaceous sand.

Another very significant show was the large flow of gas from Panarctic's Drake Point Well on Melville Island. This well blew wild for over a year before the gas zones were cut off by a relief well which indicated 10 mmcf/d from one zone and 13 mmcf/d from another with 5 feet of gassy oil. In addition there have been many smaller indications of oil and gas throughout the Territories.

Having examined what has gone on up until now let us attempt to see what the future holds.

Geology

Some 465,000 square miles of Canada, north of the 60th are underlain by sedimentary rocks; about half in the mainland and half in the islands. Figures 2 and 3 show the Precambrian Shield flanked both to the west and to the north by the Interior Plains and the Arctic Lowlands. Beyond these lie the Cordilleran and Franklinian geosynclines. On a very broad scale the geology to the north is similar to that of the Western Canada Sedimentary Basin to the south. Cratonic deposits wrap around the Shield grading westward and northward through miogeosynclinal to eugeosynclinal.

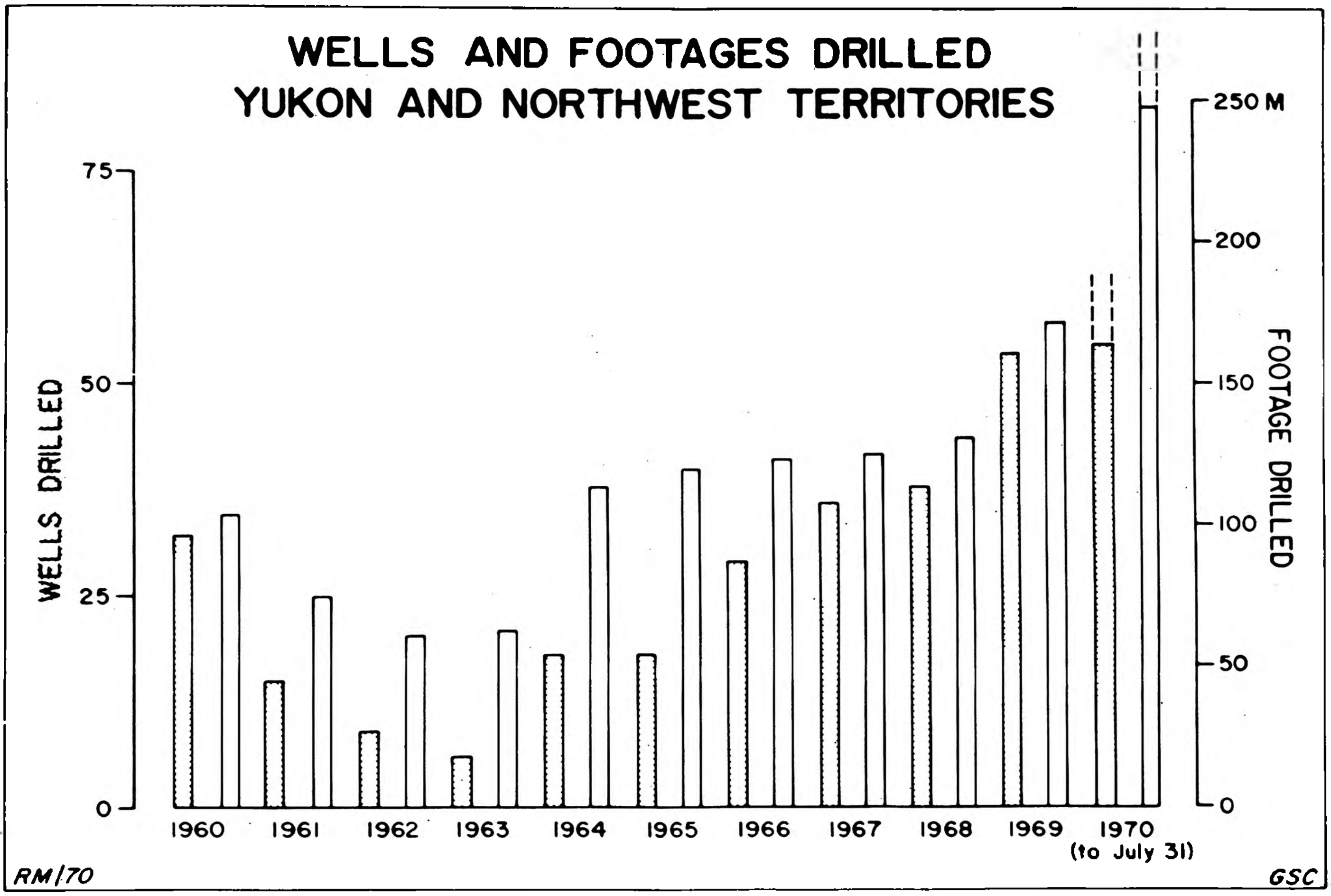

Figure 1. Drilling, northern Canada, showing a marked increase in deeper holes in 1970.

The sediments deposited during the Paleozoic were dominantly carbonates and evaporites on the cratonic shelves and in the miogeosynclines, grading to clastics northward and westward into the eugeosynclines. The Franklinian geosyncline was affected by both Caledonian and Variscan deformations the latter terminating its depositional history. The Cordilleran geosyncline was involved only with local Variscan deformation and it wasn't until Laramide time that it was regionally deformed. The Mesozoic sedimentation was dominantly clastics with minor carbonates.

One can see from figure 3 that the older rocks in the section are exposed by erosional bevelling in the Arctic just as they are in southern Canada towards the Shield area. Northern Canada can be divided into several geological provinces (Fig. 4) including the Precambrian Shield, the Interior Plains and the Arctic Lowlands flanking it to the west and north, the western Cordilleran area, the Franklinian geosyncline (indicated in the figure by the fold belts), the Sverdrup Basin, and the Arctic Coastal Plain. Of these the Precambrian Shield, the Cordilleran geosyncline and the Franklinian eugeosyncline have little or no potential for petroleum and will be discussed no further.

Interior Plains. The Interior Plains may be considered similar, in a broad, way to the cratonic type of sedimentation and in potential to the plains of Alberta (Fig. 4). This area has some 225,000 square miles exclusive of the Coastal Plain underlain by some 300,000 cubic miles of sedimentary rock some parts of which, unlike the plains farther south, have been involved in rather complex structures.

The Canadian Petroleum Association's potential reserves committee uses a figure of 45,000 Bbls per cubic mile as an average for the Western Canada Sedimentary Basin. If we use this factor we might expect something in the order of 13.5 billion barrels of oil and, using their gas to oil reserves ratio, 81 trillions of cubic feet are estimated for the Yukon and Northwest Territories mainland. The bulk of this probably will be found in Paleozoic rocks. The potential for this area can therefore be rated as fair.

Arctic Coastal Plain. A belt of dominantly Cretaceous and Tertiary rocks fringes the north

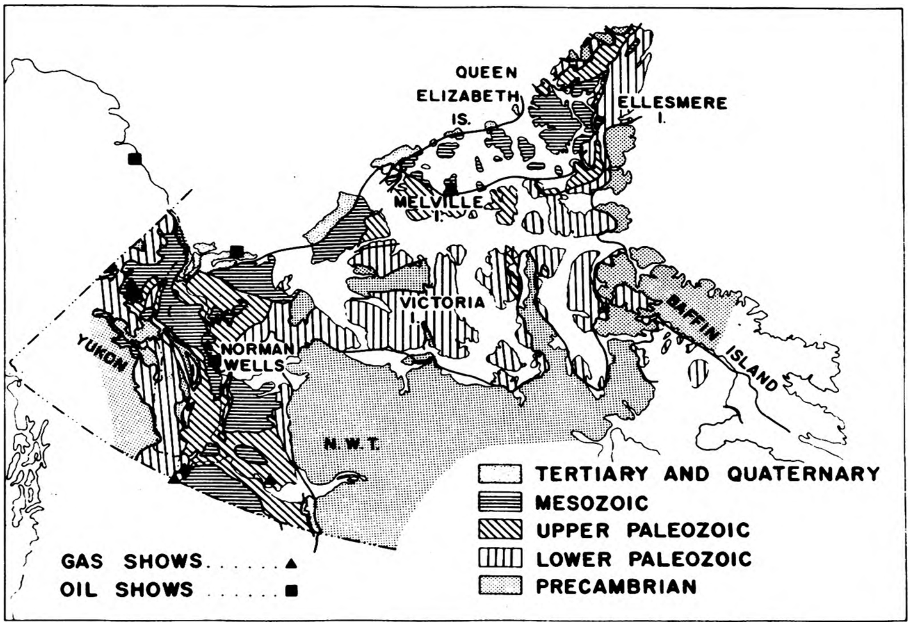

Figure 2. Generalized geological map and significant oil and gas shows.

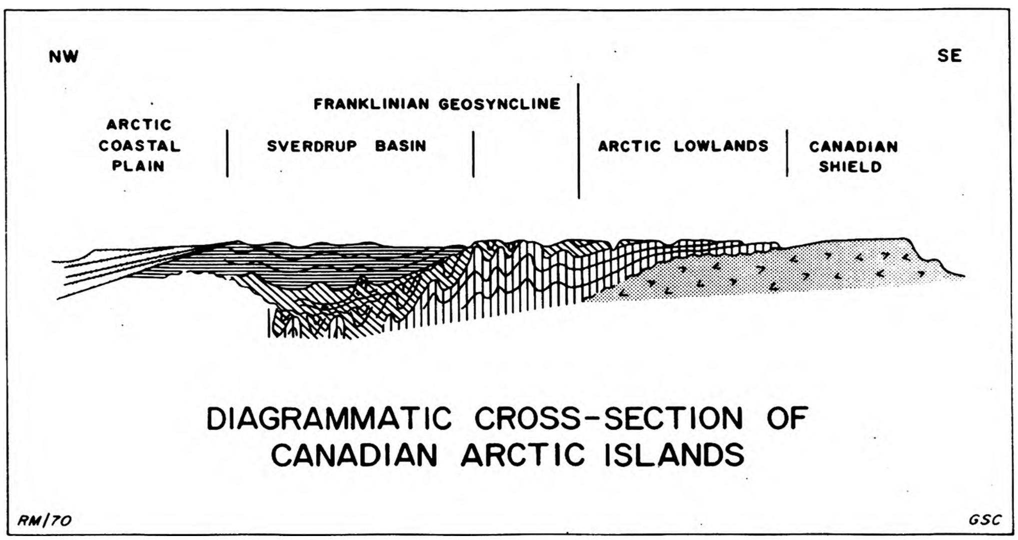

Figure 3. Schematic cross-section through Arctic Islands Basins, R. L. Christie.

coast of the mainland and the Arctic Islands. this sequence thickens in a seaward direction. In Canada, the area of the Coastal Plain exposed on the mainland is about 20,000 square miles with an additional 25,000 or so offshore. The thickness of the section is rather inperfectly known at present, though recent estimates place it as high as 30,000 feet in the Mackenzie Delta area and thicker offshore. Probably the main limitations in this area will be the possible depth of penetration of wells rather than the total thickness of section.

Some of the features can be seen on figures 5 and 6 from a paper by A. E. Pallister given to the annual AAPG meeting in June of this year. These are from the Mackenzie Bay area midway along the coast between Prudhoe Bay and the Atkinson Point discovery. Figure 5 is a seismic depth section and 6 is an interpretation. A wedge of upper Cretaceous and Tertiary strata can be seen to thicken offshore and to overly unconformably an older sequence deformed by large open folds and diapirs. All of the attributes characteristic of the

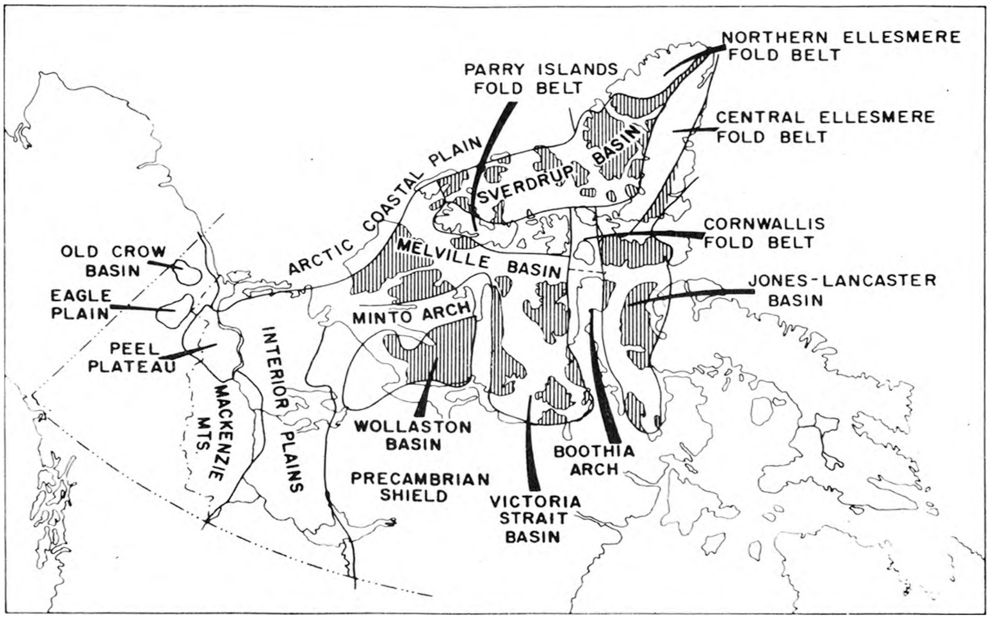

Figure 4. Arctic Basins

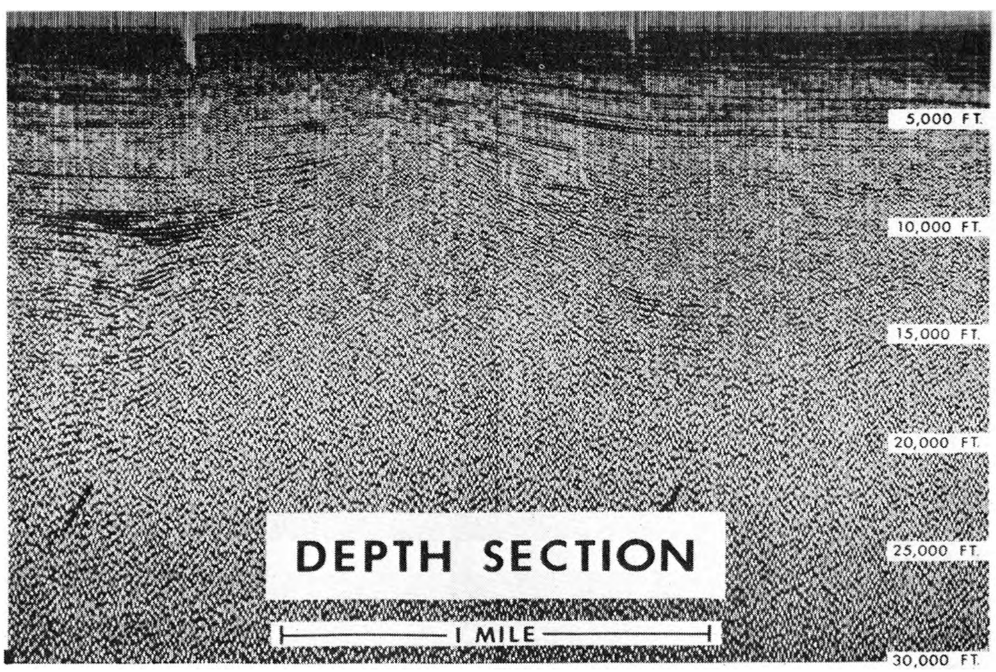

Figure 5. Seismic depth section. Mackenzie Bay area, Arctic coast. (From paper by A. E. Pallister given to 1970 AAPG annual meeting.

major oil deposits in other parts of the world are present. These include great thicknesses of relatively young rocks mostly of nearshore marine origin, burial without metamorphism, probable diapirs and other large structures especially in the offshore, as well as demonstrated porosity. How much of this potential will be fully realized will probably depend upon the rate of development of offshore drilling technologies suitable for moving pack ice and very soft bottoms. At this point the geologist usually shrugs his shoulders and says that he has every confidence that the engineers will solve these problems when the need arises. If we use Mason's yield given in the NPC Future Petroleum Provinces Volume or average Gulf Coast of 80,000 $Bbls/mile^3$ as an analogy, we would have about seven billion barrels using an average thickness of two miles.

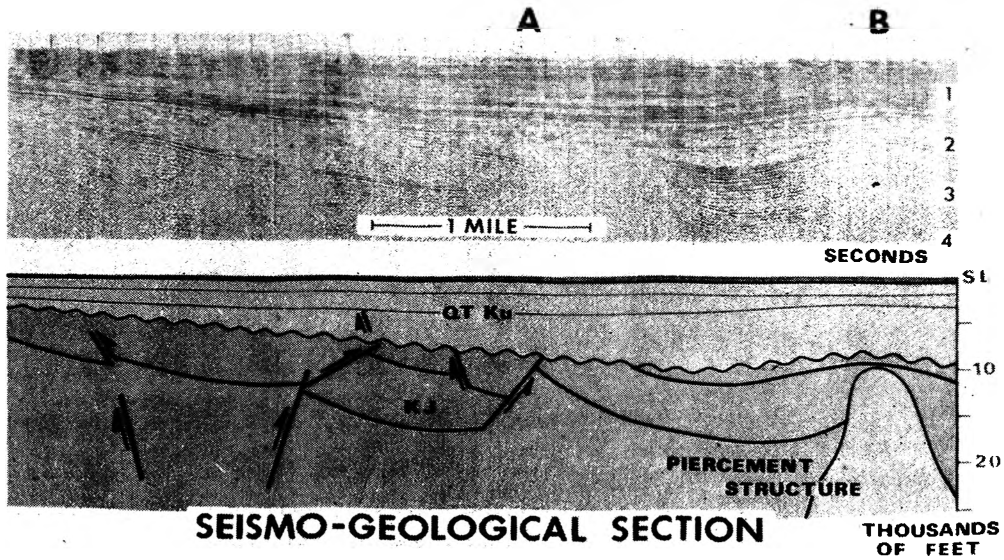

Figure 6. Interpreted seismic section, Mackenzie Bay area. (From paper by A. E. Pallister, 1970 AAPG annual meeting).

The part of the Coastal Plain bordering the Arctic Archipelago has an area of some 100,000 square miles of which about 10% is above present sea level. The geology is probably similar to the mainland coast but no estimate is made for this area although the potential could be increased correspondingly if there is a reasonable hope of exploration in the foreseeable future.

Arctic Lowlands. The Arctic Lowlands of the Arctic Archipelago lie between the Canadian Shield and the folded belts of the Franklinian geosyncline. This area is made up of several shallow basins (Fig. 4) each with a different history, but in general the geology is similar to parts of the lowlands bordering the shield in southern Canada though larger structures are present. The rocks are dominantly carbonates with some clastics, mostly Lower Paleozoic in age but with some strata as young as Mesozoic and Tertiary. The total reported thickness is more than 18,000 feet, but the complete section over most of the area is less than 10,000 feet. There are numerous indications of hydrocarbons in these rocks, but the overall general potential for major petroleum is not as great as in some of the other northern basins. This area could be grouped with the Interior Plains, but because of thinness of the section, the greater age of the rocks and the remoteness of the area, it cannot be considered as attractive. The area has been grouped together by Landes with the Franklinian miogeosyncline and assigned an area of 226,700 square miles and a volume of 416,800 cubic miles.

Franklinian Geosyncline. The eugeosynclinal part of the geosyncline outcropping on northern Ellesmere Island and the part lying at great depth beneath the Sverdrup Basin is not likely to have any potential whatsoever. The miogeosynclinal portion, however, which is cut by the Parry Island fold belt, has possibilities. The Variscan structures include long, sublinear, symmetric, gently plunging, east trending folds which gradually decrease in amplitude to the south. One unsuccessful well has been drilled on one of these anticlines. The potential for this area, however, must be considered relatively low since the section is Devonian and older. If we use the volume of 416,800 mi^3 mentioned above for the combined areas and use an arbitrary yield of somewhat less than that given to the Interior Plains of 30,000 B/mi^3 we would have 12.5 billion barrels for this area.

Sverdrup Basin. The Sverdrup Basin lies to the north and west of the Franklinian miogeosyncline and contains an aggregate of possibly 40,000 feet of strata from Carboniferous to early Tertiary age. This sequence probably did not all accumulate in one place and it seems that the axis of maximum deposition has moved westerly across the basin with time. Carbonates occur in the Carboniferous but the upper part of the section is dominantly clastic. The major deformation was Laramide and produced typically large folds with curving axes and moderate depths. A number of diapiric structures have developed some of which have penetrated very thick parts of the basin coming from Carboniferous evaporites at depth. In view of the large volume of sediment in the basin, the ample evidence of source rock and the variety of structural-stratigraphic combinations, and facies variations with reef-shale and sand-shale sequences, the petroleum potential of the area must be considered high, at least as good as the Arctic Coastal Plain. This basin according to Landes contains 262,000 cubic miles of potential sedimentary rock and is about 113,000 square miles in area. We have used the same yield factor for this basin that we used for the Arctic Coastal Plains of 80,000 B/mi^3. Although there is no geological similarity between the two we chose this number simply as being representative of a better than average basin. It would then give us a potential of 21 billion for the Sverdrup basin.

Conclusions

Exploration and development of metallic minerals and solid fuels is far enough along in northern Canada to indicate clearly a very large potential. The rate at which the potential will be realized will depend on world metal prices, changes in technology of extraction, and improvements in communications.

The 54 billion barrels that we have assigned rather arbitrarily to Arctic Canada is based on scanty evidence. Half of this is attributed to older shelf-type deposits and may be widely dispersed in relatively small pools and so not usable until communications are greatly improved. The other half from the Arctic Coastal Plain and the Sverdrup Basin will probably be harboured in pools of much larger average size. We feel that these estimates tend to the conservative and fall 10 billion barrels below those of the Canadian Petroleum Association for the Arctic Islands. As soon as we gain an idea of the geological nature of the traps in these basins from the first few discoveries and an insight into source potential from our current geochemical program we will be in a much better position to put meaningful ratings on them. I think it is safe to say even at this very early stage of exploration that major petroleum discoveries will be made within the next five years in Arctic Canada; probably within two or three at the currently anticipated rate of exploration.

R. G. McCrossan

Dr. R. G. McCrossan is presently head of the Geology of Petroleum Section, Institute of Sedimentary and Petroleum Geology, Geological Survey of Canada, in Calgary. He was granted a B.A. in Honours Geology by the University of British Columbia, S.M. in Geology by the University of Chicago, and Ph.D. also by the University of Chicago.

He was employed by the Seaboard Oil Company of Delaware in Calgary as a subsurface geologist from 1949 to 1959. During this period he obtained leaves of absence to complete his graduate work at the University of Chicago. In 1959 he joined the Exploration Research Department of Imperial Oil Limited, also in Calgary, where he remained until 1969. In that year he joined the Geological Survey of Canada to form the new Geology of Petroleum Section at the recently created Institute of Sedimentary and Petroleum Geology. His responsibilities include advising the Geological Survey in matters related to petroleum exploration, the study of oil occurrence, and geochemistry. He is also responsible for advising the basin study group at the Institute.

Dr. McCrossan has current outside professional responsibilities as Editor and Coordinator of the study of the future petroleum potential of Canadian basins, which study is intended to relate to the similar work being done for the National Petroleum Council by the AAPG in the United States; coconvenor of the program for Mineral Fuels Section of the of the 24th International Geological Congress; chairman, Petroleum Exploration Geochemistry Symposium, 1970, Canadian Institute of Mining and Metallurgy; member, Council of the Association of Professional Engineers, Geologists and Geophysicists of Alberta.

Dr. McCrossan is affiliated with the following technical and professional organizations: American Association of Petroleum Geologists, Geological Society of America, Society of Economic Paleontologists and Mineralogists, Alberta Society of Petroleum Geologists, Association of Professional Engineers of Alberta.

Richard M. Procter

Dr. Procter is presently the coordinator of the Northern Basins Analysis Program at the Institute of Sedimentary and Petroleum Geology, which is a Division of the Geological Survey of Canada, in Calgary. He received a B.Sc. Honours Geology (1953), and M.Sc. in Geology (1957) at the University of Kansas.

Prior to joining the permanent staff of the Geological Survey of Canada in 1960, he was employed by Mobil Oil of Canada, Imperial Oil Ltd., and the Geological Survey of Canada in field and well-site capacities. Dr. Procter's research interests with the Geological Survey have included subsurface stratigraphy of Late Palęozoic and Triassic rocks of northeastern British Columbia, and clay mineralogy studies. Current responsibilities are directed toward a series of integrated analyses of the sedimentary basins of northern and Arctic Canada, including evaluation of the oil and gas potential of the region.

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