OPEN FILE RELEASE
MARCH, 1981
OPEN FILE 767

CANADA'S CONVENTIONAL OIL AND GAS RESOURCES

R.M. Procter, P.J. Lee, D.N. Skibo

Geological Survey of Canada

Petroleum Resources Appraisal Secretariat,
Institute of Sedimentary and Petroleum Geology,
Geological Survey of Canada,
Department of Energy, Mines and Resources,
3303 - 33rd Street N.W.
Calgary, Alberta, Canada.
T2L 2A7

The report being open filed at this time is slightly modified from the talk presented at the Canadian Society of Petroleum Geologist's Conference: Energy Audit of the 80's, September 29 - October 1, 1980.

The estimates of hydrocarbon potential for all regions in Canada, are prepared by a committee consisting of personnel from the Atlantic Geoscience Center and Institute of Sedimentary and Petroleum Geology of the Geological Survey of Canada, the Resource Management Conservation Branch of EMR and from Indian and Northern Affairs. The activities of this Committee are coordinated by the Petroleum Resources Appraisal Secretariat located at the Institute of Sedimentary and Petroleum Geology, Geological Survey of Canada, Calgary, Alberta. This Committee on Geological Potential, consisting of some 10 geologists and geophysicists, is responsible for the finalization of estimates of undiscovered resources.

R.M. Procter,
Executive Director,
Petroleum Resources
Appraisal Secretariat.

CANADA'S CONVENTIONAL OIL AND GAS RESOURCES

(AND FUTURE DISCOVERIES - 1980 to 1990)

INTRODUCTION

The Geological Survey of Canada has been making estimates of petroleum resources for all basins of Canada since 1973. The purpose of this activity was to provide a systematic approach to making an inventory of petroleum resources for departmental planning purposes. The present paper is divided into three sections. The first section briefly describes the methodology used in petroleum resources evaluation. The second section presents the current estimates of petroleum resources of Canada. The last section deals with the questions of how much of these resources may be discovered during the 1980's.

METHODOLOGY OF PETROLEUM RESOURCE EVALUATION

The methodology used is commonly known as the probability approach. Details are available in publications[1] but here it is only necessary to describe its major parts. The objectives of estimating petroleum resources are to determine (1) how much pooled oil and gas may exist? (2) what are the reservoir characteristics of the pools? (3) where are the pools located? and (4) how certain are the estimates? Preparation of any estimate begins with a definition of the exploration play concept. These are situations in which geologists and geophysicists perceive that hydrocarbons may occur, as such they may be real plays or hypothetical plays that have yet to be tested.

[1]Oil and Natural Gas Resources of Canada, 1976: Canada, Energy, Mines and Resources Report EP77-1, pp 61-73; Roy et al, 1975.

The basic steps in evaluation of oil and gas resources include: (1) data input, (2) generation of pool size distribution, (3) evaluation of play potentials, and (4) discovery predictions.

The data used include: area of closure, reservoir thickness, effective porosity, net pay, trap fill, recovery factor, water saturation, shrinkage factor, gas fraction, hydrocarbon fraction and depth. In this approach each of the exploration plays is evaluated using both objective data from wells, seismic, etc. and subjective judgment by geologists, geophysicists, geochemists, and other scientists to supplement or fill in gaps in our knowledge base. All data are expressed in terms of a range or a frequency distribution curve.

The second step is the generation of a pool size distribution. This step combines all input data, through a Monte Carlo procedure, to produce a pool size distribution (Figure 1).

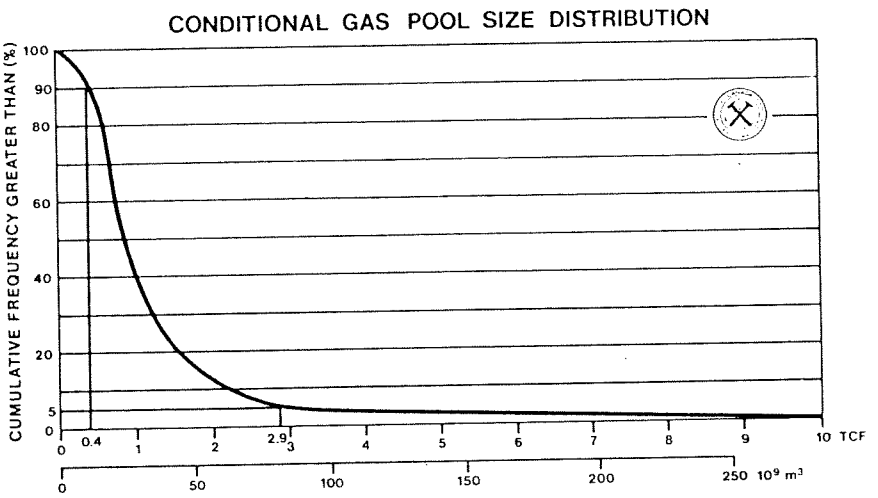

Figure 1. Cumulative frequency representation of conditional pool size distribution for an exploration play

This distribution describes the range of pool sizes that may occur in a play given the input data. The curve shown indicates 90% of the pools are expected

to be larger than 0.4 TCF. In the other case, only 5% of the pools can be expected to be larger than 2.9 TCF.

The third step is the estimation of play potential. If we known the pool sizes that occur then we need only known the number of pools to be able to estimate how much resource in total may exist. The number of pools is derived from a consideration of the number of potential targets, appropriately risked. In practice, this estimate of number of pools is combined with the pool size range to produce an estimate of the total potential that may be expected (Figure 2).

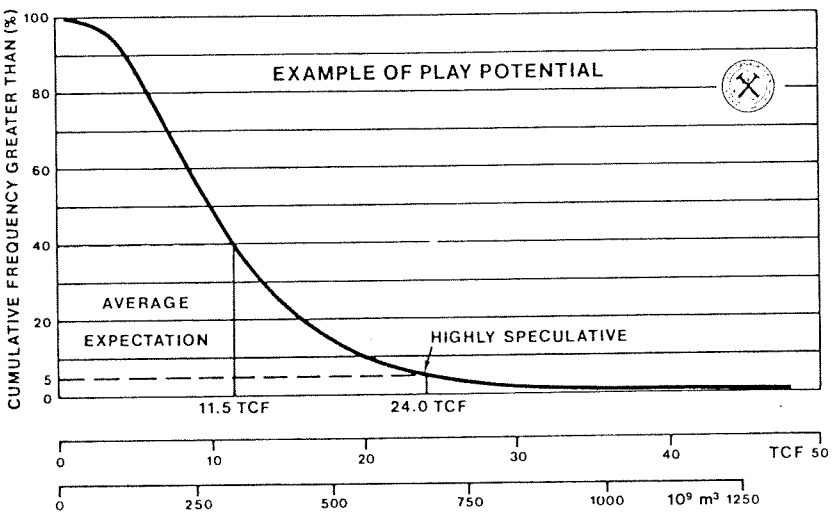

Figure 2. Cumulative frequency representation of risked potential for hydrocarbon resource in an exploration play

The steepness of the potential curve indicates the certainty of the estimation. For convenience, in this paper the potential at the 40% probability level is referred to as the average expectation, whereas the 5% probability level is called the highly speculative potential.

At this stage, no constraint has been imposed in terms of economic viability. In order to evaluate the economics related to various plays the next step is to produce a series of hypothetical pools governed by pool size distribution for the play. These hypothetical oil and/or gas pools can be arranged into a sequence according to their size as a resource population (Figure 3).

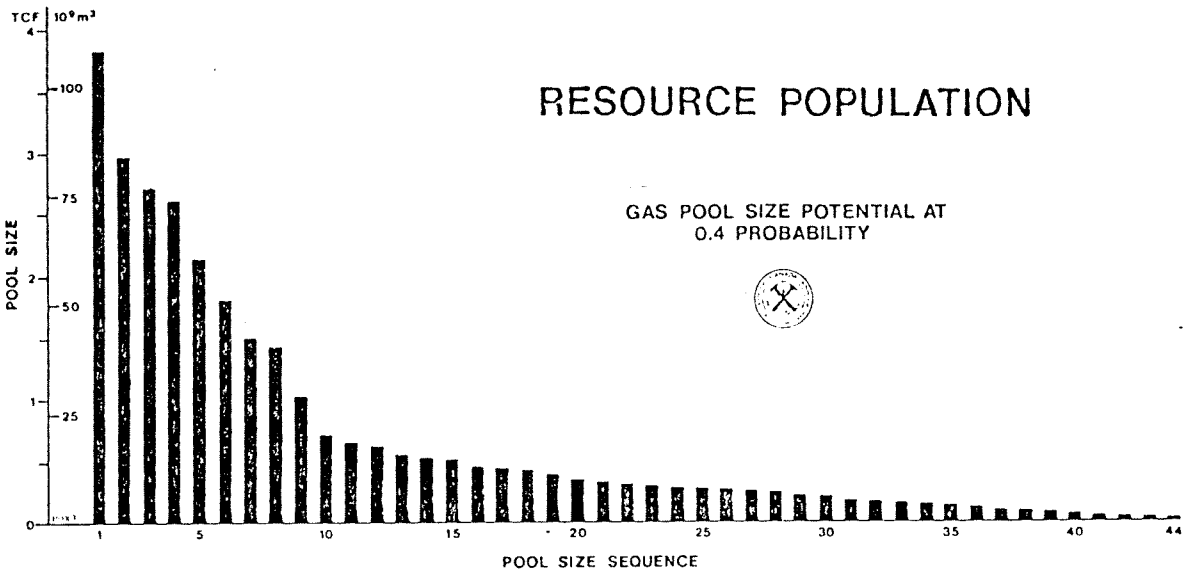

Figure 3. Hypothetical hydrocarbon pools derived from conditional pool size distribution and ranked by size

With knowledge of the resources that may exist, and their pool sizes, the last step is to predict future discovery rates. This discovery modelling process reflects both the drilling success to date and the risks and relative likelihood of discovery in future exploration (Lee, 1980). This modelling is accomplished using a Markov chain followed by sampling without replacement from the resource population made up of hypothetical pools (Figure 4).

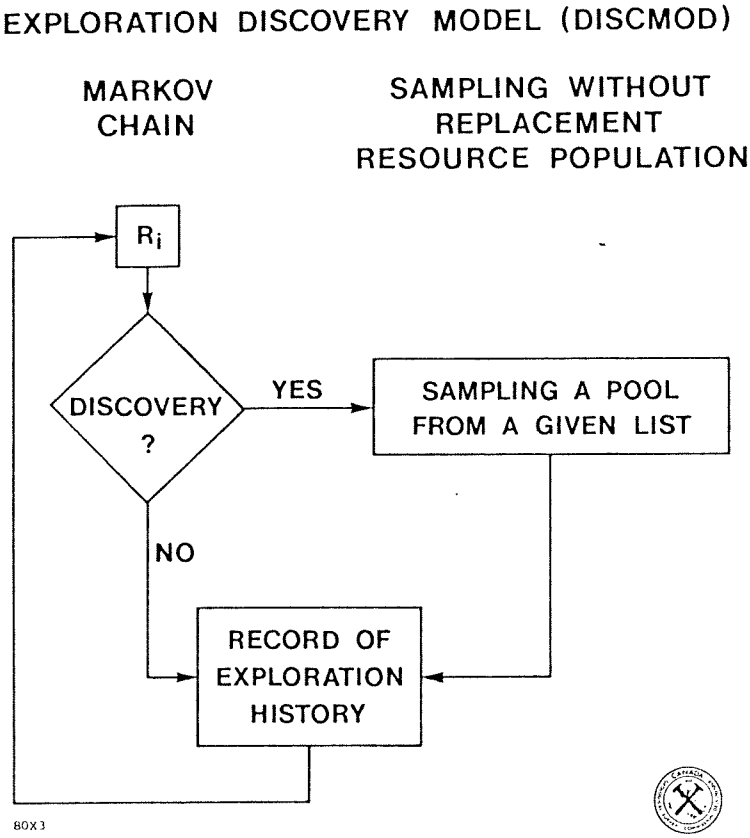

Figure 4. Diagram of Discovery Model process to predict future discovery rates for economic evaluation

Using the Labrador Shelf as an example, if the past exploration outcomes can be represented by D for a dry hole and G for a gas discovery and listed in chronological order, the following sequence is obtained: D-G-G-D-D-G-D-D-D-D-G-G-D. This tabulation indicates not only the number of discoveries but also the number of times a dry hole is followed by a discovery well. This data can be tallied

into an array (Figure 5) which indicates that the exploration history has

	DRY	GAS
DRY	4	3
GAS	3	2

Figure 5. Exploration history array obtained from past exploration record

changed four times from dry hole to dry hole state; twice from gas discovery to gas discovery; and three times from gas discovery to dry hole. This array is used to determine the probability of having a success or failure with the next wildcat. When an exploratory well succeeds, the immediate question is: how large is the discovery? The answer is obtained by sampling, without replacement, a pool from the resource population (Figure 3). The probability of a pool being sampled is controlled by three factors (Figure 6): (1) pool size, (2) play risk, and (3) exploration activity. The discovery model executes the Markov chain, and the sampling without replacement components until all pools are discovered.

FACTORS CONTROLLING A POOL TO BE DISCOVERED

1. POOL SIZE (X_i)
2. PLAY RISK (P_R)
3. EXPLORATION EFFORT (E_E)

$$P_i = X_i \times P_R \times E_E$$

Figure 6. Probability of sampling from resource population in Discovery Model process

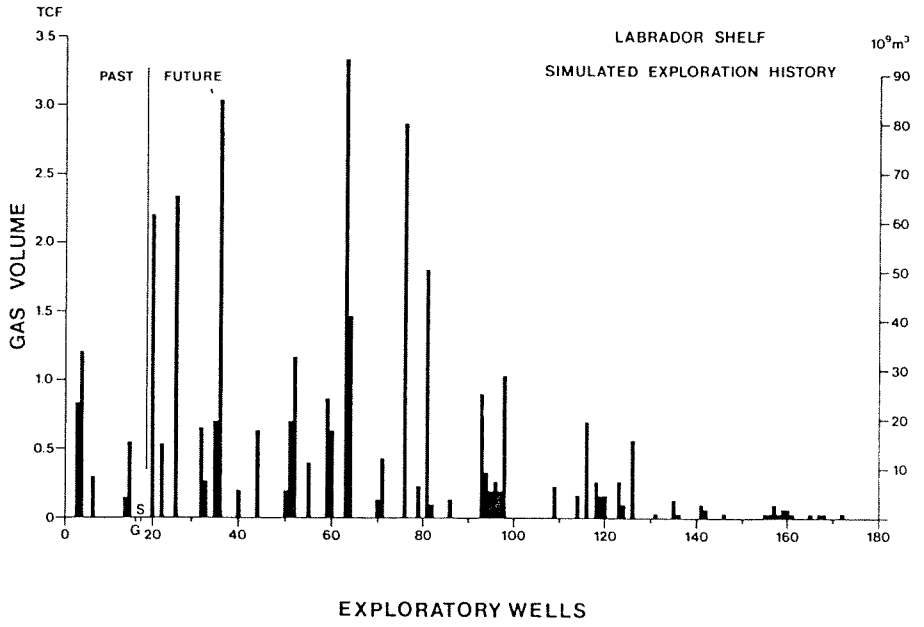

Figure 7. Example of Discovery Model output showing pool size discovery as a function of exploratory wells drilled

Figure 7 shows the past exploration history and a simulated future discovery outcome. Vertical scale is gas volume and the horizontal scale is the number of discovery wells. The figure suggests that larger prospects are found at the early stage of exploration. Figure 8 shows the same data

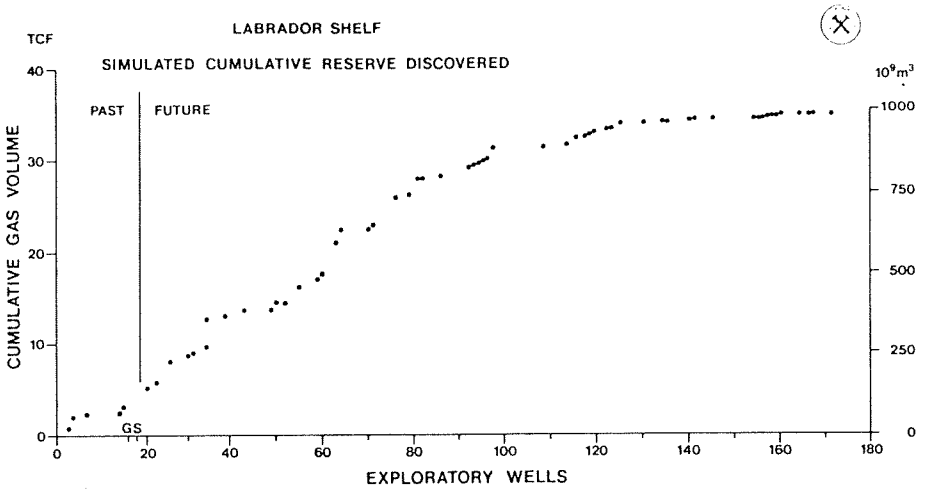

Figure 8. Example of Discovery Model output showing cumulative reserves discovered as a function of exploratory wells drilled

in cumulative form at different exploration stages and characterizes the predicted behavior of the future discovery rate for the Labrador Shelf. Obviously, repeated simulations will differ because of the nature of the simulation process, and Figure 9 shows ten simulation runs and their average as a heavy line. All exploration simulations presented here are averages of ten repeated trials.

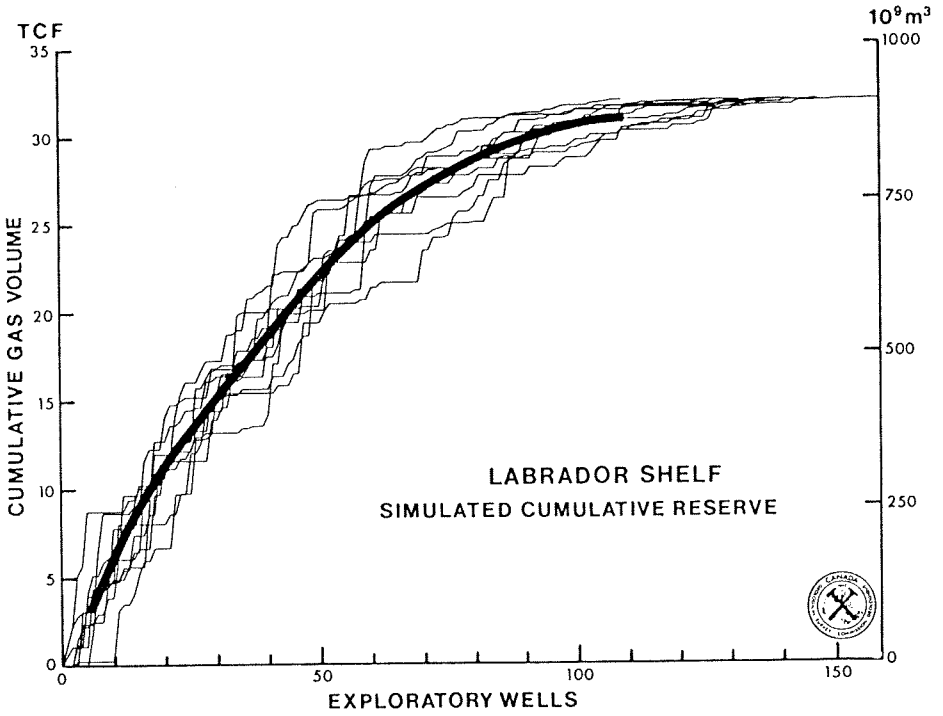

Figure 9. Ten future discovery simulations for Labrador Shelf region with their average given as heavy line

ESTIMATES OF OIL AND GAS RESOURCES

The GSC's latest estimates of Canada's oil and gas resources will be presented in 4 regions: the East Coast of Canada, the Arctic Islands, the MacKenzie Delta-Beaufort Sea region, and Western Canada.

EAST COAST OF CANADA

Geological Setting

The estimates of oil and gas resources for this region (Figure 10)

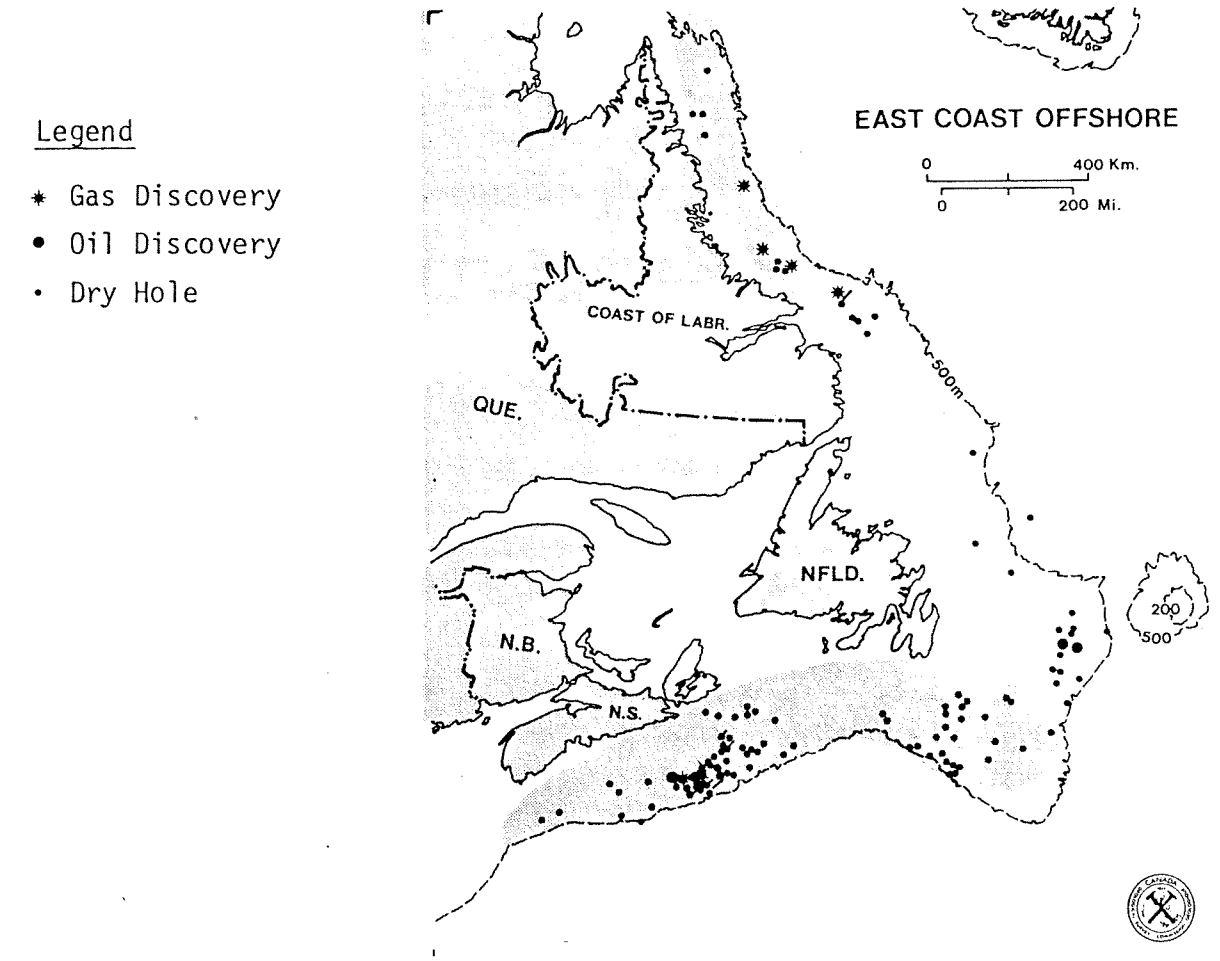

Figure 10. East Coast Canada hydrocarbon potential assessment area

cover the area extending from the Scotia Shelf into the Baffin Bay basin. More than 125 exploratory wells have been drilled in this region since 1966 resulting in recognition of a major gas province near Sable Island, the currently exciting oil province surrounding Hibernia and a narrow dominantly gas province extending up the coast of Labrador probably into Baffin Bay. The estimates are based on the analysis of 32 plays primarily in the sedimentary wedge of Tertiary and Mesozoic age that thickens off the continental shelf. Important trap types include: salt cored diapiric features, large roll-over faults, fault blocks with overlying and flanking sands, as well as a multitude of stratigraphic traps involving carbonate and clastic pinch outs and erosional surfaces. Clastic sediments are generally deltaic and with the exception of the Hibernia area contain organic material that is dominantly land-derived plant detritus. This coupled with the relative geochemical immaturity leads to the East Coast being a dominantly gas prone region.

Potential Evaluation

The estimates of potential (Figure 11) indicate an average expectation for approximately 72 TCF of gas for the East Coast region and a highly speculative potential for as much as 125 TCF. On the oil side the average expectation is for 7.4 billion barrels of recoverable oil with a highly speculative value of almost 13 billion barrels. No estimates of proven reserves are available at this time, however there is agreement that the Hibernia discovery probably contains at least 0.5 billion barrels of recoverable oil and that commercial quantities of gas, probably exceeding one trillion cubic feet, exist at the Venture discovery. Individual discoveries along the Labrador coast, although exciting, are too small to be economic at this time.

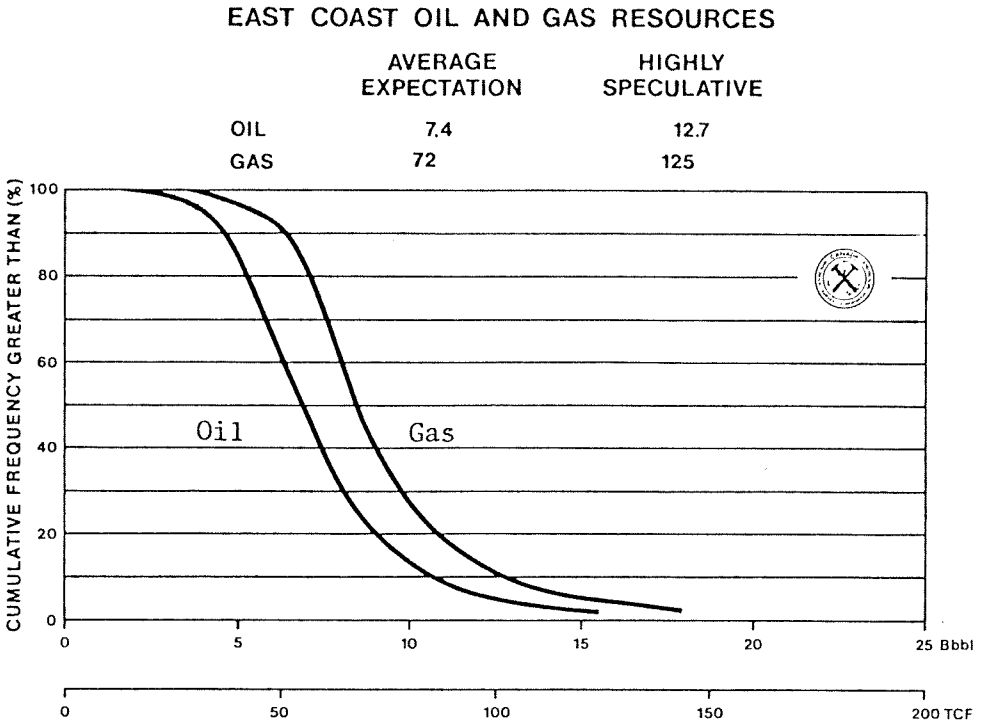

Figure 11. Estimates of oil and gas potentials for East Coast Canada

Future Discovery Rate

The exploration history for the last five years from the East Coast was used as a basis for the exploration discovery modelling.

The result from the discovery model (Figures 12 and 13) shows the projection from future exploration. The projections for oil and gas are bounded by the average and highly speculative expectations. For a given amount of exploration effort, for example 150 exploratory wells, one would project the amount of gas discovered would be in the range of 20 to 31 TCF,

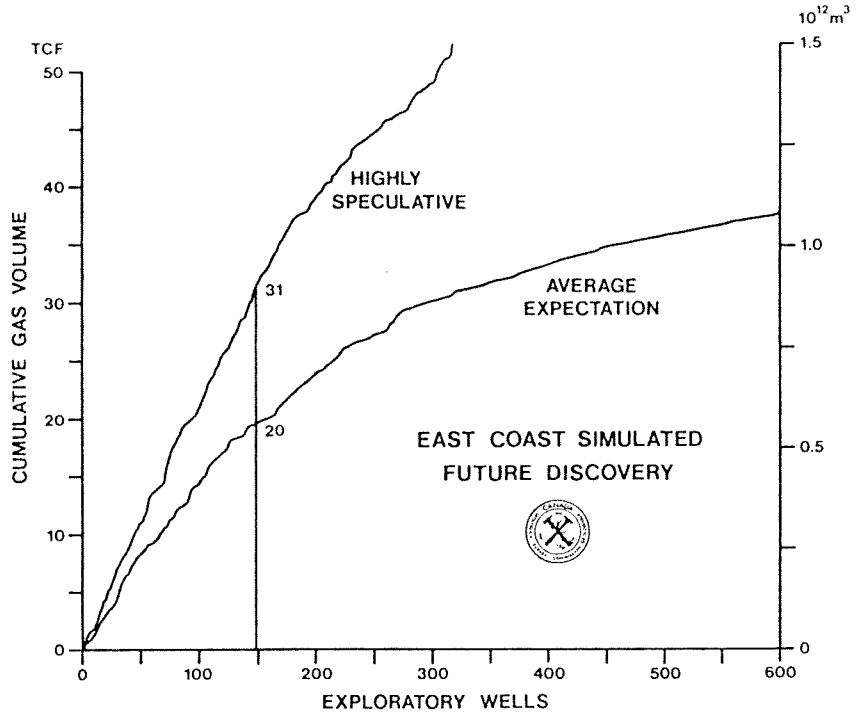

Figure 12. Projected gas discovery for East Coast Canada

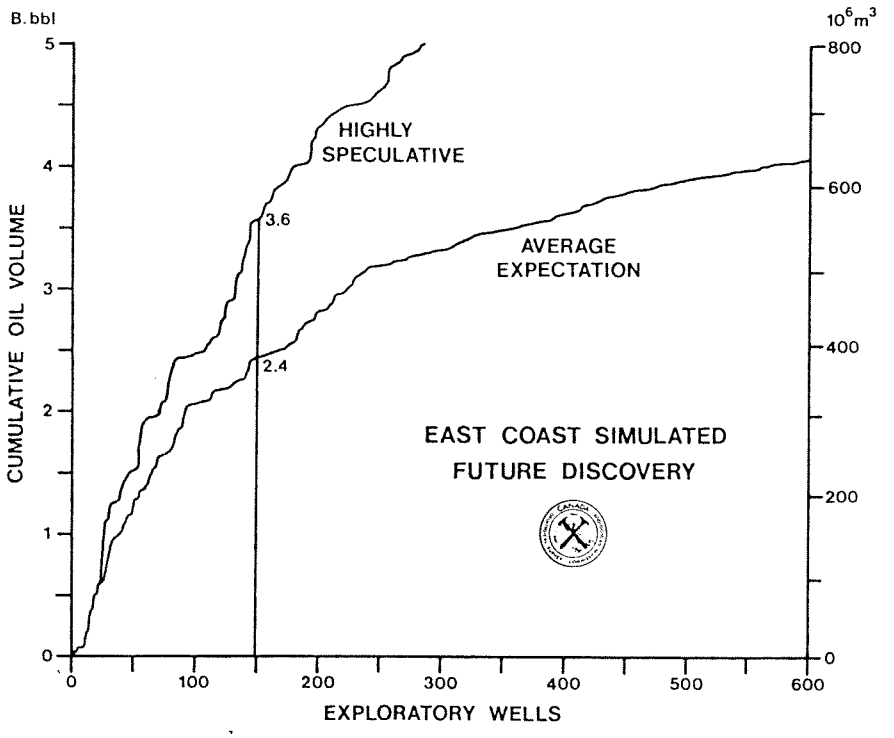

Figure 13. Projected oil discovery for East Coast Canada

and of oil would be in the range of 2.4 to 3.6 billion barrels. It is interesting to note that the curve remains quite steep for about the first 200 wells, then flattens in the mature stages of exploration. Discovery models for each region have been simulated and the results tabulated later in the paper.

ARCTIC ISLANDS REGION

Geological Setting

The Arctic Islands Region, including (Figure 14) the Stable Platform,

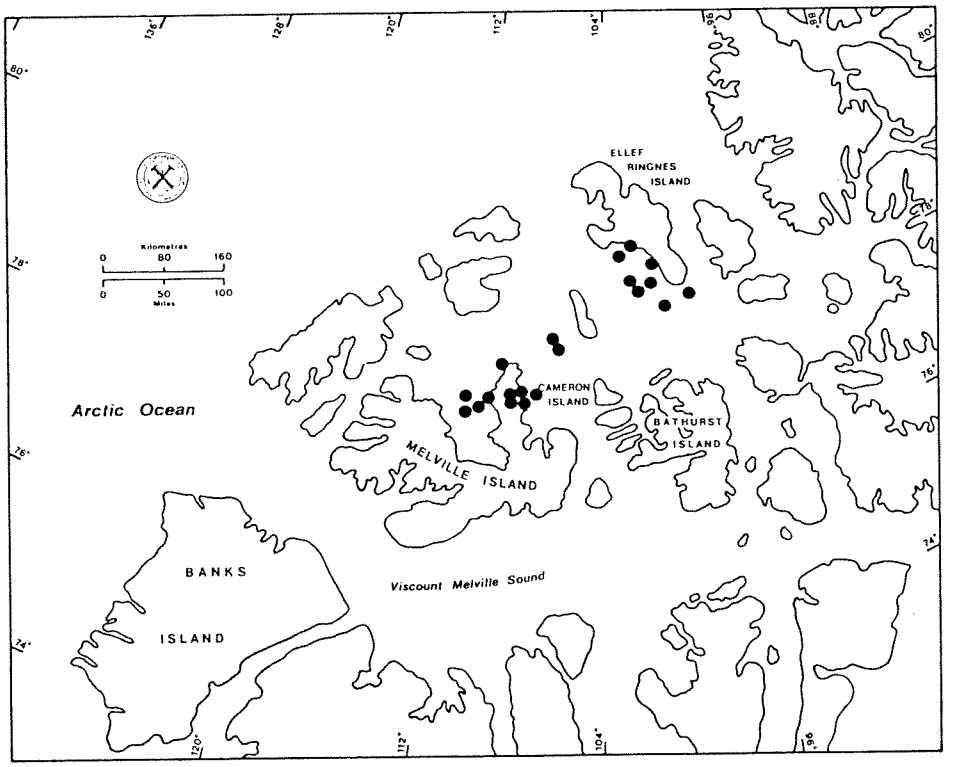

Figure 14. Arctic Islands hydrocarbon potential assessment area

the Fold Belt and the Sverdrup Basin, represents one of the most diverse areas for petroleum accumulation. Exploratory drilling began in 1961 in this large area, about half of which is covered by water. Since then, more than 140 exploratory wells have been drilled. Although exploration opportunities exist in rocks from the Precambrian through the Mesozoic, by far the greatest activity has been focused on rocks of Jurassic age. This effort has resulted in discovery of 2 and possibly 3 giant gas fields as well as others in the 1 trillion cubic foot range with total discoveries probably exceeding 15 trillion cubic feet. Oil was also discovered on Cameron Island in 1974 but attempts to find significant extensions of that play have proved frustrating to date. Although there are indications that oil will occur in other parts of the area and in a variety of plays, evidence to date suggests that the Arctic Islands region will be dominantly a gas province with only modest quantities of oil. This situation reflects the basic geochemistry of the region in which Mesozoic rocks are primarily immature with high concentrations of land derived organic material. Lower Paleozoic rocks where tested, although having oilier source materials have passed beyond the maturity level and now contain mainly gas. The best opportunities for accumulation of liquid hydrocarbons may occur in basinal marine Permo-Pennsylvanian carbonates and deeper portions of the Mesozoic sections.

Potential Evaluation

Our current estimate of resources (Figure 15) for this region includes an average expectation of 87 trillion cubic feet of gas and 4.3 billion barrels of recoverable oil. At highly speculative levels these estimates extend to 138 TCF of gas and 7.6 billion barrels of oil. These estimates include an established reserve which probably ranges from a minimum of 12 TCF which,

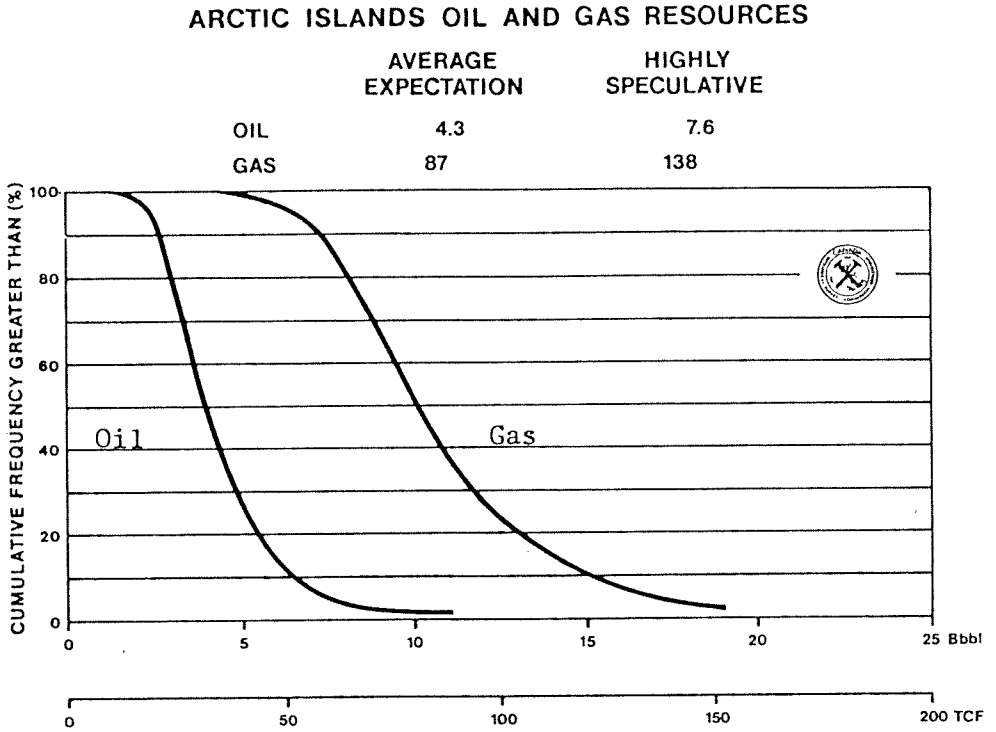

Figure 15. Estimates of oil and gas potentials for Arctic Islands region

with effective delineation drilling, may prove to be larger than 20 TCF. Oil reserves at this time are considered relatively insignificant. The estimates are the result of the analysis of 27 exploratory plays, many of which have yet to be tested, introducing a large element of uncertainty which is reflected in the distribution of estimates of potential.

MACKENZIE DELTA-BEAUFORT SEA REGION

Geological Setting

This region (Figure 16) includes the onshore part of the Mackenzie Delta

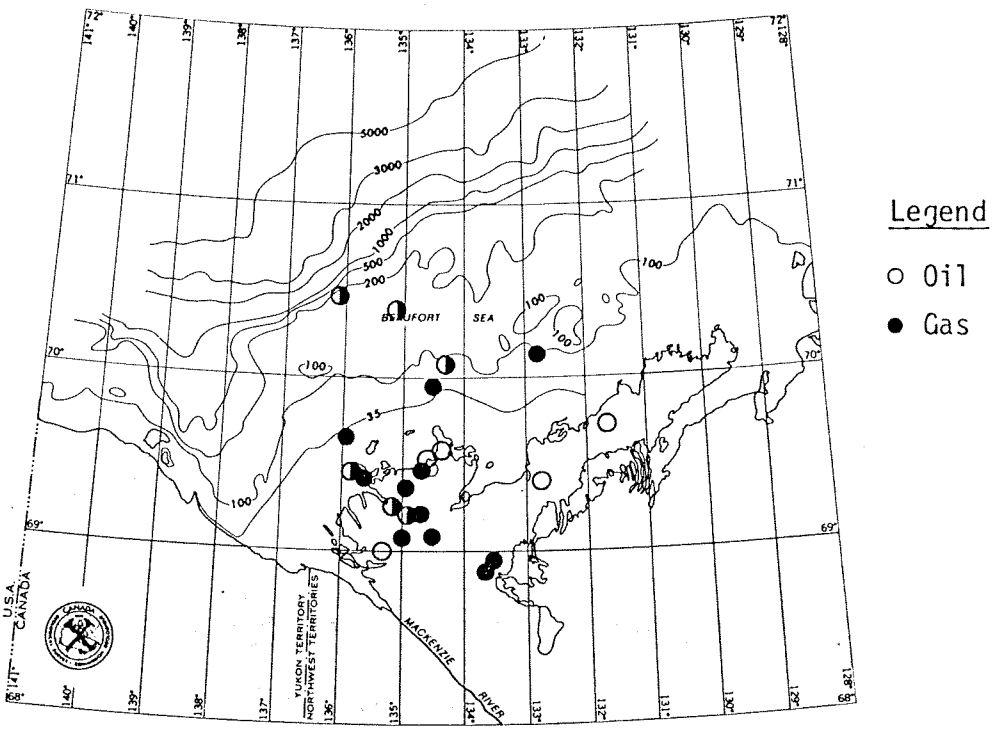

Figure 16. Mackenzie Delta-Beaufort Sea hydrocarbon potential assessment area

and that part of the offshore extending to the edge of the continental shelf at a water depth of approximately 600 feet. It also extends from the Amundsen Gulf west to the Canada/Alaska boundary. The region is underlain by deltaic sandstones and shales of Mesozoic and Tertiary age which thicken rapidly northward to more than 40,000 feet a short distance seaward from the present delta. These clastics overlie faulted Paleozoic rocks which step down steeply beneath the Mesozoic-Tertiary cover. The Tertiary sequences contain the most

important sandstone reservoirs, but additional reservoir rocks are present in both Cretaceous and Jurassic sands. Major targets have been the deformed diapiric structures formed by mud flow at depth some of which attain great magnitude and are linear in planview. Other targets result from closure provided by roll-over and growth faults, sometimes coupled with plastic deformation at depth. The main emphasis on drilling started on Richards Island and then extended into the near offshore region through artificial island building activity with reservoirs targeted primarily in the main deltaic lobes of the present and ancestral Mackenzie Delta. More recently, exploration has extended to the deeper Beaufort Sea region where drill-ships now test sedimentary wedges which have been deposited in deeper water beyond the edges of ancient continental shelves. Parts of the region such as the area extending west to the Alaska boundary have received very little exploratory effort although there are indications that features similar to those found in the Beaufort Sea are present.

Geochemically the region can be characterized as thermally immature with hydrocarbon derived from source rocks containing dominantly land derived plant material. These characteristics are inconsistent with the observed occurrences of liquid hydrocarbons and condensates. Current thinking is that an unusual concentration of resins, derived from forests, and capable of conversion to liquid hydrocarbons at relatively low temperatures, may explain the geochemical enigma. As indicated by the estimate curves the region is dominantly gas prone but is also thought to contain more oil than any of the other frontier regions.

Potential Evaluation

In preparing the estimate of resources, 17 exploration plays have been assessed. Figure 17 shows the average expectation is 112 TCF of gas and

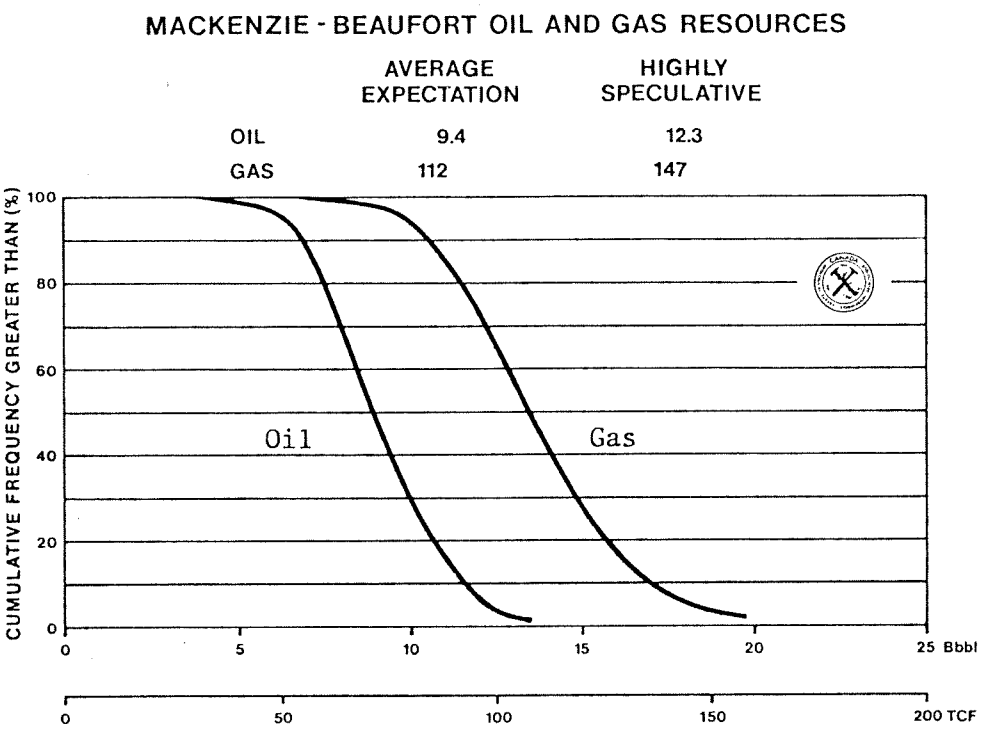

Figure 17. Estimates of oil and gas potential for Mackenzie Delta-Beaufort Sea region

9.4 billion barrels of recoverable oil. In the highly speculative range these estimates extend to 147 TCF and 12.3 billion barrels. Estimates of discovered reserves are almost as speculative as those of undiscovered potential, however, without including Dome's recent activities in the Beaufort Sea there is fair agreement that at least 6 TCF of gas have been discovered primarily in the Richards Island area and a more optimistic view that there could be as much as 10 TCF.

WESTERN CANADA BASIN

General Statement

This region consists of the western Canada sedimentary basin in the provinces of Manitoba, Saskatchewan, Alberta and British Columbia. It extends from the Precambrian shield on the east to the Rocky Mountains on the west south of 60° latitude and is in a mature stage of exploration. In trying to focus on conventional oil and gas the Lloydminster heavy oil belt, as well as gas in the deep basin occurring in rocks of unusually low permeability and generally requiring massive fracturing before production can be achieved have been excluded. Conventional components of the deep basin gas, however, are included in estimates presented here. Another component of the resources, which is not included, is the potentially large quantities of oil which may result from enhanced recovery methods.

Exploration to date has led to the discovery of more than 9000 gas pools and over 3200 oil pools. With the exception of the disturbed belt the vast majority of these pools are stratigraphically controlled and the analysis of some 65 plays throughout the basin indicates that this trend will probably continue.

Potential Evaluation

The relatively mature state of exploration is reflected in the estimates shown in Figure 18. The box-like character of the curves leaves a narrow range in the possible values for potential. For Western Canada, the estimate curves include major reserves plus potential. Thus the average expectation of 159 TCF on the gas curve is made up of initial reserves plus about 62 TCF of potential. At highly speculative levels the undiscovered gas could be as high as 100 TCF. Similarly for oil the average expectation of 19.2 billion

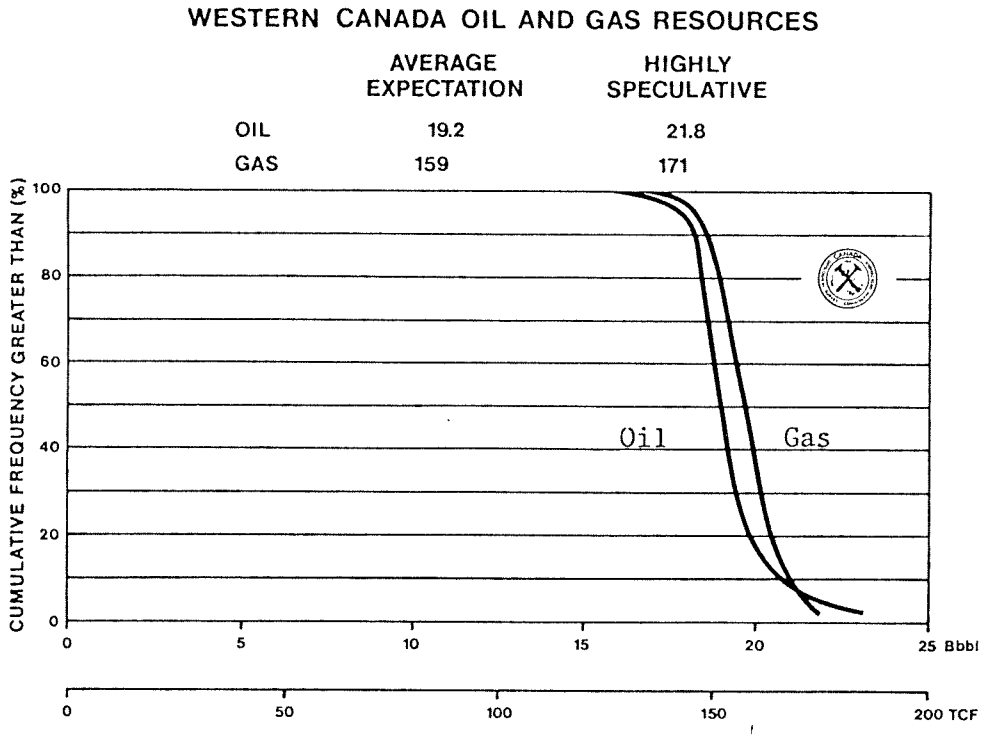

Figure 18. Estimates of oil and gas potential for Western Canada

barrels consists of initial reserves plus 3.1 billion potential. Highly speculative estimates of the undiscovered are almost 6 billion barrels.

Future Discovery Rate

Because of the large number of plays and the state of maturity of the Western Canada Basin a different approach has been used to predict the extent of discovery additions against drilling effort.

Annual drilling statistics (Figure 19) published by the Canadian Petroleum Association were plotted on logarithmic paper in order to predict the future

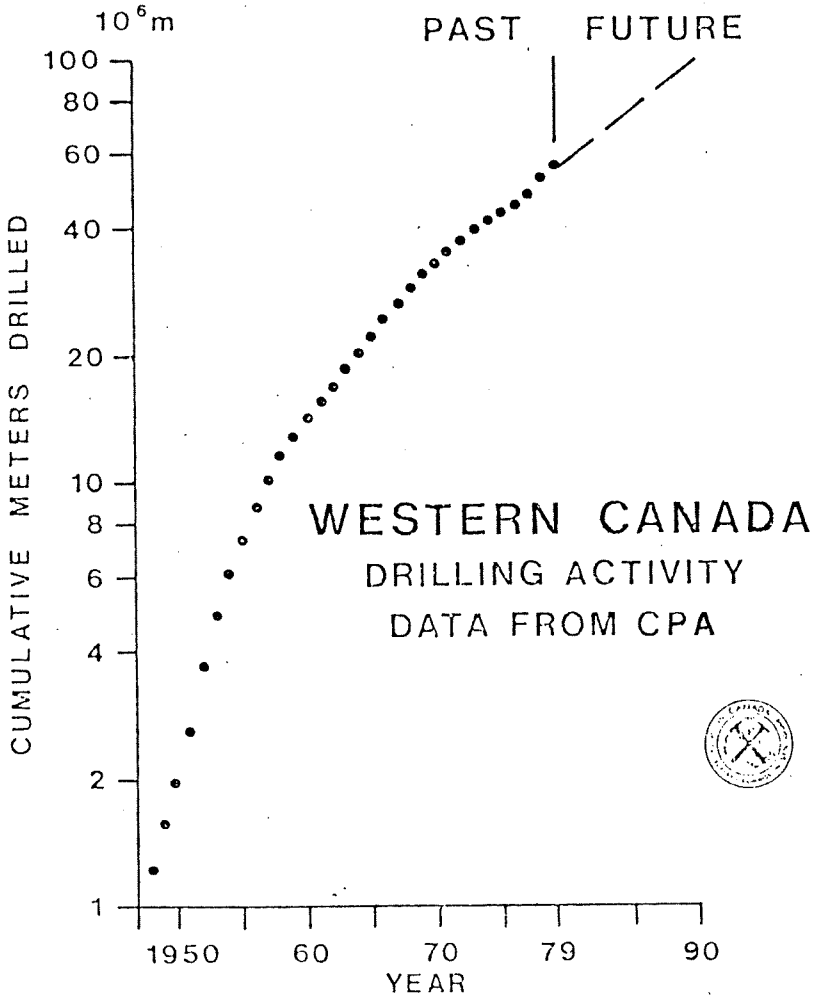

Figure 19. Annual drilling statistics for Western Canada from the Canadian Petroleum Association

trend. The last 10 years of this trend was used as a basis for projection to the year 1990, indicating that almost 45 million meters may be drilled in the next decade.

Next, the cumulative amount of gas (Figure 20) that has been discovered in the last 32 years was plotted against the cumulative meters drilled.

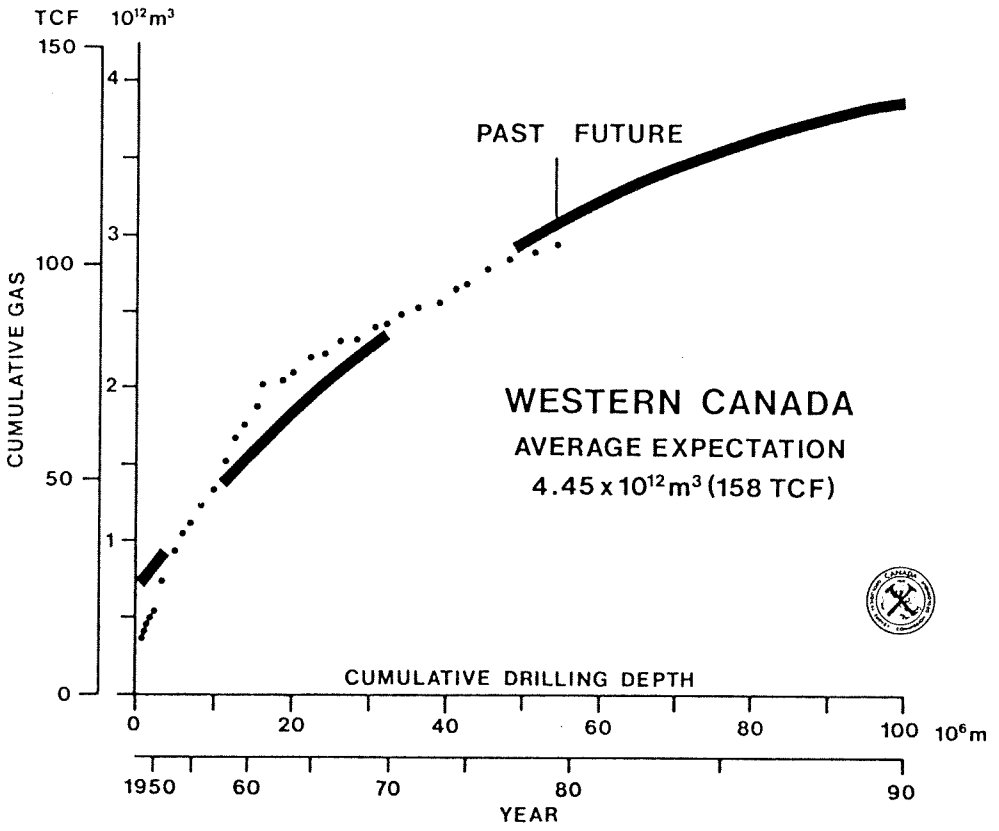

Figure 20. Cumulative gas discovered in Western Canada to date extended for estimate of discovery to 1990

This curve was extended to an additional 45 million meters to obtain an estimate of the amounts of gas that would be discovered between 1980-1990. This extension was constrained by the gas potential estimated by GSC.

The same approach was used to estimate oil discovery for the next 10 years.

OIL AND GAS DISCOVERY PROJECTION 1980-1990

The last section of this paper deals with how much of the resources may be discovered during the 1980's. A systematic approach of 141 exploratory plays by the GSC has produced estimates of substantial gas resources in three frontier regions and in Western Canada. Viewed as a whole, the frontier regions (Figure 21) are thought to contain over 270 TCF of marketable gas

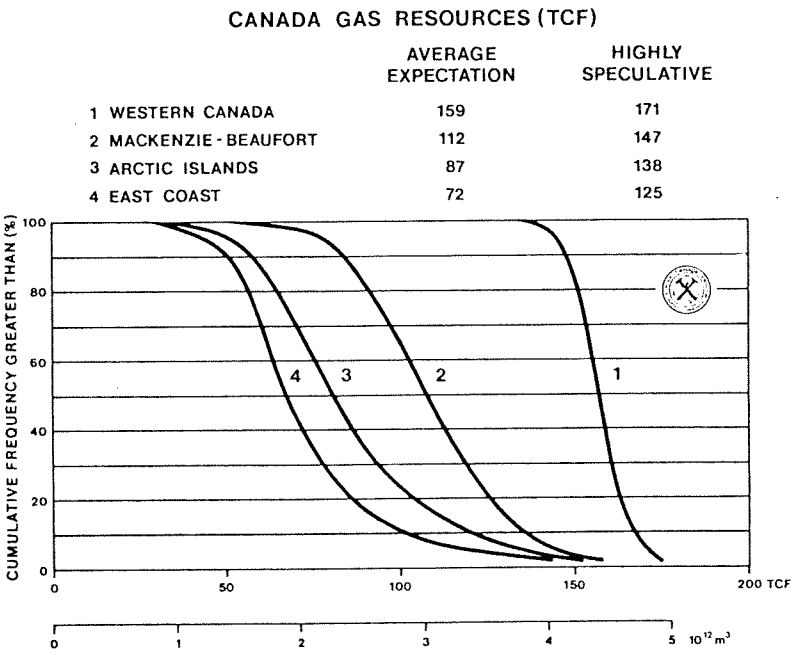

Figure 21. Comparison of estimates of gas potential of Western Canada and three frontier regions

as an average expectation. At highly speculative levels this estimate is in excess of 350 TCF. Undiscovered potential in Western Canada is estimated to be between 62 and 100 TCF.

For a prediction of the next 10 years discovery (Figure 22) we have

PROJECTED GAS DISCOVERY FOR 1980's

	DRILLING ACTIVITY (EXPLORATORY WELLS)	PREDICTIONS (TCF)	
WESTERN CANADA	22,000	35	38
MACKENZIE-BEAUFORT	75	29	40
ARCTIC ISLANDS	100	19	32
EAST COAST	150	20	31

Figure 22. Summary of ranges of projected gas discovery 1980-1990 for specified level of exploratory drilling by regions of Canada

assumed a rather generous extrapolation of current levels of exploration in each of the frontier regions and in Western Canada. Based on the level of drilling activity indicated on the figure, we can expect from 29 to 40 TCF of gas in the Mackenzie-Beaufort region, from 19 to 32 TCF in the Arctic Islands and 20 to 31 TCF in the East Coast would be discovered. In Western Canada 35 to 38 TCF of gas would be discovered at a cost of drilling about 45 million meters or about 22,000 exploratory wells.

The estimates of oil resources (Figure 23) indicate an average expectation of almost 21 billion barrels of recoverable oil in frontier regions of Canada and at a highly speculative level that estimate may be viewed in the order of more than 30 billion barrels. Undiscovered potential

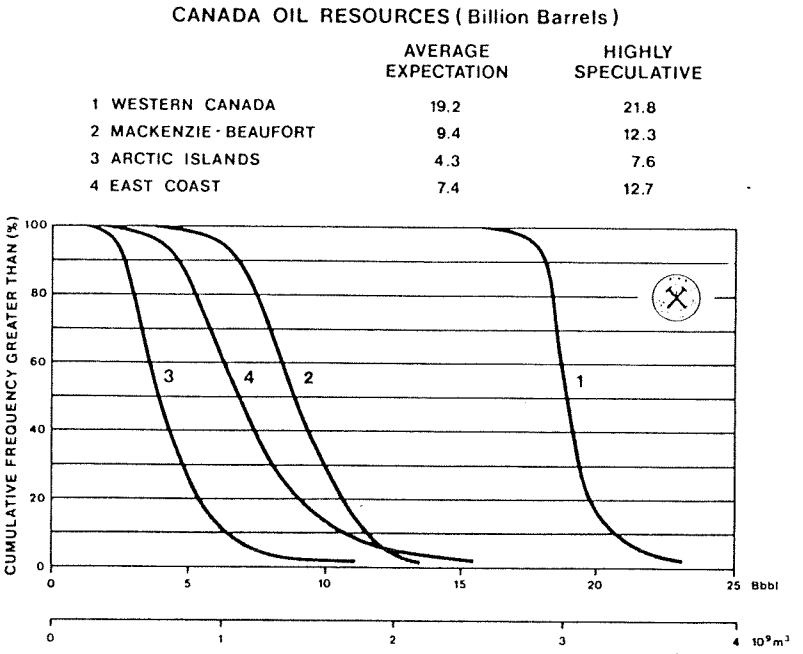

Figure 23. Comparison of estimates of oil potential of Western Canada and three frontier regions

for Western Canada is estimated to be only 3.1 billion barrels on the average expectation with a possible high of 6 billion barrels.

Projected discovery of oil for the next 10 years (Figure 24) using the same drilling activity level for both gas and oil, gives an expectation of 2.4 to 2.6 billion barrels of oil in the Mackenzie-Beaufort region, 400 to 500 million barrels in the Arctic Islands, and 2.4 to 3.6 billion barrels in the East Coast. In Western Canada, projected discoveries range from 2.6 to 3.3 billion barrels.

PROJECTED OIL DISCOVERY FOR 1980's

	DRILLING ACTIVITY (EXPLORATORY WELLS)	PREDICTIONS (BILLIONS BARRELS)	
WESTERN CANADA	22,000	2.6	3.3
MACKENZIE - BEAUFORT	75	2.4	2.6
ARCTIC ISLANDS	100	0.4	0.5
EAST COAST	150	2.4	3.6

Figure 24. Summary of ranges of projected oil discovery 1980-1990 for specified level of exploratory drilling by regions of Canada

It should be noted that the prediction of discovery during the 1980's has been made without consideration of economics. Indeed the frontier estimates include many pools which probably will not be economically viable when discovered, and perhaps for a long part of the future. Most of the frontier resources exist in areas which are extremely difficult to explore, areas which are either in very deep water or ice-infested or with serious exploitation problems. These factors will contribute to higher costs for both gas and oil than we have been accustomed to. The exploratory effort required in Western Canada to achieve the remaining component of potential will also lead to high costs for that region.

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