GEOLOGY OF THE OIL SHALE DEPOSITS OF CANADA

by

GEORGE MACAULEY

INSTITUTE OF SEDIMENTARY AND PETROLEUM GEOLOGY

GEOLOGICAL SURVEY OF CANADA

OPEN FILE REPORT - OF 754

MAY 1981

GEOLOGY OF THE OIL SHALES OF CANADA

by

GEORGE MACAULEY

OPEN FILE REPORT OFR-754

MAY, 1981

Prepared under contract
for the
GEOLOGICAL SURVEY OF CANADA
INSTITUTE OF SEDIMENTARY AND PETROLEUM GEOLOGY
3303 - 33rd Street NW
Calgary, Alberta T2L 2A7

CONTENT

Page

Illustrations

Page

Page

GEOLOGY OF THE OIL SHALE DEPOSITS OF CANADA

ABSTRACT

Oil shale deposits range from Ordovician through Cretaceous in age, occur in every Province and Territory of Canada except Prince Edward Island, and represent all classes of oil shale depositional environments.

Ordovician strata of the Collingwood shale in southwestern Ontario, the Billings shale of the Ottawa area, and unnamed shales on Southampton Island, are widespread marine black oil shales, usually less than 15 metres thick, deposited in association with carbonate beds, and with oil yields generally less than 50 litres/tonne.

Devonian oil shales of the Kettle Point Formation of southwestern Ontario are stratigraphically equivalent to Long Rapids Formation oil shales of the Hudson Bay Lowland. Gross zone thicknesses range to 100 metres of marine shale overlying carbonate, but overlain by non-organic marine shale. From sparse data, oil yields are less than 50 litres/tonne.

Lower Mississippian Frederick Brook Member oil shales of the Albert Formation in New Brunswick are the best known and most explored of Canadian deposits. These lithologically resemble the Green River shales, being lacustrine dolomite beds. At Albert County, an area 1.6 kilometres square contains oil shale to a depth of 615 metres in a structurally expanded 300 metres of gross zone. With some intervals yielding in excess of 100 litres/tonne, this area may contain in excess of 47.4 million cubic metres of in situ reserves. Equivalent oil shales, much more poorly developed and of lesser oil content, occur in the Horton Group of the Antigonish area, Nova Scotia.

Younger Mississippian strata of west-central Newfoundland contain sporadically developed low yield oil shales in the Rock Brook Formation. Data are sparse.

In Pictou County, Nova Scotia, torbanites (stellarite) occur associated with coal seams in the Pennsylvanian Pictou Group. Although yields may exceed 150 litres/tonne, zone thicknesses seldom reach 2 metres.

On the west coast, marine Jurassic Kunga Formation argillites, structurally complicated, contain the oil shales of the Queen Charlotte Islands. Limited data indicate oil yields to be less than 50 litres/tonne.

Thickness and areal extent are virtually undefined.

Along the Manitoba Escarpment of the Central Plains, the two Cretaceous "White Specks" zones (Boyne and Favel Formations) have yielded up to 100 litres/tonne, but with the best average at 45 litres/tonne in the Pasquia Hills. Zone thicknesses are 40 and 20 metres respectively over a large geographic area. These equate to the Smoking Hills ("Bituminous Zone") and Boundary Creek oil shales of the Northwest and Yukon Territories. These Cretaceous deposits are analogous neither in lithology nor in depositional environment to the generally recognized oil shale types.

Except for the New Brunswick deposit, insufficient work has currently been conducted to assess economic potential. At this point, reserves projections for Canadian oil shales would be so conjectural as to be virtually meaningless.

GEOLOGY OF THE OIL SHALE DEPOSITS OF CANADA

INTRODUCTION

Oil shales were first made known in Canada in 1847 by Albert Gesner, who outlined the Albertite mineral deposit and related oil shale of Albert County, New Brunswick.

Canada's first attempted oil shale production was in southwestern Ontario, at Craigleith, on Lake Huron, where, in 1859, a plant was established to retort fuel and lubricants from the Ordovician Collingwood shale. This operation was discontinued in 1860 upon the discovery of conventional crude oil at nearby Petrolia. Because of greater distance from crude oil supplies, there were several later attempts to retort shale oil in the Maritimes; in 1927 at Albert County, New Brunswick, and in 1929 and 1930 from torbanite deposits of Pictou County, Nova Scotia. None of the later three efforts went into production, all failing financially or by destruction of the plant by fire. Interest in the Maritimes area was maintained and re-enforced by the geological similarity, in age and character, to those oil shales being mined successfully in Scotland.

Geological interest in oil shales continued until approximately 1926, with numerous publications, both regional and local, outlining by then virtually all areas of presently known Canadian oil shale deposits; however most of these presentations were economically oriented, presenting numerous individual analyses of shale oil content, and being much repetitive of older data. Within this period, the knowledge of oil shales progressed only slightly beyond the minimal economic concept of "gallons/ton" analyses.

Since 1930, but especially in the post-war period after 1945, abundant new stratigraphic data have been acquired. Initially these were studies defining nomenclatures and geologic sequences, whereas more recently, broader studies of regional correlations and subsequent analyses of sedimentary and tectonic frameworks have been made. In some of the more remote areas, reconnaissance studies are still in progress, although any available data have in most cases been incorporated into regional concepts. Within these geological-stratigraphic studies, oil shales had been recognized, but were only incidental to the main purpose of the publications.

Two more recent periods of investigation must be mentioned. During the Second World War, a major coring and analysis program was conducted in the New Brunswick oil shale area: these results were subsequently published. Circa 1965-1966, an industry exploration program resulted in the acquisition of considerable data concerning the distribution and quality of oil shales in New Brunswick, and also along the Manitoba Escarpment in Manitoba and Saskatchewan. Although these later data are available to the public, they are nowhere incorporated into any publications, or presented in a form readily useable by, or meaningful to, investigating geologists.

This study attempts to combine the data of the various sources described above. The local and regional stratigraphic relationships of possible oil shale deposits are discussed, relative both to each other and to enclosing strata. The areal distribution and thickness variations essential for economic evaluation are outlined as well as various geological characteristics, including lithology, mineralogy and structural attitudes of these deposits. Economic consideration is also given of shale oil content, both from the qualitative and quantitative viewpoints. Where possible an evaluation of oil reserve potential is included. In other cases, a review is given of the probable investigations required to provide the necessary background geology by which the potential of the less researched deposits can be determined. In summary, this report outlines the "State of the Art" concerning oil shales in Canada at the present time.

The stratigraphic and geographic distribution of oil shales in Canada are sufficiently coincident that data can be presented on a combined geologic-geographic basis. Main organizational sections include: Ordovician and Devonian oil shales of Ontario-Quebec, subdivided into Gaspé, Ottawa area, southwestern Ontario and Hudson Bay lowland; Carboniferous of the Maritime Provinces, sub-divided with sections on New Brunswick, Nova Scotia and Newfoundland; Jurassic of the British Columbia Queen Charlotte Islands; Cretaceous oil shales of the Prairie Provinces; and Cretaceous beds of the Northwest and Yukon Territories.

Annotated bibliographies have been compiled for each area, and are here presented by Province, except for a separate Maritimes section which consists of stratigraphic papers, rather than many specific references to the oil shales and their related geology for each Province. The notations are all the comments of this writer.

Each section begins with a historic review of oil shale activity for the particular area.

Because of the cost and increasing difficulty of finding and developing additional conventional petroleum reserves, considerable recent research has focused on the origin of petroleum: this has added a new geochemical factor to the study of oil shale, primarily because oil shales are known to be the source rock for many hydrocarbon reserves. Much new knowledge is now available relative to the origin and geologic history of the organic content within oil shales, the mineralogic content of various deposits, and the environment under which the oil shales were deposited.

Many of the older geologic studies did not have the benefit of sufficient knowledge of the organic content of sediments to obtain uniform terminology and understanding of this rock component; consequently, considerable confusion has existed, and still does, as to the meaning of many geochemical terms within the geological community. In order to provide, as adequately as possible, a uniform basis for the understanding and interpretation of geochemical data, a section is here included, as a prelude to the geology, within which definitions are supplied in conjunction with a review of the concepts on which the definitions are based.

As can be recognized, this study is not a new research effort, but is based primarily on the acquisition and interpretation of previous publications, and of unpublished reports and basic data. The task of this study is the integration of the abundant available information, with subsequent interpretation of the degree of investigation of known oil shale deposits to date, and an estimation of their relative economic potential.

ACKNOWLEDGEMENTS

Any study of this nature requires the assistance and co-operation of many people, in the Geological Survey of Canada, in the Energy Resources sections of the Provincial Governments, and in the staffs of oil companies interested in oil shales as a future potential energy source. Many Provincial Government geologists provided important information for this study by ensuring that all available data within their files, both published and unpublished, were brought to my attention and copies supplied as needed. Some data, still confidential to the petroleum companies involved, were released for this study; these occurrences will be acknowledged specifically within the text of this report where they are discussed.

In Newfoundland, N. Mercer, of the Department of Mines and Energy, assisted in the review of geological literature for the province and arranged reproduction of several key unpublished reports. R.S. Hyde, currently studying the geology of the area containing the Deer Lake-Humber River deposits, kindly reviewed much of the geology and supplied as yet unpublished map data for some of the area.

W. Potter, at the Nova Scotia Department of Mines and Energy, provided copies of virtually all Nova Scotia oil shale references, many of which are otherwise unavailable today. More importantly, he supplied maps and core data from a recent unpublished program.

At the Department of Natural Resources in New Brunswick, D.N. Gemmel not only provided the regional assistance for data acquisition, but also was most conversant with oil shale problems. This project gained immeasurably from discussions with him by learning the nature of the data required to assess properly the oil shales of this country. The data necessary are much more than was recognized at the initiation of this study. Also in New Brunswick, D. Abbott, of the Research and Productivity Council, explained several research projects for the production and hydrogenation of shale oil as well as having available copies of several older hard-to-acquire oil shale reports.

P.G. Telford, and O. White, of the Ontario Geological Survey, Toronto, outlined plans for the investigations of Ontario oil shales, and P.A. Palonen, Ontario Petroleum Resources Laboratory, London, provided the background assistance for acquisition of Ontario data.

Also in Ontario, R.W. McQueen and J.F. Barker, Department of Earth Sciences, University of Waterloo, provided a tour of the laboratory facilities available to investigate the geochemistry of oil and oil shales.

Copies of the analytical data from the Sun Oil core hole program were acquired through the assistance of P. Guliov, Saskatchewan Department of Mineral Resources, Regina, and H.R. McCabe, Manitoba Department of Mines and Energy, Winnipeg. Assistance in the examination of cored oil shale sections in southern Manitoba was also arranged by H.R. McCabe.

Background data and assistance in determination of industry activity was provided in British Columbia by W. Young, Ministry of Energy, Mines and Petroleum Resources.

In addition to the above Provincial Government geologists, several members of the Geological Survey of Canada must be mentioned for their

contributions.

At the Atlantic Geoscience Center, Halifax, R.D. Howie provided an excellent summary presentation of the New Brunswick Albert oil shale deposits. In Ottawa, B.V. Sanford answered many questions on the Ontario Geology, and at the Pacific Geoscience Center, Sydney, B.E.B. Cameron was most helpful in outlining many of the geological problems of the Queen Charlotte Islands deposits.

T.G. Powell, Institute of Sedimentary and Petroleum Geology, Calgary, provided two of the most important services for the preparation of this report. His clear concise answers to the geochemical questions, and his assistance in assuring that the definitions and concepts of oil shales and related organic constituents are geochemically acceptable, is much appreciated. Secondly, his review of the initial draft of the manuscript added immeasurably to the preparation of the final presentation form.

Also, in Calgary, J.E. Brindle and R.M. Procter both contributed through numerous discussions of the general topic, and in many cases, both knowing and unknowingly, contributed to the interpretations, conclusions and organizational presentation of this report.

Last, but certainly not the least, of the Geological Survey staff in Calgary, thanks must go to M. Jones and her excellent, efficient library staff, who unfailingly found obscure reports and tracked down incomprehensible and inaccurate references. The co-operation of the administrative staff in xerox reproduction was much appreciated as was the speed and efficiency of the Calgary Cartography section, especially J. Thompson, in the quest for base maps for the many included illustrations.

OIL SHALE - DEFINITIONS AND CONCEPTS

Geology, as a science, is noted for impreciseness of terminology. This results from two controlling factors: geology is as much interpretive as factual, being an art as much as a science; and almost all rocks occur within gradational ranges between end members, with minimal actual occurrence in nature of any of the definable end members. Thus most defined terms have a latitude of meaning, often expanded or confined, when used within specific, and/or restricted, descriptive terminology.

"Oil Shale" is one of the most inexact and ill-defined of all geological inexactitudes, partly through useage of the term long before understanding of the geology of the deposits and of the chemistry of the included organic components. Only long-established useage of the term, in conjunction with present-day generally accepted uniform definition, can justify continuation in our vocabulary of "Oil Shale", a rock which does not contain oil and is not necessarily a shale.

Definition

For the purposes of this study, oil shale is a fine-grained sedimentary rock, containing indigenous organic matter, mostly insoluble in ordinary petroleum solvents, from which significant amounts of shale oil can be extracted by pyrolysis (heating in a retort).

"Significant amounts" is the open-ended phrase of the above definition but several generalized concepts are implied. The temperature of pyrolysis (heating in a retort) seldom exceeds 500° to 600°C. as, above these temperatures, additional yield of shale oil is low, and mineralogical breakdown occurs for some of the inorganic rock constituents, especially dolomite. The input heat energy necessary to raise the rock temperature to 500°C is approximately 250 calories/gram of rock. The calorific value of the indigenous organic material is generally 10,000 calories/gram; therefore, 2.5% by weight is the minimum organic content at which the amount of energy recovered as shale oil could theoretically balance the input heat. This does not allow for other energy-equivalent input (mining, transportation, etc.). A lower limit of 5% organic content is frequently used, or 25 litres/tonne, or 6 U.S. gallons/short ton. U.S. literature often quotes 10 U.S. gallons/ton as a minimum value for economic consideration, but this is an arbitrary value.

Indigenous organic matter

The indigenous organic matter of oil shale is mainly kerogen, an insoluble solid organic material, which on heating and decomposition, produces shale oil. Of particular note is the lack of solubility of kerogen in the standard organic solvents, CS_2, benzene, benzene/methanol, benzene/methanol/acetone, chloroform, ether, and cyclohexane. Also, within the organic component, there may be a small amount of bitumen, a petroleum hydrocarbon phase, soluble in the above solvents.

Both the kerogen and bitumen may have, as their source material, spores, algae, and animal remains; however, the main concensus would certainly typify algal growth as the source of the organic matter in these deposits.

In nature, maturation of the organic material takes place with increasing burial at temperatures at or below 150°C. Cracking of the kerogen results in the formation of petroleum products. Since petroleum compounds are richer in hydrogen than the parent kerogen, the residual kerogen becomes depleted in hydrogen, condensed aromatic nuclei form, and with extensive maturation the composition of the residual kerogen tends to graphite.

As can be recognized, just as petroleums vary in composition and character, so do kerogens, but kerogens, unlike oils within a reservoir, cannot become uniform across a deposit. Thus the kerogen of an oil shale varies by the initial character of the material from which it is derived and by the degree of maturation of the sediment involved. Both the character of the initial kerogen and the maturation products of the kerogen will vary with the type and amounts of indigenous organic material in the sediment; consequently, the character of kerogen will not only vary from formation to formation, but will also vary considerably from bed to bed, and laterally across the beds, within any single oil shale deposit.

Shale oil

Because "oil" can be distilled from kerogen-bearing rocks, "oil shale" has become an accepted term, but some characteristics of the recovered oil must be carefully reviewed. The character of shale oil produced from heating oil shale in the temperature range 100-500°C will depend upon the character of the kerogen present, and will always be an undersaturated (hydrogen depleted) hydrocarbon product. This is because the temperature required to crack kerogen in the short time of a commerical process is far higher than occurs naturally in petroleum generation and the chemical mechanism is somewhat different. In this respect, shale oil, the product recovered from the pyrolysis of oil shale, is not directly comparable to crude oil (petroleum), requiring additional refining (hydrogenation) to produce a petroleum analogous to that of conventional oil reservoirs. In the aspect of undersaturation, shale oil resembles the oil separated from the Alberta oil sands, although the origins are probably much different.

A kerogen-bearing rock is not necessarily an oil shale. The ability to obtain hydrocarbon products by pyrolysis is dependent on the atomic hydrogen to carbon ratio of the kerogen. Kerogen with low atomic hydrogen to carbon ratios, e.g. coal, or kerogens which have undergone natural petroleum forming processes, will yield only minimum amounts of hydrocarbons on pyrolysis.

Because of the variable nature of the kerogen to be pyrolyzed, the nature of the shale oil products may vary considerably, not only between different deposits, but also within the retorting of individual deposits. Research has also indicated that the shale oil product varies with both the rate and temperature range of retorting. Higher temperatures may produce greater quantities of natural gas component at the expense of reducing the gravity and increasing the undersaturation of the liquids phase.

Organic (organic-rich) shales

A certain class of fine-grained sedimentary rocks exist wherein kerogen is significantly present, but which will not yield any, or only minimal quantities, of shale oil on heating. Although the organic content of these sediments is often obvious on visual examination, the nature of the organic phase is indeterminate. Many of these rocks are the black and dark brown shales commonly described as bituminous, petroliferous, carbonaceous, or organic.

Petroliferous shales should contain a liquid petroleum phase: bituminous rocks should contain soluble solid hydrocarbon; and kerogenous rocks would have an insoluable kerogen content. Differentiation of the above cannot be made by visual inspection alone, chemical analysis being required, yet the terms have been used interchangeably in geological literature of the past. The term "bituminous" has been used to describe many sediments containing organic residue, of which very few are, in fact, bituminous. The term "carbonaceous" has been variably used, either to denote the presence of organic carbon, or more precisely, to denote the presence of higher plant remains, i.e. plant and root debris of the coal series with minimal hydrogen content.

In an attempt to clarify the above descriptive nomenclature difficulties, "organic-rich" is now often used to describe rocks containing more than the basic content of organic debris. Most fine-grained sediments contain a minimum 1 to 1.5% organic remains which, at that level, is not readily discernible on visual examination. Because this is a standard component, there is little advantage to describing such sediments as organic; hence, the term "organic-rich" used to describe the sediments with visible organic content, becomes overly descriptive: the term "organic" is sufficient for this purpose. Within this report, the following terminolog ry will be utilized:

An organic shale contains greater than the minimum 1.5% organic content with the organic content recognizable, or strongly suspected, by visual examination. There is no connotation that the organic component is bitumen, kerogen, or possibly even in part reduced to graphite (pure organic carbon).

Bituminous refers to a content of soluble hydrocarbon derivative. Although a minor amount of bitumen may be present in oil shales, seldom reaching 20% of the organic content, oil shales can seldom be termed bituminous; oil sands are truly bituminous.

Kerogen is the insoluble organic component of a sediment, virtually never encountered in coarse clastic strata, but being the prime component of quiet reducing environments. Kerogen includes the organic debris from both low plant life, "sapropel," and from the higher wood forms, "humus."

Carbonaceous refers to a recognizable content of higher plant and wood debris of the coal series. Coaly refers to matured carbonaceous debris beyond recognition as wood material.

Oil shale - coal relationship

Kerogen of oil shale is largely derived from the lower plant life forms, dominantly algae, and has a high atomic hydrogen/carbon ratio, whereas the kerogen of coal is the product of higher plant forms and, because of the large component derived from wood, has a low atomic hydrogen/carbon ratio. Within this report, kerogen will normally refer only to the sapropelic oil shale kerogen; in cases where differentiation of oil shale - coal kerogens is required, sapropelic and humic will be used.

The kerogen content of oil shale ranges from 4 to 35% by weight, whereas the organic content of coal generally exceeds 67%; thus, for shale, the ash (inorganic residue) is by far the greater part of rock in contrast to minimal ash content in coal. Torbanite is a unique form of oil shale, and is, in fact, an algal coal, being found only in association with coal. The organic content of torbanite may exceed 50 percent.

Major inorganic constituents

Because of the fragile nature of the biota forming kerogen, oil shales can occur only as fine-grained sediments. Those environments suited to the deposition of quartz sandstones, conglomerates and calcarenites are totally destructive to organic content; consequently, oil shales are dominantly composed of mud to silt-sized inorganic grains. The kerogen of an oil shale can be viewed as compacted organic mud.

The variety in mineral content of oil shale is virtually unlimited; however, three major mineral types are recognized. Some of the world's most significant deposits are of the calcareous type with calcite, and/or dolomite silt to mud size grains, as the dominant mineral. Clay is a second major type, whereas siliceous (quartz) and tuffaceous material are also common.

The kerogen-rich and kerogen-poor portions generally occur as alternating layers, creating a varved and/or laminated appearance, thus somewhat validating use of the descriptive term "shale," although not all, especially the carbonate type, exhibit shale fissility.

Oil shale lithologies, all kerogenous, may be limestone, dolostone, siltstone, shale, argillite, or combinations thereof. Most of the carbonate types are generally argillaceous, whereas many of the shales are calcareous.

Environments of deposition

Two major factors must be present in the environment of deposition: firstly, sedimentation must occur under quiet water conditions in order that the organic debris remain relatively intact; and secondly, the water must be euxinic (reducing) as an oxidizing environment would destroy the organic detritus by oxidation. The reducing environment also precludes the dominance of bottom scavengers and excessive bacterial decay by which the kerogen source material would also be destroyed.

Three depositional environments are ascribed to cover most of the world's oil shale deposits.

Probably the best known environment is the continental lacustrine one in which the Green River oil shales of the United States were formed. Lacustrine oil shales are finely varved, grey to black in color, and limestone and/or dolomite is the primary lithology. Various halite minerals can be present since saline conditions frequently develop.

Shallow seas, or continental platforms and shelves, constitute a second principal environment. These shales are generally areally widespread and are usually less than 10 metres thick. They are of the clay or siliceous types, although carbonate types are present, and they often occur associated with underlying and overlying widespread carbonate units. These are usually dark brown to black in color.

A third distinctive type is that associated with coal deposits. These are oil shales of limited geographic extent, being deposited in small lakes, bogs and/or lagoons associated with coal-productive swamps. These are the distinctive torbanite oil shales.

Reference material

The above definitions and concepts of oil shales and related hydrocarbons have been gleaned from numerous articles, in many cases by a combination of the data presented, and generally not directly referable to any specific author. By far the majority of the knowledge was acquired from one publication, entitled "Oil Shale," edited by T.F. Yen and L.V. Chilingarian, published in 1976. Individual chapters within this book were prepared by different authors and are individually listed in the following annotated references. Before commencing any detailed exploration/economic analysis of oil shales beyond that presented within this report, the reader is strongly advised to review the majority of the accompanying reference publications, even though some of the biologic and organic chemistry papers may be beyond the immediate scope of the reader's knowledge and interest. The discussion contained herein is insufficient to understand completely the numerous geochemical problems in the retorting and refining of oil shales. This paper was not initially designed to go beyond the geological background of oil shales in Canada, but has included this section, and will include further such discussions pertaining to specific oil shale deposits, so that the complexity of oil shales can be appreciated more fully, even though not necessarily more completely understood.

Selected References

CANE, R.F.
1976: The origin and formation of oil shale; in, Oil Shale, eds. T.F. Yen and G.V. Chilingarian; Elsevier Scientific Publishing Company, Amsterdam - Oxford - New York, p. 27-60 (excellent introductory article, good description of organic components and biochemistry of different oil shale types).

DEMAISON, G.J. and Moore, G.T.
1980: Anoxic environments and oil source bed genesis; American Association of Petroleum Geologists, Bulletin, v. 64, no. 8, p. 1174-1209, (excellent review of reducing environments).

DUNCAN, D.C.
1976: Geological setting of oil-shale deposits and world prospects; in, Oil Shale, eds. T.F. Yen and G.V. Chilingarian; Elsevier Scientific Publishing Company, Amsterdam - Oxford - New York, p. 13-26, (good description of oil shale types and environments of deposition).

FLYNN, A.E.
1926: Investigations on the treatment of Nova Scotia oil shales; Canada, National Research Council, Report No. 18, 92p.; Nova Scotia, Department of Public Works and Mines, Annual Report on the Mines for 1926, p. 210-298 (a study of the behavior of oil shales under different retorting conditions).

GALLEGOS, E.J.
1976: Biological fossil hydrocarbons in shales; in, Oil Shale, eds. T.F. Yen and G.V. Chilingarian; Elsevier Scientific Publishing Company, Amsterdam - Oxford - New York, p. 149-180, (detailed complex organic chemistry).

JACKSON, L.P., MORANDI, J.R. and POULSON, R.E.
1977: Compositional variation of retorted oil shales with stratigraphy: Wyoming core, northern Green River Basin; in, Reprints of Papers, American Chemical Society, Division of Fuel Chemistry, v. 22, no. 3, p. 66-74 (good examples of shale oil variations from different strata).

KING, L.H.
1963: Origin of the Albert Mines oil shale (New Brunswick) and its associated albertite; Canada, Department of Mines and Natural Resources, Mines Branch, Research Report R115, 24p. (detailed description of organic-inorganic mineralogy of New Brunswick oil shale with discussions of origin and maturation history).

KING, L.H., GOODSPEED, F.E. and MILLSON, M.F.
1963: A study of sedimented organic matter and its natural derivatives; Canada, Department of Mines and Technical Surveys, Mines Branch Report R114, 68p. (techniques to separate organic from inorganic constituents, to determine properties of the organic matter, to classify the organic components; complex paper).

ROBINSON, W.E.
1976: Origin and characteristics of Green River oil shale; in, Oil Shale, eds. T.F. Yen and G.V. Chilingarian; Elsevier Scientific Publishing Company, Amsterdam - Oxford - New York, p. 61-79, (good generalized descriptions of inorganic and organic components, easily understood chemistry, conclusions re conditions of deposition).

ROYAL GEOLOGICAL and MINING SOCIETY of the NETHERLANDS
1980: Geological nomenclature; ed. W.A. Visser, Martinus Nignoff, The Hague - Boston - London, p. 272-275, (definitions of hydrocarbon types, origins, and some products).

SAXBY, J.D.
1976: Chemical separation and characterization of kerogen from oil shale; in Oil Shale, eds. T.F. Yen and G.V. Chilingaran; Elsevier Scientific Publishing Company, Amsterdam - Oxford - New York, p. 103-128, (separation of kerogen from the inorganic constituents and identification of kerogen components; basic concepts, uncomplicated).

SHANKS, W.C., SEYFRIED, W.E., MEYER, W.C. and O'NEIL, T.J.
1976: Mineralogy of oil shale; in Oil Shales, eds. T.F. Yen and G.V. Chilingarian; Elsevier Scientific Publishing Company, Amsterdam - Oxford - New York, p. 81-102 (excellent detail of the inorganic mineralogy of the Green River deposits).

TISSOT, B.P. and WELTE, D.H.
1978: Oil shales: a kerogen-rich sediment with potential economic value; in, Petroleum Formation and Occurrence - a new approach to oil and gas exploration; Springer Verleg, Berlin, Heidleberg, New York, p. 225-236 (concise descriptions of oil shale, kerogen, depositional environments and properties of shale oil, excellent summary of oil shale concepts).

YEN, T.F.
1976: Structural aspect of organic components in oil shales; in, Oil Shale, eds, T.F. Yen and G.V. Chilingarian; Elsevier Scientific Publishing Company, Amsterdam - Oxford - New York, p. 129-148 (complex chemistry).

YEN, T.F. and CHILINGARIAN, G.V.
1976: Introduction to oil shales; in Oil Shale, eds. T.F. Yen and G.F. Chilingarian, Elsevier Scientific Publishing Company, Amsterdam - Oxford - New York, p. 1-12 (basic principles of oil shale and of shale oil recovery techniques).

OIL SHALES IN CANADA: GEOLOGIC-GEOGRAPHIC DISTRIBUTION

Oil shales in Canada occur through much of the geologic column, including Ordovician, Devonian, Carboniferous, Jurassic and Cretaceous, and are found in every Province and Territory of the country, except Prince Edward Island.

Perhaps the two earliest and two most significant reports were Gesner (1847), in which the albertite and oil shales of New Brunswick were first described, and Logan (1863), who, in his discussion of the geology of Canada, described the Ordovician bituminous shale beds. These beds were known prior to Logan's publication. The first attempted Canadian oil shale extraction was from the Ordovician shales on the shores of Lake Huron during the years 1859-1860, prior to the first discovery of conventional crude oil in Ontario.

During the first 50 years of Confederation, oil shales were a principal concern of all government sponsored geological agencies. Most of the initial reports of oil shale deposits were made in the annual reports of the Provincial Mines and Resources Branches, especially in the west, but with little factual data. Extensive interest was displayed by both the Geological Survey of Canada and the Mines Branch, Canada Department of Mines, although most of the reports were of location, geographic extent and retorting analyses of the individual deposits.

Much of the initial Geological Survey of Canada work was published by R.W. Ells, mostly on Nova Scotia and New Brunswick, but Ells did, in 1909, contribute the first geological review of Canadian deposits. None of the western deposits were mentioned by Ells in that report.

W.J. Wright (1922) prepared Geological Survey of Canada Memoir 129, which not only provided a detailed study of the New Brunswick shales, but included references to the rest of Canada, and also incorporated the Manitoba and British Columbia areas.

S.C. Ells, of the Canada Department of Mines, Mines Branch, published regional reviews in 1923 and 1925: these were followed by papers by A.A. Swinnerton in 1938 and 1947, with the latter paper basically reviewing the earliest attempts to produce Canadian oil shales in Ontario, New Brunswick and Nova Scotia. Within this present report, these historic data are incorporated into the sections dealing with specific geologic-geographic deposits.

If the above papers reviewing oil shales in Canada are studied in historical order, along with the many local papers referenced herein by Province, an extreme repetition of data soon becomes evident. Although each paper would add some new data, generally additional available retort recoveries and new analyses, most repeated, often almost verbatim, much of the prior knowledge; consequently, a detailed study of all the referenced literature will not compound the knowledge acquired proportionate to the investigative efforts involved. Most of the bibliography, cited for this section, is of greater historic than present interest.

A most disturbing problem relative to the preparation of reports, and concerning the library basis of this study, has become obvious in review of the regional literature. Not only are correct data carried forward, incorrect data and conclusions can also become an integral part of the geological literature by library projects. Matveyev (1974), in a Russian analysis of world oil shale deposits, cites Canadian oil shale deposits at St. John's, Newfoundland. Although Precambrian black argillites are present in that area, oil has never been recovered by retorting of these rocks. Oil shale had been reported in one of the Ells papers for the St. John's area, but had never subsequently been retracted. Similarly, early reports of oil shales in the Lytton area, British Columbia, are carried through the Canadian publications, and thence into Matveyev, representing foreign literature. Nowhere were the Lytton area shales substantiated; none appears to exist. Additionally, references to Canadian oil shales by the United Nations (1965), contain incorrect geological ages and present a potential oil shales reserves figure which is nowhere referenced or established. On the basis of this completely non-validated figure, Canada is ranked fifth in world oil shale reserves by the United Nations.

For this study, all reported oil shale deposits have been assessed, both through literature and by personal contacts with geologists who have actively worked in the areas involved. Only those deposits considered to be valid oil shales are reported in detail: wherever possible, suspected oil shales, which may or may not yield oil, are also described in order that a more accurate resume of Canadian oil shales can be presented. Some zones, which might conceivably be oil shales, but have not previously been reported as such, are also outlined.

Figure 1 is an index map of the principal oil shale deposits of Canada, including those where shale oil recoveries are proven, or virtually assured,

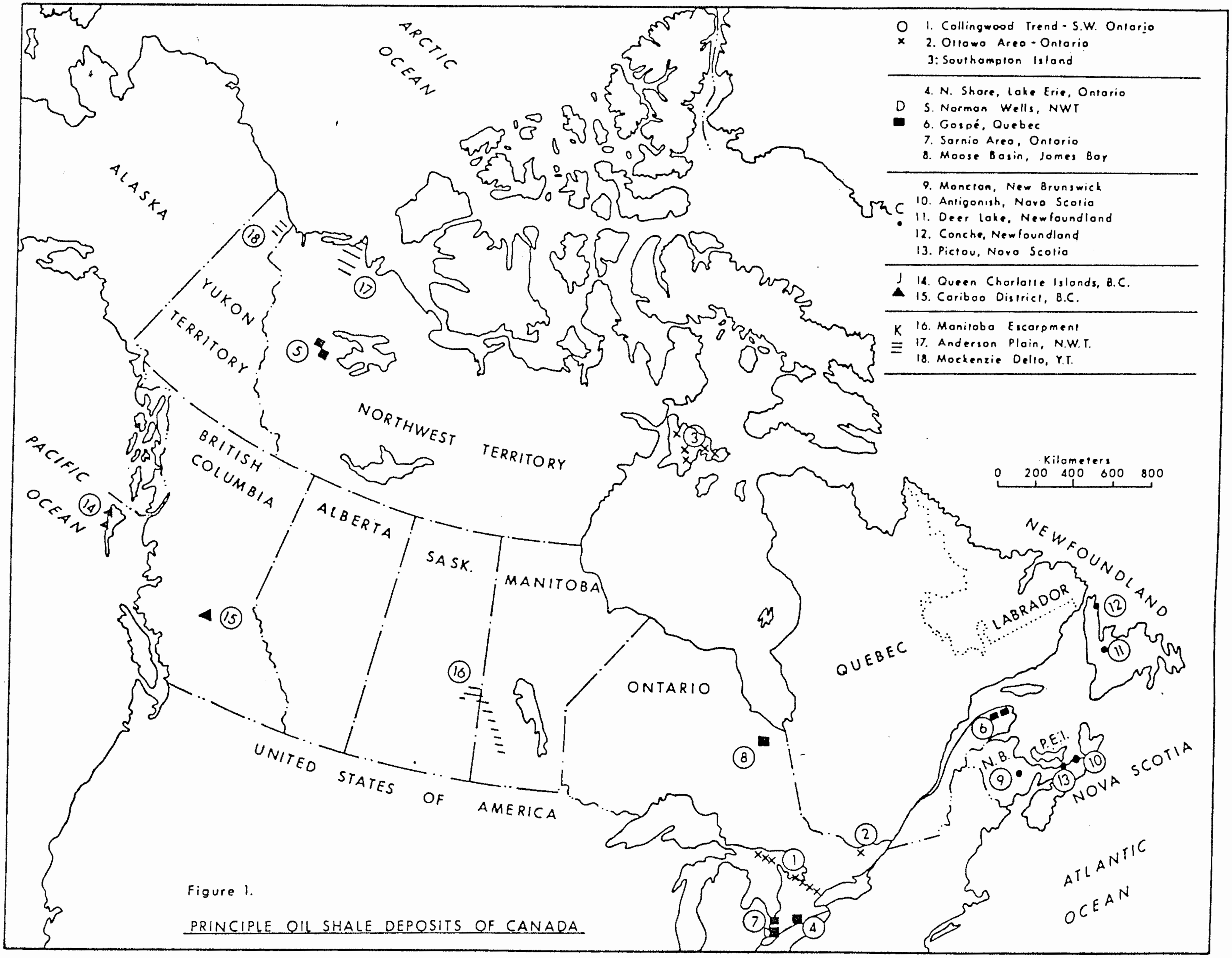


Figure 1.

PRINCIPLE OIL SHALE DEPOSITS OF CANADA

but excluding unverified potential oil shale zones. In the following descriptive list of oil shale areas, the numerical sequence corresponds to the locality numbers of the index map.

Ordovician

1. Manitoulin-Collingwood trend, Ontario; Collingwood shale outcropping parallel to the base of the Niagara Escarpment; thin widespread black shale deposited between carbonate zones on a shallow marine platform.
2. Ottawa area, Ontario; Billings shale, stratigraphically equivalent, and depositionally similar, to the Collingwood shale at the west.
3. Southampton Island; one, or possibly two, thin black shale zones between carbonates; possibly equivalent to Collingwood and Billings of south-western Ontario.

Devonian

4. Elgin and Norfolk Counties, north shore of Lake Erie, Ontario; Marcellus, a thin Middle Devonian organic shale overlying carbonate and deposited on a marine platform.
5. Norman Wells area, Northwest Territories; Canol Formation (Fort Creek), up to 100 metres thick, a marine shale deposited between non-organic marine shales, but related to carbonate, overlying and lateral to Kee Scarp reef; late Middle or Upper Devonian.
6. Gaspé Peninsula; Gaspé sandstone series, Middle Devonian, York River Formation, scattered thin beds of organic shale within a series of sandstones, many of which are bituminous; not typical oil shale and may not be a true oil shale deposit.
7. Southwestern Ontario, Windsor-Sarnia area; Kettle Point Formation, Upper Devonian, up to 30 metres black oil shale inter-zoned with gray non-organic shales; gross zone overlies carbonate; deposited in apparent marine platform environment.
8. Moose River Basin, Hudson Bay Lowland; Long Rapids Formation, Upper Devonian, geologically equivalent and comparable to Kettle Point Formation of Windsor-Sarnia area.

Carboniferous

9. Moncton sub-basin, New Brunswick; Frederick Brook Member, Albert Formation, Horton Group, Lower Mississippian, best known and discussed of all Canadian deposits and probably one of the economically most attractive; contintental lacustrine deposits up to 100 metres thick but

expanded by deformation to possibly 300 metres at the Albert Mines location: considerable section in excess of 100 litres/tonne (20 gallons/ton).

10. Big Marsh - Antigonish area, Nova Scotia; Horton Group, thin deposits of probably lacustrine origin in a continental sequence; an approximate equivalent of the New Brunswick Albert shale zone.
11. Deer Lake - Humber Valley, Newfoundland; Rocky Brook Formation, Deer Lake Group, Mississippian (younger than New Brunswick deposits), continental lacustrine environment, scattered thin oil shale beds, but investigations of limited scope to date.
12. Conche area, Newfoundland; Cape Rouge Formation, lower Mississippian, possible torbanite bed; not likely an oil shale deposit; stratigraphic equivalent of New Brunswick oil shales.
13. Pictou County, Nova Scotia; Pictou Group, Pennsylvanian, torbanite deposits associated with coal seams; areally restricted and less than 2 metres thick; best zone locally named "stellarite."

Jurassic

14. Graham Island, Queen Charlotte Islands, British Columbia; Kunga Formation, Jurassic, marine argillites; probable platform deposits; thickness indefinite because of structural deformation; sparse data only.
15. Cariboo District, Quesnel Lake area, "Harper's Camp," British Columbia; undifferentiated lower Jurassic shales have yielded minor oil on distillation, poorly exposed and virtually undefined potential.

Cretaceous

16. Manitoba Escarpment, including Riding Mountain, Duck Mountain, Porcupine Hills and Pasquia Hills, Manitoba-Saskatchewan; Boyne and Favel Formations, informally the First and Second White Specks zones, Upper Cretaceous; up to 40 and 20 metres respectively; areally extensive, occurring as grey to brownish-grey marine shales with minor internal limestone beds, within a major sequence of continuous shale deposition; not a typical oil shale deposit.
17. Anderson Plain, Northwest Territory; Smoking Hills Formation, Upper Cretaceous, closely equatable to the Manitoba Escarpment oil shales both lithologically and stratigraphically.
18. Mackenzie Delta, west side, Northwest and Yukon Territories; Boundary Creek Formation, Upper Cretaceous, equivalent to the Smoking Hills Formation of the Anderson Plain at the east.

Oil shale references - Canada

CRONSHAW, H.B

1921: Oil Shales - monographs on mineral resources with special reference to the British Empire; Imperial Institute, John Murray, Albermarle St., London, p. 33-38 (brief review of Maritimes, Ontario - Quebec and Manitoba Escarpment oil shales; mostly analyses with minimal geology; historical interest).

ELLS, R.W.

1909: Geological position and character of the oil-shale deposits of Canada; Geological Survey of Canada, Report No. 1107, 75p. (geographic distribution, limited lithology, no stratigraphy, but abundant analytical data of New Brunswick and Nova Scotia shales; good comparative review of Scottish oil shale industry; initial review of Utica (Ordovician) of Ontario-Quebec).

ELLS, S.C.

1923: Oil shales of Canada; Canada, Department of Mines, Summary Report of Investigations made by The Mines Branch, 1921, Report No. 588, pt. G, p. 41-55, (covers all Provinces, but basically reviews prior data only).

1925: Oil shales of Canada; in, Shale Oil, ed. R.H. McKee, American Chemical Society, Monograph Series No. 25, The Chemical Catalog Company Inc., New York, p. 43-60 (geographic distribution of oil shales; a review of analytical results; minimal geology).

GESNER, A.

1847: Report on the geological survey of the Province of New Brunswick; Saint John (1839, 1840, 1841, 1843) London.

LOGAN, W.E.

1863: Report on the geology of Canada; Geological Survey of Canada, Ottawa, p. 201-224, 521-528, 784-792 (extensive geological discussion of the Paleozoic strata of Ontario and Quebec, with significant attention to the Ordovician Utica bituminous shales).

MARTISON, N.W.

1966: Study of oil shale occurrences in Canada; unpublished report, University of Calgary, Gallagher Library, 44p. (concise summary with analytical data, background geology, and local maps, unfortunate this had not been a published document).

MATVEYEV, A.K.

1974: Oil shales outside the Soviet Union; in, Deposits of Fossil Fuels, v. 4; ed. E.E. Zakharov, G.K. Hall & Co., Boston, p. 91-98, (brief summary of geographic occurrences and analytical results).

SWINNERTON, A.A.

1938: Oil shales of Canada; in, Oil Shale and Cannel Coal, The Institute of Petroleum p. 210-226 (brief review of geographic distribution and analytical results; virtually no geology; reviews retorting techniques, analytical concepts and procedures).

1947: A survey of the world's oil shales; Canadian Mining Journal, v. 68, no. 4, p. 229-235 (reviews deposits of New Brunswick, Nova Scotia, and Ontario; basically outlines attempts at production in these areas).

UNITED NATIONS
1965: Progress and prospects in the utilization of oil shale; Resources and Transport Division, Department of Economic and Social Affairs, 102p. (good review of world's better-known deposits with economic considerations; minimal data on Canadian oil shales).

WRIGHT, W.J.
1922: Bituminous shales of Canada; Geological Survey of Canada, Memoir 129, p. 50-55 (brief review of geographic distribution in Ontario, Manitoba, British Columbia; analytical detail from Nova Scotia; this is an added section to a detailed review of New Brunswick deposits).

ORDOVICIAN OF ONTARIO - QUEBEC

Canada's first, and only, oil shale plant to achieve and maintain a continued period of operation was erected at Craiglieth, near Collingwood, on the shores of Lake Huron, Ontario (Fig. 2). Both Logan (1863) and R.W. Ells (1909) described the retorting of oil shale which here continued until 1861, when displaced by the less expensive conventional oil discovered at Oil Springs in the nearby Petrolia area. Several initial attempts to place the plant on production were thwarted by inadequate venting of by-product gases causing buildings to be destroyed by fire. Once operational, the plant, fired by 25 cords of wood per week, retorted 36 tons of shale per day, yielding 250 gallons of shale oil, representing 3% of the rock volume; however, of the retorted products 40-60% was burning oil, 15-40% was heavy lubricating oil, and the remaining 20-25% was pitch and waste. A retorting time was established at 2½ hours on recognition that only a further small amount of shale oil could be recovered by retorting beyond that time.

There has been some doubt that the Craiglieth retort was actually operated on the basis of quarried rock. The better oil shale zones occur at, and just below, lake level; boulders of eroded shale, obtained off the beach, were thought to be the source of the ore as the actual quarry could not be located. Martison (1966, p.23) reported that the quarry, some 9 to 10 metres deep, is now a resort swimming pool, and presented oil yield analyses from samples of that location.

Oil shale production at Craigleith was from the Upper Ordovician Collingwood Formation, which is recognized along a subcrop belt extending from Manitoulin Island at the west, through Collingwood and there south-southeasterly across southern Ontario to the Toronto-Whitby area on the shores of Lake Ontario (Fig. 2). Equivalent shales are the Billings Formation in the Ottawa area, black shales of the Lachine Formation along the St. Lawrence River northeasterly from Montreal, the Mictaw shales of Gaspé, and the Utica shales of the Lake Champlain area (Fig. 3). The latter three units occur in Quebec and are potential, rather than known, oil shale zones.

Stratigraphy

In "The Geology of Canada," Logan (1863) described the black, bituminous, graptolitic shales of Ontario and Quebec, and included them in the Utica

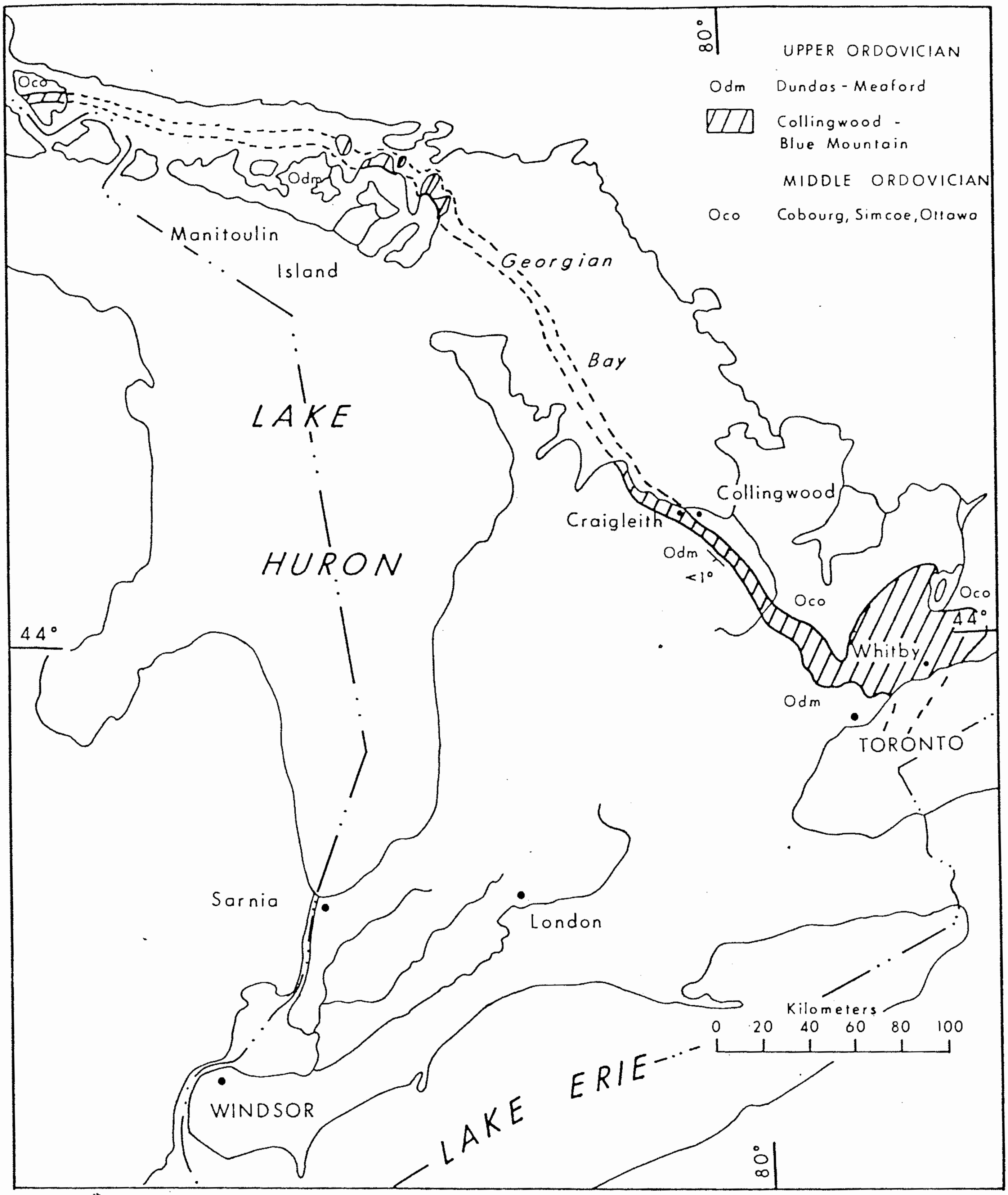


FIGURE 2. Outcrop distribution of Collingwood beds, southwestern Ontario.

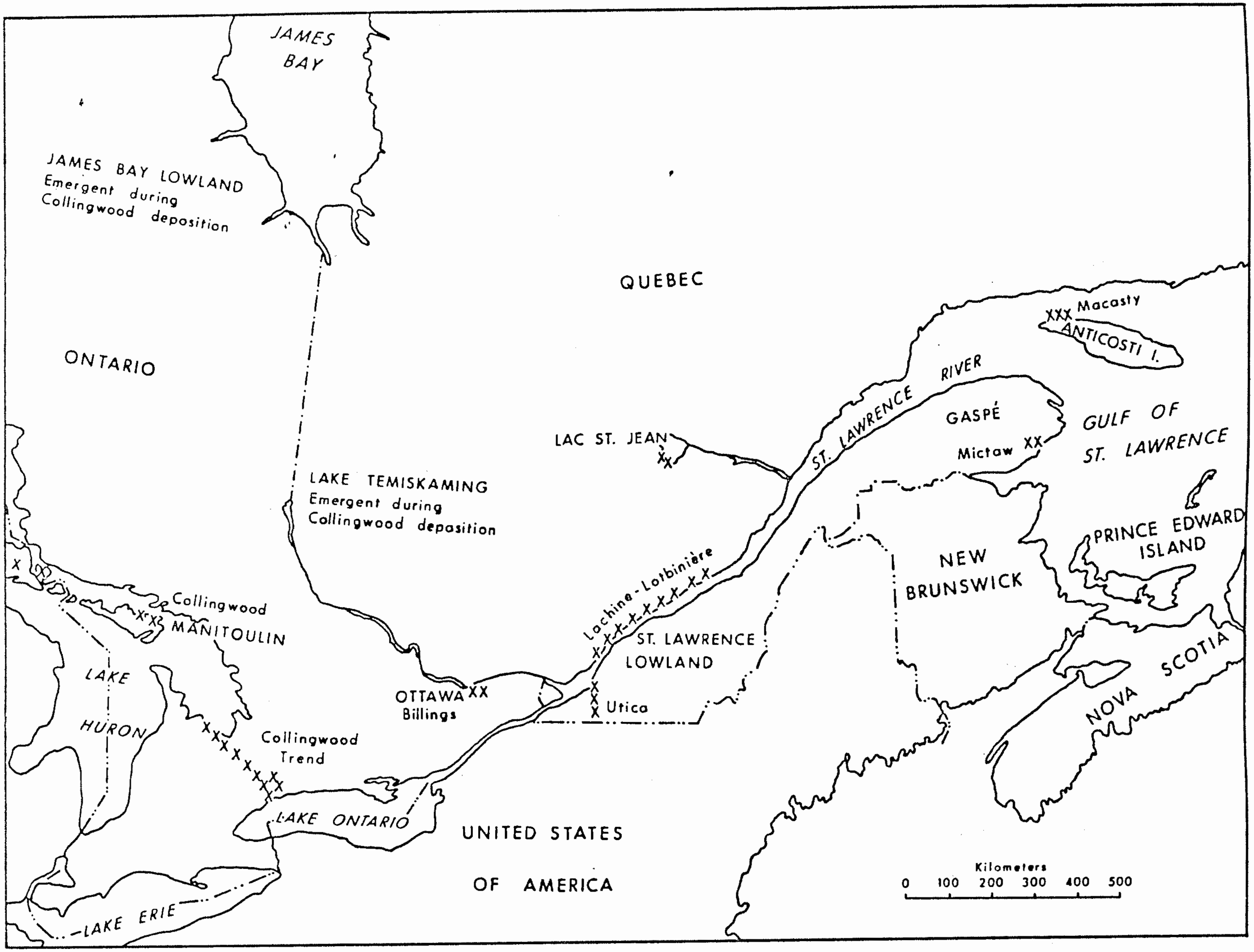


FIGURE 3. Distribution of Ordovician oil shales and potential oil shales, Ontario and Quebec

Formation. They overlie the Trenton limestones, and are in turn overlain by non-organic shales, arenaceous shales and sandstones of the Hudson River Formation. These names were derived from the nearby geological sections in the State of New York, and represented distinct lithologic entities. Paleontological data were presented for various outcrop areas, but no attempt was made to differentiate, or separate, any of the Utica black shale exposures on the basis of age. The present outcrop areas, as illustrated on Figure three, were virtually all described by Logan in this early report, although considerable additional nomenclature is now used.

Raymond (1912) defined the Collingwood Formation in the Ottawa area as a lower unit of the Utica. It consisted of soft brown shale alternating with fine grained blue limestone, overlain by darker shales, which he considered to be typical Utica. He later placed these darker shales in the Gloucester Formation. Raymond gave no reason for use of the name Collingwood in the Ottawa area at a distance greater than 300 kilometres from Collingwood, and with no intended correlation to the Collingwood oil shale.

The Ordovician faunal successions in Ontario and Quebec were described by Foerste (1916), who provided little lithologic or formational data, but stated that the Utica, as outlined in Canada, might not be an exact age equivalent of the type Utica Formation.

A more comprehensive geological faunal study of Ordovician black shale was made in southern Ontario by Parks (1928), who recognized that the interbedded limestone-shale sequence defined as Collingwood in the Ottawa area correlated faunally to uppermost Trenton limestones of the Georgian Bay area. These limestones he defined as lower Collingwood (Mesotrypa beds) and placed the black organic shales of Georgian Bay in the Upper Collingwood, equivalent to lower beds of Raymond's Gloucester Formation. In all likelihood local terminology, unpublished, defined the once-productive oil shales as Collingwood; hence Parks establishment of an Upper Collingwood Member.

This confusion was somewhat alleviated by Wilson (1946), working in the Ottawa area, who established the Eastview Formation to replace Raymond's Collingwood, and the Billings Formation to represent the black organic shale zone. In some aspects, the name Billings is superfluous, but was necessary to avoid the conflict that would occur in any attempt to change the defined Collingwood of the area. Wilson left Collingwood and Gloucester, near Ottawa, as time units, both of which are now relatively obsolete in this useage.

AGE		MANITOULIN ISLAND	GEORGIAN BAY	NORTH SHORE LAKE ONTARIO		OTTAWA AREA
ORDOVICIAN	Upper	Meaford - Dundas	Meaford - Dundas	Meaford - Dundas		Meaford - Dundas
		Sequiandah	Blue Mountain	Whitby	Blue Mountain	
		COLLINGWOOD	COLLINGWOOD		COLLINGWOOD	BILLINGS
	Middle	Simcoe	Simcoe	Cobourg		Eastview
						Ottawa

FIGURE 4. Pertinent Ordovician correlations, west-east across southern Ontario.

Two other terms are of major stratigraphic significance. In the Georgian Bay area, the Blue Mountain Formation, directly overlying the Collingwood black shales, is composed of soft blue shale (Parks, 1928). This characteristic bluish color is apparently not recognizable to the east in the Ottawa area. On Manitoulin Island, the Collingwood is overlain by Sequiandah Formation (Foerste, 1924), defined as interbedded layers of limestone and soft brownish shale. Figure 4 illustrates the nomenclatures described above west to east across southern Ontario. Sufficient references are appended that the reader can readily acquire more complete stratigraphic data for those units overlying and underlying the oil shales, if so required.

The Lachine/Lotbinière Formations represent the equivalent shales in the St. Lawrence Lowland of Quebec. On the southeasterly prominence of Gaspé, some black shales of the Mictaw Group equate to Collingwood as do black shales of the Macasty Formation underlying Anticosti Island.

Although the transition from underlying limestone to the black shale appears sharp, thin stingers of black shale generally occur in the uppermost limestone beds, and limestone stingers can be found within the black shale sequence; consequently, the contact is considered to be conformable. An erosional unconformity was proposed by Caley (1936) and Williams (1937) because of local minor erosional irregularities (less than 1 metre) at the contact; however, local erosion of shallow marine carbonates is part of the depositional process and does not necessarily indicate an erosional unconformity or significant loss of sedimentary record.

The upper contact of the Collingwood with the overlying blue to grey shales is very much transitional, with a decrease in organic content and inter-bedding of the organic and non-organic lithologies. This transitional contact can generally be picked in surface sections at either a minimal or optimal level of organic type shale, but is more difficult to define from well cuttings, even from the older cable tool cuttings which are less mixed than those of rotary rigs.

Lithology

Collingwood beds are characterized by dark grey to black organic shale containing an abundant graptolite fauna. On Manitoulin Island, Liberty (1957) described the lowermost beds as black limestone, with the lowest black shales appearing "rotten" and containing sulphides and macerated fossil remains. The section is variably calcareous and petroliferous. Wilson (1936) described the Billings shales as fissile. Liberty and Bolton (1971) described the Whitby area lower beds as dark grey to black fossiliferous shale with a few interbedded grey limestones. The shale is thinly laminated, weathering to a fissile paper shale. Carbonate is common to all the shale, but varies in amount. Liberty and Bolton state; "the shale is petroliferous, but not bituminous as often described." Their meaning of either descriptive term is not known, therefore, no interpretation of the type of organic content can be inferred. The limestone beds are grey to brownish-grey, hard, brittle, sub-lithographic, in beds 2 to 5 centimetres thick, comprising less than 15% of the zone. They also recognized a middle member of their Whitby, occurring locally as soft brown shales transitional upward to the overlying bluish-grey shale equivalent of the defined Blue Mountain Formation.

Most of the descriptions of the equivalent units in Quebec are minimal, citing only black shale, black bituminous shale, and black or grey limestone, as the lithologies encountered. Most seem to resemble closely the beds as described for Ontario.

Shales of the Collingwood and equivalent zones are all recessive weathering units. The description of a paper-shale weathering characteristic can be attributed to solution of calcite-rich laminae by surface waters in contrast to more limited weathering of the organic-rich laminae. Weathered surface samples will thus appear to contain more kerogen than will fresh surface samples and cores.

Distribution and Thickness

Within the Hudson Bay Lowland (Fig. 3), Ordovician shales are all younger than the Collingwood as this area was emergent during that period of deposition (Cumming, 1974). On the Ontario-Quebec border, at Lake Temiskaming, Ordovician carbonates, equivalent to the Coburg Group immediately underlying the type Collingwood, were reported to be overlain by Silurian strata (Hume, 1925: Bolton and Copeland, 1972). If deposited, Collingwood equivalents may have been subsequently eroded, although Hume stated that there is an interval of 10 to 13 additional metres of unknown interval between the Ordovician and Silurian: if present, the Collingwood equivalent would be in this interval. These interpretatations require a major depositional and/or erosional break between Middle Ordovician and Silurian beds in the Lake Temiskaming area: the anomaly was more rationally explained by Caley and Liberty (1957, p. 237) who identified the Ordovician of this area as younger than the Collingwood, being Richmond rather than Trenton. The Collingwood interval is therefore missing at Lake Temiskaming by non-deposition, representing a period of emergence similar to that in the Hudson Bay Lowland.

As illustrated on Figure 2, the Collingwood beds outcrop along the north shore of Manitoulin Island, most prominently on Strawberry Island, at Little Current, and along Sequiandah Bay, all at the east end of the Island (Liberty, 1957). Maximum thickness is about 7 metres, overlain by 29 metres of Sequiandah grey shale and limestone (Liberty, 1957). Williams (1937, p. 10) estimated the black shale thickness to range from 7 to 18 metres from well records: these records may tend to over-estimate the thickness values. Surface thickness estimates are also in doubt as seldom is the total section exposed at any one place.

Thickness data for the Collingwood-Blue Mountain of the Georgian Bay area near Collingwood are almost non-existant. Sanford (1969), on composite stratigraphic log sections, showed some 39 metres of Blue Mountain-Collingwood, without separating the two units. Martison (1966), estimated, from his own measurements, some 18 metres of Collingwood; by comparison of these data, the Blue Mountain may here be approximately 20 metres thick.

Within this same general area, Liberty and Bolton (1971) gave estimates of their Whitby Formation as possibly increasing nortward from 51 to 61 metres, of which, in the southerly thinner subsurface sections, the lower member (Collingwood) is 10 metres and the upper unit (Blue Mountain) is 42 metres.

Along the shores of Lake Ontario, near Whitby and Oshawa, Sanford showed 49 metres of total Whitby equivalent, but again did not separate the Blue Mountain from Collingwood facies.

Wilson (1946) estimated the thickness of Billings Formation black shale of the Ottawa area (Fig. 3) at 79 to 91 metres, considerably thicker than any of the other described total Collingwood-Blue Mountain intervals. Several factors probably contribute to the thickening within this area; facies change of Blue Mountain shale easterly to equivalent Billings black shale, the possibility that some of the Billings is also stratigraphically equivalent to part of the more westerly Dundas beds, a downward thickening by facies change of both Billings and Eastview as lateral equivalents to more westerly Cobourg limestone and finally the Ottawa area may be depositionally thicker through an increased rate of subsidence.

An increased rate of subsidence is preferred as the major thickness contributor for the Ottawa area, although the facies change of Blue Mountain to Collingwood shale types is also possible. In the St. Lawrence Lowland, Dresser and Denis (1944) reported prior data estimating 122 to 152 metres of Utica type shale at Trois-Riviere and 90 metre on the island of Orleans near Montreal (Fig. 5). These data, essentially for the combined Lachine-Lotbinière section, confirm an easterly regional thickening of the black shale beds, which were estimated by Caley and Liberty (1957) to attain thickness of 300 metres in the Quebec section. Paleontologic data are sufficient that there is no doubt of the general stratigraphic equivalence of these units, but the validity of the quoted thicknesses must be of considerable concern.

A Paleozoic outlier near Lac Saint-Jean, Quebec (Fig. 5) contains a complete section of Ordovician black shale (Dresser, 1916) as younger carbonate is preserved on a small island within the lake. Logan (1863) estimated a maximum 30 metres for this unit, but Caley and Liberty (1957) indicated Utica Series strata of 8 metres only; however, as they did not indicate the presence of younger carbonate, this would represent an erosional rather than a depositional thickness.

On Anticosti Island, the Macasty black shales, were described by Twenhöfel (1927) as black and soft, giving a petroleum odor which struck by a hammer, and burning slowly when held in a flame. No actual outcrop is known,

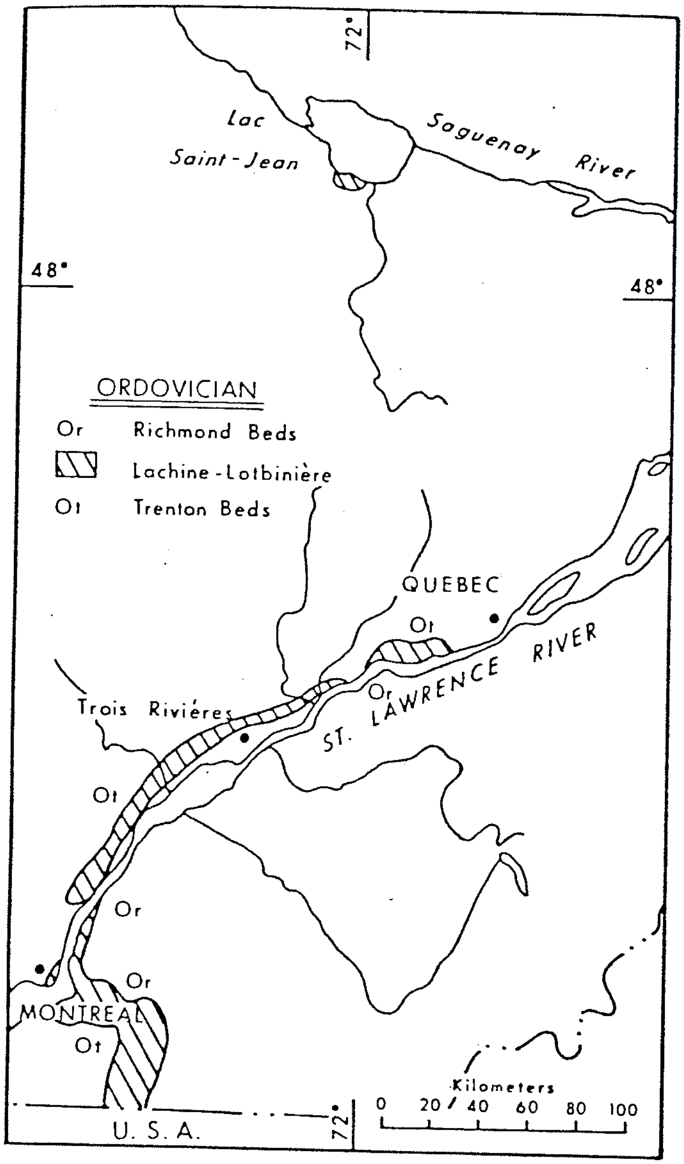


FIGURE 5. Outcrop distribution Lachine-Lotbinière (Utica) shales, St, Lawrence Lowland

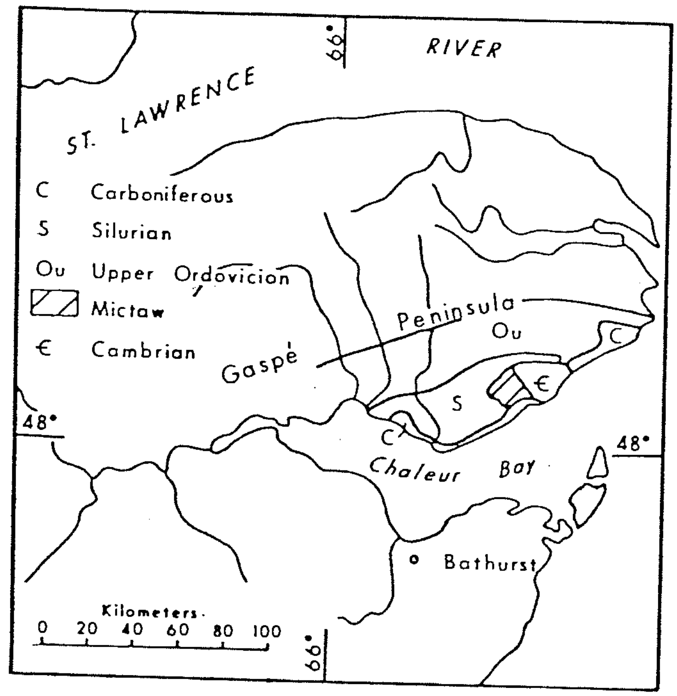


FIGURE 6. Outcrop distribution of Mictaw Group, Gaspé, Quebec

but float of the unit is found on the beaches at the northwest end of the island, near Makasti Point. No thickness data are available from the surface geology, but can probably be determined from the subsurface data of several wells drilled on the island.

Swinnerton (1933) described the occurrence of bituminous shales at Port Daniel, Gaspé, Quebec (Fig. 6) near the top of the Mictaw Series, which are the approximate equivalent of the previously described black shales of Ontario and Quebec. There is insufficient data presented to interpret thicknesses or to be geologically more descriptive. Alcock (1935, Map 330A) showed the distribution of the Mictaw Series in the area of Chaleur Bay, which separates the Gaspé Peninsula from New Brunswick.

Mineralogy

Almost no data are available on the mineralogy of the Ordovician organic shales of Ontario-Quebec. R.W. Ells (1909) gave the results from four scattered analyses of "Utica" shales, which ranged 20 to 50% calcite, 2 to 11% dolomite (high dolomite corresponded to low calcite, occurring near Ottawa), 35 to 48% clay and sand, and 2 to 8% aluminum and iron oxide. Carbon ranged about 7% except for one low value, less than 1% near St. Anne, Quebec. Pyrite has been described by almost all authors, often weathering red to rusty-brown on oxidation. No work has been reported concerning the potential presence of trace elements.

ORDOVICIAN OF SOUTHAMPTON ISLAND

Although somewhat geographically displaced from the Paleozoic strata of Ontario and Quebec, the oil shale-bearing Ordovician strata of Southampton Island, at the north end of Hudson Bay, are discussed at this point because of possible stratigraphic correlation to the Collingwood shales, and because the basin is continuous southward to the Hudson Bay Lowland of Ontario.

Stratigraphy

Oil shales were first described by Nelson and Johnson (1966), who state, "the uppermost 50 feet of Ordovician on Southampton Island, the 'oil shale interval,' is interbedded oil shale and limestone. Good outcrop sections are unknown; in almost every case the interval is represented by a belt of limestone and oil shale rubble." The limestone and shale rubble appeared to Nelson and Johnson to occur between unnamed Ordovician carbonate and overlying undivided Silurian carbonate (Fig. 7).

No similiar organic shales have been recognized at the south of Hudson

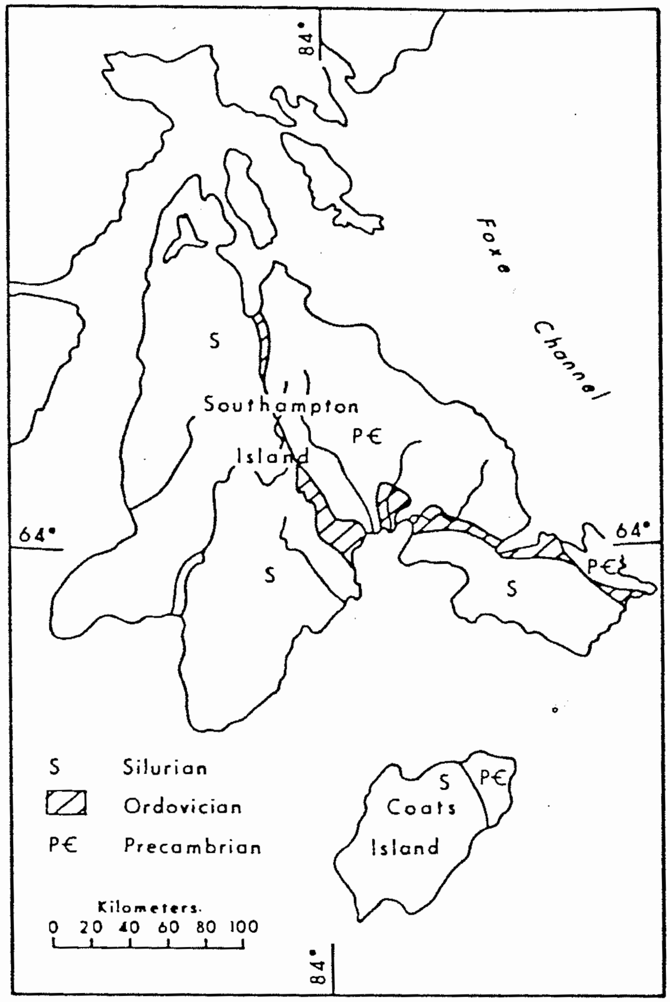


FIGURE 7. Outcrop distribution of Ordovician strata, Southampton Island

Bay in the Lowland area, despite the detailed work of Nelson and Johnson (1966), Johnson and Nelson (1968) and Sanford and Norris (1968). In describing the Hudson Platform, Sanford and Norris (1973) placed the oil shale zone between the Bad Cache Rapids Group below and the Churchill River Group above, bringing these names northward from the Hudson Bay Lowland area. In this position, the oil shale zone, still not named, became the stratigraphic equivalent of the Collingwood Formation. The oil shale zone is still identified only on Southampton Island within the Hudson Bay area.

More recently, Nelson and Johnson (1976) again reviewed the area, this time publishing considerably more surface information as well as numerous analytical data. Although re-iterating that the oil shale apparently occurred at the top of the Ordovician, immediately below Silurian strata, they also reported that the collector of many of the samples had suspected more than one oil shale zone might be present. Nelson and Johnson here concluded that two shale zones might exist in the Ordovician of Southampton Island: the final answer may not be known until cores are obtained from the Silurian, and continuing through to the Precambrian surface.

Lithology

Only minimal descriptions of the lithologies have been presented for the oil shale interval throughout the above references. The shale has been described generally as black to dark brown, with the higher oil content shales being slightly calcareous and fissile, whereas the leaner shales are moderately calcareous and non-fissile. As with other areas, the apparent fissility could relate to the weathering process by which calcite laminae are removed. The shales are interbedded with undescribed limestone which reportedly occupies up to 50% of the oil shale interval.

Distribution and Thickness

The oil shale occurs on Southampton Island (Fig. 7) and follows the Ordovician outcropping units. Because most of the knowledge of the zone is from eroded rubble, precise outcrop distribution is not known; however, the reader can acquire a good understanding of the distribution by reference to Nelson and Johnson (1976, p. 71, Fig. 1) which illustrates the locations from which the oil shale rubble was collected.

The interbedded oil shale and limestone zone was estimated to be 15 metres thick based on known carbonate outcrop, and an analysis of the relative amount of oil shale rubble versus other types across the beaches. If the limestone can be as much as 50% of the interval, and is always present to some degree, the net oil shale possibly ranges from 8 to 12 metres.

Mineralogy

Almost no data were provided in the publications on this area on the mineralogical composition of the shale zones. Nelson and Johnson (1970) reported the blacker, better oil-bearing shales to be slightly calcareous and fissile, whereas the leaner shales are moderately calcareous and non-fissile. No mention has been made of pyrite, although traces of uranium, vanadium and zinc were reported.

Ordovician oil shales - economic potential

Considering the total area of oil shale sediments, there are inadequate shale oil recovery data to provide anything but some generalized statements on the relative advantages and disadvantages of the various areas discussed herein. Table 1 is a summary of all the available oil shale retorting analyses available to date in Ontario and Quebec. Because all information has been presented in gallons/ton throughout the source data, both gallons/ton (g/t) and liters/tonne (L/t) are here used. In this way, the reader may be assisted in the conversion of the older data to the recently implemented metric system of measurements. All gallons/ton data are presented as imperial gallons/short ton (2000 lbs). Where analyses were reported in U.S. gallons/ton, conversion has been made to the imperial system.

There are no data to determine the kerogen-bitumen content of the oil shales and specific gravities are the only indication of the shale oil quality. Shale oil densities, generally ranging through specific gravity values 0.88 to 0.98, are higher than those of crude oils: the most frequent specific gravity range is 0.91 to 0.94. In this aspect, the shale oils recovered from Ordovician beds, ranging from 0.907 to 0.914, are at the lighter end of the average range. Beyond this factor, there are no data on the nitrogen, oxygen, or sulphur content of the product, or on the degree of undersaturation and organic character of the shale oil.

The thickness of the oil shale zone increases easterly from Manitoulin to the untested St. Lawrence Lowland section from 7 meters to a possible maximum 150 metres. The limited available data suggest that the net recoverable shale oil appears to decrease with increasing thickness of the total organic shale zone. This is interpreted from both the actual shale oil recoveries and unpublished organic content values of the Ontario Geological Survey.

Two factors may affect the shale oil recoveries. Kerogen content may decrease easterly within the thickening sediments as equal amounts of source organic debris had to be distributed through differing total sedimentary intervals. Barker et al (1979) noted increased downward maturation through the Devonian and Silurian section. A continuation of this work through Ordovician beds could indicate variable maturation across the area: increasing maturation will decrease net shale oil recoveries from sediments with equivalent kerogen content. The decrease of kerogen content with increasing thickness of the section is also indicated by the total organic content values.

Martison's analyses (1966) of the Collingwood quarry at Craiglieth

AREA Source	No. of Samples	Org Cont %	Oil Yields g/t			Yield L/t	Specific Gravity			Amm sulph		Others	Pot Thick
			Min.	Max.	Avge.		Min.	Max.	Avge.	lb/t.	kg/t.		
MANITOULIN ISLAND													7m
Williams 1921	2		4.8	8.1	6.5	32.3							
Martison 1966	14		3.4	10.0	7.2	36.0	0.906	0.914	0.911				
Ont Geol Surv unpubl	5	11.5-15.1											
COLLINGWOOD													10m
Logan 1863	Prod'n		6.9	8.3	7.6	38.1							
Martison 1966	18		3.5	9.6	7.1	35.4	0.891	0.925	0.907				
Ont Geol Surv unpubl	4	0.5-10.15											
OTTAWA													80m
Martison 1967	14		0.0	trace		--							
Ont Geol Surv unpubl	1	4.24											
Lac St. JEAN													
Dresser & Denis 1944	1				4.5	22.5			0.914	20.0	10.0		8m
PORT DANIEL													
Swinnerton 1933	2			0.6		3.0							?
SOUTHAMPTON ISLAND													
Nelson & Johnson 1976													10m
Rubble	71		2.1	33.9	12.7	63.6							
Core	4		4.6	7.3	6.3	31.5						U Va Z	

TABLE 1: Analytical results from Ordovician strata in Ontario and Quebec, and Southampton Island

average 8.3 gallons/ton from 5 samples. Logan's recoveries of 280 gallons from 30 to 36 tons of rock represent 6.9 to 8.3 gallons/ton, which would indicate an operating recovering in the range of 83 to 100% of analysed content. This would be an extremely high economic recovery rate, but the production data must be regarded as estimates only.

Shales oil yields on Southampton Island are considerably higher in many instances than is normal for black shale from shallow marine platform sediments. Of the 71 reported analyses, 5 exceed 30 gallons/ton, 11 are in the range 20 to 30 gallons/ton, and the remaining 55 analyses are all less than 20 gallons/ton. All the samples with yields greater than 30 gallons/ton came from one locality. There is probably a distortion on the average toward the higher yields because of the number of samples from this one area. The average yield of 63.6 litres/tonne (12.7 gallons/ton) from the rubble is double that of the in place core samples. Because the rocks are calcareous, weathering has probably increased the net oil shale content of the rubble samples; thus, a true value will be difficult to obtain until more unaltered core samples are available. Although the highest values were obtained from Southampton Island, the economic potential of the shales at this locality will be reduced because of the inter-bedding with limestones. This will restrict the net pay available from the gross 15 metre interval.

In any mining operation, by-products are a significant part of economic considerations. Except for a single analysis for ammonium phosphate at Lac Saint-Jean, and the reported presence of uranium, vanadium and zinc trace elements in the oil shale on Southampton Island, the by-product potential has thus far been completely ignored.

These are presently insufficient control data to present a reserve estimate which would have any reality or validity whatever.

Four areas of Devonian age oil shale deposits have been mapped in Ontario and Quebec. They are the Middle Devonian beds in Gaspé and on the north shore of Lake Erie, and two occurrences of stratigraphically equivalent Upper Devonian oil shale zones, located in the Sarnia area of southwest Ontario and in the James Bay Lowland area. Figure 8 shows the general geographic distribution of these four areas.

Of these occurrences, the Upper Devonian units are the best defined: the Middle Devonian of Gaspé may be closer to an oil sand than an oil shale problem and the oil shale of the Middle Devonian Marcellus Formation at Lake Erie is more conjectural than factual.

GASPÉ PENINSULA

Bituminous shales were first described in the Gaspé area by Logan (1863) and had subsequent attention by R.W. Ells (1909, 1910) and S.C. Ells (1923). All available analytical data were presented in these last three papers. McGerrigle (1950) is the most detailed stratigraphic paper on this unit.

Stratigraphy and lithology

Logan (1863) described over 2100 metres of Gaspé sandstone sequence of possible Middle Devonian age, containing reported oil shale and oil sand zones. As recognized from the name, the unit is dominantly coarse clastics: shales are a secondary lithology. Williams (1910) used the "sandstones of York River," as used informally by Logan, and defined these as the York River beds. McGerrigle has since increased the York River Formation to include all strata similar to the initially described York River beds. Figure 9, partly excerpted from Williams (1973), outlines the present generally accepted terminology of the area.

The York River Formation is composed of greenish-grey, medium to fine grained, feldspathic sandstone with interbeds and zones of greenish shale to a maximum 30 metres thickness. Calcareous and fossiliferous beds occur in the upper two-thirds of the section. The York River beds grade into York Lake Formation, in which the lithologies are finer grained and more argillaceous than those of the York River. York Lake beds represent the transition from the older Grand Grève limestones to the York River strata. The overlying Battery Point beds are coarser grained, conglomeratic, and represent a continuing upward increase in grain size distribution.

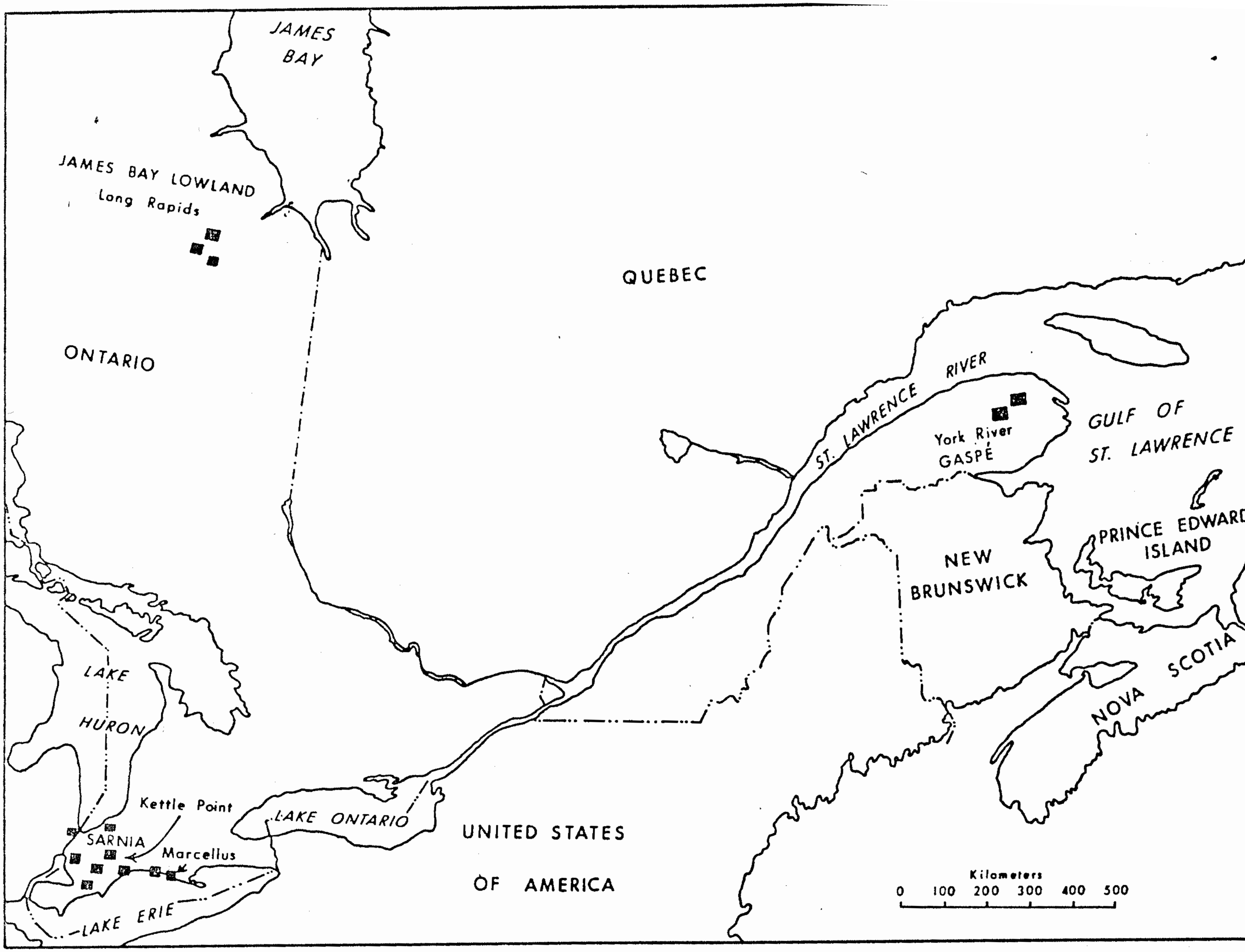


FIGURE 8. Distribution of Devonian oil shales, Ontario and Quebec

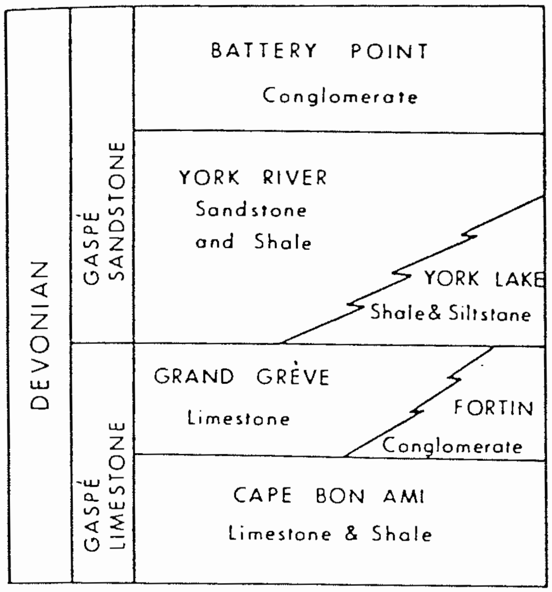


FIGURE 9. Devonian stratigraphy, Gaspé, Quebec

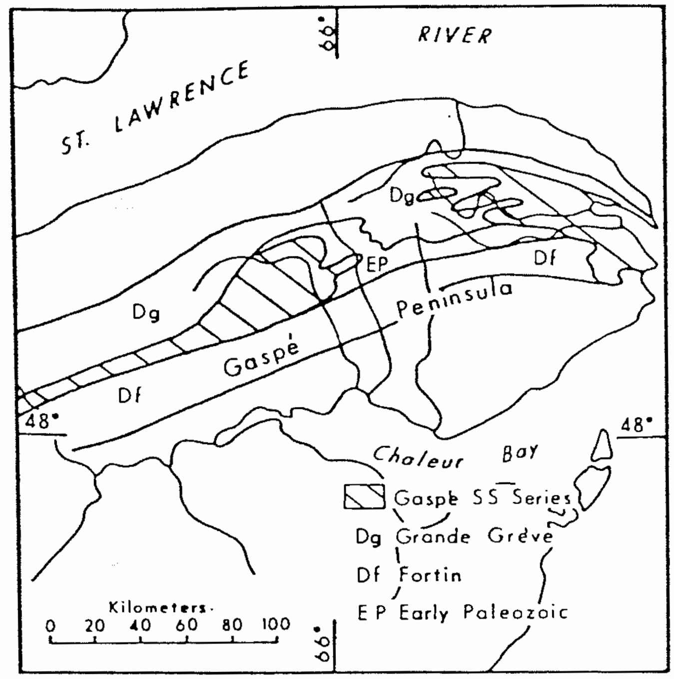


FIGURE 10. Outcrop distribution of sandstone sequence, Gaspé, Quebec

Distribution and Thickness

York River strata occur in the Gaspe fold belt (Fig. 10) and reach a maximum thickness in a range in excess of 1500 metres, but thin northward to less than 1000 metres.

York River - economic potential

Logan (1863) described the oil shale beds as containing resinous matter in irregular laminae to 1/8 inch (0.05 cm) maximum thickness, with vitreous lustre, conchoidal fracture, translucent orange-red color, and insoluble in organic solvents. This resinous material was locally called scleretinite or middletonite. The material was analyzed to contain in the range 22.8 to 52.4% volatile matter.

R.W. Ells (1908) described the oil shale beds as 1" to 15" (0.4 to 5.9 cm) thick and then, in 1910, reported the material, especially the oil sandstone phase, to burn easily. Two further analyses are available, one by S.C. Ells (1923), and one by McGerrigle (1950). Five analyses are presented in Table 2.

McGerrigle stated that most of the reported oil shales were, in actuality, oil sands and that some coal seams are present in the section involved. He also inferred that the oil occurrences were overly emphasized by previous writers and were not so common as had been indicated.

YORK RIVER BEDS Source of data	Recoveries g/t	L/t	Specific Gravity	Amm. Sulph. lb/t	kg/t
Ells (1908)					
14" band	30.0	150.1	0.962	47.0	23.6
5" band	31.5	157.8	0.977	40.0	20.0
rubble	36.0	180.3	0.953	59.5	29.8
Ells (1923)	20.0	100.0		22.0	11.0
McGerrigle (1950)					
5 m. zone	42.2	212.3	0.955	7.4	3.7

TABLE 2. Retorting analyses of York River oil shales

The specific gravities are at the heavy end of the shale oil range: from the descriptions this may not be a shale oil but may be a migrated bitumen, thus resembling the albertite sub-product of the Albert oil shales in New Brunswick. If not a bitumen derived from oil shale, the described occurrences could possibly be torbanite beds, as the yields are in the proper range, thicknesses are minimal and distribution is areally restricted. Coal is known to be present in the section.

As most of the beds are thin and areally limited, the economic potential seems poor; however, McGerrigle reported his analysis to be from a five metre thick band in a well that was drilled. If this reported thickness is correct, and the material involved is torbanite, or a concentrated product similar to albertite, this could be of some further interest. Considerable additional geological knowledge will be necessary to determine the nature and economic potential of this unit.

LAKE ERIE - NORTH SHORE

The Marcellus Formation is a wedge of Middle Devonian black organic shale, with minor limestone, that overlies the brown limestones of the Dundee Formation and is overlain by grey shales, and limestone, of the Hamilton Group. This stratigraphic sequence is directly analogous and comparable to the previously described Ordovician interval containing the Collingwood.

The outcrop of the Marcellus occurs along the north shore of Lake Erie (Fig. 11) and the zone has been penetrated in nearby wells. A maximum thickness is about 9.1 metres from the present limited data.

No analyses have been made for shale oil from any samples of the

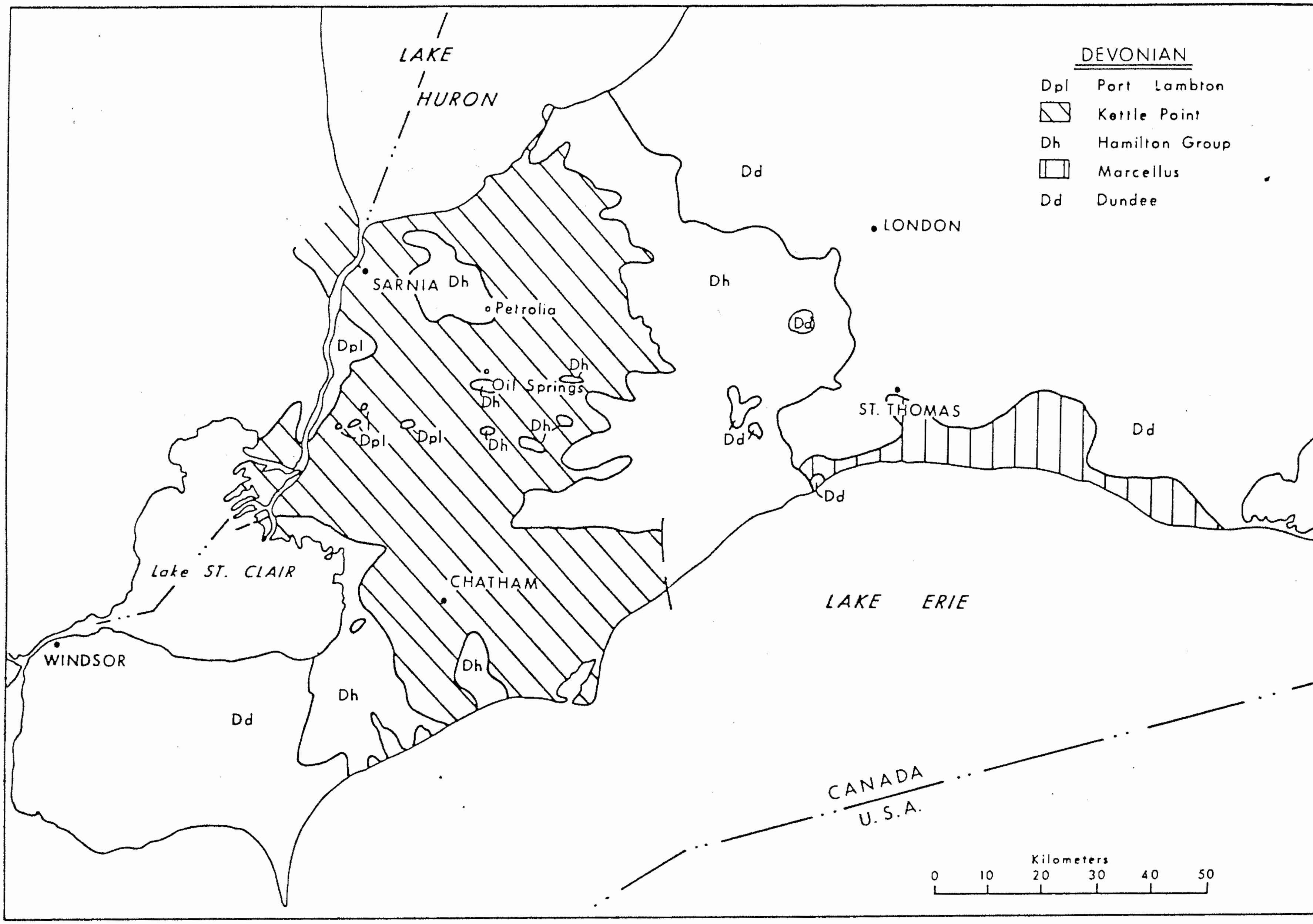


FIGURE 11. Outcrop distribution of Devonian Marcellus and Kettle Point Formations, southwestern Ontario

Marcellus; the potential of this zone as an oil shale is speculative, but is considered to be good by comparison to the older Ordovician Collingwood and because of the lower thermal maturation level in the Devonian (Barker et al., 1979). A detrimental factor is the presence of thick drift cover, up to several hundred feet (100 metres) over much of the outcrop area. This may preclude any possibility of open-pit mining techniques.

SARNIA AREA AND JAMES BAY LOWLAND

Upper Devonian organic shales occur in the Kettle Point Formation of southwestern Ontario near Sarnia (Fig. 11) and in the Long Rapids Formation of the James Bay Lowland (Fig. 12): there seems little doubt as to the exact stratigraphic equivalence of these two units.

Stratigraphy

Within the Sarnia area of southwestern Ontario, the Kettle Point Formation overlies limestones and shale of the Hamilton Group and is overlain in turn by green shale, micaceous sandstones and siltstones of the Port Lambton Group, although black shale is again present in the uppermost Lambton section (Sanford, 1969, and Winder and Sanford, 1972).

Although described by Logan (1863), the first nomenclatural subdivision of this Upper Devonian sequence was made by Williams (1919) who described two subdivisions of the Ohio strata; a lower unit, the Huron shales, which were characterized by "kettles;" and an upper Cleveland shales, barren of "kettles." Both zones yielded shale oil on retorting, although the better recoveries were from the Huron unit. In 1943, Caley proposed the name Kettle Point Formation, supposedly equivalent to the Huron of Williams, but Kettle Point contains all the oil-shale beds, so this intended correlation cannot be exact. The terms Huron and Cleveland are now obsolete in this area. The overlying Part Lambton Group had been proposed earlier by Stauffer (1915). Undoubtedly the term Kettle Point had been used prior to definition by Caley. Caley (1946) stated the Kettle Point to be the equivalent of the Antrim shale of Michigan, and it can also be equated to a sequence of Devonian black shales in the western Appalachian Basin trending north-south through Ohio, West Virginia and Kentucky. Within this same report, Caley expressed doubt as to the significance of the Port Lambton as a separate unit from the Kettle Point because Port Lambton green shales occur within Kettle Point black shale sequences in well sections of the Sarnia area.

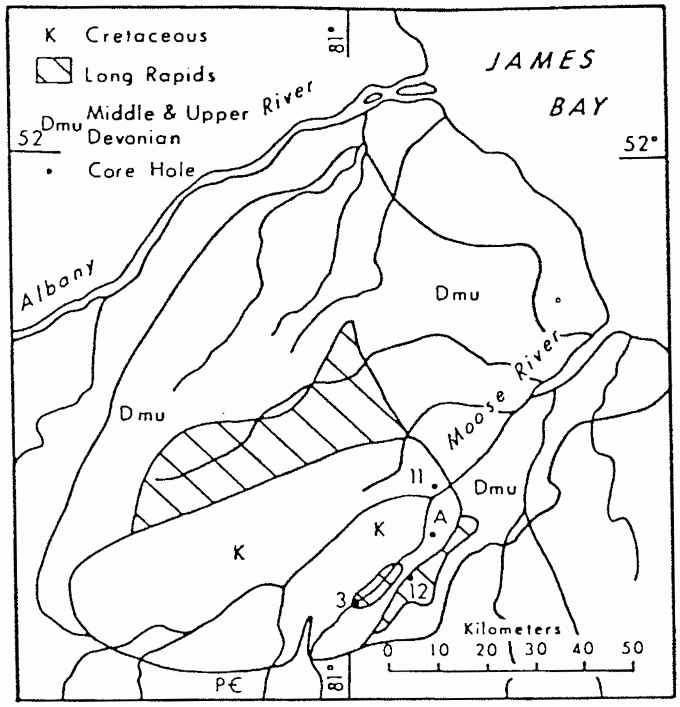


FIGURE 12. Outcrop distribution of Devonian Long Rapids Formation, James Bay Lowland

Rocks of the Long Rapids Formation were first recognized at Long Rapids on the Abitibi River in the Moose River Basin by Williams (1919), but were not defined until 1919 when described briefly by Savage and van Tuyl. Dyer (1932), on the basis of the Onakawana test hole, informally divided the Long Rapids into three units, comprising a lower greenish shale, a medial black organic zone, and an upper greenish shale. Subsequent work has failed to confirm this tentative subdivision, which is no longer used.

The contact of the Long Rapids Formation with the underlying Williams Island limestone is nowhere exposed: a thin drift cover, 9 metres or less, is always present over the contact, so the conformability of the formation is not known. The oil shale interval is overlain by Cretaceous strata: although this contact is also covered, an erosional unconformity must occur between these units (Sanford and Norris, 1975).

Lithology

Kettles were described by Caley (1946) to be "composed of radiately fibres of impure carbonate of lime extending from an amorphous shaly center, and occurring in zones divided by concentric amorphous bands," and also stated, "shale bedding occurs above and below the concretions." These concretions range in size from 1 to 6 centimetres in diameter. Sanford and Norris (1975) described "clay ironstone nodules up to 1.5 feet (7 centimeters) maximum diameter .... These nodules are analogous to the "kettles" in the Kettle Point Formation."

At the type locality, the Kettle Point shales are thin bedded to laminated, paper-thin weathered, dark grey to black, weathering rusty colored and with greenish coloration on some bedding plans. Amber colored spore cases are common. Greenish and greenish-grey shale zones appear in many well sections, at apparently different non-correlative intervals.

A description of the Long Rapids lithology is virtually identical, generally dark grey to black, non-calcareous, organic, rust-stained, containing spores, and with scattered thin greenish argillaceous dolomite beds. Well data (Satterly, 1953) show the presence of greenish-grey shale zones within the darker shale sequence, and indicate that these lighter colored shales do not appear to be in correlative zones, analogous to the color-organic content relationship encountered in Kettle Point section. This interbedding of lithologies is the basis of Caley's doubt as to the necessity for the Port Lambton Group, as the greenish-grey shale of the Port Lambton is identical in description to that of the Kettle Point.

Distribution and Thickness

Figures 11 and 12 illustrate the outcrop areas of Kettle Point and Long Rapids Formations respectively.

Winder and Sanford (1972) reported a maximum subsurface thickness of 77 metres of Kettle Point near the foot of Lake Huron, presumably where Port Lambton beds protect the total depositional interval. The interval gradually thickens across the southern shore of Lake Erie to more than 310 metres in the equivalent American sections. From the scattered outliers of Port Lambton and inliers of Hamilton beds, the outcrop pattern can be intrepreted to indicate an irregular thickness distribtion for Kettle Point strata. Considerable investigation of black versus greenish-grey shales will be necessary to define the oil shale potential of this unit.

A maximum known thickness of the Long Rapids Formation is 87 metres, encountered in the Onakawana "A" drillhole, where the unit consists of 31 metres greenish-grey shale, a medial 29 metres black organic shale, and an upper section, 22 metres, of greenish grey shale. At the Moose River Oils No. 3 well, Satterly (1953) described, in ascending order, 7 meters dominantly organic shale, 7 meters grey clay, fine grained sandstone, black shale and some limestone, 3 metres sandy shale and grey shale, and 2 meters calcareous shale, a total of 19 metres of section. In the MacDyke drillholes 11 and 12, continuous black shale sequences, of 12 and 66 meters respectively, at both locations overlie a basal 3 metres of blue clay. From these data, the definition of net black shale distribution and thickness is complicated by the same probems encountered for the Kettle Point Formation.

Mineralogy

Data are not available concerning the nature of the clay minerals of these shales. Calcite will be a significant component of the Kettle Point shales, as evidenced by the concretions and probably also by the paper-thin weathering characteristic. Calcite may be less significant in the Long Rapids, as the shales are described as non-calcareous, and dolomite beds are mentioned: dolomite and siderite may be the dominant carbonate components. Pyrite nodules are common and are evident by the rust colored weathering.

No studies have been published on minerals containing potentially economic trace elements in either of these areas.

Devonian oil shales - economic potential

Only a limited number of analyses are available for the Upper Devonian oil shales of Ontario: table 3 is a summary of these data.

A few comments and observations can be made. There are so few available analyses that their significance is questionable: these data prove only that the black shales of the Kettle Point and Long Rapids are potential units for shale oil production.

The specific gravities on the oil shale recovered from the Kettle Point are considerably lower than Martison's (1953) data for the Long Rapids: Martison reported a gas yield of 515 to 730 cubic feet/ton in conjunction with the heavier gravity shale oil for the Long Rapids Formation. This may indicate differing stages of maturation for the two areas.

Data are also insufficient to provide any realistic evaluation of potential net oil shale thicknesses, an important factor when considering the areally large outcrop distribution of these two units. Although Williams (1919), using 13 metres as an average shale thickness, estimated 116,000,000,000 tons (105 million tonnes) in round numbers of Kettle Point oil-shale reserves, this figure has little geological validity: no estimate of potential reserves of Kettle Point-Long Rapids oil shales can be justified from present knowledge.

AREA Source	No. of Samples	Org Cont %	Oil Yields g/t Min.	Oil Yields g/t Max.	Oil Yields g/t Avge.	Yield L/t	Specific Gravity Min.	Specific Gravity Max.	Specific Gravity Avge.	Amm Sulph lb/t.	Amm Sulph kg/t.	Others	Pot Thick
KETTLE POINT													?
Logan 1863	1				10.0	50.0	0.868	0.887	0.878	6	3		
Williams 1919	2		3	4	3.5	17.5				13	6.5		
	3				10est	50				20.6	10.3		
Ells 1923	9				7.8	39.1							
Ont Geol Surv unpubl	6	7.44-11.9											
LONG RAPIDS													?
Ells 1912	?		7	16						16	8		
Williams 1919	3		3.5	12						18.8-38.8	9.4-19.4		
Martison 1953	3		1.6%	5.5%	3.7%								
	3		2.9	3.6	3.4	17.0	0.940	0.940	0.940				

TABLE 3: Analytical results from Devonian strata in Ontario

ALCOCK, F.J.
1935: Geology of the Chaleur Bay Region: Geological Survey of Canada, Memoir 183, p. 135 (distribution of Ordovician Mictaw black shales).

BAER, A.J., POOLE, W.H., and SANFORD, B.V.
1971: Rivière Gatineau; Geological Survey of Canada, Map 1334A, (outcrop distribution of Billings Formation at Ottawa and Lachine-Lotbinière in St. Lawrence Lowland

BÉLAND, J.
1969: The geology of Gaspé; Canadian Institute of Mining and Metallurgy, Bulletin, v. 62, p. 811-818 (excellent review of tectonic history and related sedimentation).

DRESSER, J.A.
1916: Part of the district of Lake St. John, Quebec; Geological Survey of Canada, Memoir 92, 88p., p. 36-40 (outline of Collingwood shale; lithology and paleontology).

DRESSER, J.A., and DENIS, T.C.
1944: Geology of Quebec, descriptive geology; Quebec Department of Mines, Geological Report 20, v. II, 544p., p. 123-124, 213-215, 266-268, 271-272, 296 (descriptions of all geologic units in Quebec, specific references only to Collingwood shale equivalents).

ELLS, R.W.
1909: Geological position and character of the oil-shale deposits of Canada; Geological Survey of Canada, Report No. 1107, p. 59-61, (brief description of oil shale zones in Gaspé sandstone sequence).

1910: Oil-shales of eastern Canada; Geological Survey of Canada, Summary Report, 1909, p. 212-216 (describes Gaspé sandstone sequence).

ELLS, S.C.
1923: Oil Shales of Canada; Canada Department of Mines, Summary Report of Investigations made by the Mines Branch, 1921, Report No. 588, pt. G, p. 51-52 (minimal description of Gaspé sandstone, 4 analyses).

1925: Oil shales of Canada; in, Shale Oil, ed R.H. McKee; American Chemical Society, Monograph Series No.25, The Chemical Catalog Company Inc., New York, p. 53-56 (verbation repeat of 1923 paper).

FOERSTE, A.F.
1916: Upper Ordovician formations in Ontario and Quebec; Geological Survey of Canada, Memoir 83, p. 5-6 (background paleontology for correlations).

LAURIN, A.F.
1969: Geological map of Quebec; Quebec Department of Natural Resources, Mines Branch, geological staff, co-ordinator A.F. Laurin (surface distribution of black shale sequences).

LOGAN. W.E.
1844: Geological sections on Chaleur Bay and coast of Gaspé; Geological Survey of Canada, Report of Progress, 1843, p. 80-110 (historial interest only).

1863: Report on the geology of Canada; Geological Survey of Canada, Ottawa, p. 201-224, 394-404, 521-528, 784-792 (descriptions of Utica (Ordovician) shales, Gaspé sandstone sequences, good lithologic-paleontologic discussions, a few analyses).

MARTISON, N.W.
1966: Study of oil shale occurrences in Canada; unpublished report, University of Calgary, Gallagher Library, p.13 (summarizes McGerrigle's data).

McGERRIGLE, H.W.
1950: The geology of eastern Gaspé; Quebec, Department of Mines, Geological Report 35, p. 23-24, 78-84, 122-125, (reviews Gaspé Devonian stratigraphy, large scale outcrop map, and most analyses).

PARKS, W.A.
1929: Report on the oil and gas resources of the Province of Quebec; Quebec Bureau of Mines, Annual Report, 1929, pt. B, p. 62-67, (early review of Utica shales and Gaspé sandstones, updated in both McGerrigle, and Dresser and Denis).

RAYMOND, P.E.
1919: The Trenton Group in Ontario and Quebec; Geological Survey of Canada, Summary Report, 1912, p. 348-350 (describes Utica shales along St. Lawrence River).

SWINNERTON, A.A.
1933: Report on oil shales from New Glasgow area, Pictou County, Nova Scotia, and from Port Daniel, Bonaventure County, Quebec; Canada Department of Mines, Mines Branch Report #725, 1930-1931, pt II, sec. IV, p. 145-148 (describes unsuccessful attempts to distill oil from the Ordovician Mictaw series).

1938: Oil shales of Canada; in, Oil Shale and Cannel Coal; The Institute of Petroleum, p. 215 (lists areas of Utica outcrop, not a significant reference).

TWENHOFEL, W.H.
1927: Geology of Anticosti Island; Geological Survey of Canada, Memoir 154, 481 p., p. 15, 22 (brief mention of Macasty shales).

WILLIAMS, E.P.
1973: St. Lawrence Lowlands, Gaspé and Gulf of St. Lawrence areas; in, Future Petroleum Provinces of Canada, A. Symposium; ed. R.G. McCrossan, Canadian Society of Petroleum Geologists, p. 570-574 (concise Gaspé stratigraphic section and definition of Gaspé fold belt).

WILLIAMS, H.S.
1910: Age of the Gaspé sandstones; Geological Society of Smerica, Bulletin, v. 20, p. 688-698 (background for Middle or Upper Devonian age).

WILSON, A.E.
1936: A synopsis of the Ordovician of Ontario and western Quebec and the related succession in New York; Geological Survey of Canada, Memoir 202, p. 1-17 (origin and definition of Ordovician nomenclature).

1946: Geology of the St. Lawrence Lowlands, Ontario and Quebec; Geological Survey of Canada, Memoir 241 (shows Ordovician Lachine-Billings equivalents missing along southern end of St. Lawrence River).

Bibliography - Ontario

BAER, A.J., POOLE, W.H., and SANFORD, B.V.
1971: Gatineau River; Geological Survey of Canada, Map 1334 A (distribution of Billings, Lachine and Utica shales).

BARKER, J.E., LEGALL, P., FRITZ, P., and BARNES, C.R.
1979: Source, correlation, and thermal maturation history of hydrocarbon mineral deposits of southern Ontario: Ontario Geological Survey, Miscellaneous Paper 87, p. 7-10 (temperature of oil formation and depth of burial for Ontario Silurian and Devonian sequences).

BOLTON, T.E., and COPELAND, M.J.
1972: Paleozoic formations and Silurian biostratigraphy, Lake Temiskaming region, Ontario and Quebec; Geological Survey of Canada, Paper 72-15, 49 p. (mostly biostratigraphy, paleontology, reference that Collingwood equivalents not present).

CALEY, J.F.
1936: The Ordovician of Manitoulin Island; Geological Survey of Canada, Memoir 202, p. 30-39 (general description of Collingwood lithology, distribution and thicknesses, and also of overlying Sequiandah).

1943: Paleozoic geology of the London area, Ontario; Geological Survey of Canada, Memoir 237 (defines Kettle Point equal to Huron section, suggests Billings as potential oil shale, good background stratigraphy).

1945: Preliminary map, Owen Sound, Ontario; Geological Survey of Canada, Paper 45-18 (production data from Craiglieth plant, map of Collingwood distribution).

1946: Paleozoic geology of the Windsor - Sarnia area; Geological Survey of Canada, Memoir 240, p. 16-17, 46-49 (minor description of Billings - Collingwood; equates Kettle Point to Antrim of Michigan, describes "Kettles").

CALEY, J.F., and LIBERTY, B.A.
1957: St. Lawrence and Hudson Bay Lowlands and Paleozoic outliers; Geological Survey of Canada, Economic Geology Ser. No. 1, 3rd ed., p. 207-246 (generalized geology, good background reference).

ELLS. R.W.
1909: Geological position and character of the oil-shale deposits of Canada: Geological Survey of Canada, Report No. 1107, p. 61-64 (describes Craiglieth retorting operations, general distribution of "Utica shales").

ELLS, S.C.
1923: Oil shales of Canada; Canada Department of Mines, Summary Report of Investigations made by the Mines Branch, 1921, Report No. 588, pt. G, p. 52-53, (a few analyses of Collingwood and Kettle Point in southwestern Ontario and Long Rapids of Hudson Bay Lowland).

1925: Oil shales of Canada; in, Shale Oil, ed. R.H. McKee; American Chemical Society, Monograph Series No. 25, The Chemical Catalog Company, New York, p.56-57 (verbatim repeat of 1923 paper).

FOERSTE, A.F.
1916: Upper Ordovician formations in Ontario and Quebec; Geological Survey of Canada, Memoir 83, p. 5-61, (paleontological data, little lithologic or stratigraphic discussion).

1924: Upper Ordovician faunas of Ontario and Quebec; Geological Survey of Canada, Memoir 138, p. 1-58 (defines Sequiandah Formation on Manitoulin Island).

HUME, G.S.
The Paleozoic outlier of Lake Temiskaming, Ontario and Quebec; Geological Survey of Canada, Memoir 145, 129 p., p. 27-28 (describes Ordovician-Silurian geology of the outlier; specifically indicates Collingwood equivalents to be missing).

KINDLE, E.M.
1914: Notes on the Oriskany sandstone and the Ohio shale of the Ontario Peninsula; Geological Survey of Canada, Summary Report, 1912, p. 280-290 (definite correlation of Kettle Point area shales to Ohio shales across Lake Erie; Kettles formed as far south as Kentucky; defines Huron beds in Ontario).

LIBERTY, B.A.
1957: Manitoulin Island, District of Manitoulin, Ontario; Geological Survey of Canada, Map 20-1957 (outcrop distribution detail for Collingwood).

LIBERTY, B.A., and BOLTON, T.C.
1971: Paleozoic geology of the Bruce Peninsula area, Ontario, Geological Survey of Canada, Memoir 360, 163p., p. 20-22 (most explicit of publications available for stratigraphic and lithologic detail of the Paleozic section, no economics of oil shale).

LOGAN, W.E.
1863: Report on the geology of Canada: Geological Survey of Canada, Ottawa, p. 201-224, 521-528, 784-792, (excellent description of Ordovician "Utica" shale distribution, details of Devonian Gaspé sandstones, good review of bitumen, oil, oil shale characteristics).

MARTISON, N.W.
1966: Study of oil shale occurrences in Canada; unpublished report, University of Calgary, Gallagher Library, p. 20-25, (contains many of the few southwest Ontario Collingwood and Billings analyses).

ONTARIO GEOLOGICAL SURVEY
1979: Geological highway map southern Ontario; Ontario Ministry of Natural Resources, Geological Survey, Map 2441 (outcrop reference map).

PARKS, W.A.
1928: Faunas and stratigraphy of the Ordovician black shale and related rocks in southern Ontario; Royal Society of Canada, Transactions, ser. 3, v. 22, sec. 4, p. 39-90 (mostly fossil data, some thickness concepts, recognized facies change of limestone to limestone and shale below the Collingwood.

RAYMOND, P.E.
1912: Invertebrate, field work, Ottawa Valley; Geological Survey of Canada, Summary Report, 1911, p. 351-356 (defines Collingwood Formation).

1914: The Trenton Group in Ontario and Quebec; Geological Survey of Canada, Summary Report, 1912, p. 342-347 (minor additional data beyond 1912 publication).

SANFORD, B.V.
1961: Subsurface stratigraphy of Ordovician rocks in southwestern Ontario; Geological Survey of Canada, Paper 60-26, p. 12 (minor description of Collingwood).

1969: Geology, Toronto-Windsor area, Ontario; Geological Survey of Canada, Map 1263A (most detailed of outcrop maps for Collingwood and Kettle Point).

SCHMOKER, J.W.
1980: Organic content of Devonian shale in western Appalachian Basin; American Association of Petroleum Geologists, Bulletin, v. 64, no. 12, p. 2156-2165 (organic content detail of Upper Devonian shales equivalent to Kettle Point).

STAUFFER, C.R.
1915: The Devonian of southwestern Ontario; Geological Survey of Canada, Memoir 34, 341 p., p. 13, 215 (defines Port Lambton beds).

SWINNERTON,
1947: A survey of the world's oil shales; Canadian Mining Journal, v. 68, no. 4, p. 229-235 (describes Collingwood as successful until Petrolia).

WILLIAMS, M.Y.
1919: The Ohio shales of southwestern Ontario; Geological Survey of Canada, Summary Report, 1917, pt. E, p. 26-28 (discusses Huron and Cleveland types in Upper Devonian shales; several analyses).

WILLIAMS, M.Y.
1921: Oil possibilities of Manitoulin Island; Geological Survey of Canada, Summary Report, 1920, pt. D. p. 32 (two analyses of Collingwood oil shale).

WILLIAMS. M.Y.
1937: General geology and petroleum resources of Manitoulin and adjacent islands, Ontario; Geological Survey of Canada, Paper 37-25, p. 10-11, 28-30 (generalized descriptions of Collingwood and Sequiandah).

WILSON, A.E.
1936: A synopsis of the Ordovician of Ontario and western Quebec and the related succession in New York; Geological Survey of Canada, Memoir 202, p. 11-12 (recognizes problems of poorly defined Collingwood in Ottawa area relative to Collingwood; good review of origin and definition of units in the area).

1946: Geology of the St. Lawrence Lowland, Ontario and Quebec; Geological Survey of Canada, Memoir 241, 66 p, p. 26-28 (defines Billings to negate problem of poorly defined Collingwood near Ottawa).

WINDER, C.G., and SANFORD, B.V.
1972: Stratigraphy and paleontology of the Paleozoic rocks of southern Ontario; International Geological Congress, Montreal, 24th Session, Guidebook A45-C45 (brief, concise summary of sections involving Collingwood and Kettle Point Formation).

WRIGHT, W.J.
1922: Bituminous shales of Canada; Geological Survey of Canada, Memoir 129, p. 51 (brief comments only, no significant data).

<u>Bibliography - Hudson Bay Lowlands and Southampton Island</u>

CUMMING, L.M.
1975: Ordovician strata of the Hudson Bay Lowlands; Geological Survey of Canada, Paper 74-28 (shows Collingwood equivalent not deposited in Hudson Bay Lowland).

DYER, W.S.
1928: Geology and economic deposits of the Moose River Basin; Ontario, Department of Mines, Annual Report v. XXXVII, Pt. 6, p. 28-29 (three analyses of Long Rapids shales).

1932: Stratigraphy and oil and gas prospects of Moose River Basin; Geological Survey of Canada, Economic Geology Series No. 2, p. 89-103 (describes Long Rapids Formation and variable lithology, considers shales as source, not as potential oil shale).

ELLS, S.C.
1923: Oil shales of Canada Department of Mines, Summary Report of Investigations made by the Mines Branch, 1921, Report No. 588, pt. G, p. 52-53 (references to Williams reports on Long Rapids, no additional data).

1925: Oil shales of Canada; in, Shale Oil, ed. R.H. McKee; American Chemical Society, Monograph Series No. 25, The Chemical Catalog Company Inc., New York, p. 56-57, (verbatim repeat of 1923 paper).

HOGGAN., SATTERLY, J., and WILSON, A.E.
1953: Drilling in James Bay Lowlands; Part I-Drilling by the Ontario Department of Mines; Ontario Department of Mines Annual Report, 1952, v. 61, pt. 6, p. 115-140 (drilling data).

JOHNSON, R.D. and NELSON, S.J.
1968: Aquitaine Kaskattama Province # 1 Well, Hudson Bay Lowland, Manitoba; in, Earth Science Symposium on Hudson Bay; Geological Survey of Canada, Paper 68-53, p. 215-226, specifically p. 221 (Ordovician beds younger than Collingwood, Long Rapids eroded).

1969: Subsurface and outcrop, Hudson Bay Basin; Bulletin of Canadian Petroleum Geology, v. 17, no. 4, p. 370-375 (confirmation of areas where Collingwood equivalents not deposited and Kettle Point eroded).

KEELE, J.
1920: Clay and shale deposits of the Abitibi and Mattagami Rivers; Ontario Department of Mines, v. 29, pt. 2, p. 31-51, (discounts Devonian organic shales for fire clay, pyrite present).

MARTISON, N.W.
1953: Petroleum possibilities of the James Bay Lowlands area; Ontario Department of Mines, v. 61, 1952, pt. 6, p. 1-58, appendices 59-95 (brief description of Long Rapids, several oil shale analyses).

NELSON, S.J., and JOHNSON, R.D.
1966: Geology of Hudson Bay Basin; Bulletin of Canadian Petroleum Geology, v. 14, no. 4, p. 536, 566-567 (report of Ordovician oil shale on Southampton Island).

1976: Oil shales of Southampton Island, northern Hudson Bay; Bulletin of Canadian Petroleum Geology, v. 24, no. 1, p. 70-91 (distribution of oil shale rubble and 95 analyses).

NORRIS, A.W., and SANFORD, B.V.
1968: Paleozoic and Mesozoic geology of the Hudson Bay Lowlands; in, Earth Science Symposium on Hudson Bay; ed. P.J. Hood, Geological Survey of Canada, Paper 68-53, p. 194 (brief description of Long Rapids Formation).

1973: The Hudson Platform; in, Future Petroleum Provinces of Canada; ed. R.G. McCrossan, Canadian Society of Petroleum Geologists, Memoir 1, p. 387-409 (interpretive geology of the area, correlates Southampton Island oil shale to Collingwood of southwest Ontario).

1975: Devonian stratigraphy of the Hudson Platform - stratigraphy and economic geology; Geological Survey of Canada, Memoir 379, pt. 1, p. 2, 13, 18-19, 72-80, 85, 89 (defines and briefly describes Long Rapids Formation).

SANFORD, B.V., NORRIS, A.W., and BOSTOCK, H.H.
1968: Geology of the Hudson Bay Lowlands (operation Winisk); Geological Survey of Canada, Paper 67-60, 118 p. (stratigraphic background data).

SATTERLY, J.
1953: Drilling in James Bay Lowland: Part II - Results of other drilling; Ontario, Department of Mines, Annual Report, 1952, v. LXI, pt. 6, p. 141-157 (descriptions of core holes through Long Rapids).

SAVAGE, T.E., and VAN TUYL, F.M.
1919: Geology and stratigraphy of the area of Paleozoic rocks in the vicinity of Hudson and James Bay; Geological Society of America, Bulletin, v. 30, p.341, 373, 377 (limited description of Devonian Long Rapids Formation, outlining "bituminous" content).

WILLIAMS, N.Y.
1920: Paleozoic rocks of Mattagami and Abitibi Rivers; Geological Survey of Canada, Summary Report, 1920, pt. G. p. 11-12 (brief reference to oil shales and some analyses).

MARITIME PROVINCES

CARBONIFEROUS

The climax of the Acadian orogeny occurred during Middle to early Upper Devonian in the Maritimes, at which time the area was uplifted and eroded: downwarp and sedimentation re-commenced during the Upper Devonian and continued through the ensuing Carboniferous and Permian. The downward phase was accompanied by tectonic activity, which is defined, in this area, as the Maritimes Disturbance. With the exception of a Middle Mississippian marine incursion, a thick series of terrigenous clastics was deposited along a complex geosynclinal trend, the Fundy Geosyncline (Fig. 13). The Fundy Geosyncline is a composite of individual troughs, sub-basins and intervening uplift areas, showing an irregular history of positive and negative movement which decreased with time. Sediments of Upper Pennsylvanian and

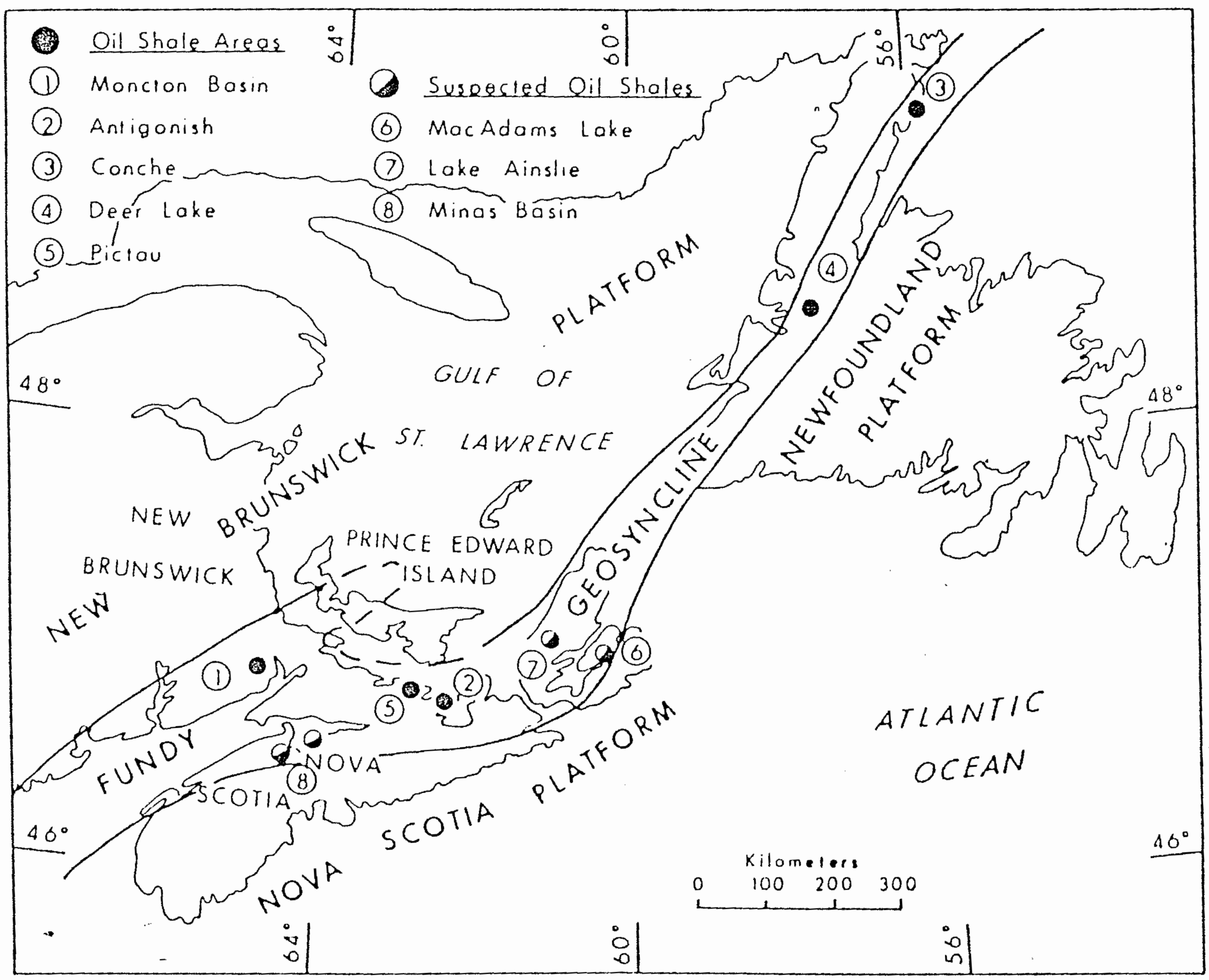


FIGURE 13. Major tectonic elements and potential oil shale areas, Maritime Provinces

Permian age are thick in the basinal downwarps, but are only gently warped and/or faulted in contrast to the more severely affected earlier Devonian and Mississippian strata. Initially the Fundy Geosyncline was narrow, but widened with time by encroachment onto the bordering platform areas.

Because of the tectonic irregularity, with local areas of uplift and erosion occurring within only kilometres of depositional areas, and the constant geographic shifting of the tectonic activity, probably no single area will provide a complete stratigraphic history of the Fundy Geosyncline. The entire record of this period can only be represented by a composite of sections throughout this geosynclinal area. All known Maritimes oil shales were deposited within Carboniferous time in the Fundy Geosyncline.

Virtually the entire stratigraphic sequence of Nova Scotia and New Brunswick was established between 1921 and 1929 by W.A. Bell: most of his nomenclature is still in use today, although one significant modification has been made. Bell's initial units were called "Groups," but were based primarily on paleontological boundaries: as such, the units were "Series" rather than lithologically defined groups. Disconformities separated all Bell's units, a factor which he considered important through the belief that these disconformities were everywhere continuous. Additional knowledge of the area has established the local character to his disconformities, and has also recognized the diachronous nature of the upper and lower boundaries of the Middle Mississippian marine incursion into the otherwise entirely continental sequence. Thus Bell's units have now been re-defined as lithologic groups only, completely removing the initially inferred time connotation.

Because of the continental depositional environment, macro-paleontological data are sparse: most of the age dating and correlation is dependent upon miospores. Investigations of this type have increased considerably in the past few years and will undoubtedly do much to assist in better correlations across the area especially for the Pennsylvanian part of the section, wherein many problems still exist.

Figure 14 is a generalized correlation chart of the Maritimes Upper Devonian-Carboniferous section. Although the oil shales could be described in considerable detail without this regional stratigraphic-tectonic background, an appreciation of the sedimentary framework is considered beneficial to understand better the origins and subsequent geologic history of the individual oil shale areas. Intervals containing oil shales are indicated on the correlation diagram.

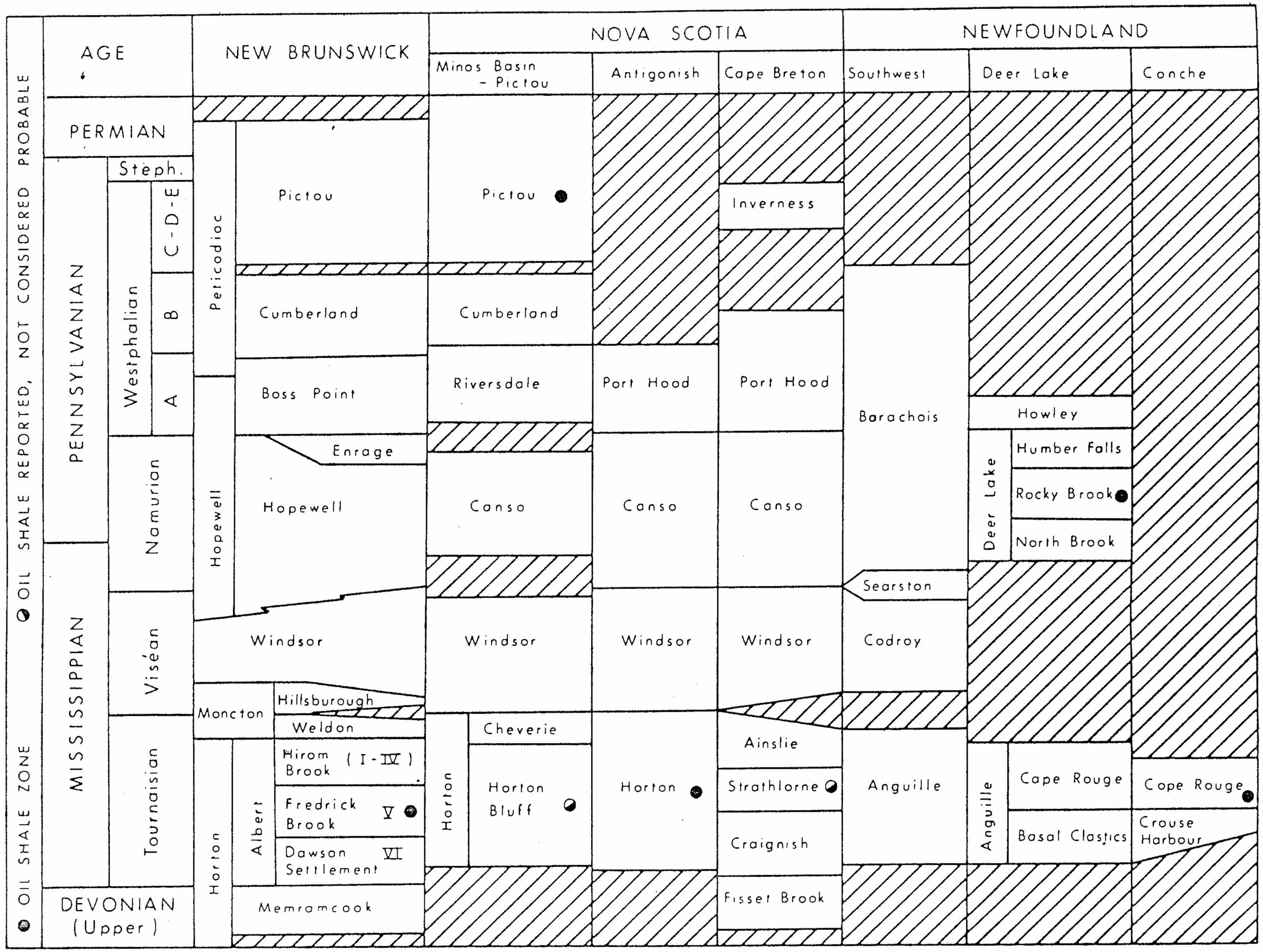


FIGURE 14. Carboniferous correlations, Maritime Provinces

This has been a brief summary statement of the tetonic history and regional stratigraphic problems of the area. Where pertinent, more specific references and detail will be made as each oil shale area is reviewed. A following reference list provides a basis for this summary. Of the selected publications, the reader should definitely review Kelley (1967) for stratigraphic detail and Poole (1967) for a tectonic history prior to becoming involved in any more detailed an approach to specific areas than is presented herein. Hacquebard (1972) is also a preferred reference for the sedimentary framework of the Maritimes Carboniferous.

Selected references - Maritimes

BAIRD, D.M., and COTE, P.R.
1964: Lower Carboniferous sedimentary rocks in southwestern Newfoundland and their relations to similar strata in western Cape Breton Island; Canadian Institute of Mining and Metallurgy, Bulletin, v. 57, no. 5, p. 509-520 (southwestern Newfoundland standard correlations, does not include stratigraphy of oil shale area).

BELL, W.A.
1927: Outline of Carboniferous stratigraphy and geological history of the Maritime Provinces of Canada; Royal Society of Canada, Transactions, ser. 3, v. 21, p. 75-108 (good review of Bell's concepts; newer articles make this one historical).

BELT, E.S.
1968: Carboniferous continental sedimentation, Atlantic Provinces, Canada; Geological Society of America, Special Paper 106, p. 127-176 (interpretation of environments from sedimentary structures with correlation of sedimentary environments to tectonic history).

1968: Post-Acadian rifts and related facies in eastern Canada; in, Recent Advances in the Geology of Northern Appalachians, eds. J.B. Hadley, J.B. Thompson, W.S. White and E. Zen; John Wiley and Sons, New York, p. 97-106 (a proposed tectonic framework for Carboniferous sedimentation).

DAWSON, J.W.
1855, 1868: Acadian Geology: an account of the geological structure and mineral resources of Nova Scotia and portions of the neighboring Provinces; Oliver and Boyd, Edinburgh (1st ed.); Macmillan and Co., London (2nd ed.) (comparison of Maritimes Carboniferous to that of Scotland, historical interest).

ELLS, R.W.
1909: Bituminous shales of Nova Scotia and New Brunswick: with notes on the geology of the oil-shales of Scotland; Geological Survey of Canada, Summary Report, 1908, p. 132-142 (locations and analyses, no significant geology, quantity-quality comparisons to Scotland shales).

ELLS, R.W.
1909: Notes on the geology of the oil-shales of Scotland, and their relations to somewhat similar oil-shales in eastern Canada; Royal Society of Canada, Transactions, section IV, p. 35-44 (historical interest, generalized lithologic comparisons only).

1910: The oil-shales of the Maritime Provinces; Mining Society of Nova Scotia, Transactions XIV, p. 1-13 (historical interest, generalized descriptions, comparisons to Scotland).

1910: Oil-shales of eastern Canada: Geological Survey of Canada, Summary Report, 1909, p. 200-216 (geographic distribution and analytical data, little geology, historical interest).

GEOLOGICAL SURVEY OF CANADA
1941: Possible future oil provinces of eastern Canada; American Association of Petroleum Geologists, Bulletin, v. 25, no. 8, p. 1551-1555, 1558-1562 (generalized oil shale references only).

HACQUEBARD, P.A.
1972: The Carboniferous of eastern Canada; International Congress on Carboniferous Stratigraphy and Geology, 7th, Germany, Compte rendu, v. 1, p. 63-90; Geological Survey of Canada, open file report no. 76 (a preferred reference for regional sedimentary framework).

HOWIE, R.D.
1970: Oil and gas exploration - Atlantic coast of Canada; American Association of Petroleum Geologists, Bulletin, v. 54, no. 11, p. 1989-2006 (generalized regional geology, not specifically related to oil shales, excellent reference list for stratigraphy).

HOWIE, R.D., and BARSS, M.S.
1975: Upper Paleozoic rocks of the Atlantic Provinces, Gulf of St. Lawrence, and adjacent contenental shelf; in, Offshore Geology of Eastern Canada, ed. W.J.M. van der Linden and J.A. Wade, Geological Survey of Canada, Paper 74-30, p.2,35-50 (good stratigraphic references).

1975: Paleogeography and sedimentation in the Upper Paleozoic, eastern Canada; in, Canada's Contenental Margins and Offshore Petroleum Exploration, eds. C.J. Yorath, E.R. Parker and D.J. Glass; Canadian Society of Petroleum Geologists, Memoir 4, p. 45-57 (good general background geology).

KELLEY, D.G.
1967: Some aspects of Carboniferous stratigraphy and depositional history in the Atlantic Provinces; in, Geology of the Atlantic Region, eds. E.R.W. Neale and H. Williams; Geological Association of Canada, Special Paper 4, p. 213-227 (essential reference to understand stratigraphy and nomenclatural history of the area).

1970: Geology of southeastern Canada; in, Geology and Economic Minerals of Canada, Economic Geology Report #1, ed. R.J.W. Douglas; Geological Survey of Canada, p. 284-296 (basically the same as 1967 publication).

PLAYFORD, G.
1968: Miospores from the Missippian Horton Group, eastern Canada; Geological Survey of Canada, Bulletin 107, p. 38-43 (example of the correlation value of miospores in the Carboniferous).

POOLE, W.H.
1967: Tectonic evolution of the Appalachian region of Canada; in, Collected papers on geology of the Atlantic Region; Geological Association of Canada, Special Paper 4, p. 9-51 (required reading for background tectonic history of the Maritimes).

ROSEWARNE, P.V., CHANTLER, H. McD., and SWINNERTON, A.A.
1936: Analyses of Canadian crude oils, naphthas, shale oil and bitumen; Canada Department of Mines, Mines Branch, Report No. 765, p. 9-12 (scattered analytical data, illustrates comparative differences of shale oil and crude oil).

Van de POLL, H.W.
1972: Stratigraphy and economic geology of Carboniferous basins in the Maritime Provinces; International Geological Congress, Montreal, 24th Session, Guidebook A60, 96p. (quick reference to Maritimes regional stratigraphy).

1978: Paleoclimatic control and stratigraphic limits of synsedimentary mineral occurrences in Mississippian - early Pennsylvanian strata of eastern Canada; Economic Geology, v. 73, p. 1069-1081 (interesting relationship of mineralization to the stratigraphic sequence assists understanding of the sedimentary framework).

WILLIAMS, E.P.
1973: St. Lawrence Lowlands, Gaspé and Gulf of St. Lawrence areas; in, Future Petroleum Provinces of Canada, A Symposium, ed. R.G. McCrossan; Canadian Society of Petroleum Geologists, p. 561-564, 576-580 (brief equation of stratigraphy - tectonics, and oil shale, to petroleum potential).

YOUNG, G.A.
1909: A descriptive sketch of the geology, and economic minerals of Canada; Geological Survey of Canada, Report no. 1085, p. 57-58 (mostly locations, minor geology, comparison to Scotland shales, historical reference).

CARBONIFEROUS OF NEW BRUNSWICK

Interest in the oil shales of New Brunswick started, not with the shales themselves, but with albertite, a black vertical vein, variably one third of a metre to 5 metres thick, cutting through the associated oil shale strata. In the 1852 court case of Gesner vs. Cairns, Cairns owned the mining rights to coal: Gesner contended that albertite was not coal because of its intersection rather than parallelism with enclosing strata and its ease of ignition compared to coal. In spite of these geological and chemical considerations, the court ruled albertite to be a coal product.

Albertite was then mined during the years 1863-1874, shipping a total of 154,800 tons to the United States. The vein was mined to a depth of 335 metres at which time the major reserves had been exhausted. At a selling price of $20.00/ton, the albertite yielded 100 gallons shale oil and 14,500 cubic feet of gas per ton. Because the albertite was defined as coal, coal royalties applied, yielding slightly over 8,000 dollars to the Government.

The first significant oil shale exploration was conducted in 1907-1908 by a local company, with the Geological Survey of Canada providing supervisory assistance. Some 45 tons of oil shale were shipped to the Pumpherston Oil Company, Midcalder, Scotland, and the results published by the Canada Department of Mines (R.W. Ells, 1909). This sample averaged 40 gallons/ton (200 L/tonne) and 77 lbs/ton (38.5 kg/tonne) ammonium sulphate.

From 1917 to 1927, the D'Arcy Exploration Company periodically drilled for oil shales in New Brunswick and constructed an experimental plant near Rosevale. The plant operated more or less for 9 months in 1921-1922, retorting oil shale mined from various outcroppings in the area. The final result of this operation was reportedly 37 gallons shale oil and 60 lbs ammonium sulphate per ton (185 litres and 30 kilograms/tonne respectively).

During this same period, Wright (1922) published the first detailed study of the Albert Mines area, where the albertite had been mined; he made the first subdivision of the Albert oil shales into several distinct outcropping beds, and discussed the variable oil content of his different zones. This report summarized the bore-holes to that date and included 47 analyses of surface samples, most of which were well below the yields indicated by previous work. This was the first publication to include maps whereby the sample locations and drill hole sites were located for the reader. His comments on the working shaft of the Albertite mine and on the three main tunnels, and his use of sampling techniques that were not based on high-grading, formed a report from which most of the conclusions concerning the prospectiveness of the Albert Mines property could then have been made.

In 1927, the Maritime Eduction Co. Ltd. erected a plant near Rosevale, but closed through bankruptcy in 1928 before achieving any significant production.

The largest exploration program of the area was conducted in 1942 by the Canadian Department of Mines and Resources, when 79 holes were drilled, totalling 24,500 feet (7483 metres) in three areas, with 36 holes near Rosevale (10,380) feet, 3163 metres), 36 at Albert Mines (13,128 feet, 4000 metres) and 7 at Taylor Village (1052 feet, 320 metres). The relative geographic distribution of these areas is illustrated on Figure sixteen. From the results, published as the Canada Department of Mines and Resource Report #825 (Timm et al., 1948), Albert Mines was considered to have 100,000,000 tons (90,700,00 tonnes) of oil shale to a depth of 400 feet (122 metres) with an average yield of 10.6 gallons/ton (53.1 litres/ton).

Exploration remained dormant until 1967-1968 when the Atlantic-Richfield Company drilled 10 holes to test oil shale values at depth. These data have just recently been released by the company, several years prior to the expiry of confidential status, and will be included herein.

Further deep drilling was conducted in 1976 by Canadian Occidental Petroleum Ltd., but data from this program are still confidential.

Although numerous other publications are referenced in the time span up to 1950, only the above mentioned are now of much more than historic interest. Those outlined above are dominantly economic papers.

Gussow (1953) published the first comprehensive study of Carboniferous stratigraphy and structural geology of New Brunswick: this paper was the start of continued interest in both the stratigraphy and the geology, with considerable attention paid to the interpretation of depositional environments. Most of the papers referenced since 1953 are significant to the geological understanding of this area, especially Greiner (1962, 1974), Howie (1980), Pickerill and Carter (1980), Roulston (1978) and St. Peter (1974). Of these reports, Howie and/or Pickerill and Carter will provide the most comprehensive recent update of the geology directly pertinent to the Albert oil shales.

Stratigraphy

Carboniferous strata rest with pronounced angular unconformity on a basement of earlier Paleozoic and Precambrian rocks. Ordovician, Silurian and Devonian beds are crystalline limestones, slates, arkosic sandstones and quartzites, all of which were metamorphosed during the Acadian orogenic uplift. Gneiss, schist, quartzite, slate and greenstone are present in the Precambrian section. These rocks all constituent an effective basement for any hydrocarbon or oil shale potential.

Oil shales occur within the Horton Group, which is divisible into 3 distinct color zones, including basal and uppermost red units, with a medial grey sequence. The grey sequence, the Albert Formation, contains the oil shale interval.

The "Lower Red Beds" (Gussow, 1953), the Memramcook Formation of present terminology (Fig. 14), is composed of conglomerate, sandstone, siltstone and shale, commonly red, often distinctively purplish-red, and with green intervals. The upper contact is generally conformable with, and gradational to, the overlying Albert Formation although local disconformities are suspected. Because of the interlensing of the color types, the contact has been defined in the subsurface by drillers at the top of the uppermost red bed. The contact has arbitrarily been placed where either red or grey becomes dominant. Hacquebard (1972) indicated a late Devonian age on the basis of miospores.

Overlying the Memramcook, the Albert Formation, which was proposed by Hayes (1927) and formally defined by Norman (1932), is primarily a grey shale sequence. Arkosic sandstones, both arkosic and greenstone conglomerates, and dark dolomite marls (oil shales) are also present. A localized salt sequence occurs in the uppermost part of formation.

Greiner (1962) proposed a three-fold subdivision of the Albert Formation (Fig. 14) to include a lower unit of sandstone, siltstone, shale and conglomerate, the Dawson Settlement Member, a medial Frederick Brook Member of oil shale, limestone, calcareous shale and siltstone, and the uppermost Hiram Brook Member of siltstone, shale and calcareous sandstone. The local salt-bearing zone, the Gautreau evaporite occurs within the Hiram Brook Member.

An original oilfield terminology was established by the drillers during development of the Stony Creek field (Fig. 14) whereby the upper Albert was divided into 4 sandstone-bearing intervals, I through IV, overlying the interval of dominant oil shale, zone V, and with sandstone zone VI at the base. Although attempts have been made to utilize this subdivision beyond the field limits, the rapid lateral facies changes has prevented this nomenclature supplanting that of Greiner. The grey color of the Albert in places grades into the red of the Weldon Formation, whereas in other places the contact is abrupt.

This formational boundary was placed by the drillers at the base of the last red bed, but can also be arbitrarily chosen at the change of color dominance.

A Mississippian age was assigned to the Albert Formation by Dawson (1878) and Bell (1927) on the basis of plant remains. Varma (1969), on the basis of miospores, correlated to the Horton Group of Nova Scotia and was able to differentiate Greiner's three zones. More recent work indicates the Albert Formation to range from possible late Upper Devonian (Fammenian) through Tournasian to possible Viséan (essentially lower Mississippian) (Pickerill and Carter, 1980).

The uppermost red sequence, the Moncton Group, can locally be divided into a lower Weldon Formation and overlying Hillsborough Formation. These beds were the uppermost Horton Group, if correlated to the biostratigraphic unit defined by Bell, but are now locally removed from the Horton under the general re-definition of that Group.

Sediments of the Weldon Formation are red mudstones, shales, siltstones and sandstones, and are overlain by coarser grained red conglomerate of the Hillsborough Formation. In places there is a transition in grain size from fine to coarse upward, representing a conformable sequence: at these localities, the Moncton Group is not subdivided. Elsewhere, the lower finer units are obviously eroded and structurally contorted below the Hillsborough conglomerates. The Moncton Group is an excellent example of the local discontinuities and irregularities that could occur due to tectonic activity within the framework of the geosynclinal downwarp. The upward transition from the Hillsborough clastics to the carbonates and evaporites of the Windsor Group is probably mostly continuous and conformable, but also appears to be diachronous. Sediments of the Moncton Group are probably all Viséan in age, corresponding to that of the overlying Windsor Group. An attempt has been made to illustrate the facies and age relationships of these units on Figure 14 in the regional correlation section.

Both Greiner's and the driller's subdivision are based on recognition of the oil shale facies, but this facies laterally give way to deltaic sandstone-shale deposits. Within these areas, the total unit is mapped as the undivided Albert Formation. Correlations are made by grain size variations, by mineral aggregrates, and by miospore zones, wherever possible. There seems to be a desire among those publishing on the area to establish a single terminology, but this is a virtual impossibility for a sedimentary sequence of this nature.

Lithology

General lithologies have been described for the major stratigraphic zones, which are required as a background for the geological understanding of the oil shale unit of this area. No further lithologic detail will be provided for these other zones. The reader should review Gussow (1953), Howie (1980), and Pickerill and Carter (1980) if further detail is desired. The lithology discussed in this section will be entirely that of the Frederick Brook Member, the oil shale zone.

Albert oil shales are rhythmically thinly bedded, laminated to papery, dark brown to black, kerogenous dolomite marlstone, typical of a lacustrine environment. These marlstones are associated with some massive dolomite marlstones, sandy marlstones and thin beds of argillaceous siltstone. The laminated marlstones contain an abundant well-preserved paleoniscid fish fauna which at times has been the subject of as much interest as has the oil shale potential.

King (1963) described the basic lithologic variations in considerable detail. His report is essential for a comprehensive understanding of the distribution of kerogen within the lithologic types encountered.

1. Blocky laminated marlstones contain 30-40% kerogen and 30-40% very fine dolomite grains (X-ray identification). The laminae become easily contorted, containing numerous microfolds and faults. Laminae are present in couplets, alternately high and low in dolomite and kerogen respectively. The varves are created by the alternating mineral layers (kerogen and dolomite): this lamination is the justification for use of the descriptive term "shale." The organic matter is present as elongate, fusiform-shaped bodies, which appear to be capped by a thin anhydrite layer.

These laminae are definitely not glacial varves, but appear to be related to the seasonal growth of surface algae. Algae, utilizating CO_2 from the water, reduce the solubility of calcium and magnesium by destruction of the soluble HCO_3 ion, thus precipitating calcite or dolomite from the water. This can account for the dolomite laminae: organic matter is deposited as the algae are seasonally destroyed at the lake surface. The possible anhydr te layer could result from alteration of the last carbonate vestiges on the algal surface by sulphates at the reducing water-sediment interface.

2. Papery marlstone has fewer pure organic laminae than does the blocky variety, and the carbonate content may also diminish as feldspar and quartz increase. The varves are still evident, but are somewhat less distinct.

3. Sandy marlstone consists of thin beds containing detrital quartz within the dolomite-kerogen ooze, with additional inter-bedded layers of clay-kerogen complex.

4. Massive dolomite marlstone is a thicker bedded admixture of detrital grains and kerogen, with some spherical dolomitic bodies resembling algae.

When highly contorted, the blocky marlstones are described as "curly beds." In all forms, the blocky marlstones are the richest in organic content, although for some time after the discovery and first investigations of the oil shales, the "curly beds" were ignored because of an erroneous impression that shale oil recoveries from them would be low.

From the above generalizations of lithologic types, lateral and vertical gradations to the grey shales, sandstones, siltstones and dolomites of the other Albert Formation members and facies can be readily visualized. On a generalized lithologic log of well no. 67 from the Stony Creek field (Howie, 1980, Fig. 4), driller's zone V, the Frederick Brook equivalent, is illustrated as interbeds of bituminous shale, grey shale, and sandstone.

Distribution and Thickness

Exposures of the Albert Formation, and consequently of the Frederick Brook oil shale member, are entirely within the Moncton sub-basin of the Fundy Geosyncline (Fig. 15). The sub-basin is bounded on the northeast by the Kingston uplift, beyond which deposits of the New Brunswick platform are recognized. The sub-basin is limited southeasterly by the Caledonia uplift and northeasterly by the Westmorland uplift and also by deepening into a possible area of geosynclinal subsidence under Prince Edward Island and the Gulf of St. Lawrence.

Equivalent Horton Group sediments are present in the Cumberland and Minas Basins of Nova Scotia, east-southeasterly of the Caledonia Arch. Most writers conclude that deposition of the Horton Group was discontinuous across the Caledonia Arch: the present geographic distribution is considered to

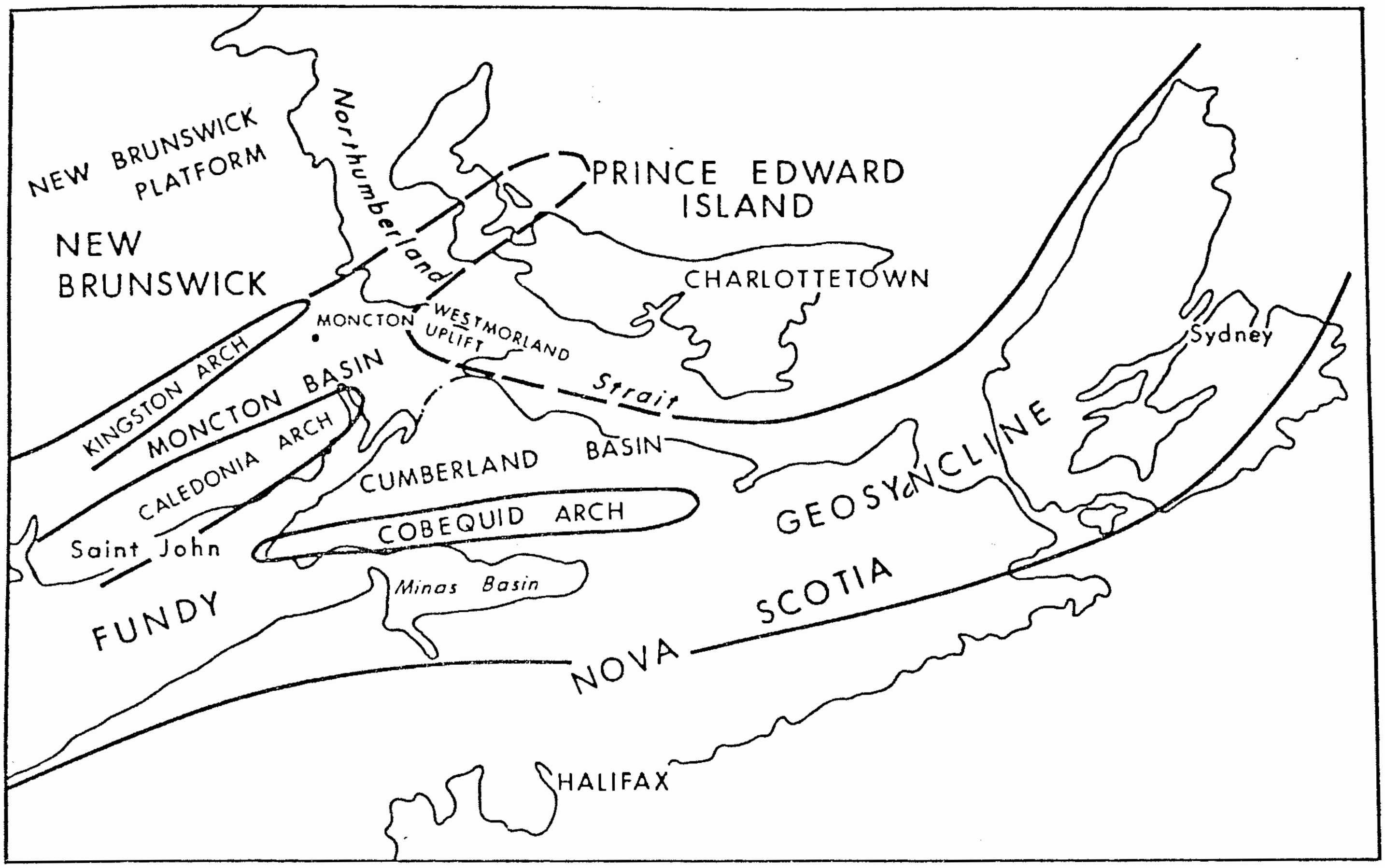


FIGURE 15. Tectonic elements of the Fundy Geosyncline, New Brunswick and Nova Scotia

resemble closely the initial depositional extent. Environmental patterns of sedimentation have been mapped on this belief. Some consideration must be given to the possibility of depositional continuity, with subsequent uplift and erosion, across the arch area. Some of the observed contacts of Frederick Brook oil shale with the underlying effective basement rocks may be uplift fault controlled rather than depositional: this could severely alter structural-stratigraphic interpretations for some areas.

Conglomerate pebbles of the Round Hill Formation (McLeod, 1980), an alluvial fan bordering the northeasterly end of the Caledonia uplift, contain material derived from the adjacent arch. Howie (1980) described the arkosic content of some of the Albert deltaic coarse grained sequence and recognized that their source was probably south of the present Minas Basin. The recognition of different source areas probably signifies discontinuity of uplift along the Caledonia Arch during Horton time.

Although numerous recent publications are available in which the Albert Formation is discussed in considerable detail (Greiner 1962, 1974; Howie, 1980; McCutchin, 1978; McLeod, 1980; McLeod and Ruitenberg 1978; Pickerill and Carter, 1980; and St. Peter, 1974), two publications must be relied upon to provide most of the data to map the surface distribution of the oil shale zone. The older report of the two, by Bailey and Ells (1878), is generalized and published without maps, but gives good geographic description: more importantly, the Albert Formation compilation (Carter and Shaw, 1979) has an excellent map of the Albert outcrop. From the text, a distributional pattern of the oil shales can be inferred. Figure 16 here illustrates the distribution of the Albert Formation, with an attempt to outline oil shale areas from interpretation of the published data.

All literature, both early and recent, refers to the outcrop areas of Albert Formation by geographic names. Specific exposures, within each outcrop trend, were identified by local topographic features; consequently, several location names have been applied for each outcrop grouping. The most prominent name has here been selected for each outcrop area, but other prominent names are also listed.

Albert oil shales (Frederick Brook) outcrop along east-northeasterly trends across the southerly part of the Moncton sub-basin paralleling the Caledonia Arch. Of these two trends, the southernmost is probably the better known, containing the best oil shale development, and including the Rosevale

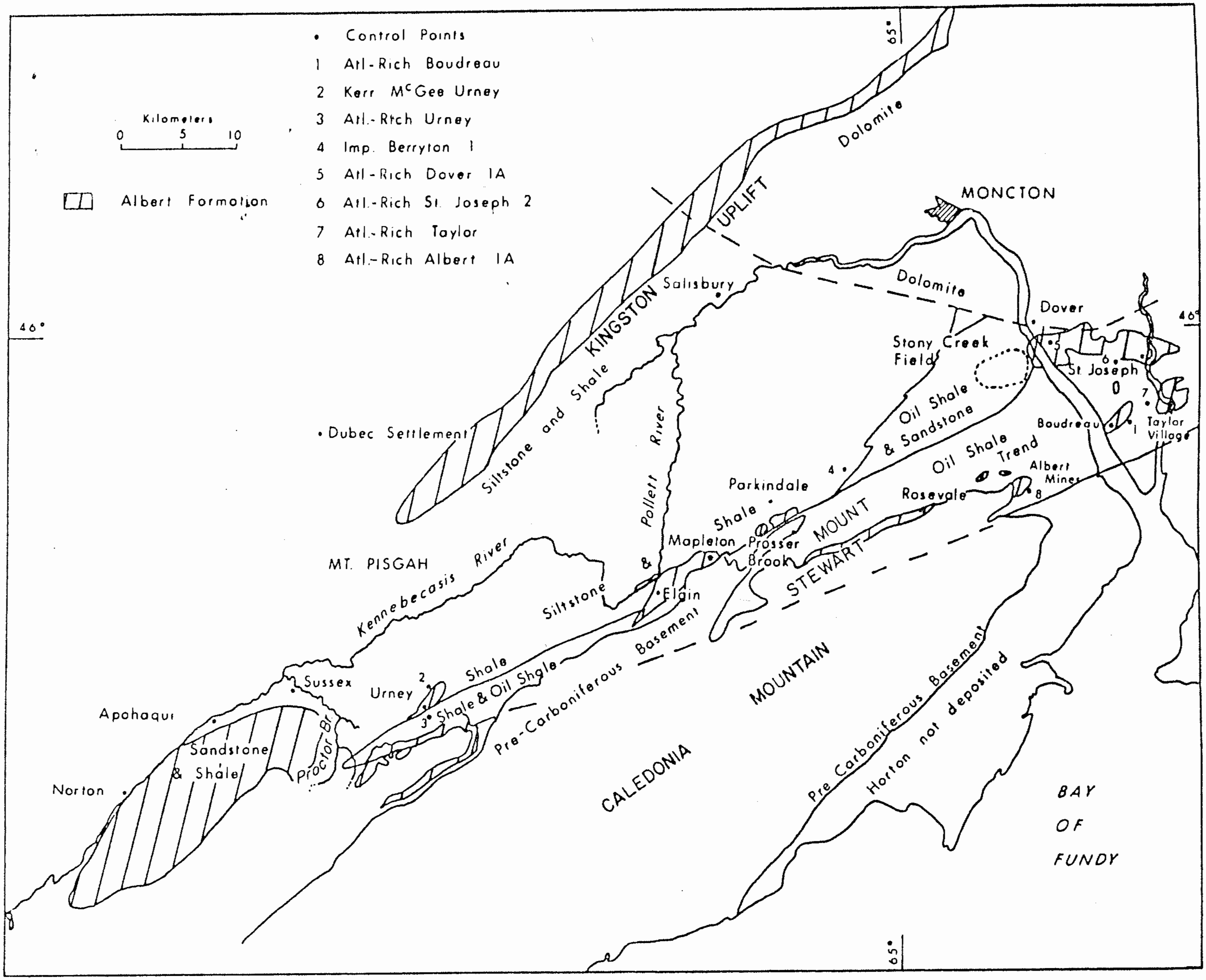


FIGURE 16. Outcrop areas of Albert Formation with interpreted lithologies of the Frederick Brook Member, New Brunswick

area (Turtle Creek, Prosser Brook, Baltimore, Weldon Creek), the Albert Mines deposit, and Taylor Village (Dorchester, upper Dorchester and Boudreau). The more northerly trend, also described west to east, includes Urney (Sussex, Proctor Brook), Mapleton (Elgin, Pollett R., Pleasant Valley, Goshen), and Dover (Stony Creek, Beliveau and St. Joseph).

Rosevale:

The Albert Formation, including some exposures of Albert oil shale, outcrops along a trend of 8.8 kilometers length and an average width of 335 metres. Most of the surface rocks are greenish-grey shale-siltstone facies, organic shales and underlying conglomerates. Beds dip northward at angles reportedly less than 45 degrees. Of the 37 boreholes drilled in 1942, the maximum thickness penetrated was 154 metres of oil shale zone, most cores encountered between 61 and 85 metres of zone and two penetrated about 113 metres. Considering that the thickest boreholes may have partly followed dip, the zone thickness is probably less than 100 metres (300 feet). There is no evidence of extreme folding or repetition of section in this area. Figure 17 is a map showing the distribution of the core holes. Howie (1970) reported that the Atlantic-Richfield Rosevale #1 directional corehole, located at the eastern (?) end of the outcrop trend, penetrated the Moncton Group (Hillsborough), which overlaid 172 metres of the Hiram Brook Member, 61 metres of Frederick Brook oil shale; and bottomed in Dawson Settlement. This may indicate that the possible 100 metres average thickness estimated from the Rosevale cores may be excessive: an average net thickness may be closer to 60 metres.

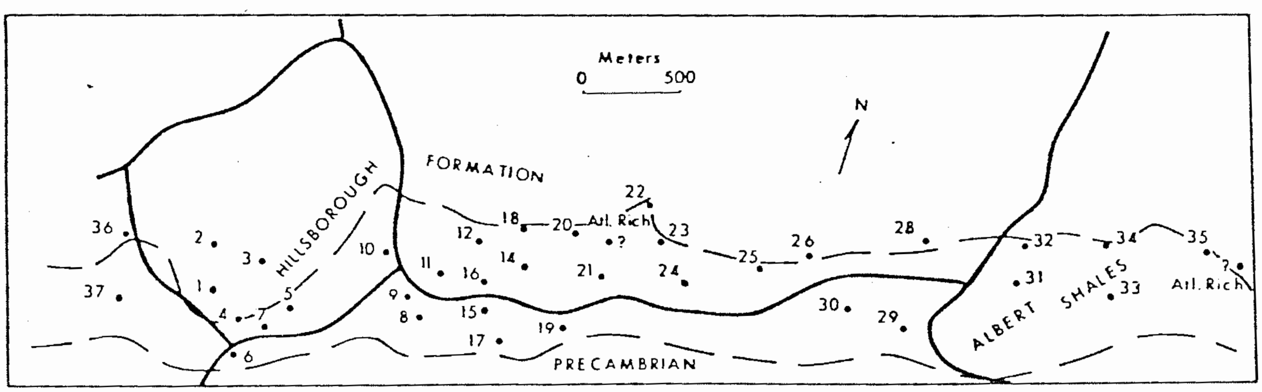


FIGURE 17. Corehole distribution, Rosevale area, New Brunswick

Albert Mines:

Oil shales at Albert Mines outcrop over a small geographic area (Fig. 18) about 1.6 kilometres square (2.6 square kilometres, or 1 square mile). The zone is brought to the surface by a major southwest plunging anticline, with the shales deformed by drag-folding and faulting.

Wright (1922) recognized three lithologic zones at Albert Mines, including a basal conglomerate (Zone 1), oil-rich beds (Zone 2), and inter-bedded sandstone and shale (Zone 3), the same subdivision as later defined by Greiner (1962). Wright estimated the total thickness of oil-bearing zone at approximately 244 metres. Three tunnels had been driven through the oil shales during the early mining of the Albertite vein. From interpretation of the dips recorded in the tunnels, the anticline is evidently a complex structure (Fig. 19). The structural complexity leads to the conclusion that surface thickness estimations, and those of drill holes (even if initially directed into the dip), cannot provide a realistic value for depositional thickness. Although thicknesses up to 300 metres may be locally useable for the mining reserves estimations, this thickness is composed of repeating intervals resulting from the extremely complex structural uplift. Atlantic-Richfield Albert #1A, located on the southeastern flank of the feature, penetrated oil shale to a depth of 515 metres.

Taylor Village:

Scattered oil shale outcrops occur in an inlier of Albert Formation crossing the Memramcook River from Taylor Village at the west to Dorchester at the east. The net surface area of oil shale is estimated by St. Peter (1974) at 5 square kilometres (2 square miles). Three kilometres westerly of Taylor Village, a small outcrop of Albert Formation is present at Boudreau, on the Peticodac River. The structure is here a northeasterly trending anticline, one limb having a slight northwesterly dip and the other varying from 20° to 60° to the southeast.

Of the seven holes drilled in 1942 (Fig. 20), the maximum penetrated oil shale thickness was 41 metres (Alcock, 1948). The Atlantic-Richfield Boudreau hole, between the outcrop areas, penetrated 650 feet (198 metres) of oil shale in the log interval 1003-1653 feet (306-504 metres), but oil yields from several intervals of the gross zone were poor. Without a more extensive study of the area, these figures can only be considered as a maximum possible Frederick Brook thickness.

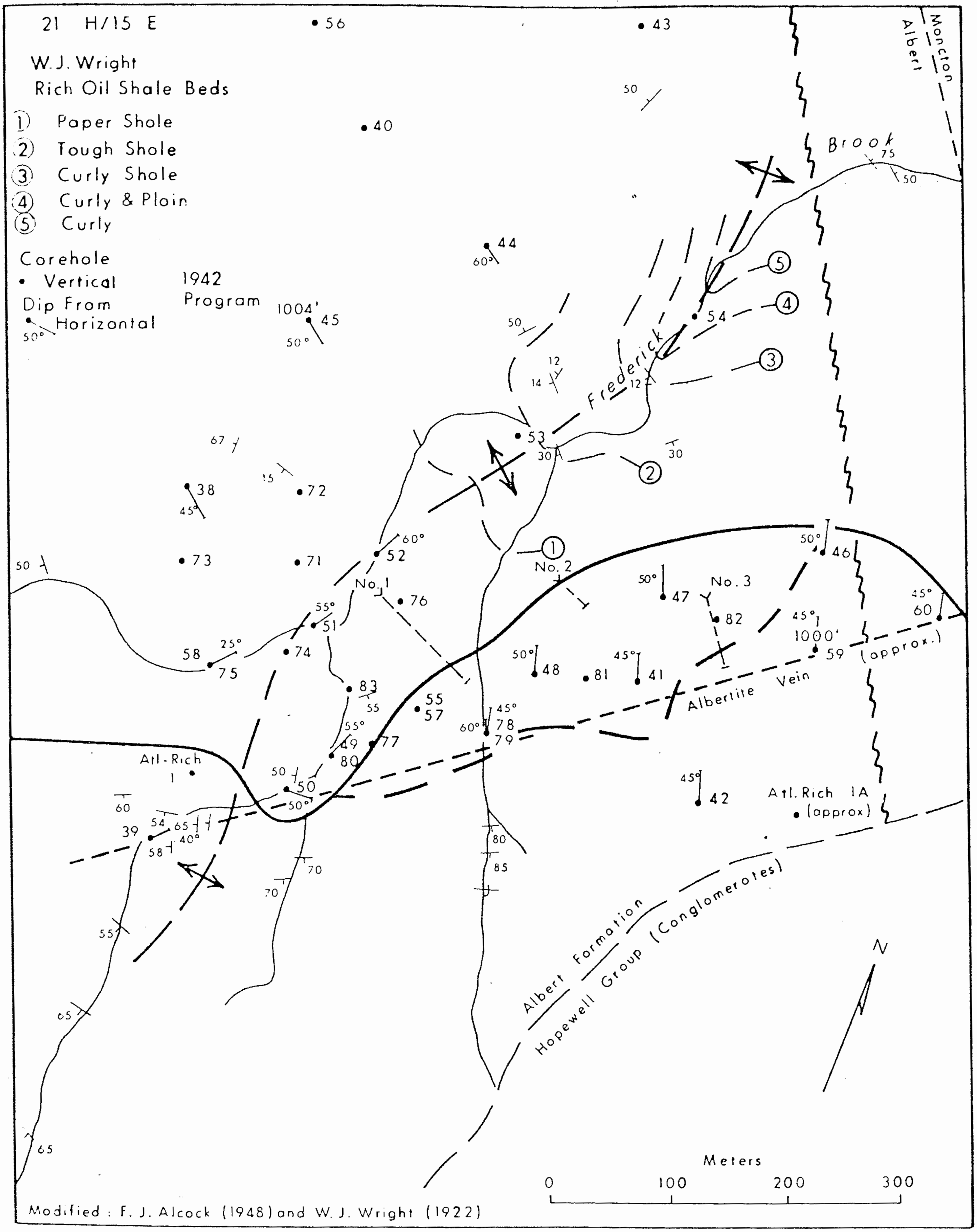


FIGURE 18. Corehole distribution and general surface geology, Albert Mines, New Brunswick

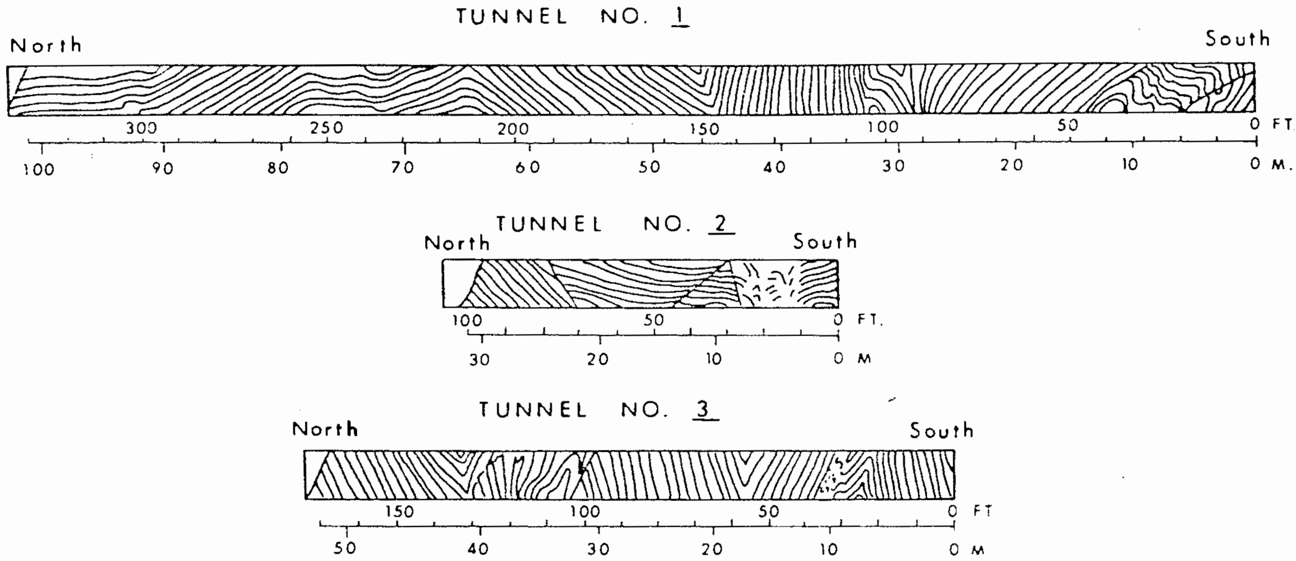


FIGURE 19. Structural attitudes of oil shale beds in tunnels at Albert Mines, New Brunswick

Urney

In the Urney area (Fig. 16), only a few limited outcrops of oil shale are mapped. Most surface rocks of the Albert Formation are sandstones, calcareous sandstones and shale, dominantly the Hiram Brook Member. On Proctor Brook, a thin 1.5 metre bed of oil shale has been reported, but no significant sections are present to establish thickness values. Just north of the outcrop area, Keer McGee Urney #1 penetrated 186 metres of probable Frederick Brook Member as interpreted from the well log prepared by Howie (1980). Howie illustrates this interval as shale, but does not show organic content on his diagram.

Also in the Urney area, the Atlantic-Richfield Urney core hole did not penetrate any significant oil shale zones to a total depth of 957 feet (291 metres), excepting one narrow interval of 4 feet (1.3 metres) which yielded 6.4 gallons/ton.

This outcrop area is essentially continuous westerly to the Apohaqui area were the Albert Formation is exposed. No oil shales were mapped in the Apohoqui exposures, which consists primarily of shales, sandstones and

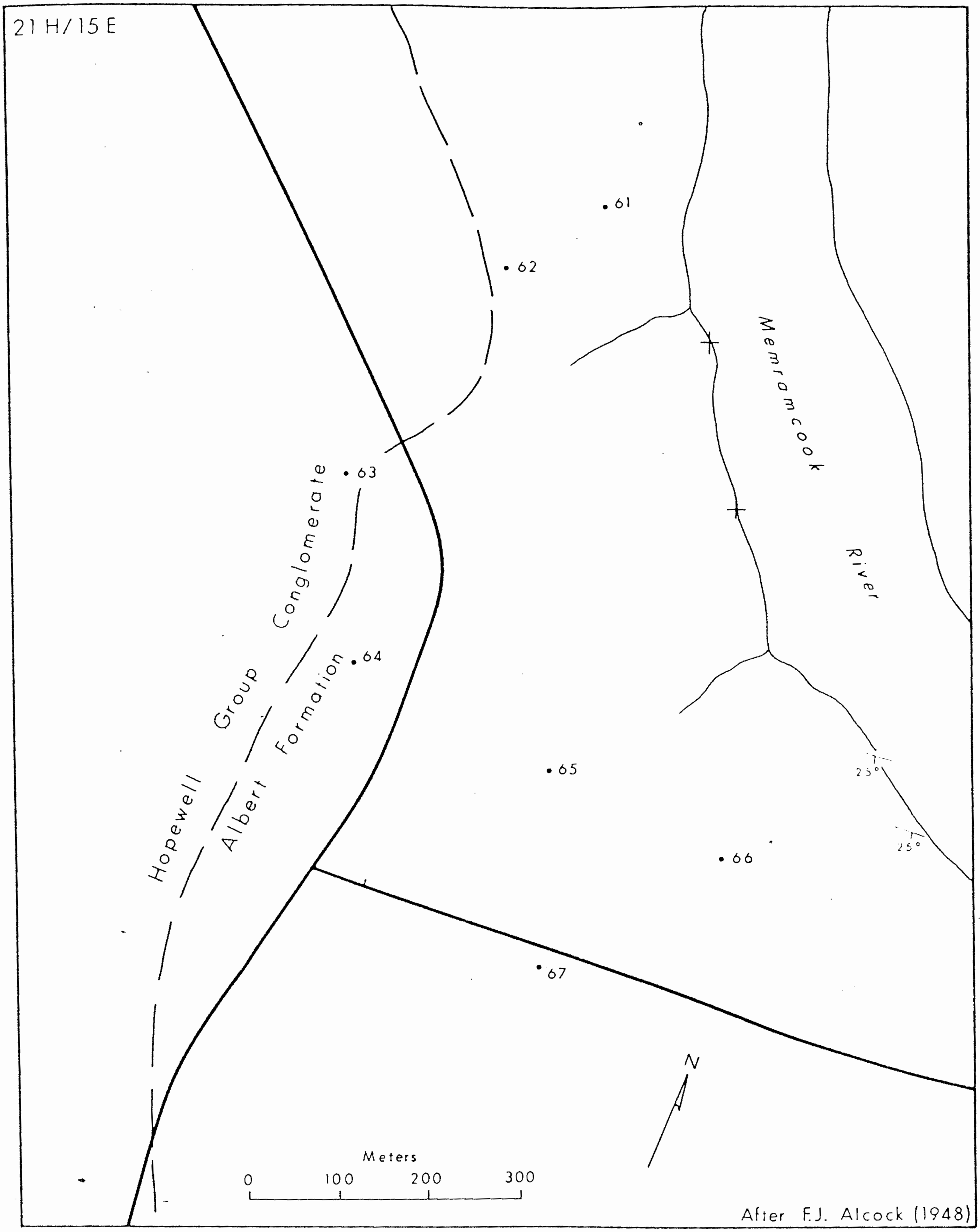


FIGURE 20. Corehole distribution, Taylor Village, New Brunswick

conglomerates (McCutcheon, 1978). Howie (1980) considered oil stained arkosic sandstone on a small westerly outcrop to represent driller zone VI: if correct, the oil shale may be missing at this westerly area due to a facies change.

Mapleton:

Most of the Mapleton area exposures are a grey shale-siltstone facies, with an upper conglomerate, and a similar zone at the base of the section. From the older reports, only scattered thin beds of oil shale occur along the Mapleton outcrop area.

Three kilometres easterly along the Mapleton trend, and 2.5 kilometres north of the Rosevale area, Imperial Berryton #1 hole penetrated a full section of Albert without encountering any significant oil shale beds.

Dover:

Wells in the Stony Creek oilfield (Norman, 1932, Hume, 1932), located west of the Peticodiac River, penetrated through the oil shale beds (driller zone V), at most locations. Howie (1980, Fig. 11) has illustrated the structure and thickness of the driller units across the Stony Creek field. The general thickness of unit V is 130 to 150 metres maximum. Not all of this interval is organic shale, as sandstones are also present (Howie, Fig. 5). In his text, Howie gave a maximum thickness of 107 metres for zone V, which he described to comprise bituminous shale, non-butuminous shale, and siltstone. The proportion of sandstone increases from east to west across the Peticodiac River from the Dover outcrop area to the Stony Creek field. Howie placed the Dover area east of the delta which traverses the area of the Stony Creek field.

Considerable subsurface well control is present in the Dover - St. Joseph area (Dover near river, St. Joseph at east end of outcrop trend) southerly to the Taylor Village area. Most of the reported formational tops do not differentiate beyond Moncton-Albert-Memramcook; consequently, without detailed sample and log studies, estimates of oil shale thickness are not possible.

Atlantic-Richfield drilled two deep test holes in the area, Dover 1A to 275 metres and St. Joseph #2 to 778 metres. Shale oil was recovered from several thin zones in the Dover 1A hole, but these results are difficult to interpret without core examination. Similarly, good yields were obtained throughout most of the section at St. Joseph #2, but again their significance for oil shale thickness is not known.

Kingston Uplift:

From Geology by McCutcheon (1978), the Albert at the western end of the uplift, at Apohaqui, is dominantly sandstone, siltstone, some conglomerates, and non-organic shale. Greiner (1962) indicated the northeasterly end of the uplift to be dolostone in the Albert shale equivalent. No significant oil shales have been reported along this uplift.

Oil Shale Distribution

Greiner (1962, Fig. 2) illustrated a generalized facies distribution for the Albert Formation. Starting with his general concept, and including new data, Figure 16 outlines the present interpreted area for the distribution of oil shale facies within the total Albert Formation. This interpretation is conjectional, implies that some Frederick Brook Member did encroach further onto the area of the present Caledonia Uplift. Subsequent uplift and erosion of that area created the present distribution.

Because of inadequate thickness data, no attempt has been made to present isopach contours for potential oil shale in the area. Much additional work and interpretive analysis will be necessary to prepare such a map.

Mineralogy

King (1963), in an analysis of the origin of the oil shale and the associated albertite, conducted petrographic and X-ray studies of shales from the Albert Mines area. The basic minerals were found to be organic kerogen and dolomite, with the type of marlstone varying with the kerogen-dolomite ratio. Kerogen ranged 30-40% of the rock in the higher yield oil shales. The observed shale oil yields in the range 10 to 30 gallons/tons (50 to 150 litres/tonne) are far less than would be expected if all the kerogen were to dissociate to shale oil.

Quartz and orthclase feldspar may be present, generally in grains less than 20 microns in diameter but ranging to 60 microns in some instances, and with quartz also occurring as a secondary mineral. Pyrite may range up to 2% volume.

Clays may also be present, especially as a clay-kerogen complex. The clay type was not identified by King.

The kerogen is lemon-yellow in the blocky and papery marlstones, assumes a reddish tinge in the sandy marlstones, and is reddish-brown in the massive marlstone. As all zones have probably undergone similar depths of burial and subsequent tectonic activity, a similar maturation history may have created different results if the initial quantities and types of kerogen were not uniform from zone to zone.

Abbott and Barnett (1968) identified the clays as illite and kaolinite, with the kaolinite being an anticipated clay component of the fresh water environment. Analcite (sodium-aluminum silicate) was also present, but the aluminum content is low as dawsonite (sodium-aluminum carbonate) is absent. This is in contrast to the Green River oil shales. Hematite, possibly pyroxene, and a mica-like mineral were determined in the shale ash.

Abbot and Barnett also conducted analyses for trace elements in the ash remaining after complete combustion of oil shale samples. Some 23 trace elements were recognized, and determinations were made for vanadium, nickel, molybdenum and copper. Pickerill and Carter (1980) presented analytical data for 23 elements from 53 surface locations of Albert Formation; however, only a small number were representative of oil shale strata.

Albert oil shale - economic potential

Until 1922, all the reported shale oil recoveries were from isolated outcrop areas, with no attempts made to sample systematically a continuous oil shale section. Wright (1922) published sufficient data to establish that the shale of the Albert Mines area varied from oil-rich to barren, and that the richer shales were more resistant to weathering. This established the "high-grade" character for most of the previous analyses.

To establish a more comprehensive analysis of the different lithologic types, the three tunnels, utilized in mining the albertitie, were examined by Wright, with samples taken when bedding character changed. In all, 43 samples were retorted, yielding shale oil from a maximum 32.2 gallons/ton (160 litres/tonne) to two samples with no recovery. An average of these samples is 15.1 gallons/ton (76 litres/ton), considerably less than the previous high yields. These data cannot be used to indicate reserves as the sampling did not account for thickness variations of the various beds. The specific gravity of the recovered shale oil ranged 0.812 to 0.880, with a 0.848 average value.

Albert Mines:

More detailed information on the Albert Mines was presented by Alcock (1948) in summarizing the 1942 Canada Department of Mines program. Log summaries from 36 diamond boreholes, ranging in depth from 249 to 1004 feet (76 to 306 metres), indicated average recoveries per hole ranging from 4.4 to 14.3 gallons/ton (27.0 to 71.6 litres/tonne). These holes were drilled at angles from vertical to 45^{o}, depending on the location on the crest or flank of the anticline. Two deep holes exceeded 1,000 feet (300 metres) on the outer limbs of the feature. Only the thicknesses of various grade of oil shale were recorded; therefore the degree of interbedding of rich and lean zones cannot be interpreted from the Alcock report. Table 4 and figure 18 of this report repeat those data and illustrate the distribution of the cores from the wartime exploratory program. From the results of that program, the earlier tunnels appear to have traversed a more prolific area of the deposit and the data provided by Wright (1922) represent a richer-than-average yield than is anticipated for the total area.

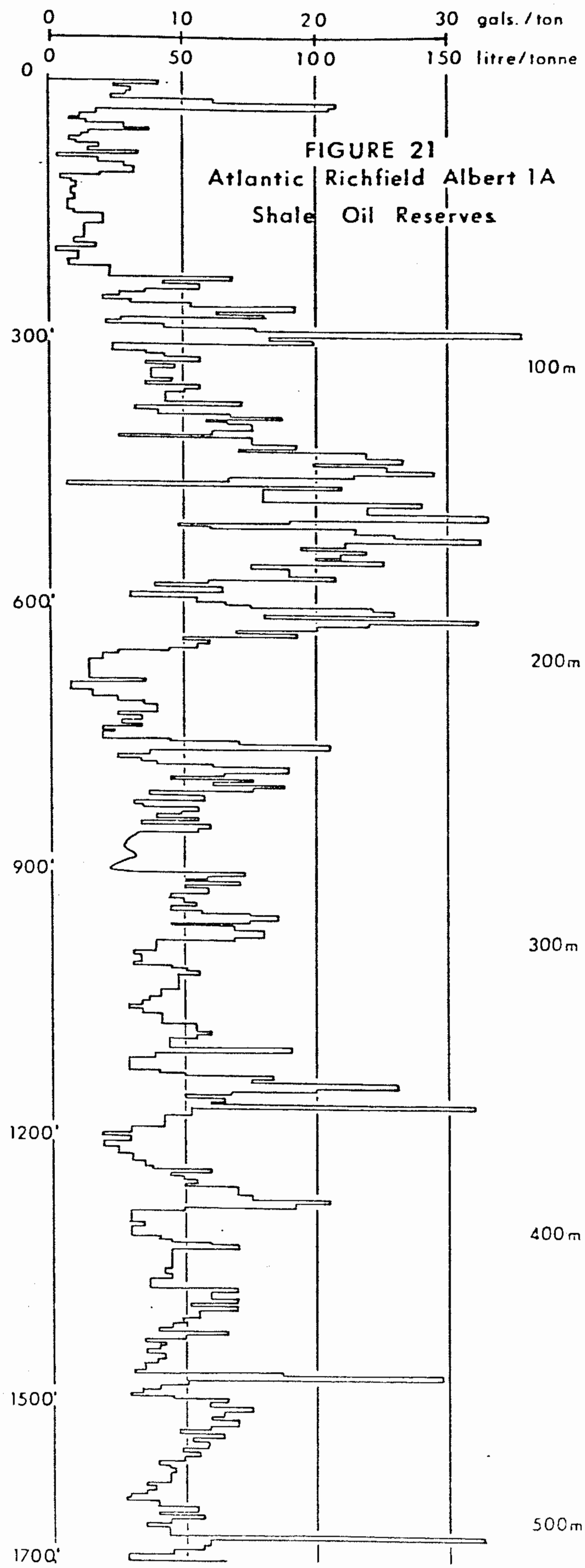
The Atlantic-Richfield Albert Mines 1-A penetrated oil shale to a depth of 1690 feet (515 metres) and encountered good oil shale at 230 feet through to 658 feet for a total thickness of 428 feet (130 metres) of relatively continuous high yield zone (Fig. 21). With analyses conducted over each 4 feet of core, the total cored interval averaged 11.2 gallons/ton (51 litres/ton). Data for this core have been prepared in a form comparable to those of Alcock and are presented at the end of Table four. Except for the greater total thickness of oil zone, the results are quite similar to those of the earlier core program.

Alcock (1948, Fig. 4) showed two cross-sections of the anticline, correlating the shale oil recoveries obtained in the various inclined boreholes. One section, illustrating the northwest limb of the anticline, indicated a high grade zone in the more northwesterly wells. This unit may be comparable to the better interval of the Atlantic-Richfield Albert 1A core. Alcock illustrated only generalized dips, insufficient in detail to assist structural interpretation. From our present knowledge of the tunnel bedding characteristics, dips within the cores are likely to be much more complex than were illustrated. Unforunately, time did not permit core examination of the Atlantic-Richfield cores for incorporation into this study; therefore, structural attitudes are not illustrated.

From the above analytical data, some type of reserves estimate should be possible, but several factors reduce considerably the potential accuracy of any such estimate. Data from the 1943 core program are available, in published form, only as gross interval values. In the Alberta 1A core, isolated high-grade zones are present which may never be mineable because of limited thickness within low grade intervals. The reserves will probably

Hole No.	Footage of various grades g/t					Thickness & avge oil content			
	0-5	5-10	10-15	15-20	20+	Feet	g/ton	Metres	L/tonne
38	130	21	55	55	100	361	12.8	110.0	60
39	295	80	50			425	4.4	129.5	22
40	25	125	124	65	30	369	11.9	112.4	60
41	40	15	40	20	35	150	12.7	45.7	64
42	185	125	40	40	13	403	7.6	122.8	38
43	97	75	45	20	15	252	8.0	76.8	40
44	5	63	110	40	10	228	11.3	69.5	57
46	15	135	135	30		315	10.3	96.0	52
47	25	100	55	25	19	224	11.0	68.3	55
48	120	10	25	24	45	224	9.9	68.3	50
49	54	90	10	10		164	7.2	50.0	36
50	67	5		10		82	5.8	25.0	29
51	42	54	37	59	47	239	14.3	72.8	72
52	69	158	133	108	32	500	11.6	152.4	58
53		131	84	61	18	294	11.9	89.6	60
54	365	228	129	20	25	767	7.0	233.7	35
55	100	85	90	65	30	370	10.4	112.7	52
56	240	410	250	55	26	981	9.0	298.9	45
57	50	75	95	45	110	375	14.1	114.3	71
58	97	79	64	63	60	363	12.9	110.6	65
59	253	370	225	80	35	963	9.0	293.4	49
60	251	110	30	10		401	5.1	122.2	26
71	65	80	45	20	15	225	9.0	68.6	45
72	55	30	30	10	5	130	7.8	39.6	39
73	110	40	85	60	80	375	12.5	114.3	63
74	57	129	60	50	40	336	10.4	102.4	52
75	176	170	65	35	25	471	8.0	143.6	40
76	122	95	25	5	5	252	6.0	76.8	30
77	50	90	80	30	30	280	11.4	85.3	57
78	93	46	40	10	25	121	9.2	36.9	46
79	110	80	30	40	10	279	8.0	85.0	40
80	15	55	30	5		105	8.9	32.0	45
81	108	70	40	10	12	240	8.0	73.1	40
82	140	40	35	5		220	5.3	67.0	27
83	28	91	79	48	69	315	13.4	96.0	67
Atl.Rich 1A	272	746	382	148	132	1680	10.3	511.9	52

TABLE 4. Analytical results of coreholes in the Albert Mines area.


0 10 20 30 gals./ton
0 50 100 150 litre/tonne
FIGURE 21
Atlantic Richfield Albert 1A
Shale Oil Reserves
0
300'
600'
900'
1200'
1500'
1700'
100m
200m
300m
400m
500m

be contained within the indicated high-grade interval, but the depth and distribution of this zone has not been mapped. Correlation of the core data in respect of lithologic types, as defined by King (1963), and integration of all core dips into a structural interpretation, especially of large folds and minor faults, have still to be undertaken.

In spite of the missing geological background, some "ball park" estimates are possible. Alcock (1940) stated, "there are 100,000,000 tons of 10.6 gallons shale above the 400 foot level." This would necessitate an open pit mine with vertical walls. St. Peter (1974) disputed this estimate because of the impossibility of vertical walled pits, and the difficulty of mining to 400 feet because of Frederick Brook, which would have to be diverted for a project of this depth. St. Peter doubted that shale could be mined below 175 feet by an open pit method, and estimated 13,414,000 tons mineable shale, averaging 12 to 14 gallons per ton, for a yield of 5,000,000 barrels of shale oil. This is definitely a more pessimistic approach to the problem than can be justified by today's increasing prices and product demand. Alcock's data calculated 30,000,000 barrels recoverable shale oil.

The New Brunswick Department of Mineral Resources, partly on the basis of further unpublished core data, estimates 300 million barrels (47.4 million cubic metres) of in situ reserves to a depth of 2000 feet (615 metres) at the Albert Mines property. Five oil shale zones are reportedly definable, 3 of which exceed an average 10 gallons/ton (Toronto Globe and Mail, March 16, 1981, p. B 36).

A few additional data on the Albert Mines shale oil may be of some interest: these are excerpted from Alcock, 1948.

Several rock sample specific gravities were correlated to the analytical recoveries, a relationship that is essential to calculation of tonnages present. There is an approximate inverse straight-line relationship.

6.4 Gallons/ton	2.37 Specific gravity
9.1 "	2.23 "
11.4 "	2.22 "
20.6 "	1.97 "
36.5 "	1.83 "

Characteristics of Shale Oil

S.G. @ 60^{o} F	0.861	API @ 60^{o}F	32.8
Sulphur, % by wt.	0.75	Pour Point, ^{o}F	60

Approximate Summary

	% by volume	S.G.	Degrees A.P.I.	Saybolt Viscosity 100^{o}F
Light gasoline	4.9	0.697	71.5	
Gasoline & Naptha	25.0	0.758	55.2	
Kerosene	5.7	0.823	40.4	
Gas oil	24.0	0.857	33.6	below 50
Non-viscous lubricating distillate	15.3	0.876 to 0.902	30.0 to 25.4	50-100
Viscous lubricating distillate	?			above 200
Residuum	19.5			
Distillation loss	0.7			

Rosevale:

Table 5 summarizes the core data from the 1942 Department of Mines activity in the Rosevale area, and is repeated from S.C. Ells (1948). Data from Atlantic-Richfield Rosevale #1 are added to the bottom of the table for comparison. A weighted average yield from 834 feet (254 metres) of analyzed core at the Atlantic-Richfield hole is 4.06 gallons/ton.

In all of the test holes, only limited footages had yields exceeding 10 gallons/ton (50 litres/tonne): the shale oil recoveries of this area are considerably less than at Albert Mines. Figure 17 illustrates the distribution of the core hole pattern, as provided by Ells and generalized along the outcrop trend. All the holes are presumed to be vertical as no inclinations are given. The beds are mapped with dips of less than 45^{o}, but are definitely not flat-lying.

Published data are not sufficient to determine the degree of structural deformation in the cores, or whether a better zone, equivalent to that of the Albert Mines area, exists at Rosevale. If the oil shales are all one single lacustrine deposit, it is considered probable that the gross zonation can be carried across the entire area.

The shale oil quality at Rosevale is similar to that at Albert Mines, but is slightly heavier, S.G. 0.884 and API gravity 28.6, has slightly less sulphur at 0.58%, and has 2 to 4% less of each lighter fraction with

Hole	Footage of various grade g/t					Thickness & avge oil content			
No.	0-5	5-10	10-15	15-20	20+	Feet	g/ton	Metres	L/tonne
1	138	123	11	10	5	287		86	
4	322	19	9	10	8	368		110	
5	203	33	12	7	10	265		80	
6	224	13				234		70	
7	190	30	17		8	245		74	
8	128	45	7			160		48	
9	104	75	15			194		58	
10	70	22	22	10		124		37	
11	160	27	5			192		59	
12	156	91	19	7		313		94	
13	124					124		37	
14	311	17	8			336		101	
15	212	17		5		234		70	
16	211	70	4			285		86	
17	53					53		16	
18	190	45	35	10		280		84	
19	167					167		38	
20	83	64	34	6		187		56	
21	111	20	7			138		41	
22	94	10				104		31	
23	263					263		79	
25	267					267		80	
26	375					375		112	
28	200	112	10			322		97	
29	48					48		14	
30	213					213		64	
31	141	64	15			220		66	
32	205	63	25			291		87	
33	254	163	30	33	20	500		150	
34	273	87	32	10		402		121	
35	192	135	88	22		437		131	
36	163	63	37	13	6	272		82	
37	214	47	15			276		83	
Atl-Rich 1	559	191	43	6		799	4.1	243	20

TABLE 5. Analytical results of coreholes in Rosevale area.

correspondingly more viscous lubricants and residuum.

Taylor Village:

Alcock (1948) summarized the Department of Mines drilling for this area: table 6 and figure 20 reproduce these data and locations.

Hole No.	Footage of various grade g/t					Thickness & avge oil content			
	0-5	5-10	10-15	15-20	20+	Feet	g/ton	Metres	L/tonne
61	20	98	5			123	6.4	66.9	32
62	43	53	27			123	7.0	66.9	35
63	36	73	25			134	6.0	70.2	30
64	60	72				132	5.7	69.6	28
65	40	35	30	20		125	8.7	36.5	44
66	52	72	5		5	134	6.1	70.2	31
67	130	5				135	1.8	70.5	9
Atl-Rich Taylor	84	62	22	8	4	180	6.5	54.8	33
Dover 1A	591	138	46	8	5	788	3.7	240.0	19

TABLE 6. Analytical results of coreholes in Taylor Village area

Atlantic-Richfield drilled one additional test at Taylor Village, west of the previous program. Data are appended to the table for this additional location. The values of the more recent Atlantic-Richfield hole vary little from those of the earlier program, indicating only a minimal thickness of higher grade oil shale.

Dover

Atlantic-Richfield drilled two test holes at Dover. The #1 hole, to 432 feet (132 metres), averaged 3.1 gallons/ton, whereas the deeper 1A location averaged 3.7 gallons/ton to a depth of 903 feet (275 metres). The statistical data of this latter hole are appended to the Taylor Village information (Table 6). Gravities of the shale oil ranged from 0.851 to 0.896, averaging 0.872, and are between the Albert Mines and Rosevale values. No component breakdown is available.

Of particular interest in this area is a deep core test, Atlantic-Richfield St. Joseph #2, located just south of, and centrally along, the Dover St. Joseph outcrop area. This hole penetrated 3 significant zones, 1187-1220 feet averaging 8.9 gallons/ton, 1610 to 1690 feet averaging 12.5 gallons/ton, and the third zone, 2415-2555, yielding 12.3 gallons/ton. Although too deep for strip mining, these results may be significant for underground mining and/or in situ production, or for surface potential if they can be located at shallower depths. Oil sandstones are also understood to be present in this deep test. Gas shows were reported in the interval 2415-2455 (Carter and Shaw, 1979), but no lithologic descriptions are available to define whether the zone is entirely shale or contains sandstone lenses. Some oil sand could be present in the analyzed section as the oil specific gravities range as low as 0.818 in the lower unit, and are broadly similar to the oil gravities encountered in the Stony Creek field. Average specific gravities for the three zones, top to bottom are 0.876 (0.866 to 0.904), 0.875 (0.800 to 0.910) and 0.865 (0.818 to 0.909).

Summary Statement

Considerable additional geological study is still required before any precise determination of shale oil potential can be made; even the general figures for Albert Mines are based on minimal interpretive geology.

One good quality zone, possibly four hundred feet (130 metres) thick, is reasonably anticipated, and may by itself be the ultimate recoverable part of the sequence by surface or underground mining, or by in situ retorting. The distribution of better zones, and the relationship of recoveries to lithologic types as well as oil quality, must be determined if realistic estimates are to be made. There are probably 300 million in situ barrels (47.4 million cubic metres) of shale oil at Albert Mines, but the recovery factor is still a complete unknown.

Trace elements may be a complicating factor, as these are recoverable only as the by-product of a mining process. If in situ recoveries are used, secondary minerals will be lost. Investigation into the distribution of trace elements must be continued as these may strongly influence recovery economics.

Bibliography - New Brunswick

ABBOTT, D., and BARNETT, D.E.

1968: Composition of oil shale and coal ashes, New Brunswick; New Brunswick, Research and Productivity Council, Research Note 14, 13 p. (most comprehensive mineralogical and trace element study available for Albert oil shale).

ALCOCK, F.J.

1948: Exploration of oil shales in the Taylor Village area; in, Timm et al, Summary of investigations of New Brunswick oil shales; Canada Department of Mines and Resources, Report No. 825, p. 9-10 (reviews results of 7 core holes drilled in 1942 at Taylor Village).

1948: Exploration of oil shales in the Albert Mines area; in, Timm et al, Summary of investigations of New Brunswick oil shale; Canada Department of Mines and Resources, Report No. 825, p. 11-18 (reviews results of 36 core holes drilled in 1942 at Albert Mines).

BAILEY, R.W.

1898: The mineral resources of the Province of New Brunswick; Geological Survey of Canada, Annual Report, 1897, v. X, pt. M, p. 68-71 (historical interest).

BAILEY, L.W., and ELLS, R.W.

1878: Report on the lower Carboniferous belt of Albert and Westmorland Counties, N.B., including the "Albert Shales;" Geological Survey of Canada, Report of Progress 1876-77, pt. XII, p. 356-371 (best of earliest descriptions on occurrences of Albert shales).

BAILEY, L.W., MATTEW, G.F., and ELLS, R.W.

1880: Report on the geology of southern New Brunswick, embracing the counties of Charlotte, Sunbury Queen, Kings, St. John and Albert; Geological Survey of Canada, Summary Report, 1878-79, pt. D., p. 16-17 (historical interest only).

BELL, W.A.

1927: Outline of Carboniferous stratigraphy and geologic history of the Maritimes Provinces of Canada; Royal Society of Canada, Transactions ser. 3, v. 21, p. 75-108 (biostratigraphic approach to Horton and Windsor Groups).

BELT, E.S.

1968: Carboniferous continental sedimentation, Atlantic Provinces, Canada; Geological Society of America, Special Paper 106, p. 127-176 (interpretation of environments from sedimentary structures and correlation of environments to tectonic history).

BRIGGS, W.E., LEWIS, J.E., RENGARAJAN, S., and TRANQUILLA, J.

1980: Dielectric properties of Albert County oil shales; University of New Brunswick, Electricl Engineering Department, interim report to Province of New Brunswick, Department of Natural Resources, Mineral

Resources Branch (an extensive reference list for research into microwave heating of oil shales as a pyrolysis technique).

CARR, P.A.
1968: Stratigraphy and spore assemblages, Moncton map-area, New Brunswick; Geological Survey of Canada, Paper 67-29, p. 9-10 (age determinations from spores with attempts to clarify some of the biostratigraphic problems).

CARTER, D., and SHAW, R.
1979: Albert Formation compilation; New Brunswick Department of Natural Resources, Mineral Resources Branch, open file Report 79-33 (a compilation of all available data sources on the Albert Formation).

CLAPP, F.G.
1915: Petroleum and natural gas resources of Canada - the Albert Mines; Canada Department of Mines, Mines Branch, Report no. 291, v. II, pt. 1, Eastern Canada, p. 23-57 (historical interest only).

DAWSON, J.W.
1853: On the Albert Mine, Hillsborough, New Brunswick; Geological Society of London, Quarterly Journal, p. 107-114 (historical interest).

ELLS, R.W.
1886: Geological formation of eastern Albert and Westmorland Counties, New Brunswick; Geological Survey of Canada, Summary Report, v. 1, pt. E, 1885 (historical reference).

1903: The Albert shale deposits of Albert and Westmorland Counties, N.B.; Geological Survey of Canada, Annual Report, New Series, 1902, v. XV, pt. A, p. 363-369 (historical reference).

1906: Southern New Brunswick: Geological Survey of Canada, Summary Report, 1906, p. 136 (historical).

1907: The geology and mineral resources of New Brunswick; Geological Survey of Canada, Publication 983, p. 107-114 (historical reference).

1908: The carbonaceous and bituminus mineral of New Brunswick; Canadian Mining Institute, Journal 11, p. 204-219 (historical).

1908: Surveys in southern New Brunswick; Geological Survey of Canada, Summary Report, 1907, p. 74-76 (historical only).

1909: Geological position and character of the oil-shale deposits of Canada: Geological Survey of Canada, Report No. 1107, p. 7-21 (geographic areas, quite complete, for oil shales; a few analyses, no geology, historical).

1909: Bituminous shales of Nova Scotia and New Brunswick: with notes on the geology of the oil-shales of Scotland; Geological Survey of Canada, Summary Report, 1908, p. 132-142 (locations and a few analyses, historical).

1909: Notes on the geology of the oil shales of Scotland, and their relations to somewhat similiar oil-shales in eastern Canada; Royal Society of Canada, Transactions, sec. IV, p. 35-43 (comparison of Canadian section to that of Scotland, historical interest).

1910: Oil-shales of eastern Canada: Geological Survey of Canada, Summary Report, 1909, p. 201-207 (essentially repeats 1909, Report 1107: historical).

1910: The oil-shales of the Maritime Provinces; Mining Society of Nova Scotia, Transactions XIV, p. 1-12 (very general discussion, historical).

ELLS, S.C.

1923: Oil shales of Canada; Canada Department of Mines, Summary report of investigations made by the Mines Branch, 1921, Report No. 588, pt. g., p. 45-51 (historical interest).

1925: Oil shales of Canada; in, Shale Oil, ed. R.H. McKee, American Chemical Society, Monograph Series No. 25, The Chemical Catalog Company Inc., New York, p. 48-55 (historical).

1948: Exploration of oil shales in the Rosevale area; in, Timm, et al, Summary of investigations of New Brunswick oil shales; Canada Department of Mines and Resources, Report No. 825, p. 4-8 (summary of analyses from 36 holes cored in 1942 at Rosevale).

FLAHERTY, G.F. and NORMAN, G.W.H.

1941: Albert sheet, Albert County, New Brunswick; Geological Survey of Canada, Map 648A with descriptive notes.

GESNER, A.

1847: Report on the geological survey of the Province of New Brunswick; Saint John, (1839, 1840, 1841, 1843) London (historical - first reference to albertite).

GREINER, H.R.

1962: Facies and sedimentary environments of Albert shale, New Brunswick; American Association of Petroleum Geologists, Bulletin, v. 46, no. 2, p. 219-234 (necessary reading for environmental understanding).

1974: The Albert Formation of New Brunswick - a Paleozoic lacustrine model; Geologische Rundschau, v. 63, p. 1103-1113 (some repeat, variations, and additions to 1962 paper).

1977: Crossopterygian fauna from the Albert Formation, New Brunswick, and its stratigraphic - paleoecologic significance; Journal of Paleontology, v. 51, no. 1, p. 44-56 (age dating and some environmental interpretations).

GUSSOW, W.C.

1953: Carboniferous stratigraphy and structural geology of New Brunswick, Canada; American Association of Petroleum Geologists, Bulletin, v. 37, no. 7, p. 1713-1816 (the basic geologic-stratigraphic paper for New Brunswick).

HACQUEBARD, P.A.
1972: The Carboniferous of eastern Canada; International Congress on Carboniferous Stratigraphy and Geology, 7th, Compte rendu, v. 1, p. 63-90 (preferred reference for regional sedimentary framework).

HAYES, A.O.
1927: Bituminous shales and other mineral occurrences in the vicinity of Sussex, N.V.; Geological Survey of Canada; Summary Report, 1925, pt. C, p. 125-127 (historical reference).

HITCHCOCK, C.H.
1865: Albert coal or Albertite of New Brunswick; American Journal of Science (2) v. 39, p. 267-273 (historical).

HONEYMAN, D.
1866: Note on the identification of the Scotch and N.B. "Albertites;" Minerolog Magazine, v. 7, p. 77-78 (historical).

HOWIE, R.D.
1980: The Albert Formation, New Brunswick - deltas and oil shale; Geological Survey of Canada, open file Report 671 (excellent paper on environment and source directions).

HUME, G.S.
1932: Relation of Stony Creek oil and gas field to structure; in, Oil and gas in Eastern Canada; Geological Survey of Canada, Economic Geology Series No. 2 (Report No. 2294), p. 173-182 (historical review of Stony Creek field but little geology).

JACKSON, C.T.
1850: An asphaltum recently discovered in New Brunswick; Boston Society of Natural History, Proceedings 3, p. 297-299 (historical).

1851: An asphaltic tar of New Brunswick; Boston Society of Natural History, Proceedings 4, p. 55-56, 64-65 (historical).

1851: Discovery of fossil fish in the coal formation of New Brunswick; American Journal of Science, 2nd ser., v. 12, p. 281-282 (historical, note reference to oil shale as coal formation).

1852: On fish and plants from the coal formation of Hillsborough, New Brunswick; Boston Society of Natural History, Proceedings v. 4, p. 138-143 (historical).

KELLEY, D.G.
1967: Some aspects of Carboniferous stratigraphy and depositional history in the Atlantic Provinces; in, Geology of the Atlantic Region, ed. E.R.W. Neale and H. Williams; Geological Association of Canada, Special Paper 4, p. 213-228 (essential reading for stratigraphic nomenclature of the area).

1970: Geology of southeastern Canada; in, Geology and Economic Minerals of Canada, economic Geology Report #1, ed. R.J.W. Douglas; Geological Survey of Canada, p. 284-296 (essentially same as 1967 paper).

KING, L.H.
1963: Origin of the Albert Mines oil shale (New Brunswick) and its associated albertite; Canada Department of Mines, Research Report R115, 24 p. (essential reference for shale oil content versus lithologic type).

LAMBE, L.M.
1910: Palaeoniscid fishes from the Albert shales of New Brunswick; Geological Survey of Canada, Memoir 3, Contributions to Canadian Palaeontology, VIII (quarto), pt. V. (discussion of starved lagoon concept to create abundance of fish remains).

LEIDY, J.
1860: On the albertite of New Brunswick; Philadelphia Academy of Natural Science, Proceedings, p. 54 (historical).

MARTISON, N.W.
1966: Study of oil shale occurrences in Canada; unpublished report, University of Calgary, Gallagher Library, p. 27-29 (general comments only).

McCUTCHEON, S.R.
1978: Geology of the Apohaqui-Markhamville area, map area R-25 (21H-11W, 21H-12E); New Brunswick Department of Natural Resources, Mineral Resources Branch, Map Report 78-5, p. 7-13 (detailed geology of Albert section in Apohaqui area to assist facies interpretations).

McLEOD, M.J.
1980: Geology and mineral deposits of the Hillsborough Area; New Brunswick Department of Natural Resources, Mineral Resources Branch, Map Report 79-6 (detailed map and descriptions to assist facies interpretations).

McLEOD, M.J., and RUITENBERG, A.A.
1978: Geology and mineral deposits of the Dorchester area, map area W-22, W-23 (21H/15E, 21H/16W); New Brunswick Department of Natural Resources, Mineral Resources Branch, Map Report 78-4, p. 7-8 (detailed maps and descriptions to assist facies interpretations).

McMULLEN, W.E.
1922: Boreholes in the vicinity of Frederick Brook, Albert Mines - albertite vein; New Brunswick Crown Land Department, 61st Annual Report of Activities, 1921, Mining, p. 51-52 (historical).

1928: Oil shale, Rosevale, Albert County; New Brunswick Department of Lands and Mines, 67th Annual Report, 1927, Mining Inspector's Report, p. 49-50 (historical).

MILNER, W.C.
1912: History of albertite; Mineral Society of Nova Scotia, Journal 17, p. 62-69 (historical).

NORMAN, G.W.H.
1932: Stratigraphy of the Stony Creek oil and gas field, N.B.; in Oil and Gas in eastern Canada; Geological Survey of Canada, Economic Geology Series no. 9 (Report no. 2294), p. 167-173 (historical stratigraphic reference).

1941: Moncton sheet, Westmorland and Albert Counties, New Brunswick; Geological Survey of Canada, Map 646A, with descriptive notes.

1941: Hillsborough sheet, Albert and Westmorland Counties, New Brunswick; Geological Survey of Canada, Map 647A, with descriptive notes.

PICKERILL, R.K., and CARTER, D.
1980: Sedimentary facies and depositional history of the Albert Formation; New Brunswick Department of Natural Resources, open file Report 80-3 (essential reference for facies analysis, trace element data).

RODGERS, W.B.
1860: On the albertite of New Brunswick; Philadelphia Academy of Natural Science, Proceedings, p. 98 (historical).

1860: On the coal vein at the Albert Mines, New Brunswick; Boston Society of Natural History, Proceedings 7, p. 294-295 (historical).

ROULSTON, B.V.
1978: Stratigraphy of the Albert Formation, Urney area, New Brunswick; unpublished report, New Brunswick Department of Natural Resources, Mineral Resources Branch, 7 p. (useful to assist facies interpretations).

RUITENBERG, A.A., McCUTCHEON, S.R., VENEGOPAL, V., and PIERCE, G.A.
1977: Mineralization related to post-Acadian tectonism in southern New Brunswick; Geoscience Canada, v. 4, no. 1, p. 13-22 (of interest relative to trace elements).

RUTHERFORD, J.
1898: Notes on the albertite of New Brunswick; Federal Canadian Mining Institute, Journal 3, p. 40-46 (historical interest).

SIMPSON, L.
1919: Oil-yielding shale in the Province of New Brunswick; Canadian Mining Institute, Bulletin, no. 82, January, p. 42-47 (historical reference).

ST. PETER, C.
1974: Oil shale resources of southern New Brunswick; New Brunswick Department of Natural Resources, Mineral Resources Branch, Topical Report 74-3, 15 p. (good review of previous core work and map showing specific oil shale outcrop localities).

SWINNERTON, A.A.
1928: Oil shale from Rosevale, New Brunswick; Canada Department of Mines, Mines Branch, Report No. 689, 1926, p. 104-105 (historical).

1938: Oil shales of Canada; in, Oil Shale and Cannel Coal; The Institute of Petroleum, p. 212-215 (generalizations only, historical interest).

TAYLOR, R.C.
1951: On the vein of asphaltum at Hillsborough in Albert County, New Brunswick; American Philosophical Society, Proceedings, no. 5, p. 241-243 (historical).

TIMM, W.B., ALCOCK, F.J., SWINNERTON, A.A., and ELLS, S.C.
1948: Summary of investigations of New Brunswick oil shales; Canada Department of Mines and Resources, Report No. 825, 24 p. (reviews 24,554 feet of core from Rosevale, Taylor Village and Albert Mines from 1942 program, summarizes all analyses).

VARMA, C.P.
1969: Lower Carboniferous miospores from the Albert oil shales (Horton Group) of New Brunswick, Canada; Micropaleontology, v. 15, p. 301-324 (interprets fresh water origin of Albert shales, correlates to Nova Scotia).

WEBB, G.B.
1963: Occurrence and exploration significance of strike-slip faults in southern New Brunswick, Canada; American Association of Petroleum Geologists, Bulletin, v. 47, no. 11, p. 1904-1927 (necessary reading because of structural complexity of the area).

WRIGHT, W.J.
1922: Preliminary report on the geology of the Moncton map-area; Geological Survey of Canada, Memoir 129, p. 1-50 (describes Albert Mines from tunnels and shafts of albertite mine; shows surface outcrop pattern of beds with variable oil content; essential historical reading).

YOUNG, G.A.
1909: A descriptive sketch of the geology and economic minerals of Canada; Geological Survey of Canada, Report No. 1085, p. 57-58 (historical).

1912: Geology of the Moncton map-area, Westmorland and Albert Counties, New Brunswick; Geological Survey of Canada, Summary Report, 1911, p. 309-321 (historical).

CARBONIFEROUS OF NOVA SCOTIA

Coal has always been a major component of Nova Scotia energy resources. During development of coal seams in the Pictou area on Northumberland Strait, stellarite was discovered in 1859 near the present town of Stellarton (Fig. 13). Stellar coal was so named because "stars of fire" dropped from it when a flame had been applied and removed. As reported by How (1868), the stellarite occurred in a 5 foot seam, of which 1'10" was stellarite, 1'4" bituminous coal and 1'10" bituminous shale. The three lithologies were readily differentiated by organic/ash content.

	Coal	Stellarite	Oil Shale
% Volatiles	33.58	66.58	30.65
% Fixed carbon	62.09	25.23	10.88
% Ash	4.33	8.21	54.47

The high volatile content, and the ability to distill shale oil from the stellarite at rates up to 150 gallons/ton, removed it from the coal series to a shale oil type. As such, the stellarite is an exceptionally high grade torbanite, an "algal coal" containing much more sapropelic than humic material, but deposited in a fresh swamp environment similar to that of coal, and with a limited inorganic mineral content (ash).

Within this area, seams of torbanite oil shales, deposited in swamp or bogs (often called "boghead coal"), with normal oil shale ash content greater than 35% of the rock, were encountered during the continuing coal exploration.

How also described oil shales of the Antigonish area, which he recognized to occur in the Lower Carboniferous and equated these to the non-productive Coal Measures of Hants County (southside of Minas Basin). The early recognition that these beds were stratigraphically equivalent to the Albert oil shales of New Brunswick added an impetus to examine everywhere the "Horton Series" for possible oil shale intervals.

Along the south side of Minas Basin (Fig. 15), the Horton Group has been divided into the Horton Bluff Formation, a lower grey colored clastics sequence, and the Cheverie Formation, an upper greenish to reddish clastics interval overlain by carbonate of the Windsor Group. Miospore correlations (Varma, 1969) indicated the Cheverie to equate to the Hiram Brook Member of the Albert Formation in New Brunswick (Fig. 14), with basal Windsor beds of this Nova Scotia area stratigraphically equivalent to Moncton red beds of the Moncton sub-basin (Kelley, 1967). Black shales of the upper Horton

Bluff, containing palaeonscid fish scales, were readily correlated to the Albert oil shales. These black shales were described in many early publication as potential oil shales, but R.W. Ells (1910a), after detailed surface studies, concluded that most were carbonaceous, containing woody and coaly material rather than a sapropelic kerogen which would yield oil on pyrolysis.

On Cape Breton Island, at Lake Ainslie, the Horton Group was divided by Murray (1960) into the Craignish, Strathlorne and Ainslie Formations, in ascending order. All are clastic sequences, being coarser grained and red at the base and top, and finer grained grey in the medial Strathlorne Formation. Kelley (1967) stated that the sequences may be color correlative to the Horton of New Brunswick, but the ages are different. On the basis of fossil fish remains, which may be an indication of lacustrine environment only, MacNeil (1949) considered the color zones to be correlative. The color change is indicative of differing source rocks and all the oil shales and/or dark shales are lacustrine deposits. The equivalence of these strata seems probable based on regional considerations of changing source material and decrease of sediment supply and grain size, resulting in the establishment of a lacustrine environment. The organic matter in the dark grey to black shales of this area also appears to be more humic than sapropelic.

A second area on Cape Breton Island, at MacAdam Lake, also contains black shales in undifferentiated Carboniferous - Devonian strata. R.W. Ells (1910b) reported that a shaft was sunk some 20 years earlier to a maximum depth of 175 feet, and a retort erected. Apparently no full operations ever materialized. Ells reported the materials dump contained "black and dark grey carbonaceous shales, with crushed and slickensided surfaces, portions of which were graphitized." In 1976, the Nova Scotia Department of Mines drilled two holes in an attempt to follow up this show, but no oil shales were encountered (Potter, 1977). D.C. McGregor, Geological Survey of Canada, identified spores from a coal seam as possible Devonian. The significant degree of structural deformation and graphitization in this area would preclude much oil shale potential, although Gilpin (1899) reported MacAdam Lake shales to be combustible, variably yielding 15-20 gallons/ton, comprising 20% kerosene, 20% machine oil, 40% heavy lubricating oil, and 20% pitch.

The above areas, although apparently not containing any significant oil shales are described herein because of common reference to them throughout the geological literature of Nova Scotia. In addition to the MacAdam Lake drill holes, Potter reported a renewed surface program at most of these areas by which oil shales might be recognized; however, the retorting attempts of suspected oil shale zones have not yet yielded any significant results.

BIG MARSH (ANTIGONISH).

How (1868), quoting Campbell (reference not given), says of the Antigonish area oil shales: "The bituminous beds appear to be divided into two groups, the lower of which appears to be about 70 or 80 feet in thickness, 20 feet of which may be regarded as good oil shale including 5 feet of curly cannel rich in oil. The upper band cannot be much short of 150 feet in vertical thickness of strata containing a large percentage of oil."

Stratigraphy

Rocks of the Antigonish (Big Marsh) oil shales (Fig. 14) occur in Horton Group strata, although shown on the geological map of Nova Scotia (Keppie, 1979) as Devonian - Carboniferous undivided. Potter (1974) reported that these shales occur about 1500 feet below the Horton - Windsor contact. On the basis of their stratigraphic position, and the lithologic similarity of the zones, the oil shales at Big Marsh are almost certainly the equivalents of the New Brunswick Frederick Brook Member. These Nova Scotia oil shales can be informally referenced as the Big Marsh oil shales, relative to the area name generally applied to description of these deposits by the Nova Scotia Department of Mines.

As in the area south of the Minas Basin, Horton beds here rest directly on the pre-Carboniferous basement complex, as these two areas remained emergent during deposition of the lower red bed interval of the Horton Group, the Memramcook of the Moncton sub-basin.

Lithology

Few good lithologic descriptions are available for the Big Marsh oil shales. From a tunnel through the zone, which ended in a coal bed, Fletcher (1892) described the shales as black, some being a curly cannel type with a somewhat polished appearance. The coal was described as lenticular, crushed and of the cannel type. This description was largely taken from How (1868).

Horton shales of Nova Scotia are generally described as blacker than those of New Brunswick, which have a more brownish tinge. Few will ignite, except for those of the Big Marsh area: Horton oil shales of Nova Scotia have a brownish streak in contrast to the black character of the shales which do not pyrolyze. Fish and plant remains are common. The black shales can be interbedded with grey micaceous shales. Only one reference was noted to the presence of a calcareous admixture in the shale.

Lithologic descriptions are insufficient to define adequately the depositional environment: certainly many characteristics resemble the Albert oil shale and lacustrine deposition is probable for the Big Marsh zone.

Distribution and thickness

The outcrop distribution of the Big Marsh oil shale has been excerpted from an unpublished map of the unit prepared in 1974 by the Nova Scotia Department of Mines. From a series of diamond drill holes, the zone thickness was established at 355 to 400 feet (109 - 122 metres) at Big Marsh and at 250 feet (76 metres) at Beaver Settlement near St. George's Bay (Fig. 22). These zones are probably continuous across the intervening area.

Mineralogy

No investigations have as yet been on the mineralogic content of Big Marsh oil shales, either for inorganic minerals, or for the nature and degree of maturation of the organic phase.

Big Marsh - economic potential

R.W. Ells (1909a) provided seven analyses of the Big Marsh oil shale. They ranged from 4.0 to 23 gallons/ton, averaging 8.8 gallons/ton (44 litres/tonne) with a specific gravity range from 0.890 to 0.917 (average 0.900) and with ammonium sulphate ranging from 8.7 to 38.0 lbs/ton, averaging 24.0 lbs/ton (12.0 kg/tonne). Ells (1910a) added one further analysis which was almost an exact average of the first series. A few further analyses were added by S.C. Ells (1923), but these did not add to our knowledge of the potential of this zone.

In 1975, the Nova Scotia Department of Mines completed 9 boreholes in the Big Marsh area (Potter, 1976). The results of these holes have been supplied for this study: locations are shown on figure twenty-two.

At the most southerly outcrop area, borehole #5 rated 330 feet (101 metres) of oil shale, yielding a maximum 7.27 gallons/ton and an average 3.54 gallons/ton (17.7 L/tonne). Further south on this outcrop trend, holes #8 and #9 encountered 390 feet (119 metres) and 414 feet (126 metres)

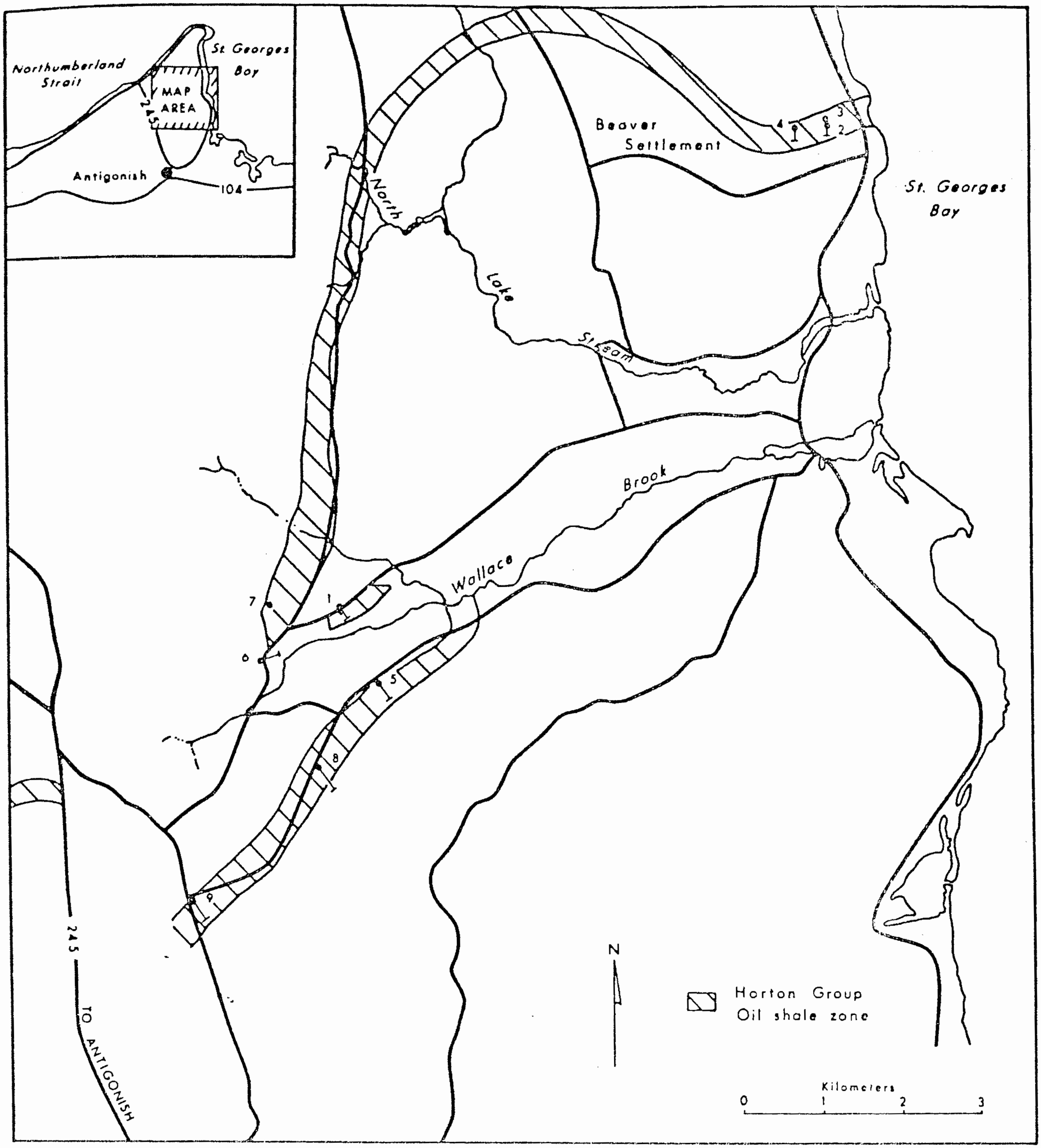


FIGURE 22. Surface distribution of Horton Group oil shales, Big Marsh, Nova Scotia

respectively of oil shale zone, but the assays indicated minimal shale oil potential.

Hole #1 attempted to locate a medial remnant between the two trends which are offset by faulting, but failed to encounter oil shale even at a depth of 333 feet (101 metres). Hole #6 also failed to encounter any oil shale section in this structurally disturbed area. West of these locations, drill hole #7 penetrated 137 feet (42 metres) of oil shale interval, but no significant shale oil recoveries were made.

At Beaver Settlement, near St. George's Bay, hole #2 averaged 3.26 gallons/ton (16.3 litres/tonne) over 200 feet (61 metres) gross zone with a maximum yield of 7.87 gallons/ton. About 400 metres further at the west, hole #4 averaged 3.84 gallons/ton (19.2 litres/tonne) from 212 feet (64.6 metres) with a maximum 8.82 gallons/ton yield. The better yields within the Big Marsh area are definitely in this northerly outcrop section, but are still much below presently defined economic levels.

PICTOU (McLELLAN BROOK)

The Stellarite band has been known in Nova Scotia since before 1860: a stope was reportedly driven into the zone about 1856, with some of the oil shale shipped to England.

R.W. Ells (1909a) collected eight samples of the oil shales and stellarite, which yielded 42, 14.5, 8, 3, 14, 4, 9 and 14.3 gallons/ton. As only one sample yielded in excess of 40 gallons/ton, no further work was done at that time. The next year, Ells (1910a), added one further analysis, which yielded 44.8 gallons/ton from a stellarite zone. Ells (1909a) was also the first to recognize the coal-stellarite-oil shale relationship based on ash content and shale oil yield.

Further attempts have been made to assess the value of the torbanites, including sampling by Wright (1922) and several core holes from the Nova Scotia Coal Company published by Bell (1924). None of these efforts resulted in any significant recoveries, and nowhere were the high yield of the stellarite (53, 74, and 123-129 gallons/ton; How, 1868) ever repeated.

In 1929, Canadian Torbanite Products sank a short stope into the torbanite seam that was mined prior to 1860, but closed down after retorting only a few thousand gallons of shale oil. In 1930, Torbanite Products Ltd., drove a stope along a four foot seam, but operations were of short duration as the plant burned down the following year.

Douglas and Campbell (1941) reported the results of a comprehensive field study and supplied the first maps showing in detail the outcroppings of the various oil shale - torbanite zones, mostly along McLellan's Brook, and the tributary Marsh Brook. Analyses of surface samples ranged from 4.15 to 50.0 gallons/ton from 10 samples.

The Nova Scotia Department of Mines drilled 15 core holes in 1956, the results of which are available at the Department of Mines, but which have not been published. Only limited values were obtained: of 259 distillation tests, only 12 ranged 20-30 gallons/ton, 45 between 10-20 gallons/ton, and the remaining were below 10 gallons/ton, the majority being under 5 gallons/ton. The few high recoveries were also sporadically located as thin zones within thicker low grade intervals. Because of the poor results, the program was discontinued.

At the Department of Mines, W. Potter supplied an unpublished, untitled detailed map of all the surface exposures of oil shales and torbanites, with structural attitudes at all outcrop locations. No attempt was made to correlate individual zones or to integrate these data with the 1956 core hole program. This map would provide an excellent base for further investigations.

Stratigraphy

Stellarite occurs in the Pictou Group, locally defined as the Stellarton Group (Bell, 1940, uses term "Series"). Stellarton was defined to include the economic coal seams, excluding those of the Pictou Group which were impure. The term Pictou is now generally used in preference to Stellarton for the entire area.

The Pictou Group is a non-marine sequence of red and grey sandstones, siltstones, some conglomerates and interspersed coal, oil shale and torbanite beds (stellarite is actually a high-grade torbanite). The coal and oil shale beds locally intersperse with grey to red sandstone and shale.

As defined by Bell, the Pictou Series contained a Wesphalian C and D flora; however, the general practice now assigns all Paleozoic above the regional unconformity to the Pictou Group. Because of the widened time limits, the group now ranges from Westphalian C through Permian (van de Poll, 1972).

Lithology

Generalized lithologies have been described above in both the introduction and stratigraphic review of the Pictou area. Coal seams are readily defined and differentiated from the oil shale zones. Within the oil shale-torbanite sequence, the units appear to be gradational as shale oil yields range from minimal to greater than 50 gallons/ton (250 litres/tonne).

Torbanites are deposited in local swamps, generally associated with coal beds. During coal deposition, the swamps are overgrown by higher plant forms and the influx of inorganic material is minimal. During torbanite formation, the swamp is a small algae filled lake with lower plant life predominating, and again with limited inorganic influx, although generally the lake area will have a much higher sediment inflow. As can be readily visualized, the ratio of humic to sapropel to inorganic sediment can vary between many extremes with a wide range of resulting rock type. These variations appear to be the reason for the wide range of shale oil recoveries from Pictou area oil shale zones.

Distribution and thickness

Douglas and Campbell (1941) showed the general distribution of several coal seams and oil shale beds. From their distribution, considerable structural complexity is suspected for this area. Strike and dip data shown by Potter (unpublished) confirm this suspicion.

Indicated thicknesses of the oil shale beds and torbanites range from inches to less than 3 metres, similar thicknesses to those shown for the coal beds. No attempt has been made to integrate the detailed surface data with the core hole information.

Mineralogy

Oil shales of the Pictou area were investigated by Flynn (1926), primarily on the basis of treatment procedures, but the work did involve thin sections and study of the organic materials within the stellarites and torbanites.

The stellarite contains bright yellow organic particles, which are distorted commenserate with the curly character of the rock. In contrast, an organic shale directly underlying a torbanite showed orange particles which appeared to be laminated vegetable humus. The organic globules of the torbanites reportedly showed internal structure whereas those of the oil shales did not. Flynn correlated the results of oil yields and gas fractions, from which he differentiated two types of oil shales, having different carbon contents, and with varying oil content, gravity, and gas recoveries. Undoubtedly these can be related to the humus - sapropel ratio of the torbanite - oil shale deposits. That study can well be used as a guide to studies in other areas where different lithologic oil shale types are encountered: different lithologies cannot be lumped together on the basis of gross shale oil recoveries for the purpose of reserves calculations.

Pictou area - economic potential

Unforunately, the torbanites and oil shales of the Pictou area are much too thin and locally irregular to be of much economic value at the present time. These zones are also a hindrance to coal properties as the ash is too high to include the torbanites as a coal resource.

Bibliography - Nova Scotia

BELL, W.A.

1924: Investigations of coal-bearing formations in Nova Scotia - some analyses for oil content of Carboniferous shale from Pictou County: Geological Survey of Canada, Summary Report, 1923, pt. C II, p. 33-35 (analyses of oil shales from two holes in Pictou County).

1929: Horton-Windsor district, Nova Scotia; Geological Survey of Canada, Memoir 155 (describes Horton Bluff Formation).

1940: The Pictou coalfield, Nova Scotia; Geological Survey of Canada, Memoir 225, p. 80 (detailed maps of Pictou (Stellarton) coal seams and review of structure).

1960: Mississippian Horton Group of type Windsor-Horton district, Nova Scotia; Geological Survey of Canada, Memoir 314 (lithologic descriptions of Horton Bluff and Cheverie Formations).

CLAPP, F.G.

1915: Petroleum and natural gas resources of Canada - possibilities of the oil-shale industry in Nova Scotia; Canada Department of Mines, Mines Branch, Report no. 291, v. II, pt. 1, eastern Canada, p. 6-15 (summarizes history of Scottish oil shale industry, then summarizes Ells (1909); historical).

DOUGLAS, G.V., and CAMPBELL, C.D.

1942: Pictou County oil shales, Nova Scotia Department of Mines, Annual Report 1941, p. 1-14 (details of outcrop distribution of stellarite, torbanite, and oil shale beds).

ELLS, R.W.

1909a: Geological position and character of the oil-shale deposits of Canada; Geological Survey of Canada, Report No. 1107, p. 21-40 (describes areas from How (1868) with further detail; historial).

1909b: Bituminous shales of Nova Scotia and New Brunswick, with notes on the geology of the oil-shales of Scotland; Geological Survey of Canada, Summary Report, 1908, p. 134-138 (generalized descriptions of oil shale areas, and torbanite-cannel coal deposits; historical).

1909c: Notes on the geology of the oil shales of Scotland and their relations to somewhat similar oil-shales in eastern Canada; Royal Society of Canada, Transactions, sec. IV, p. 35-43 (recognition that Horton and Albert Series may be more Mississippian than Devonian; historical).

1910a: Oil-shales of eastern Canada; Geological Survey of Canada, Summary Report, 1909, p. 207-212 (reviews all prior data, good descriptions of Cheverie-Truro area, mostly carbonaceous).

1910b: The oil-shales of the Maritime Provinces; Mining Society of Nova Scotia, Transactions XIV, p. 1-13 (reviews oil shale knowledge and activity to that date; historical interest).

ELLS, S.C.

1923: Oil shales of Canada: Canada Department of Mines, Summary Report of Investigations made by the Mines Branch, 1921, Report No. 588, pt. G., p. 42-45 (brief summary of older data; historical).

1925: Oil shales of Canada; in, Shale Oil, ed. R.H. McKee; American Chemical Society, Monograph Series No. 25, The Chemical Catalog Company Inc., New York, p. 45-48 (almost verbatim repeat of 1923 brief summary of older data).

FLETCHER, H.

1887: Report on geological surveys and explorations in the Counties of Guysborough, Antigonish and Pictou, Nova Scotia; Geological Survey of Canada, Annual Report 1886, v. II, pt. P, p. 112-113 (discusses oil shales being mistaken for coal; historical only).

1892: Report on the geological surveys and explorations in the Counties of Pictou and Colchester, Nova Scotia; Geological Survey of Canada, Annual Report, 1891, pt. P., p. 173-174 (describes locations of oil shales relative to local land-marks and land-owners, historical only).

FLYNN, A.E.

1926: Investigations on the treatment of Nova Scotia oil shales; National Research Council, Canada, Report No. 18; 92p. Nova Scotia Department of Public Works and Mines, Annual Report on the Mines for 1926, p. 210-298 (shows variations in recovered oil and gas from different initial oil shale types).

GILPIN, J.E.

1899: Oil shale in Cape Breton; Nova Scotia Institute of Science, v.10, p. 85-86, (description of shale at Macadam Lake with distillation results and character of distillate).

HOW, H,
1868: The mineralogy of Nova Scotia; Charles Annand, Halifax, 217 p.

KELLEY, D.G.
1967: Baddeck and Whycocomagh map-areas, with emphasis on Mississippian stratigraphy of central Cape Breton Island, Nova Scotia (11 K/2 and 11 F/14); Geological Survey of Canada, Memoir 351 (descriptions of Craignish, Strathlorne and Ainslie Formations of Horton Group).

1967: Some aspects of Carboniferous stratigraphy and depositional history in the Atlantic Provinces, in, Geology of the Atlantic Region; eds. E.R.W. Neale and H. Williams; Geological Association of Canada, Special Paper 4, p. 213-228 (essential for stratigraphic background).

KEPPIE, J.D.
1979: Geological map of the Province of Nova Scotia; Nova Scotia Department of Mines and Energy.

MARTISON, N.W.
1966: Study of oil shale occurrences in Canada; unpublished report, University of Calgary, Gallagher Library, p. 26-27 (considers Pictou area results too low to be economic).

McNEIL, D.J.
1948: Petroleum possibilities of the Big Marsh area, Antigonish County, N.W.; unpublished report prepared for the Pictou Petroleum Company, available at Nova Scotia Department of Mines and Resources (best available descriptions of lithologic sequence (Horton-Windsor) and comparisons to Cape Breton and to New Brunswick sections).

POTTER, W.
1974: Oil shale and torbanite analysis; Nova Scotia Department of Mines, internal report, 6 p. (comparison of yields and hydrocarbon analyses of oil shale and torbanite retorting products).

1975: Oil shale project; Nova Scotia Deparment of Mines, Mineral Resources Division, Report of Activities, 1974, Paper 75-1, p. 41-43 (brief description of results of field study, places Big Marsh oil shales 1500 feet below Horton-Windsor contact).

1976: Oil shale survey; Nova Scotia, Department of Mines, Report 76-2 p. 49-54 (results of nine boreholes at Big Marsh; lithologic descriptions and analyses).

1977: Oil shale survey; Nova Scotia Department of Mines, Report 77-1, p. 23-26 (results of MacAdam Lake boreholes).

SWINNERTON, A.A.
1930: Oil shale from Pictou County, Nova Scotia; Canada Department of Mines, Mines Branch, Report No. 712, p. 13-24 (results and analyses from surface sampling of 4 beds in Pictou area; first significant analyses).

1933: Report on oil shales from New Glasgow area, Pictou County, Nova Scotia, and from Port Daniel, Bonaventure County, Quebec; Canada Department of Mines, Mines Branch, Report #725, 1930-31, pt. II, sec. IV, p. 136-145 (additional surface samples beyond 1930 report; results of 6 boreholes; shale oil distillation analyses).

1938: Oil shales of Canada; in, Oil Shale and Cannel Coal; The Institute of Petroleum, p. 210-217 (brief summary of locations and results; historic interest only).

VARMA, C.P.
1969: Lower Carboniferous miospores from the Albert oil shales (Horton Group) of New Brunswick, Canada; Micropaleontology, v. 15, no. 3, p. 301-324 (correlations of Horton Group from New Brunswick to Nova Scotia).

VAN de POLL, H.W.
1972: Stratigraphy and economic geology of Carboniferous basins in the Maritime Provinces; International Geological Congress, Montreal, 24th Session, Guidebook A-60 (good stratigraphic summary).

WILLIAMS, M.Y.
1914: Arisaig - Antigonish district, Nova Scotia; Geological Survey of Canada, Memoir 60, p. 150-151 (describes oil shales at Maryvale and Pleasant Valley, near Big Marsh; all from "Ardness Formation;" historical).

WRIGHT, W.J.
1922: Bituminous shales of Canada; Geological Survey of Canada, Memoir 129, p. 52-55 (summary of data to 1922; historical).

YOUNG, G.A.
1909: A descriptive sketch of the geology and economic minerals of Canada; Geological Survey of Canada, Report No. 1085, p. 57-58 (historical).

CARBONIFEROUS OF NEWFOUNDLAND

Oil shales have been recognized in the Carboniferous rocks of western Newfoundland since the early work of Murray (1881) and Howley (1892), but did not receive the attention given to those of Nova Scotia and New Brunswick. Newfoundland was not a Province of Canada during the many year of interest shown by R.W. Ells and others in the Canadian Maritimes area by the Geological Survey of Canada. Ells (1910) did refer to possible oil shales of Newfoundland, one at Port-au-Port Bay on the west coast which is probably not an oil shale, and a second on Notre Dame Bay, geographically misplaced from Pilier Bay.

Hatch (1919) conducted a private study of the concessions controlled by a Newfoundland paper company, most adequately describing the oil shale lithologies, and the number and quality of individual beds. Except for detail, his work was an excellent review of the Deer Lake-Humber River-Grand Lake oil shale area (Fig. 23). Nomenclature had not been proposed for the Carboniferous units at that time.

Considerable additional geology was added from 1950 to 1966, when D.M. Baird, Newfoundland Geological Survey, prepared several reports, some of which remained unpublished, covering the Deer Lake region and Conche-Groais Island area (Fig. 23) toward the north tip of the island. Within this period, the most significant work was completed by H.J. Werner (1956), who established the Deer Lake Group and the formational sub-division of the central Carboniferous area. Oil shales were placed within the Rocky Brook Fm. Although the work was completed for a mining company, the nomenclature has been accepted: copies of his report are on file, and can be obtained, at the Newfoundland Department of Mines and Energy.

Within the past 3 years, R.S. Hyde, Newfoundland Department of Mines and Energy, has been involved with detailed mapping of the Deer Lake Basin, of which some reports are published and some data are still in map preparation. All of Hyde's work maps were kindly supplied for this review.

The Ells report (1910) of possible oil shales at Port-au-Port Bay (Fig. 23) in southwestern Newfoundland seems to refer to the Middle Ordovician Table Head Group of which the uppermost unit is thin bedded black shale. These rocks are badly crumpled and overlain with significant angular unconformity by Carboniferous beds. From these descriptions, the potential of the Ordovician for shale oil content appears minimal.

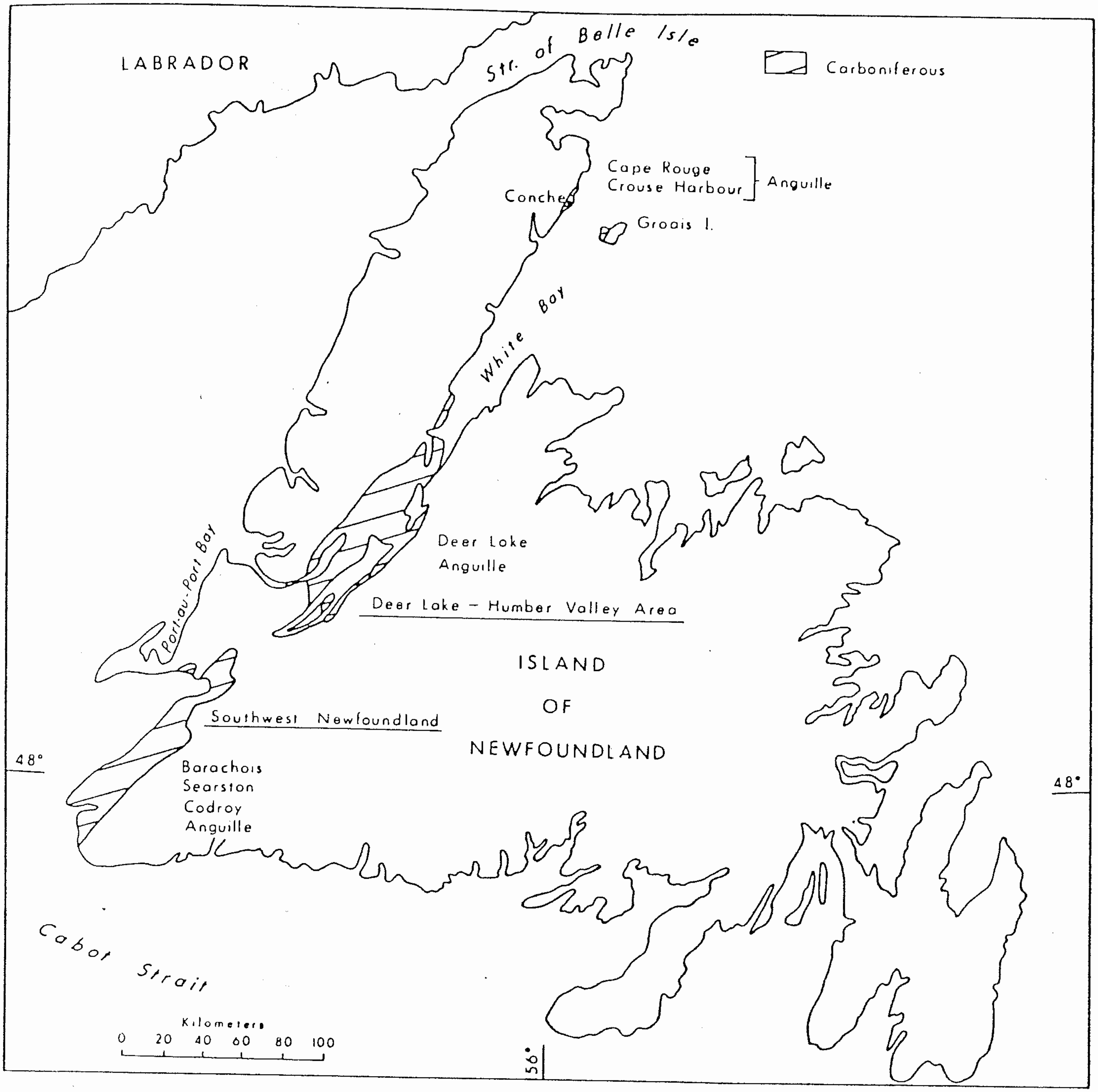


FIGURE 23. Outcrop distribution of Carboniferous strata,, Newfoundland.

Matveyev (1974), in a Russian review of world oil shales, quoted deposits outside of St. John's, where Precambrian slates are present, but no oil shales. Completely inaccurate thickness data were also presented for the Deer Lake deposits, as well as incorrect interpretation of the types of oil layers, probably indirectly from Hatch (1919). The Russian data were mostly acquired from S.C. Ells (1925), in which statements were probably based on sketchy information in the early reports of Murray and Howley.

One further area, Conche-Groais Island, does not contain oil shales, but will be discussed in some detail prior to review of the Deer Lake-Humber River area. The geology of the Conche area is significant to the regional distribution of strata and to interpretation problems on the stratigraphy of the Deer Lake Group.

CONCHE - GROAIS ISLAND - WHITE BAY

Several thousand feet of Carboniferous rock are present on the Conche and Cape Rouge Peninsulas and offshore Groais Island. The basal unit, a conglomerate composed of boulders of various origins, has a sand matrix and sandstone intervals. The composition of these beds varies rapidly and considerably across the area.

Overlying the basal Crouse Harbour conglomerate, and in part laterally equivalent, is a thick section of fine grained sandstones, siltstones and shales of the Cape Rouge Formation. Fossil plants in the Cape Rouge Formation identify the unit as lower Carboniferous (Tournasian), equivalent to the Horton Group of the Maritimes mainland (Fig. 14).

Within the Cape Rouge Formation at Pilier Cove on Pilier Bay, immediately west of Pyramid Point (Johnson, 1918), bituminous beds were reported to be interbedded in thin layers, possibly as much as 15 metres net in a gross 150 metres of section. R.W. Ells (1910) reported cannel coal from this area, with 36% volatiles, 35% fixed carbon and 29% ash.

Baird (1957) could find only a thin (less than 1 cm) bed of organic shale, apparently as a small pocket within a slip zone. The organic content occurred as lens-shaped masses parallel to the bedding and as irregular masses with indistinct boundaries. Fine banding was magnified by dissolving calcite laminae with hydrochloric acid.

There seems to be considerable difficulty in finding any notable oil shale bands. This differs from the previously reported 15 metres of composite potential. Although not of apparent economic importance, this zone is geologically interesting as the stratigraphic equivalent of the oil shale zones in Nova Scotia and New Brunswick.

Equivalent strata are now mapped at White Bay as the Cape Rouge Formation, although initially defined as the Spear Point Formation. The Anguille Group strata represent this interval in the Deer Lake region and in southwest Newfoundland, indicating subsidence and deposition along virtually the entire length of the Fundy geosyncline (Fig. 13).

DEER LAKE - HUMBER RIVER - GRAND LAKE

Although several reports are referenced, Hyde (1979) in conjunction with Werner (1956), probably will provide all the background geology required for this area.

Stratigraphy

Because of limited available fossil material, the stratigraphic position of the oil shale beds was in doubt for considerable time.

Werner made the first subdivision of the section, establishing the Deer Lake Group with three formations. The lowermost North Brook Formation consists of arkose, greywacke, conglomerate, grading upward to sandstone. Both red and grey colors were described. The medial Rocky Brook Formation consists of shales, siltstones, limey beds, and only occasional coarse arenaceous zones. Shales are maroon, green, grey, brown and black, of which some of the brown to black are oil shale intervals. Initially Werner defined the upper unit as the Big Falls Formation, even though the term Humber Falls had been used informally, as he believed the latter term to have been pre-empted. Later writers re-instated the name Humber Falls, and the term, Big Falls Formation, is no longer in use. The Humber Falls is an upper red colored course clastics sequence.

Hatch (1919) considered the oil shale beds to be Middle Carboniferous, younger than the oil shales of Nova Scotia, New Brunswick and Scotland, even though his faunal evidence consisted only of unidentified fish remains. Baird (1950) suggested a correlation of the Deer Lake Group to the Windsor Group of Nova Scotia. In the intervening area of southwestern Newfoundland, the Codroy Group, consisting of clastics and carbonates, is a definite Windsor equivalent: a northward regional change of facies carbonate to clastics would be implied by this correlation. Belt (1969) established a correlation of the Deer Lake Group to the Canso Group of Nova Scotia, establishing that a significant time period of Middle Mississippian (Visean) is unrepresented in the Deer Lake area. Hacquebard (1972) illustrated these correlations in a series of diagrams for the basic biostratigraphic intervals. Correlations on Fig. 14 illustrate these last interpretations.

Nowhere in the Deer Lake region does Deer Lake Group rest directly on the older Anguille: the contact between these units is always a fault surface. Considering that such a time period is missing from the sedimentary record, Hyde (1979) particularly noted that debris of Anguille rocks has not been anywhere incorporated into the basal North Brook conglomerates. Uplift and erosion must have been minimal during the intervening time.

Lithology

According to Werner, the grey and black shales contain carbonaceous matter derived from fragmented plant material and fish remains. Some are calcareous and become light grey to brown on the weathered surface, accenting the plant and fish debris. Red shales are more common in the lower part of the unit, decreasing upward as black coloration increases. The formation also includes red and grey siltstones, some fine grained red sandstones, and grey calcilutites and calcarenites. The upward change from red to black is attributed by Hyde to a lateral expansion of the lake system and related increase in water depth. Mud cracks are common in the red bed sequence, indicating extremely shallow conditions.

Baird (1950) described the oil shales as more massive than the enclosing shales, having a brown streak, weathering light grey, and with thin bedding to laminae, possibly some cross-laminations, evident on the weathered surface.

Two types of oil shales were reported by Landell-Mills (1954). The better type is well laminated, fissile, brownish-black, like an indurated mudstone, with yellow bodies in distinct bands. Poorer quality oil shales are compact, hard, grey-weathering, looking like tilestone. Hatch described the oil shales as both fissile and blocky, similar to the Landell-Mills types. Hatch reported the best beds to show paper structure, but reported that only one instance of curly shale was encountered.

Distribution and thickness

Deer Lake strata are preserved in two synclinal trends, one paralleling the Deer Lake and Humber River, the second along Grand Lake (Fig. 24). The total area is also considerably faulted and structually complex.

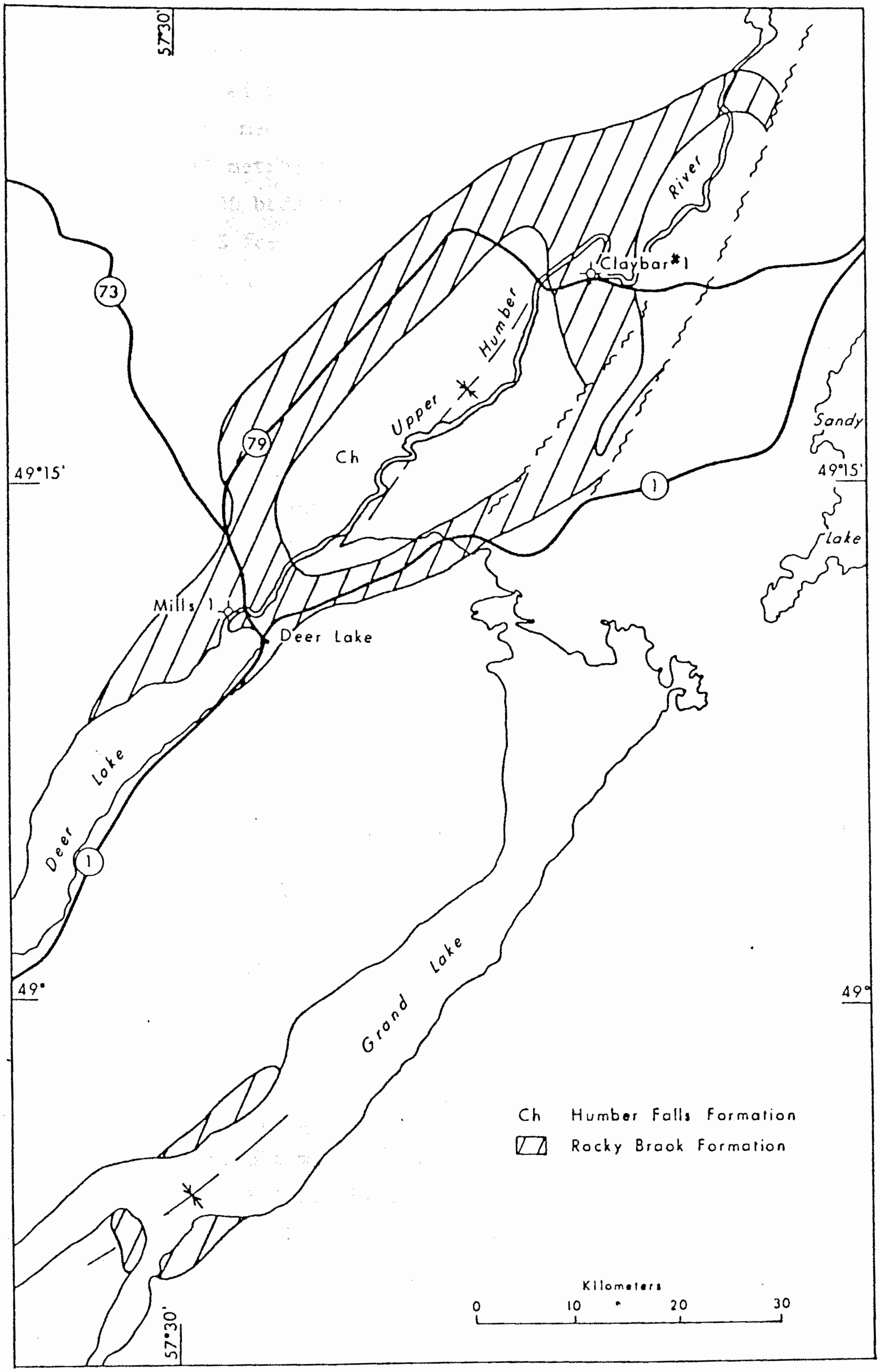


FIGURE 24. Outcrop distribution of Rocky Brook Formation, Deer Lake - Humber Valley - Grand Lake area, Newfoundland.

Hatch (1919) has given the most detailed mapping description of the oil shale beds. He divided the beds into three groups, those that burned at low heat, those requiring medium heat, and those that were hard to ignite. Only beds over 3 feet (1 metre) thick were considered.

Group I, low heat, 20 beds total, 8 at Deer Lake, 8 at Humber River, 4 at Grand Lake, range 3 feet to 5 feet (1 to 1.5 metres) thick.

Group II, medium heat, 4 beds on Rocky Brook, 3 to 5.8 feet (1 to 1.8 metres).

Group III, hard to ignite, 6 beds on Rocky Brook, 3 to 6 feet (1 to 2 metres).

The Claybar Uranium and Oil No. 1 hole, also known as Newkirk #1, was drilled to a depth of 1554 feet (474 metres), penetrating 979 feet (298 metres) of Rocky Brook Formation below thin drift and above 390 feet (119 metres) of North Brook sandstones and conglomerates overlying Ordovician basement rocks. Within the Rocky Brook, 203 feet (62 metres) of black shale were described, of which 16 feet (5 metres) were considered to be oil shales by Werner.

Better oil shales were reported by Hatch at Grand Lake than at Deer Lake - Humber River. A dam has subsequently been constructed, raising the lake level sufficiently that most of his reported outcrops are now under water. Few occurrences of oil shale can presently be found in the Grand Lake area.

Oil shale beds occur only as scattered thin zones, generally less than 2.1 metres (7 feet) thick, and not likely to aggregate more than 15 to 30 metres (50 to 100 feet) within the overall Rocky Brook Formation, which has a thickness range from possibly 500 to 1500 metres.

Mineralogy

The matrix material is dominantly fine grained clay minerals and some sericite, with very fine grained angular quartz (.002-0.07 mm), euhedral calcite, opaque carbonaceous matter (probably humic) and some yellow sapropel bodies in the better oil shales. Pyrite occurs in the red shales whereas marcasite is present in the black shales and oil shales. Calcite in the black shales is always disseminated as fine crystals: in the red shales, calcite is present as concretionary growths. The clay mineralogy has not been reported in any publications to date.

Rocky Brook Formation - economic potential

Only a limited number of verified analyses are available for the

Deer Lake oil shales.

Two shale oil recoveries were reported by Hatch (1919), one near Deer Lake at 7.5 gallons/ton (37.5 L/tonne). This led to his conclusion that Grand Lake contained the better oil shales. At Deer Lake, 14 samples were analyzed for volatile matter, averaging 9.27% with shale oil yields of 5.80 gallons/ton (29.2 L/tonne) for a ratio of 0.63 gallons/ton per 1% volatile matter. At Humber River, 2 samples had a similar ratio with 9.83% volatile matter and yields of 6.19 gallons/ton (31.0 L/tonne). At Grand Lake, probably from high grade curly shale samples, 3 analyses averaging 10.84% volatile matter, yielded 10.8 gallons/ton (54 L/tonne).

Several seams were mapped by Landell-Mills (1954) with the following general results (actual seam locations not provided):

Seam A-2, dark brown, 2 feet (0.6 m), 29 gallons/ton (145 L/tonne), S.G. 0.878, ammonium sulphate 18 lbs/ton (9 kg/tonne).

25" Seam, brownish-black, 31.0 gallons/ton (155 L/tonne), S.G. 0.884

Seam M, 4 feet (1.1 m), 10" at 24 gallons/ton (120 L/tonne) and 38" at 6 gallons/ton (30 L/tonne), 33 lbs/ton (16.5 kg/tonne) ammonium sulphate.

Seam KPI, 2'11" at 7 gallons/ton (35 L/tonne), 6' @ 17 gallons/ton (85 L/tonne) and 7" at 26 gallons/ton (130 L/tonne), S.G. 0.889.

From these data, Landell-Mills established the high quality fissile oil shale and the low quality compact hard shales.

At the Mills Borehole #1, an analysis of 0.5 feet oil shale at a depth 200.5-201 feet (61m) yielded 4 gallons/ton (20 L/tonne) and a shallower test at 80-81.5 feet (24m) retorted 6 gallons/ton (30 L/tonne).

The individual oil shale beds are thin and widely dispersed in a total thick unit. The ore is structurally complicated, and generally the shale oil yields are poor. These factors combine to preclude the Deer Lake region as a significant oil shale area at the present time. Even though some beds do yield in excess of 20 gallons/ton, their thicknesses are so limited as to offset the higher recovery values.

Bibliography - Newfoundland

BAIRD, D.M.
1950: Oil shales of the Deer Lake region; Newfoundland Geological Survey, unpublished report, p. 9-23 (good descriptions of lithologies encountered in section that encloses the oil shales).

1957: Carboniferous rocks of the Conche-northern Grey Island area; unpublished report, Newfoundland Department of Mineral Resources, 25 p. (descriptions of the Crouse Harbour conglomerate and Cape Rouge shales).

1959: Geology, Sandy Lake (west half), Newfoundland; Geological Survey of Canada, Map 47-1959 (map detail of Deer Lake - Humber River area).

1966: Carboniferous rocks of the Conche-Groais Island area, Newfoundland; Canadian Journal of Earth Sciences, v. 3, no 2, p. 247-257 (publication of 1957 paper).

BAIRD, D.M., and COTE, P.R.
1964: Lower Carboniferous sedimentary rocks in southwestern Newfoundland and their relations to similar strata in western Cape Breton Island; Canadian Institute of Mining and Metallurgy, Bulletin, v. 57, no. 5, p. 509-520 (correlations of southwest Newfoundland sections to Cape Breton; no reference to Deer Lake area).

BELL. W.A.
1948: Early Carboniferous strata of the St. George's Bay area, Newfoundland; Geological Survey of Canada, Bulletin 10, p. 1 (general lithologies; no oil shale descriptions).

BELT, E.S.
1969: Newfoundland Carboniferous stratigraphy and its relation to the Maritimes and Ireland; American Association of Petroleum Geologists, Memoir 12, p. 734-753 (establishes age correlation for Deer Lake Group).

ELLS, R.W.
1910: The oil-shales of the Maritime Provinces; Mining Society of Nova Scotia, Transactions, v. XIV, p. 11-12 (reference to bituminous shales on Port-au-Port Bay and on Notre Dame Bay; historical).

FLEMING, J.J.
1970: Petroleum exploration in Newfoundland and Labrador: Province of Newfoundland and Labrador, Department of Mines, Agriculture and Resources, Mineral Resources Division, Mineral Resources Report No. 3 (brief review of Deer Lake area; correlations since revised).

HACQUEBARD, P.A.
1972: The Carboniferous of eastern Canada; International Congress on Carboniferous Stratigraphy and Geology, 7th, Germany, Compte rendu, v. 1, p. 63-90 (illustrates Deer Lake Group as equivalent to Canso Group rather than Windsor as previously believed).

HATCH, H.B.
1919: Deer Lake, Humber River and Grand Lake shale area; private report to Reid Newfoundland Co., in files of Newfoundland Department of Mineral Resources, 27 p. (good lithologic description of oil shales, and describes numbers and general quality of beds encountered).

HAYES, A.O., and JOHNSON, H.
1938: Geology of the Bay St. George Carboniferous area; Newfoundland Geological Survey, Bulletin 12.

HEYL, G.R.
1937: The geology of the Sops Arm area, White Bay, Newfoundland; Newfoundland Department of Natural Resources, Bulletin No. 8 (initial description of Anguille rocks; historical).

HOWLEY, J.P.
1892: Humber Valley; Newfoundland, Geological Survey, Reports for 1891-1892, Chapter XI, p. 171 (historical).

HYDE, R.S.
1979: Geology of Carboniferous strata in portions of the Deer Lake Basin, western Newfoundland; Newfoundland Department of Mines and Energy, Report 79-6, 43 p., maps 79-2 (Hampden), 79-3 (Sheffield Lake), 7942 (Pasadena), 7943 (Corner Brook) and 7944 (The Topsails) - (most recent correlations and environmental interpretations; most complete report available).

1980: Cormack and part of Silver Mountain, Newfoundland; Newfoundland Department of Mines and Energy, Map 8011 (most recent map detail for outcrop distribution of Rocky Brook Formation in Humber River area).

1981: Deer Lake, Humber East District, Newfoundland; Newfoundland Department of Mines and Energy, Map in preparation (most recent map detail of Rocky Brook distribution at north end of Deer Lake).

JOHNSON, H.
1941: Newfoundland; in Possible future oil provinces of eastern Canada; American Association of Petroleum Geologists, Bulletin, v. 25, no. 8, p. 1558-1562 (clarifies Ordovician at Port-au-Port and clarifies that Mississippian of Notre Dame Bay is at Pilier Bay (Ells, 1910), mention Deer Lake; historical).

1951: Paleozoic geology and petroleum in western Newfoundland; unpublished report, Newfoundland Geological Survey, p. 25-31 (describes location of Pilier Bay oil shale).

1951: Piliers Bay; Geological Survey of Newfoundland, unpublished reports, reported in, Future Petroleum Provinces of North America; American Association of Petroleum Geologists, Tulsa, Oklahoma, p. 344 (cannel coal from Piliers Bay and brief mention of Deer Lake Mississippian).

LANDELL-MILLS, T.
1954: Report on the Oxley oil and oil shale concession in the Deer Lake district, Newfoundland; unpublished private report, in files of, Newfoundland Department of Mineral Resources, 7 p. (several analyses, describes two types of oil shale).

MARTISON, N.W.
1966: Study of oil shale occurrences in Canada; unpublished report University of Calgary, Gallagher Library, p. 27 (brief mention only of Deer Lake area).

MATVEYEV, A.K.
1974: Oil shales outside the Soviet Union; in, Deposits of Fossil Fuels, v. 4; ed. E.E. Zakharov; G.K. Hall & Co., Boston, p. 91-98 (some incorrect references to Newfoundland oil shales).

MURRAY, A.
1881: Geological Survey of Newfoundland, Annual Reports 1864-1879; London, Sanford, p. 44-45 (historical).

WERNER, H.J.
1956: The geology of Humber Valley, Newfoundland; unpublished report for Newkirk Mining Corporation, available at Newfoundland Department of Mines and Energy, 116 p. (defines Deer Lake and the North Brook, Rocky Brook and Big Falls Formations - good lithologic descriptions, recommended reading).

WILLIAMS, H.
1966: Geology, Island of Newfoundland; Geological Survey of Canada, Map 1231 A (good original map for distribution of Carboniferous strata).

BRITISH COLUMBIA

JURASSIC

From historic accounts, Richardson (1874) was probably the first to see the Queen Charlotte Islands oil shales, although at that time the carbonaceous surfaces on crushed and slickensides zones were mistaken for coal. Although Dawson described the interval containing the oil shale beds in 1880, no mention was made of oil shales being present. In both 1914 and 1915, Clapp mentioned the presence of oil shales on the Queen Charlotte Islands, but placed them in the Cretaceous section instead of Jurassic because of erroneous paleontological data. These are the most significant of the known or suspected British Columbia oil shales to date.

In the British Columbia Annual Reports for the Department of Mines, published 1904 and 1905, Robertson mentioned four other oil shale areas, with retort analysis made at only one.

Along Beaver Creek, at "Harper's Camp," west of Quesnel Lake in the Cariboo district (Fig. 25), a single analysis from a Jurassic shale sequence yielded 3% shale oil by weight, with a specific gravity of 0.97 (Robertson, 1905). S.C. Ells (1923) equated this value to 7 gallons/ton (35 L/tonne), No further data have since been reported in this area: the writer has interpreted the probable oil zone from correlation of the published data to the Geological Survey of Canada Map 3-1961, prepared by Campbell (1961).

Two other reported areas occur near Ashcroft, in the southern reaches of the Thompson River, and near Lytton, where the Fraser and Thompson Rivers meet. No analyses, or attempts to retort shale oil, have apparently ever been made from these areas. At Ashcroft (Fig. 26), black carbonaceous shales reportedly outcrop along Minaberriet Creek; map unit 12 of Geological Survey of Canada Map 1010A (Duffell and McTaggart, 1952) is thought to be the probable suspected oil shale. These shales are black, metamorphosed, quite brittle, and contain ammonite fragments which establish a Jurassic age. From the same Map 1010A, map unit 19, Cretaceous arkose, conglomerate, shale and greywacke, as outlined on Figure 27, is the only map unit which might contain suspected oil shale beds, if such beds actually exist in the Lytton area.

A fourth area, in the Flathead Valley of southeastern British Columbia, has also never been examined since the early report of oil shales. This area will be discussed under the section on further areas of interest for oil shale consideration.

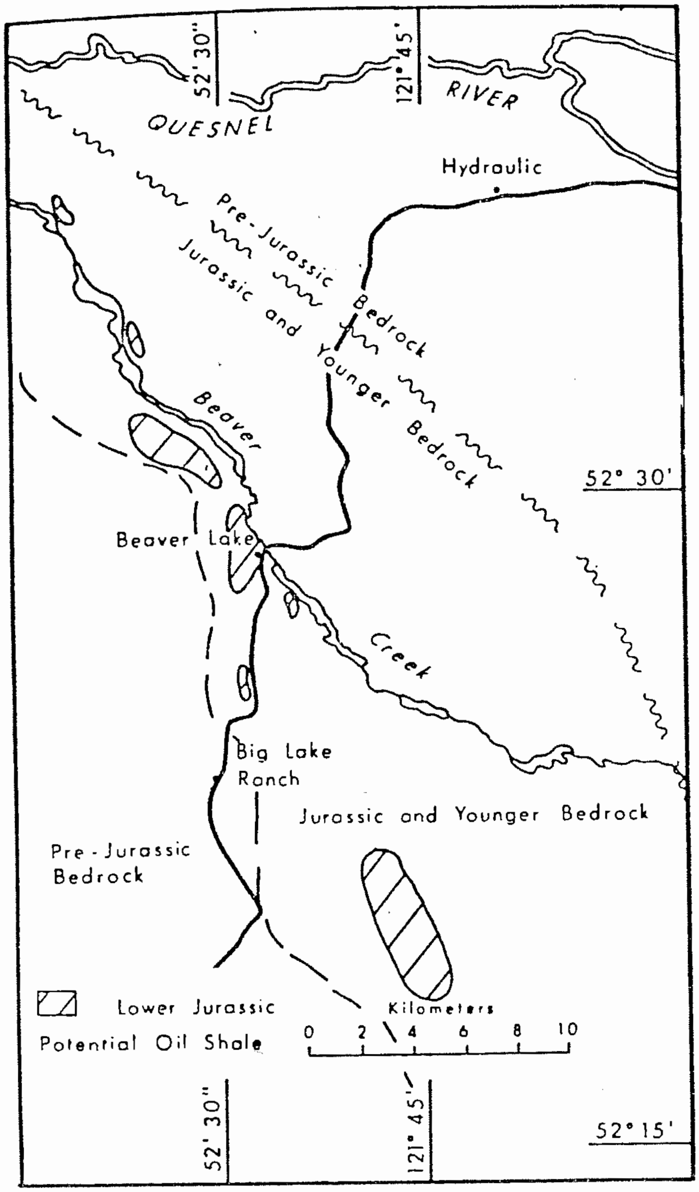


FIGURE 25. Outcrop distribution of potential oil shale, Beaver Creek, Cariboo district, B.C.

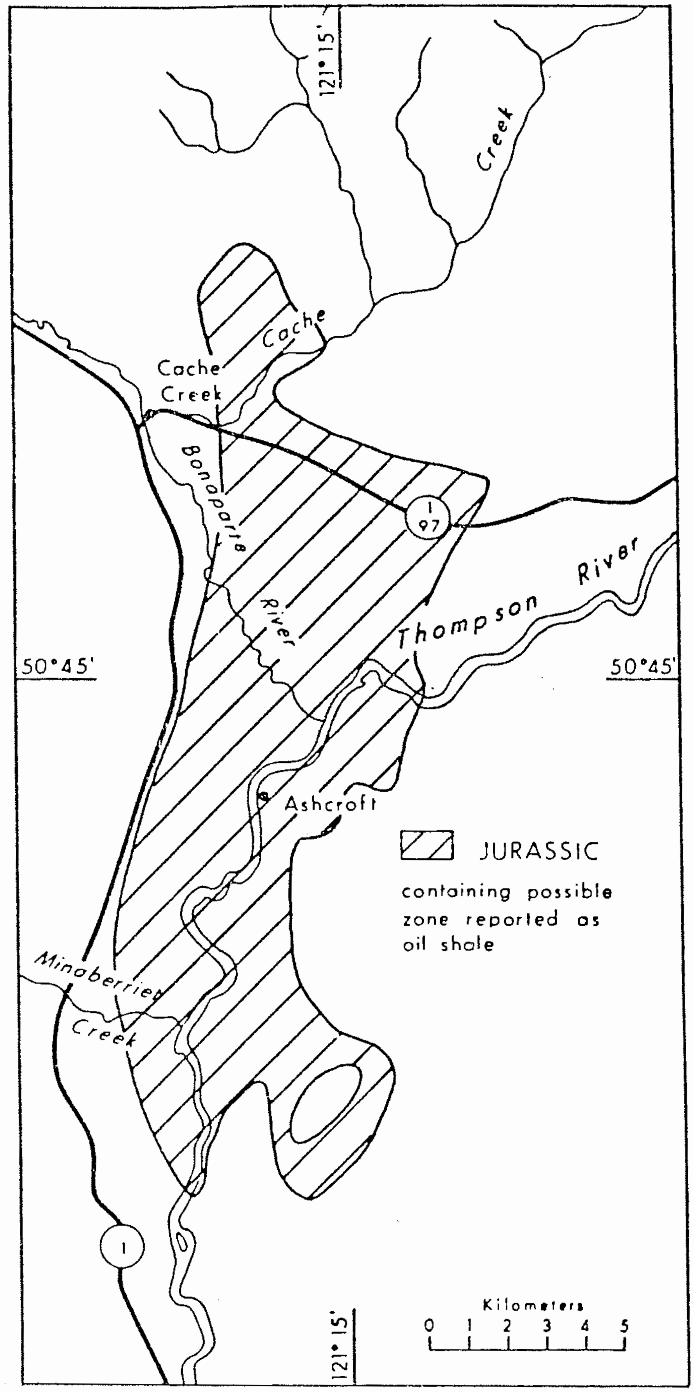


FIGURE 26. Outcrop distribution of carbonaceous shale unit, Ashcroft, B.C.

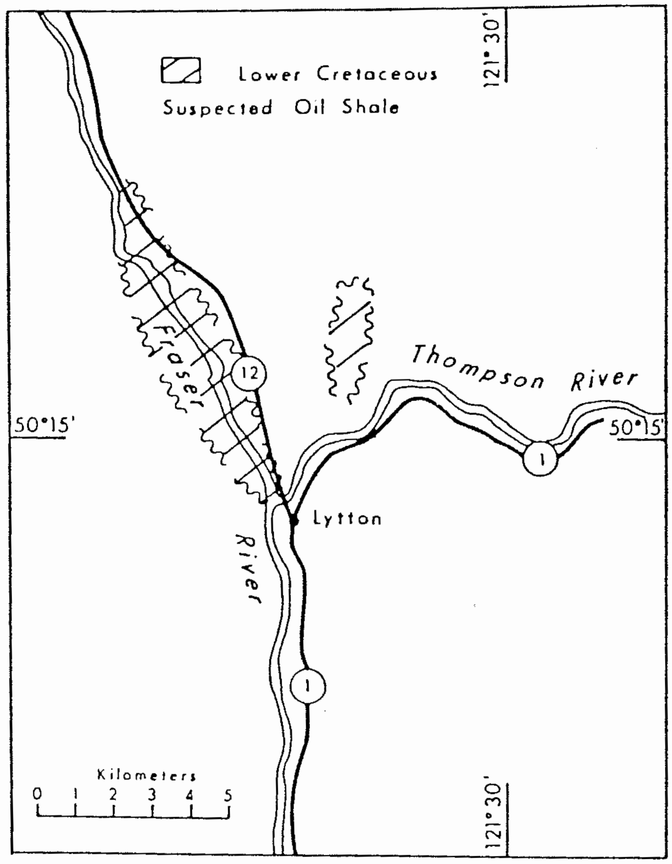


FIGURE 27. Outcrop distribution of questionable oil shale, Lytton, B.C.

QUEEN CHARLOTTE ISLANDS

The Queen Charlotte Islands are currently the only area for which any pertinent data are available: even these data are sparse. Oil shale beds occur in the Jurassic Kunga Formation (Fig. 28): although this unit does outcrop over the length of the island chain, the economic potential is restricted to the more northerly Graham Island because of facies changes and increasing metamorphism occurring in a southerly direction.

Stratigraphy

MacKenzie (1915, 1916) established the Vancouver Group to include the Yakoun and Maude Formations, with the Maude containing the oil shale zones, and, in the latter year, presented an excellent description of the lithologies involved and established the proper Triassic-Jurassic age of the Maude Formation.

An initial age dating problem had occurred when J.F. Whiteaves received fossil collections from several localities of the Queen Charlotte Islands,

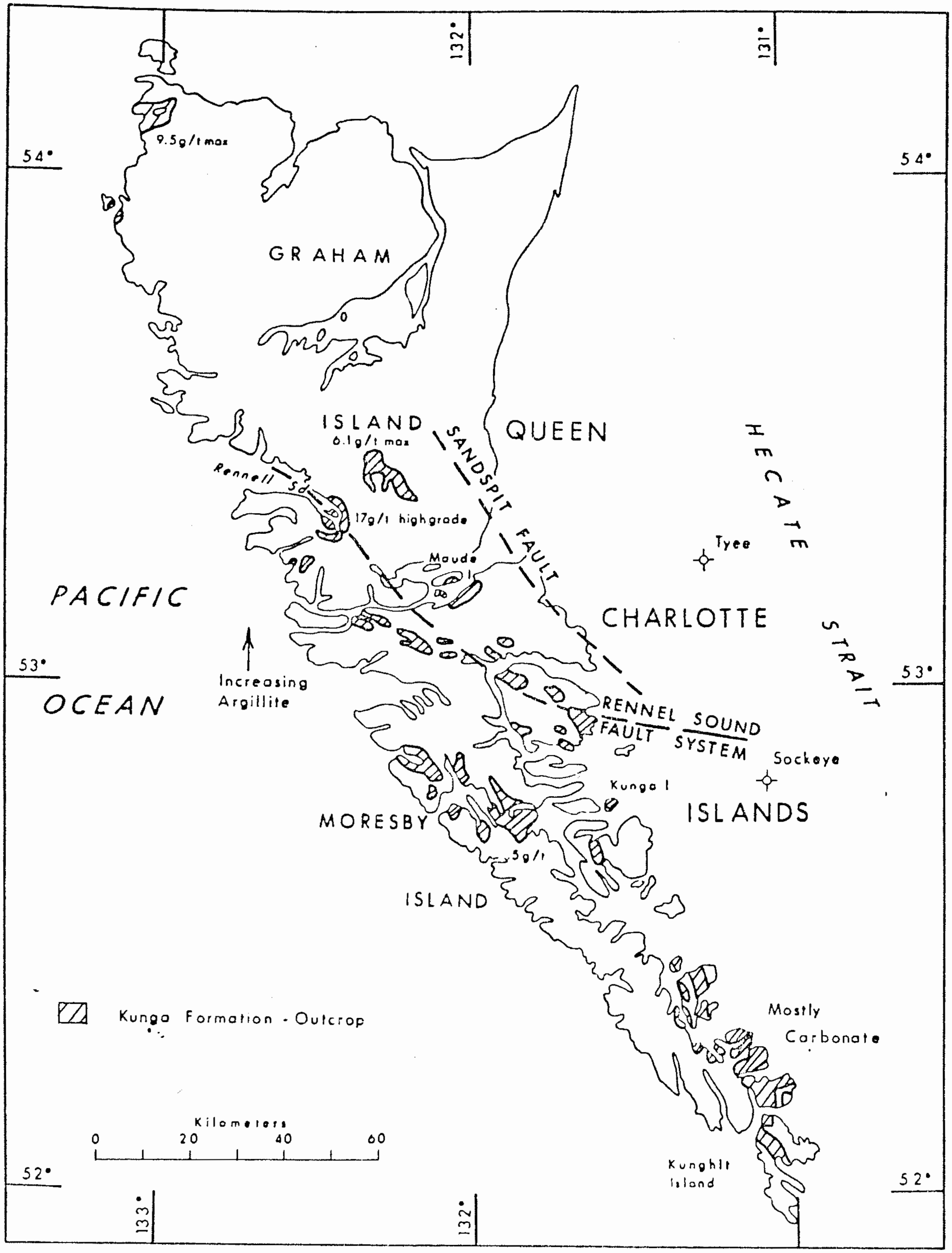


FIGURE 28. Outcrop distribution of Kunga Formation, Queen Charlotte Islands, B.C.

and did not realize that more than one zone was represented. Difficulties arose as both Jurassic and Cretaceous were determined within one apparent fossil suite. Although Mackenzie had corrected this problem in his papers, the confusion was not clarified in detail until 1949 by McLearn.

Every area has a classic report in which the basic geologic framework is established: "Geology of the Queen Charlotte Islands", by Sutherland-Brown (1968) fills that role for the Queen Charlotte Islands.

Sutherland-Brown expanded the Vancouver Group to contain the Triassic-Jurassic sequence of the area, comprising a basal volcanic interval (Karmutsen), conformably followed by the limestone-argillite Kunga Formation, grading upward to the Maude Formation of shales, argillite and sandstones, all disconformably overlain by a final volcanic sequence, the Yakoun Formation (Fig. 29). Sutherland-Brown restricted the Maude, as defined by MacKenzie, to the uppermost beds containing the coarser clastics, and separated the underlying argillite-limestone Kunga Formation as a distinct unit. Under this classification, all oil shale beds occurred within the uppermost argillites of the Kunga; however, Cameron and Tipper (1981), during recent field studies, encountered some Maude beds, younger than previously known, which contain apparent oil shale intervals.

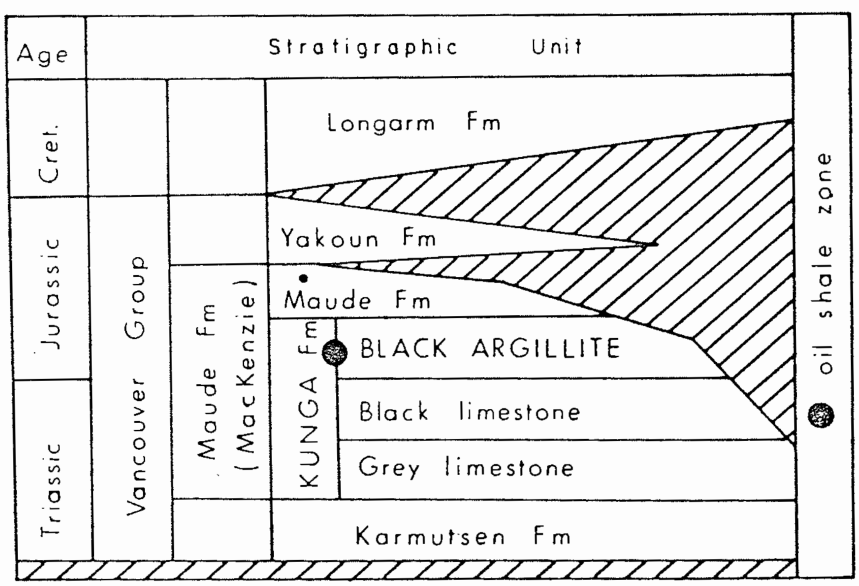


FIGURE 29. Triassic - Jurassic stratigraphic section, Queen Charlotte Islands, B.C.

A three fold subdivision of the Kunga Formation was also established by Sutherland-Brown. A lower zone of a grey massive limestone is overlain by a thinly bedded black limestone, which is succeeded by an upper thinly bedded black argillite unit. The uppermost argillites contain the oil shales.

Petro-Canada Exploration Inc., through T.P. Chamney, kindly provided analytical data and some interpretive geology to assist in the review of this area, for which little specific data was available. Chamney noted that the three unit subdivision occurs laterally as well as vertically: the black argillite member thickens northerly at the expense of the underlying massive grey carbonate. In this respect, grey limestone - black bedded limestone - black argillite can also be projected as a south to north facies relationship. These oil shales are marine platform deposits related to a carbonate sequence, of similar environmental origin to the Ordovician and Devonian oil shales of Ontario.

Lithology

The grey limestone member is uniform, consisting of grey-weathering crystalline limestone, generally thick bedded (30 centimetres to 3 metres) to massive. The fresh surface is a dark grey, exhibiting few textures except for possible coral-like organisms and gastropods.

Thinly bedded black carbonaceous limestones dominate the middle member; carbonaceous here probably implies a kerogen content. Chamney's work indicated mostly sapropel, but some humic phase, within the organic content of the Kunga. This zone also contains beds of calcarenite, fissile laminated black limestone, and some thin bedded flaggy black argillites. Beds of black limestone are generally 2.5 to 10 centimetres with inconspicious internal lamination which locally become fissile.

The black argillite member somewhat resembles the black limestone, except that argillite dominates, and often looks like "ribbon chert." Beds are also 2.5 to 10 centimetres thick with internal laminations evident. Distinct variations occur in fissility and organic content. The oil shale beds appear to be irregularly dispersed within the section. Insufficient mapping has been done to determine whether or not any thick continuous sections of oil shale are present. Within the upper member, there are also interbeds of black limestone, grey limestone, dark grey lithic sandstone and grey-green calcareous shale. In some areas the zone weathers to multi-colored yellow, orange and black in conspicuous alternating bands.

Distribution and thickness

Outcrop distribution is illustrated on Figure 28, but greater detail can be acquired from the large scale maps of Sutherland-Brown (1968).

The Kunga Formation would be assumed to be present under most of the Tertiary-Quaternary cover on the northern part of Graham Island. From analysis of the tectonics of the area, as outlined in Chase, et al (1975), Jones et al (1977), and Yorath and Chase (1981), that area east of the Sandspit fault has been moved into the present position since Jurassic time. In this case, Kunga will not necessarily be present. At the Tyee well location, in Hecate Strait, Jurassic rocks are reportedly absent as pre-Jurassic basement rocks were penetrated. Further south, the carbonate equivalent of the Kunga is understood to be present at the Sockeye well location.

Projected thicknesses of the argillite member are also difficult, as the entire area has been structurally very much deformed. Within any folded structure, the argillite beds fold, crumple, contort, shear and fault internally far beyond the effects of the larger feature. This is analogous to the difficulty of thickness estimation for the crumpled Frederick Brook oil shales in the anticlinal feature at Albert Mines, New Brunswick.

Thicknesses for the argillite member are up to 580 metres, and for the black limestone, 215 to 275 metres, by Sutherland-Brown on his stratigraphic chart. A section, described on Kunga Island, has almost 500 metres of argillite member.

Mineralogy

Both the argillites and black limestones are mineralogically similar with the calcite decreasing as the fine rock fragments increase from limestone to argillite. Beds are commonly composed of fine sand to silt size grains of volcanic rock fragments, with considerable plagioclase and virtually no quartz. Calcite crystals can vary throughout as does finely disseminated pyrite. Considerable opaque ground mass (volcanic?) can be present: organic material varies considerably. The kerogen has been described as yellow, indicating that thermal maturation has not yet passed the stage for any futher shale oil generation.

Kunga Formation - economic potential

Only a few analyses are available in the Kunga oil shales of the Queen Charlotte Islands: Petro-Canada Exploration has been supplied 13 analyses, from three areas (Fig. 28).

On Moresby Island, one analysis yielded 0.5 gallons/ton (2.5 L/tonne) with 0.920 specific gravity. Six analyses from the outcrop area of central southern Graham Island ranged from 1.3 to 6.1 gallons/ton (6.5 to 31 L/tonne), averaging 3.2 gallons/ton (1.6 L/tonne). No change was noted in specific gravity from the more southerly area analyzed. At the northwest end of the island, 6 analyses ranged 0.8 to 9.5 gallons/ton (4 to 48 L/tonne), averaging 4.9 gallons/ton (25 L/tonne) with a specific gravity range 0.920 to 0.934, slightly heavier than the more southerly shale oils.

Six samples, all from the outcrops at the southern end of Graham Island, had been analyzed for a company exploring these deposits. Recoveries were 16.5, 16.8, 17.3, 17.9, 27.0 and 34.0 gallons/ton, all changed to imperial gallons from reports in both U.S. and imperial systems. Undoubtedly these are high grade samples but they do reflect potential for recoveries beyond those of the PetroCanada investigations.

There are currently too few analyses to attempt any economic evaluation of the area; however, a few general conclusions are probably justifiable.

Oil shales quality appears to increase northward with little chance of any significant reserves except on Graham Island. Because of the structural complexities, considerable additional geological mapping will be required to determine the potential thickness of individual oil zone intervals. There is a supicion that the section is similar to that of the Deer Lake area in Newfoundland where no thick continuous zones appear to be developed. Any further field investigations should include attempts to locate and sample accurately the oil shale beds to be analyzed.

Until such time as more data become available, this area can be described only as "potentially interesting" for oil shale deposits.

Bibliography - British Columbia

CAMERON, B.E.B., and TIPPER, N.W.
1981: Jurassic biostratigraphy, stratigraphy and related hydrocarbon occurrences of Queen Charlotte Islands, B.C., Project 750035; Geological Survey of Canada, Current Research, Paper 81-1A, p. 209-212 (recognize additional Maude below Yakoun with some possible oil shale beds).

CAMPBELL, R.B.
1961: Quesnel Lake, West half, British Columbia; Geological Survey of Canada, Map 3-1961 (outcrop of possible Jurassic oil shale at Beaver Creek (Harper's Camp), Cariboo area).

CHASE, R.L., TIFFIN, D.L., and MURRAY, J.W.
1975: The western Canadian continental margin; in Canada's Continental Margins and Offshore Petroleum Exploration, eds. C.J. Yorath, E.R. Parker and D.J. Glass; Canadian Society of Petroleum Geologists, Memoir 4, p. 701-721 (tectonic movements to help define possible present limits of Kunga Formation).

CLAPP, C.H.
1914: A geological reconnaissance of Graham Island, Queen Charlotte Group, B.C.; Geological Survey of Canada, Summary Report, 1912, p. 39-40 (mentions presence of oil shales, places them in Cretaceous; historical).

CLAPP, F.G.
1915: Petroleum and natural gas resources of Canada; Canada, Department of Mines and Resources, Mines Branch, Report no. 291, v. II, p. 364 (historical).

DAWSON, G.M.
1880: Report on the Queen Charlotte Islands; Geological Survey of Canada, Annual Report, 1878, pt. B (general descriptions of Maude rocks, although not then named; historical).

DUFFELL, S., and McTAGGART, K.C.
1952: Ashcroft map area; Geological Survey of Canada, Memoir 262, map 1010A (area of early reported oil shales; probably not oil shales)

ELLS, R.W.
1906: Report on the geology of Graham Island, B.C.; Geological Survey of Canada, Annual Report, New Series, 1904, v. XVI, pt. B. p. 1-46 (describes Cretaceous coal beds, east coast only, no mention of oil shales; historical).

ELLS, S.C.
1923: Oil shales of Canada; Canada Department of Mines, Summary Report of Investigations made by the Mines Branch, 1921, Report No. 588, pt. G. p. 54 (comments only; historical).

1925: Oil shales of Canada; in Shale Oil, ed. R.H. McKee, American Chemical Society, Monograph Series No. 25, The Chemical Catalog Company Inc., New York, p. 58 (comments only, historical; mentions Lytton area).

JONES, D.L., SILBERLING, N.J., and HILLHOUSE, J.
1977: Wrangellia - a displaced terrain in northwestern North America; Canadian Journal of Earth Sciences, v. 14, p. 2505-2577 (good background paper to understand structural displacements in Queen Charlotte Islands).

MacKENZIE, J.D.
1915: Graham Island, British Columbia; Geological Survey of Canada, Summary Report, 1914, p. 34-36 (Jurassic - Triassic Vancouver Group of Yakoun and Maude Formations; report of oil shales in Maude; historical).

1916: Geology of Graham Island, British Columbia; Geological Survey of Canada, Memoir 88, p. 40-47, 86-89, 159-160 (excellent summary of lithologies, mineralogy and kerogen content of "Maude" limestones and shaly argillites).

MARTISON, N.W.
1966: Study of oil shale occurrences in Canada: unpublished report, University of Calgary, Gallagher Library, p. 13 (minimal comments; considers few analyses too low; considerable maturation because of tar on bedding planes).

McLEARN, F.H.
1949: Jurassic formations of Maude Island and Alliford Bay, Skidegate Inlet, Queen Charlotte Islands, British Columbia; Geological Survey of Canada, Bulletin no. 12, p. 1-9 (describes MacKenzie's work (1916) to sort Cretaceous-Jurassic paleontological confusion; historical).

RICHARDSON, J.
1874: Coal-bearing rocks of the Queen Charlotte Islands; Geological Survey of Canada, Progress Report 1872-1873, p. 7, 56-63 (probably called some of the Maude argillite coal because of black carbonaceous surfaces of crushed and slickensided zones, historical).

ROBERTSON, W.F.
1904: Progress of mining - oil shales; British Columbia Department of Mines, Annual Report, 1903, p. 24 (initial report of Harper's Camp (Beaver Creek) oil shale and Flathead oil shale; historical).

1905: Progress of mining - oil shales; British Columbia Department of Mines, Annual Report, 1904, p. 23-24 (analysis of oil shale at Beaver Creek in Cariboo district; historical).

SHOULDICE, D.H.
1971: Geology of the western Canada continental shelf; Bulletin of Canadian Petroleum Geology, v. 19, no. 2, p. 405-436 (good regional geology for background knowledge).

STRONACH, N.
1981: Regressive cycles in the Fernie Formation (Jurassic) of southwest Alberta; in, Annual Core and Field Sample Conference, ed. F.A. Stoakes; Canadian Society of Petroleum Geologists, Calgary, p. 10-14 (organic carbon content of Fernie Formation).

SUTHERLAND-BROWN, A.
1968: Geology of the Queen Charlotte Islands, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin no. 54, p. 50-66, 179 (re-defined Maude Formation by limitation to upper interval: lower part, including oil shales, became Kunga Formation).

SWINNERTON, A.A.
1938: Oil shales of Canada; in, Oil Shale and Cannel Coal; The Institute of Petroleum, p. 216 (geographic list of possible oil shale areas; no data; historical).

WRIGHT, W.J.
1922: Bituminous shales of Canada; Geological Survey of Canada, Memoir 129, p. 50-51 (mentions Queen Charlotte oil shale, says no data available; historical).

YORATH, C.J., and CHASE, R.L.
1981: Tectonic history of allocthonous terranes, northern Canadian Pacific continental margin; Canadian Journal of Earth Sciences, in press, (tectonic history of Queen Charlotte Islands to define present Kunga distribution).

PRAIRIE PROVINCES

UPPER CRETACEOUS

Tyrrell (1892) was the first geologist to report the presence of oil shales along the Manitoba Escarpment as he described the petroliferous odor emanating from the rocks when struck by a hammer. The first analysis from Manitoba, 7 imperial gallons/ton (35 litres/tonne) with 22.5 lbs. ammonium sulphate/ton (11.2 kg/tonne) was listed by McInnes (1913): however, the first significant comments came from S.C. Ells (1923). Ells stated, "Oil shales of New Brunswick and Nova Scotia were deposited under different conditions from those of Manitoba and Saskatchewan." Although not directly defined, Ells did understand that the depositional environment consisted of a marine "muddy sea" in the Manitoba-Saskatchewan area in contrast to the lacustrine environment of the New Brunswick oil shales. The Prairie Provinces oil shales do not fit any of the classified standard oil shale environments, i.e.: lacustrine, restricted swamp or bog (torbanite); or shallow marine platform deposits related to carbonates. Ells also noted that the "oil" content of the Manitoba beds did not prevent weathering, in contrast to the resistive nature of Maritime shales.

Two oil shale zones are present, an upper Boyne Formation, and a lower Favel Formation, separated by a non-oil shale, the Morden Formation. Both the oil shale zones are characteristically the same, composed of white speckled calcareous shale, with foraminiferal debris causing the white specks. The zones are traceable across the three Prairie Provinces, excepting for a central area of Saskatchewan where only one unit is present (Fig. 30).

Stratigraphy

Development of terminology for the Manitoba Escarpment, and subsequently the subsurface of Manitoba and Saskatchewan, has been relatively straightforward, although several complications have arisen.

Ells (1923) first used the term "Boyne" to refer to the white speckled shale zone which was faunally equated to the Niobrara of the more southerly United States sections. He also used the term Morden for the underlying shale. Although a basal unit, the Assiniboia shale, was used in his geologic column, this was not described in his text.

In 1930, Kirk officially defined the Boyne as a member of the Vermilion River Formation (Fig. 31), a sequence of dark shale, speckled shale, dark

FIGURE 30. Outcrop distribution of Upper Cretaceous oil shale zones, Prairie Provinces

<table>
<tr><th colspan="3">Generalized present terminology</th><th>As used herein</th><th colspan="3">Proposed by McNeil & Caldwell</th></tr>
<tr><td colspan="3">Riding Mountain Fm</td><td>Riding Mountain Fm</td><td colspan="3" rowspan="2">Pierre Shale</td></tr>
<tr><td rowspan="3">Vermilion River Fm</td><td colspan="2">Pembina Member</td><td>Pembina Fm</td></tr>
<tr><td>BOYNE MEMBER</td><td>1st Spx</td><td>BOYNE Fm</td><td colspan="3">NIOBRARA Fm</td></tr>
<tr><td colspan="2">Morden Member</td><td>Morden Fm</td><td colspan="3"></td></tr>
<tr><td rowspan="2">FAVEL Fm</td><td>Assiniboine Member</td><td rowspan="2">2nd Spx</td><td rowspan="2">FAVEL Fm</td><td rowspan="2">FAVEL Fm</td><td>Assiniboine</td><td>Marco calcarenite</td></tr>
<tr><td>Keld Member</td><td>Keld</td><td>Laurier limestone</td></tr>
<tr><td colspan="3">Ashville Fm</td><td>Ashville Fm</td><td colspan="3">Belle Fourche shale</td></tr>
</table>

FIGURE 31. Pertinent Upper Cretaceous stratigraphy, Manitoba Escarpment

shale, overlain by pale greenish-grey shales of the Riding Mountain Formation and overlying a sequence he called the Assiniboine. The Assiniboine was composed of speckled shale and thin limestone, overlying a significant limestone bed and speckled shales of the Keld, which in turn overlay dark non-oil shale of the Ashville Formation. Wickenden (1945) established the Favel Formation to include the Assiniboine and Keld, but did not make the Boyne into an equivalent formation, even though both zones were lithologically and stratigraphically of equivalent rank.

Recently, McNeil and Caldwell (1980) raised the Boyne and Morden to formational status, but suggested that Niobrara would be preferable to Boyne. Because of past common useage, the term Boyne will probably continue to be used in Canadian literature, and will be used in this report.

In his unpublished thesis, Park (1965) illustrated the westerly thinning and eventual loss of the intervening Morden shale between the Boyne and Favel: ultimately an area exists where only one shale unit is present (Fig. 30). Price and Ball (1971, 1973) recognized from faunal evidence that only the Boyne is present at two of the potash shafts near Saskatoon: they suggested that the underlying Morden and Favel were absent because of non-deposition rather than deposition with subsequent uplift and erosion. This is basically the same conclusion reached by Park. In 1968, T.P. Chamney, then of the Geological Survey of Canada, Calgary, described this Morden unconformity to outline the loss of stratigraphic interval in a talk at Regina: in personal discussion, Chamney inferred that he also considers non-deposition to be the prime reason for the absence of this stratigraphic interval.

McNeil and Caldwell involved several unconformities in the section to explain thickness changes and lithologic variations along the Manitoba Escarpment.

Some suggested unconformities may represent uplift and erosion, some may be non-deposition, and some may be facies changes. All of these possibilities were discussed by the authors. One additional factor must also be considered. The periodic differential solution of underlying salt section of the Middle Devonian Prairie Evaporites has created anomalous conditons throughout the overlying geological section. Many of the single well anomalies may be attributable to underlying differential salt solution.

One of the problems for evaluating oil shale potential at the surface lies in being able to distinguish between the two lithologically similar units. The Boyne-Morden speckled shale-dark shale sequence is macroscopically identical to the Favel-Ashville sequence; however, the Boyne and Favel speckled shales can be differentiated by micropaleontology (Parks 1965, North and Caldwell, 1975; McNeil and Caldwell, 1980).

Both zones are present in the subsurface of Alberta where the informal terms "First White Specks" and "Second White Specks," in descending drilling order, have been used by the petroleum industry: no need has been felt for more formal nomenclature. In the outcrop area of northwestern Alberta, the first speckled zone (Boyne) is represented by part of the Puskwaskau Formation: the second zone, not readily definable as an outcrop unit, is separated from the upper zone by a considerable thickness of sediment, and equates approximately to the lower part of the Kaskapau Formation (Fig. 30).

Lithology

Both white speckled zones consist of identical lithologies, dark grey to brownish-grey shale, with variable content of white speckling by foraminiferal debris. The shales may be finely laminated to fissile, but fissility decreases as the fossil content increases.

The zone may grade to bands of lime marl where the fossil debris becomes the dominant rock component. The limestone beds may reach several feet in thickness to represent semi-regional units, such as the Marco calcarenite and Laurier limestone proposed by McNeil and Caldwell (1980).

Bands of pure shale, barren of fossil debris, may be present within the speckled intervals. The basic color of the rock was described by Ells (1923) as greenish-grey, similar to that of the overlying Riding Mountain shale above the Pembina-Boyne interval: Ells attributed the dark color to the hydrocarbon content. Along the southern part of the Manitoba Escarpment, where hydrocarbon content is considerably less than at the north, lighter colors are more prevalent. The shales everywhere weather light grey.

Within the Favel Formation, the limestone bed at the top of the Keld Member is the Laurier limestone: the Marco calcarenite occurs at the top of the Assiniboine Member. These are the two most distinctive relatively pure limestone beds in the section.

Thin bentonite beds occur within the Favel section, although Kirk (1930) placed the boundary of the Keld-Ashville at the top of a group of 3 bentonite clay bands.

The intervening Morden beds, where developed, are dark grey, laminated, fissile to sub-fissile, non-calcareous shale. This description also fits the underlying Ashville, and the overlying Pembina where present. In southern Manitoba, these units are also lighter colored, as are the oil shales. Undoubtedly, there is sufficient organic content throughout the section below the Riding Mountain Formation to effect color darkening in a northward direction.

Although the impure limestone marls, or calcarenites, are somewhat resistive to erosion, the white speckled oil shale beds are generally recessive. This is marked contrast to the resistance of the Maritimes Carboniferous oil shales to weathering effects.

Distribution and thickness

The distributional pattern has already been fairly well outlined in discussion of the stratigraphy of the two units. The Boyne (upper zone) generally averages 30 to 45 metres (100-150 feet) at the outcrop area, thinning to approximately 18 metres (60 feet) in a central Saskatchewan where only a single unit is present, and thickening again westerly to a range of 36 to 61 metres (150 to 200 feet) in the Alberta subsurface.

Favel beds attain a general maximum of 18 metres (60 feet) along the Escarpment, thinning to zero (or centimetres only) in central Saskatchewan, and thickening westerly to 36 to 61 metres, similar to the First Specks, in the subsurface of Alberta.

The intervening Morden shale thins westerly from as much as 45 metres in the outcrop to zero in central Saskatchewan and from there thickens westerly to considerably greater than 100 metres in the Alberta subsurface and up to 300 metres along the Albert Foothills.

There appears to be a general southeasterly thickening along the Manitoba Escarpment.

Mineralogy

Clay mineralogy data are available from analyses submitted to the Manitoba Government by Aquitaine Company of Canada Ltd. Montmorillonite is by far the dominant clay, with lesser mixed layer illite-montmorillonite and minor illite. Chlorite is also present. Jarosite and selenite are recognized, as well as glauconite and phosphatic debris which probably represent fish remains. Only traces of quartz are present. There is no kaolinite.

Calcite, because of the detrital nature of the white specks, is a significant, variable mineral component, with clay decreasing as calcite increases.

Pyrite is present, but much of the sulphide appears altered to sulphate as selenite is common, and crystallizes on the surface of cores or outcrop. Considerable elemental sulphur also crystallizes on the surfaces of core or outcrop. Mineral alteration is sufficiently great that an estimated one to three metres must be drilled or excavated to acquire fresh rock. The crystallization of sulphur is also reflected in the analysis of the recovered shale oil, where the sulphur content can be as high as 6.87 percent.

Boyne and Favel Formations - economic potential

Gas was discovered in the vicinity of Kamsack (Fig. 32) and was produced from the Boyne Formation at depths of about 70 metres. The reservoir was probably in low porosity bands of limestone calcarenite: no sandstones are present in the formation at that depth. The field had dropped from 33 to 23 lbs/sq in pressure from 1940 to 1943, but was supplying some Kamsack buildings at the time of the report by Wickenden (1945).

Near Hudson Bay Junction, Wickenden also reported a gas show from the Favel from two of a series of Kakwa test wells. Again the gas probably came from porosity in a calcarenite band.

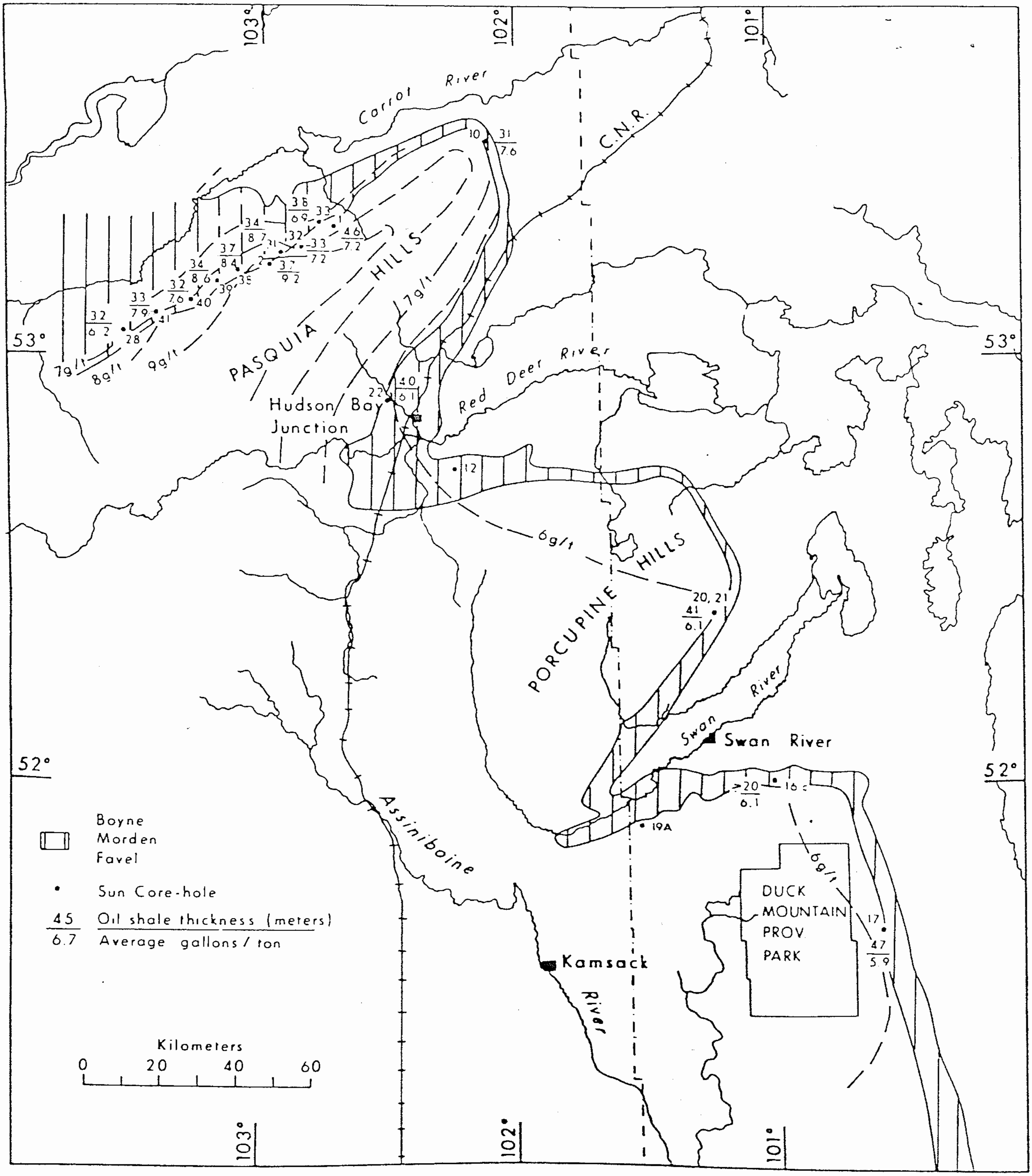


FIGURE 32. Outcrop distribution of oil shales on the Manitoba Escarpment, with generalized oil content data

In addition to discussing the oil potential, Beck (1974) also outlined tests of the limestone beds for possible use as a cement rock. Some equivalent beds in Manitoba are reportedly utilized for cement manufacture.

Beck also indicated some interest for uranium within the Pasquia Hills area; however, outcrop samples, within the area of an airborne anomaly, yielded the highest values (5.00 and 9.28 ppm) from samples of non-calcareous Vermilion River Formation.

From visual examination of three cores cut by the Atlantic-Richfield Company in southern Manitoba (Fig. 30), the hydrocarbon content was seen to be maximum in the zones of moderately speckled shale, decreasing with lesser carbonate debris, but the marlstones to pure carbonates were also virtually barren of kerogen. In this aspect, the limestone beds may be a serious impediment to any mining operation as they would be hard to remove, increasing stripping costs considerably. This additional cost might be overcome if the limestone could be used as a base for a cement byproduct.

Additionally, the oil shale interval is not an exact duplication of the speckled shale beds; consequently, oil shale may be encountered for some distance above, or below, the Boyne and Favel Formations, in the adjacent dark shale beds of the Pembina, Morden, or Ashville. These contacts appear to be gradational, with the initiation of kerogen preceding the influx of pelagic fossil debris and continuing somewhat after the fossil input had ceased.

The above comments on kerogen distribution are based only on the three available cores at the Manitoba Department of Natural Resources. Cores from some 40 additional locations, part of a Sun Oil Company program, have been lost or destroyed. The distribution of shale oil recoveries and occurrences of barren zones suggests that the same conditions occur along the entire escarpment trend.

Considering that analyses are available from over 40 recent coreholes along the trend, the few older analyses are of little consequence, except that MacInnes (1913) not only reports 7.0 gallons/ton (35 L/tonne), but also 22.5 lbs/ton (11.2 kg/tonne) of ammonium sulphate.

Table 7 is a summary of the analyses from the key locations penetrating near complete sections of Boyne or Favel Formation. Most penetrate the Boyne, but Favel beds are also analyzed in the southern part of Manitoba. The averaged recoveries have been plotted (Fig. 32), from which a general

Hole No.	Oil Yield g/t		Avge. L/tonne	Thickness		Specific Gravity		
	Max.	Avge.		Feet	Metres	Max.	Min.	Avge.
Sunoco								
1	10.8	7.6	37	152	46	0.991	0.931	0.960
2	20.1	9.2	46	110	33	0.992	0.930	0.965
10	12.9	7.6	37	102	31	0.996	0.961	0.976
12	10.2	7.9		49+				0.968
16C	8.9	6.1		67+				0.963
17	8.7	5.9	30	115	35	0.973	0.958	0.967
19A	7.6	6.6		44+				0.970
22	11.2	6.1	31	135	41	0.975	0.957	0.965
28	9.7	6.2	31	108	33	0.974	0.964	0.969
31	25.0	8.7	44	115	35	0.979	0.944	0.967
32	19.2	7.2	36	109	33	0.984	0.956	0.969
33B	11.7	6.9	35	126+	38+	0.985	0.950	0.971
38	18.5	8.4	42	124	37	0.974	0.951	0.964
39	11.7	8.6	43	102	31	0.975	0.952	0.965
40	12.2	7.6	38	106	32	0.972	0.953	0.965
41	18.4	7.9	40	109	33	0.970	0.961	0.964
Atl-Rich.								
2	12.5	3.9	17	167	50			0.962
3	10.8	3.0	15	172	52			0.958
4	5.6	1.0						0.954

TABLE 7: Analytical results from Manitoba Escarpment coreholes

optimum area, in excess of an average 9 gallons/ton, over about 37 metres, is mappable along the northwest edge of the Pasquia Hills. The regional southerly decrease in shale oil recoveries is indicated on Fig. 32, where generalized average recovery isopachs have been prepared from partial penetrations of the Boyne and from a few surface analyses.

Favel data are available along the Manitoba part of the Escarpment. The limited data would appear to be similar in distribution to that of the Boyne.

Beck (1974) estimated that a zone 1.6 to 19 kilometres (1 to 12 miles) width by 56 kilometres (35 miles) length could be mineable along the northwest flank of the Pasquia Hills. Using an average thickness of 30 metres, and with grade of 8 U.S. gallons/ton, he estimated 2.6 billion barrels of oil in place. The estimated thickness is probably much too high as an average would not likely exceed 18 metres (60 feet): the average gallons/ton seems quite realistic. A reduction of the average zone would bring the in place oil down to 1.6 billion barrels. From a brief review of recovery distribution within the cored Boyne intervals, the basal 10 metres if often very low grade; consequently, the average pay thickness may more realistically be reduced to about 14 metres (45 feet), which would reduce oil in place to 1.25 billion barrels (200 million cubic metres).

The above figure is ballpark only, as no detailed analysis was conducted of the distributional patterns of good and poor zones within the Boyne oil shale interval. From the recovery distribution, the maximum potential reserves should be under the Pasquia Hills, probably necessitating mining or an in-situ recovery.

Potash shafts at Esterhazy and near Saskatoon (Fig. 30) penetrated oil shale beds in the Boyne-Favel intervals: M.O. Fluglem (Geological Survey, Calgary, personal communication) stated that the two White Specks zones, when encountered in well cuttings in east-central to northwestern Alberta, could often be ignited in an alcohol flame. Equivalent beds in the United States northern Great Plains (Schultz, et al, 1980) are also oil shales.

Because of the large areal extent, the continuous good gross zone thickness, and the lack of structural complication, the Boyne and Favel, in spite of lower yields relative to other areas, contain vast quantities of shale oil: as such, these zones must be considered as primary oil shale targets.

Ells noted the geological difference of these oil shales to those of the Maritimes. These shales exude much greater odor, and distill over a much poorer gravity product (SG 0.95 to 0.98, API 11.5^{o}), are higher in sulphur (almost 7%) and seem to have a much higher gas fraction. This greater component of natural gas may be beneficial if in-situ mining operations are attempted. Because of the 7% content, extraction of the sulphur could be a profitable by-product operation rather than a nuisance cost.

Bibliography - Manitoba and Saskatchewan

BANNATYNE, B.B.
1970: The clays and shales of Manitoba; Manitoba Department of Mines and Natural Resources, Mines Branch, Publication 67-1, 107 p. (generally accepted nomenclature).

BECK, L.S.
1974: Geological investigations in the Pasquia Hills area; Saskatchewan Department of Mineral Resources, Report 158, 16 p. (estimates of in-place oil; Boyne-Favel differentiation problems; limestone beds as cement).

CLAPP, F.G.
1915: Petroleum and natural gas reserves of Canada - oil shales; Canada Department of Mines, Mines Branch, Report no. 291, v. II, pt. 2, Western Canada, p. 251 (repeats McInnes (1917) analysis; historical).

ELLS, S.C.
1923: Cretaceous shales of Manitoba and Saskatchewan as a possible source of crude petroleum; Canada Department of Mines, Summary Report of Investigations, 1921, Report No. 588, p. 34-41 (described differences of Manitoba shale to those of Maritimes; several analyses; good generalized lithologic descriptions).

1925: Oil shales of Canada; in, Shale Oil, ed. R.H. McKee; American Chemical Society, Monograph Series No. 25, The Chemical Catalog Company Inc., New York, p. 57-58 (brief comments and generalized yields, historical).

KIRK, S.R.
1930: Cretaceous stratigraphy of the Manitoba Escarpment; Geological Survey of Canada, Summary Report, 1929, pt. B, p. 112-134 (defines Boyne and Morden as members of Vermilion River).

MacLean, A.
1915: Pembina Mountain, Manitoba; Geological Survey of Canada, Summary Report, 1914, p. 69-71 (descriptions of Boyne; historical).

1916: Pembina Mountain, northern Manitoba; Geological Survey of Canada, Summary Report, 1915, p. 131-133 (descriptions of Boyne; historical).

MARTISON, N.W.
1966: Study of oil shale occurrences in Canada; unpublished report, University of Calgary, Gallagher Library, p. 14-19 (reviews Sun Oil core program results and economics estimated for Sun).

McINNES, W.
1908: Pasquia Hills and lower Carrot River Region; Geological Survey of Canada, Summary Report, 1907, p. 45 (states 120 feet of bituminous shale overlying thin limestone bed to be Niobrara equivalent; historical).

1913: The basins of Nelson and Churchill Rivers: Geological Survey of Canada, Memoir 30, p-68, 127, 133-134 (three analyses from Niobrara oil shale section of Pasquia Hills; historical).

McLEARN, F.H. and WICKENDEN, R.T.D.
1936: Oil and gas possibilities of the Hudson Bay Junction area, Saskatchewan; Geological Survey of Canada, Paper 36-8 (reported gas flows from Keld-Assiniboine (Favel) in Kakwa test holes).

McNEIL, D.H., and CALDWELL, G.E.
1980: Cretaceous rocks and their foraminifera in the Manitoba Escarpment; Geological Association of Canada, Special Paper No. 21 (detailed comprehensive review of biostratigraphy and lithostratigraphy of Manitoba Escarpment; uses Favel, raises Morden to Formation and suggests replacement of Boyne as a formation by Niobrara; suggest several unconformities in this part of section).

NORTH, B.R., and CALDWELL, W.G.E.
1975: Cretaceous foraminifera from Saskatchewan and Manitoba; Geological Survey of Canada, Paper 74-38 (detailed foraminiferal lists to differentiate Cretaceous zones; pertinent to recognition of Boyne versus Favel).

PARK, J.M.
1965: Biostratigraphy of the Upper Cretaceous white speckled shales in central Saskatchewan; unpublished M.Sc. thesis, University of Saskatchewan, Saskatoon (recognized area in central Saskatchewan where only Boyne deposited; suggests single zone by merging of the two speckled units; established faunal criteria for the Boyne and Favel).

PRICE, L.L., and BALL, N.L.
1971: Stratigraphy of Duval Corporation potash shaft no. 1, Saskatoon, Saskatchewan; Geological Survey of Canada, Paper 70-71, p. 23-30, 54-47 (description of geological section penetrated by shaft; Favel missing).

1973: Stratigraphy of Cominco potash shaft no. 1 Vanscoy, Saskatchewan; Geological Survey of Canada, Paper 72-11, p. 35-42, 73-76 (geological section penetrated by shaft; Favel missing as only Boyne represented: suggests non-deposition rather than deposition and subsequent erosion to explain missing Favel).

SCHULTZ, L.G., TOURTELOT, H.A., GILL, J.R., and BOERGNEN, J.G.
1980: Composition and properties of the Pierre shale and equivalent rocks, northern Great Plains region; United States Geological Survey, Professional Paper 1064-B, p. 15-17.

SUN OIL COMPANY
1965: Manitoba and Saskatchewan, oil shales research; unpublished report, Manitoba Department of Mines and Resources, open file (reviews retorting procedures used to analyze Manitoba Escarpment oil shales).

SWINNERTON, A.A.
1938: Oil shales in Canada; in, Oil Shale, ed. R.H. McKee., The Institute of Petroleum, p. 216 (brief reference only, historical).

TYRRELL, J.B.
1888: Notes to accompany a preliminary map of Duck and Riding Mountains in north-western Manitoba; Geological Survey of Canada, Annual Report, New Series, 1887-1888, v. III, pt. E (first geological description of the area).

1892: North-western Manitoba with portions of the Districts of Assiniboia and Saskatchewan; Geological Survey of Canada, Annual Report, 1890-1891, v. 5, pt. 1, Report E (recognized oil content of shale by hitting with hammer).

WALLACE, R.C.
1921: The search for oil in the Pasquia Hills; The Canadian Mining Journal, July 8, p. 540-542 (generalized comments in oil shale potential; historical).

WALLACE, R.C., and GREER, L.
1927: Oil shales, non-metallic resources of Manitoba; Manitoba, Industrial Development Board.

WICKENDEN, R.T.D.
1931: Variations in thickness of Cretaceous formations in southern Manitoba; Geological Survey of Canada, Summary Report, 1930, pt. B, p. 72-73 (generalized descriptions of Boyne and Assiniboine-Keld).

1945: Mesozoic stratigraphy of the Eastern Plains, Manitoba and Saskatchewan; Geological Survey of Canada, Memoir 239, p. 23-50, 58-59 (defined Favel Formation, good update of stratigraphy to to that date; no significant further work until McNeil and Caldwell in 1980).

WILLIAMS, G.D., and BURK, C.F.
1964: Upper Cretaceous: in, Geological history of western Canada, eds. R.G. McCrossan and R.P. Glaister; Alberta Society of Petroleum, Geologists, Calgary, p. 169-189 (correlations to northwest Albeta).

WRIGHT, W.J.
1922: Bituminous shales of Canada; Geological Survey of Canada, Memoir 129, p. 51 (minimal comments, historical).

NORTHWEST TERRITORY - YUKON TERRITORY

UPPER CRETACEOUS (& DEVONIAN)

For most of Canada, the presentation of oil shale occurrences has been able to follow both geological continuity upward in the section as well as geographic organization of the material. One occurrence, not well known or defined, of Middle to Upper Devonian oil shale in the Northwest Territory, is the exception to the organizational system used for this report.

LOWER MACKENZIE RIVER AREA

Kindle and Bosworth (1921) named the Fort Creek shales as a unit of "dark, almost black, bituminous clay shale with thin seams of black limestone and calcareous sandstone. These shales are so bituminous that their odour is perceptible at a distance. In many places they are undergoing slow combustion and are burnt to a bright brick-red color." Hume (1953) more fully described the Fort Creek shales relative to the Kee Scarp limestone and also discussed an upper "non-bituminous" member, which was a transition from the Fort Creek organic shales upward to the sandstone-bearing Imperial Formation. Hume quoted paleontological data which indicated the organic shales to be late Middle or early Upper Devonian: this age range is still accepted, with individual preferences for Middle noted in different publications.

Yorath and Balkwill (1968, 1970), published detailed surface maps of the lower Mackenzie River area; figure 33 outlines the distribution of Canol Formation (the Fort Creek bituminous zone) as excerpted from these maps.

Canol shales, generally about 30 to 40 metres thick, are black, often siliceous, with yellow, orange and red secondary minerals on the weathered surface. In part the beds are laminated, but may also be described as blocky: the unit is a recessive - weathering zone. Pyrite is common, and oxidizes at the surface to create reddish-brown hematite patches.

Oxidation of the pyrite certainly creates considerable heat, but the burning appearance probably relates also to ignition of the kerogen content by the oxidizing pyrite. Samples can reportedly be ignited by a flame. Kindle and Bosworth indicated that the only attempted retorting of Canol shales was unsuccessful because of poor equipment. Although not proven, the Canol interval is certainly indicated to be an oil shale zone.

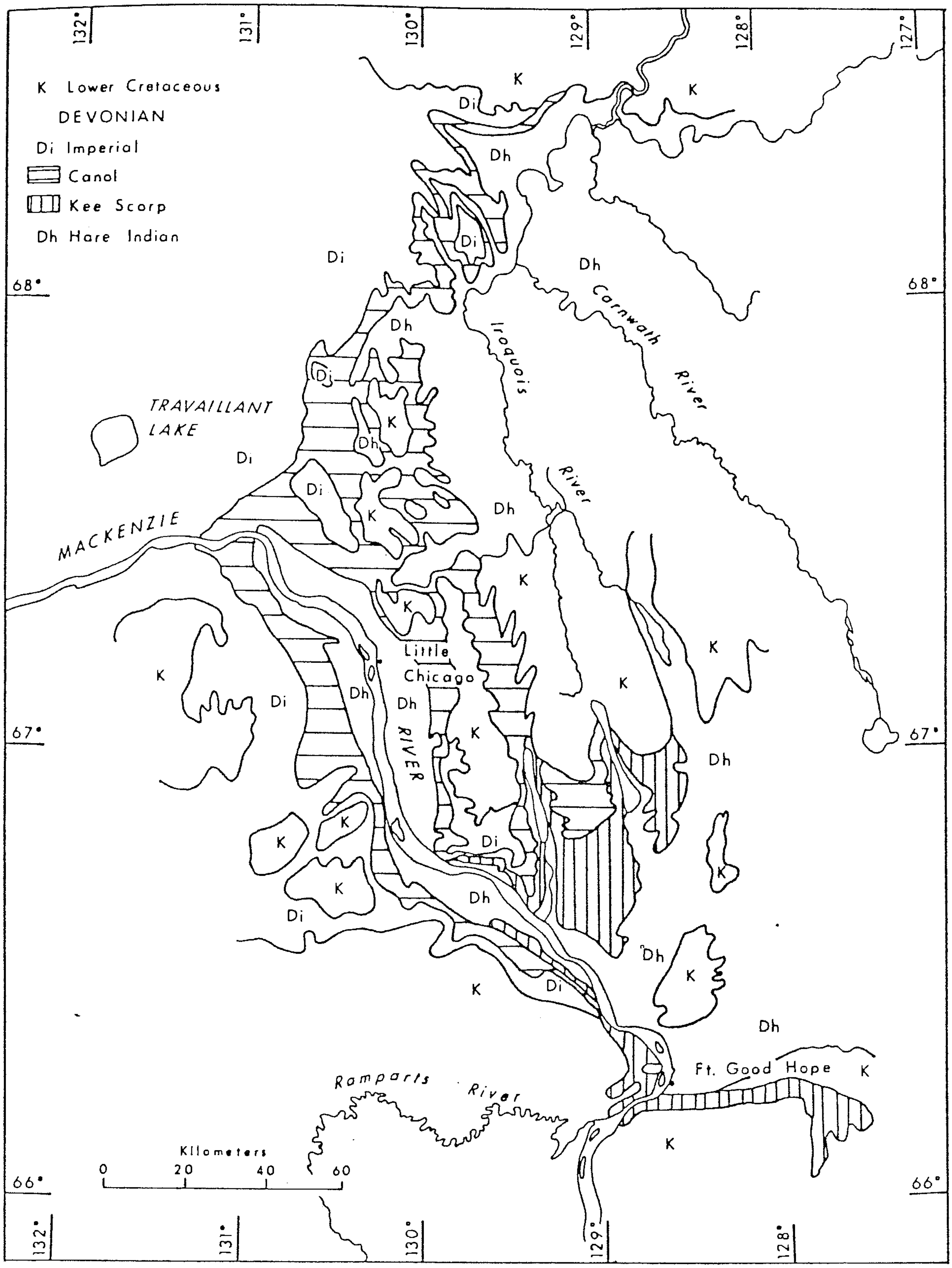


FIGURE 33. Outcrop distribution of Canol Shale, lower Mackenzie River, N.W.T.

Shales of the Canol Formation are deposited both overlying, and lateral to, Kee Scarp carbonate beds. Where Kee Scarp carbonate is absent, Canol overlies non-organic grey shales of the Hare Indian Formation. Canol oil shales are a shallow marine platform deposit related to carbonate deposition.

ANDERSON PLAIN - MACKENZIE DELTA

Within the Northwest and Yukon Territories, the greatest areal extent and thickness of possible oil shale zone are represented by the Smoking Hills - Boundary Creek Formations, initially informally called the Upper Cretaceous "bituminous zone." This unit is the stratigraphic correlative of the two white specks zones, the Boyne and Favel, already outlined as oil shales along the Manitoba Escarpment.

Bocannes, typified by smoke and sulphurous fumes emanating from burning surface rocks (Crickmay, 1967), are distinctive in the Smoking Hills physiographic sub-area of the Anderson Plain (Fig. 34). Here beds of the Smoking Hills Formation smoke from the bocannes, with the areas of smoking changing frequently. Although often attributed entirely to the oxidation of pyrite, the smoking must entail burning of some of the kerogen content of the rocks, as the oxidation of pyrite in non oil shale rocks occurs without the emission of smoke and burning. Although the equivalent Manitoba Escarpment shales do not create bocannes, the oil shale of the tailings pile did catch fire spontaneously at one of the potash shafts.

<u>Stratigraphy</u>

The surface distribution of the Smoking Hills Formation was initially mapped as the informal "bituminous zone" underlying the "pale shale" unit (now the Mason River Formation of the Anderson Plain) by Balkwill and Yorath (1970), Yorath and Balkwill (1970), and Yorath, Balkwill and Klassen (1963). The formal terminology was proposed by Yorath, Balkwill and Klassen (1975).

Further west, at the south end and west side of the Mackenzie Delta, Jeletzky (1960) recognized upper Cretaceous strata, informally defined as the "upper Cretaceous shale division," which are now further defined by Young (1975) with introduction of Boundary Creek and overlying Tent Island Formations (Fig. 35). These are stratigraphic equivalents of the Smoking Hills - Mason River sequence. On the east side of the Mackenzie Delta, a large area intervenes where no Upper Cretaceous beds are exposed.

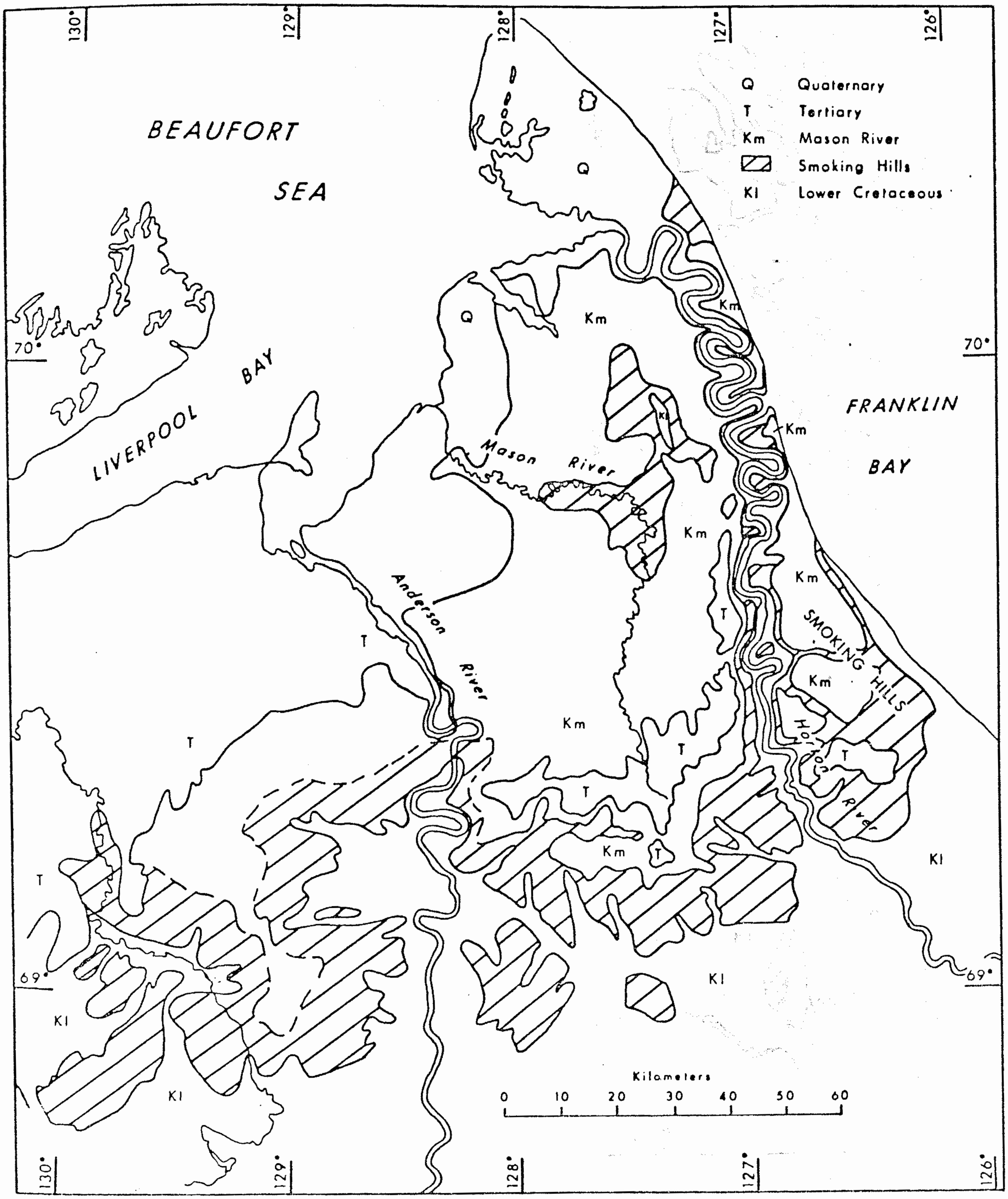


FIGURE 34. Outcrop distribution of Smoking Hills Formation, N.W.T.

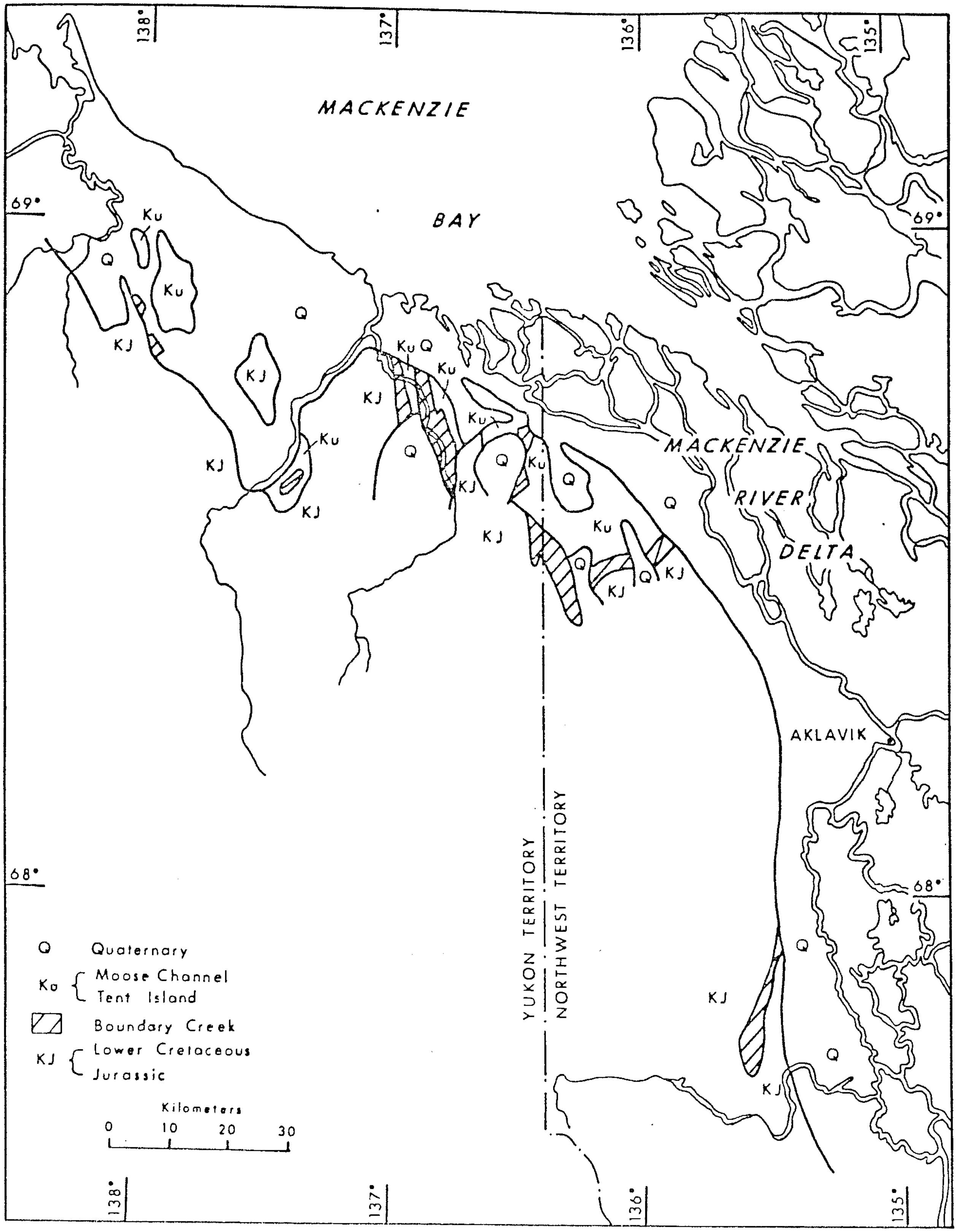


FIGURE 35. Outcrop distribution of Boundary Creek Formation, Y.T.

Young, Myhr and Yorath (1976) presented a more regional paper covering the Beaufort - Mackenzie Basin. Here the Smoking Hills of Anderson Plain represents the Santonian-Campanian interval of the Upper Cretaceous with a significant time period missing where the Smoking Hills rests disconformably on Albian Horton River Formation. At the west, in the Richardson Mountains, the Boundary Creek seems to represent most of Cenamonian through Campanian time, with much less missing sedimentary record. This is directly analogous to the Prairie Provinces situation where some of the record is missing in the Boyne-Favel area at the east, but which is more complete in the deeper subsurface and foothills areas of Alberta.

Lithology

The Smoking Hills Formation is composed of interbedded black to medium grey, soft but commonly fissile organic shale, with white to dark yellow and orange weathering, waxy to crumbly, thin to thin-bedded jarosite laminae. There is a sporadically distributed basal conglomeratic sandstone, indicating some possible area of erosional unconformity on the underlying beds.

The Boundary Creek is described by Young (1975) as constant in lithologic character, consisting of grey to black, soft shale, oxidizing to yellow, red and mahagony brown. Beds of bentonite are present, concentrated in zones with seams to 0.3 metres. A few thin carbonate beds have been described in the lower part of the unit.

Both the overlying Mason River and Tent Island Formations are represented by soft grey shales, similar in character to the light greenish-grey Riding Mountain shales overlying the Vermilion River (Boyne) in Manitoba.

Distribution and thickness

Figures 34 and 35 illustrate the distributional pattern of these Upper Cretaceous strata, which are preserved as erosional remnants in broad to local synclinal features. Toward the coastline, Cretaceous beds are covered by Quaternary deposits: additional areas of Smoking Hills - Boundary Creek under the Quaternary beds and under the Beaufort sea can be projected from the outcrop pattern. The presence of the zone below Quaternary along the Arctic coastal plain has been illustrated by Snowdon (1980) on a well section.

The Smoking Hills Formation in the Anderson Plain ranges 30 to 46 metres thick near the Horton River, thickening southwesterly to 31 to 60 metres around Anderson River.

Various sections of the Boundary Creek Formation vary from 165 to 240 metres, indicating a regional westerly thickening of the initial deposits commensurate with the increasing time span represented.

Mineralogy

The basic mineralogy is the same in both areas, with montmorillonite, illite and kaolinite as the basic clay minerals (kaolinite is not present in Manitoba). Other constituents include considerable quartz, aluminite, aluminum sulphate octahedra hydrate, gypsum, selenite, jarosite, many of which are weathering products of the iron and sulphur in the rock. Some of the clays are considered to be of volcanic origin and fine volcanic lapilli were encountered in some of the digestions for microfauna. As stated, bentonite occurs in distinct beds and laminae.

Smoking Hills and Boundary Creek Formations - economic potential

No attempts have been made to retort shale oil from this Upper Cretaceous interval of the Northwest and Yukon Territories. Oil shale is considered to be present from the lithologic descriptions, from the bocannes, and from the direct comparison to those of the Manitoba Escarpment. Recovered shale oil is expected to have similar characteristics to that of the White Specks, including a high sulphur content, because of the abundance of surface weathering sulphur-bearing minerals.

Studies have been conducted on the Boundary Creek Formations as a potential source rock. These were analyzed and summarized by Snowdon (1980) who concluded that this is an excellent source rock, and has been the source of several oil occurrences within the Mackenzie Delta area. Snowdon also concluded that considerable humic material is present and that the source kerogen is not particularly mature. The heavy gravity of the Manitoba Escarpment shale oil could be a concern, especially for potential recovery volumes, if the gravity relates to increased maturity; however, Snowdon's conclusions for the Boundary Creek zone are probably applicable to the Boyne and Favel oil shales. Both areas may contain significant humic kerogen.

Because of the geographic locations, the Boundary Creek and Smoking Hills oil shales are probably of limited economic potential at the present time. Although some retorting analyses should be made, further understanding of these zones may be more easily gained through research carried out on the geologically comparable Manitoba - Saskatchewan oil shale intervals.

Bibliography - Northwest and Yukon Territories

BALKWILL, H.R., and YORATH, C.J.
1970: Simpson Lake map-area, District of Mackenzie (97B); Geological Survey of Canada, Paper 69-10, p. 6-7, map 16-1969 (surface distribution and brief description of "bituminous zone").

COOK, D.G., and AITKEN, J.D.
1969: Fort Good Hope, District of Mackenzie; Geological Survey of Canada, Map 4-1969 (surface distribution of Canol-Hare, Indian-Kee Scarp beds).

CRICKMAY, C.H.
1967: A note on the term bocanne; American Journal of Science, v. 265, no. 7, p. 626-627 (origin and meaning of "bocanne").

HUME, G.S.
1953: The lower Mackenzie River area, Northwest Territories and Yukon; Geological Survey of Canada, Memoir 273, p. 34-40 (relationship of Ft. Creek Shale to Kee Scarp and Imperial; age determination).

JELETZKY, J.A.
1960: Uppermost Jurassic and Cretaceous rocks, east flank of Richardson Mountains between Stony Creek and lower Donna River, Northwest Territories; Geological Survey of Canada, Paper 59-14, p. 20-22 (shales equivalent to "bituminous zone" present westerly of south end of Mackenzie Delta from descriptions of Upper Cretaceous beds).

KINDLE, E.M., and BOSWORTH, T.D.
1921: Oil-bearing rocks of lower Mackenzie valley; Geological Survey of Canada, Summary Report, 1920, pt. B, p. 47-49, 54-55 (described burning characteristic of Fort Creek shale).

SNOWDON, L.R.
1980: Petroleum source potential of the Boundary Creek Formation, Beaufort-Mackenzie Basin; Bulletin of Canadian Petroleum Geology, v. 28, no. 1, p. 46-58.

YORATH, C.J., and BALKWILL, H.R.
1968: Crossley Lakes, District of Mackenzie; Geological Survey of Canada, Map 8-1969 (surface distribution of "bituminous zone, also northernmost outcrop of Canol).

1970: Stanton map-area, Northwest Territories (107D); Geological Survey of Canada, Paper 69-9, p. 4, map 15-1969 (surface distribution of "bituminous zone").

YORATH, C.J., BALKWILL, H.R., and KLASSEN, R.W.
1969: Geology of the eastern part of the northern interior and Arctic coastal plains, Northwest Territories; Geological Survey of Canada, Paper 68-27, p. 19-20 (brief description and regional map of "bituminous zone" distribution in the Anderson Plains area).

1975: Franklin Bay and Mallock Hill map-areas, District of Mackenzie; Geological Survey of Canada, Paper 74-36 (detailed mapping and definition of "bituminous zone" as Smoking Hills Formation).

YOUNG, F.G.
1975: Upper Cretaceous stratigraphy, Yukon Coastal Plain and northwestern Mackenzie Delta; Geological Survey of Canada, Bulletin 249 (defined Boundary Creek Formation).

YOUNG, F.G., MYHR, D.W., and YORATH, C.J.
1976: Geology of the Beaufort-Mackenzie Basin; Geological Survey of Canada, Paper 76-11 (regional review of total area combining results of the more local papers).

POSSIBLE OIL SHALE ZONES

Several areas of possible oil shales have already been mentioned relative to the known oil shale deposits; beyond these a few additional areas seem to warrant consideration (Fig. 36).

Black shales of the Lachine-Lotbinière sequence in the St. Lawrence Lowland (Figs. 5, 36) and those of the Macasty Formation (Fig. 3, 36) of Anticosti Island were discussed previously as part of the Ordovician potential of Ontario and Quebec. Because of the eastward decrease in shale oil recoveries from the Collingwood to Ottawa area, commensurate with thickening section, the thick Lachine-Lotbinière is not regarded optimistically as a potential oil shale interval. At Anticosti Island, the Macasty shales occur just below sea level, and are recognized by erosional rubble rather than outcrop. Although not suitable for an open-pit mining process, the Macasty shales reportedly will burn when held in a flame and may be potential when an economic in-situ recovery technique is developed.

Ordovician black shales of the Table Head Group, reportedly Middle Ordovician and not necessarily the equivalent of the Macasty of Anticosti Island, were considered as possible oil shales in Newfoundland. Located on Port-au-Port Peninsula (Figs. 23, 36), the available rock descriptions indicate a degree of structural deformation and probable thermal metamorphism such that oil shale potential is considered poor.

Siluro-Ordovician black graptolitic shales of the Road River Formation outcrop in the Ogilvie and Richardson Mountains of the Yukon Territory. The Road River has never been described as an oil shale, and has been subjected to a considerable depth of burial and tectonic deformation. This unit is widespread, is several hundreds of metres thick, and should warrant the minimal efforts required to confirm that the zone has matured beyond oil shale conditions.

Powell (1978) prepared "An Assessment of the Hydrocarbon Source Rock Potential of the Canadian Arctic Islands" (Geological Survey of Canada, Paper 78-2), in which a comprehensive source rock study was made from subsurface samples for the complete geological section of the Artic Islands. Although prepared as a source rock study, these are useable interpretive data for this study as oil shales are the source rocks of the geological future, or of the immediate future of man if successful extractive techniques can be developed. None of Powell's results indicated good oil shale potential within the Arctic Islands.

Black shales of the Siluro-Ordovician Cape Phillips Formation, stratigraphically equivalent to the Road River Formation of the Yukon Territory, are exposed on Bathurst and Cornwallis Islands. At these locations, the unit has been described as limy petroliferous shales and as dark brown petroliferous shales: no data are available to confirm any potential for shale oil yield.

Late Middle to early Upper Devonian organic shales of the Horn River Formation outcrop recessively and with poor exposures around the Horn Plateau of the Northwest Territories. This unit is stratigraphically and geologically very similar to the Canol Formation of the Norman Wells area; both have been included within the "Fort Creek Formation," an early term encompassing all dark shales in the Devonian of the Northwest Territory. Ranging from 15 to 70 metres in thickness, the Horn River organic shales could represent a new oil shale interval. The zone has not apparently been deeply buried and is part of a gentle westerly dipping homocline. Structural deformation has been minimal.

Some of the early historical reports mentioned oil shales on Melville Islands but these are now known to be Triassic tar sands deposits.

Dark grey to black bituminous shales have been described in the Jurassic Deer Bay Formation with dark shales in the underlying Savik Formation on Axel Heiberg Island, but there is no present evidence that these units represent oil shales. Some Cretaceous dark shales, with brown streak, have been described from the same general area.

Oil shales were briefly mentioned in the Flathead Valley of southeastern British Columbia in early Government reports. Although no later references have been made to this area, the zone involved was undoubtedly the "poker-chip" shale of the Jurassic Fernie Formation. These shales are dark brown to black with a brown streak, are laminated, and are known to contain up to 7% organic carbon; however, the exact nature of the carbon content is unknown and the degree of maturation of any kerogen has not been determined. Fernie shales are present easterly along the mountain fronts of Alberta and north-eastern British Columbia and are significant mappable units within the more easterly adjacent subsurface areas. Within the subsurface of west-central Alberta, carbonate and sandstone facies of the Nordegg Formation, a lower unit of the Fernie Group, contain heavy oil and gas. The Fernie shales are the probable source of these hydrocarbons, as well as the possible source of hydrocarbons in underlying Mississippian and overlying lower Cretaceous productive zones. In this respect, the Fernie shales are worthy of investigation both for source rock and for oil shale potential.

Reported oil shales of the Ashcroft (Fig. 26) and Lytton (Fig. 27) areas of the interior of British Columbia have already been described; although not considered as probable oil shale deposits, some futher sampling and analytical investigation may be justified to confirm the present conclusions.

SUMMARY

Of known Canadian oil shale deposits, those of the Albert Formation, Frederick Brook Member, at Albert Mines, New Brunswick, are the best studied and defined, and are the most economically attractive at the present time.

A possible minimum 100 metres of zone averaging in excess of 100 litres/tonne (20 gallons/ton) can be mapped over an area of approximately 2.6 square kilometres (one square mile). The retorted shale oil has averaged 0.861 specific gravity (28° API), considerably better than recovered from most oil shales (Green River Basin, S.G., 0.91 to 0.94). This would indicate an excellent atomic hydrogen/carbon ratio, requiring a minimum hydrogenation process for upgrading of this fuel. Many refineries around the world operate normally on crude oil of no better quality. Sodium salts are absent, an environmentally important facet of the mineralogy as readily soluble sodium and chlorine will not be part of the waste material.

On the more negative side of the economics, the deposit is structurally much contorted, which may create difficulties in open pit and/or underground mining and virtually precludes any type of currently anticipated in situ recovery. The deposits are also present over a relatively flat surface area, necessitating a deep open pit, as the oil shales are known to a depth of almost 700 metres below ground level. Diversion of the Frederick Brook watercourse, which crosses the oil shale area, will be necessary to mine to any significant open pit depth; however, water supply will probably not be a significant problem.

This New Brunswick deposit is definitely the most important of all Canadian oil shales for continuing exploration and research.

The occurrences along the Manitoba Escarpment are also of considerable interest. Although of lesser average yield, covering an area of the Pasquia Hills with a maximum 45 litres/tonne (9 gallons/ton) average, the Boyne and Favel white speckled shale zones are significant because of the large subsurface as well as surface areal extent, and the excellent zone thicknesses, averaging 40 and 20 metres for the upper and lower zones along the Manitoba Escarpment. The shale oil quality is not so good as desired, about 0.980 specific gravity (11° API), very much a heavy crude and requiring some upgrading prior to refinery processing. This is still several degress higher than recovered from the oil sands of the Ft. McMurray area, and is in the range of crude obtained in the Lloydminster heavy oil area of

Alberta-Saskatchewan. When Canada discontinues the high-grade refinery use of premium oils only, the 11^{o} API product of the Manitoba Escarpment oil shales will be much closer to standard refinery crude than at present.

Oil shales on the Manitoba Escarpment are structurally homoclinal, with only a low southwesterly rate of dip. Occurring along an escarpment, strip mining may be more practical than for the New Brunswick deposits. Retorting of these shales appears to give a greater gas yield than encountered in other Canadian deposits: this may be significant for in situ techniques. Also relative to the in situ processes, a high water content of the Boyne and Favel shales may assist production by steam drive from the heating process. The degree of sulphur recovery may also here be more economical, as the shale oil contains up to 7% sulphur component. No data are available for any of the deposits to demonstrate the nature of the sulphur content: is there only pyrite in the rock, or is the sulphur bound into the kerogen molecule? The presence of mercaptans would introduce a significantly different refining cost than mere removal of pyrite sulphur alone.

Oil shales of the Manitoba Escarpment are definitely the second most significant deposit in Canada. Their complete dissimilarity, in virtually every respect, from those of New Brunswick, means that experimental lack of success, or success, cannot be automatically attributed to each area. All experimental research will, of necessity, have to be applied to each of these deposits.

Beyond these two areas, data are presently insufficient to compare the economic potential of the other known oil shales.

Those of the Smoking Hills and Boundary Creek Formations of the Northwest and Yukon Territories are suspected to be significant because of the geologic similarity to the Boyne and Favel of the Manitoba Escarpment. Because of the geographic location, interest must presently be limited, but further knowledge of the northern deposits will be easily acquired at minimum effort by continued comparison of the northern oil shales, with a few samples only, to the results of research on the Manitoba - Saskatchewan units.

The few analyses available of the Ontario - Quebec Ordovician and Devonian beds are not encouraging because of low yields from zones of limited thickness. Fortunately, within the area of interest in southwestern Ontario, numerous subsurface data are available from conventional oil and gas field development; consequently, areas of greatest thickness may be mappable to direct further programs of coring and analytical study.

Data are obscure for the oil shales of both the Deer Lake area, Newfoundland, and the Queen Charlotte Islands, British Columbia. These areas have too few analyses to be meaningful, and thickness projections are really unknown. Both are structurally much disturbed: the increased thickness of good oil shale zones by crumpling of the better intervals, as at Albert Mines, New Brunswick, could be a bonus feature of either area. From present knowledge, both areas are worthy of continuing investigation until more meaningful thicknesses and oil contents have been obtained.

Probably the torbanite and oils shales of the Pictou area, Nova Scotia, associated with coal seams, are the most difficult to assess. In areas where the three kerogen types, oil shale, torbanite and coal, combine to create a mineable seam (possibly 2 metres or greater), some technique for the joint energy consumption of the three types should be feasible.

The oil shale deposits of Canada are all so geologically different that none can safely be ignored. All experiments for the removal of kerogen, or kerogen - derivative shale oil, from the oil shale beds must be applied to all the rock types. The zones are all lithologically and mineralogically so different that reactions to any specific treatment will be extremely variable from deposit to deposit.

FORECAST

"Every other source of energy should be found to replace wherever and as much as possible this precious oil which should, in my opinion, in future - not too distant, I hope - be used for the noble purpose of the petrochemical industry." Shahanshah Arya Mehr Mohammed Reza Pahlavia of Iran, as quoted in Chemical and Engineering News, p. 5, January 7, 1975.

"Increasing demand for hydrocarbons both for fuels and for chemical feedstocks and the current awareness of the finite nature of petroleum deposits results in renewed interest in alternate sources of fossil hydrocarbons." H.C. Carpenter, H.B. Jensen and A.W. Decora, in Potential Shale Oil production processes; American Chemical Society, Division of Fuel Chemistry, v. 22, no. 3, p. 48, 1977.

"Kerogen is the most abundant molecule on earth. It has been estimated by McIver that, whereas all the intercellular carbon in the biosphere amounts to 3.10^{17}g, kerogen is at least 10,000 times as abundant."

T.F. Yen, Structural aspects of organic components in oil shales; in, Oil Shale, eds. T.F. Yen and G.V. Chilingarian, Elsevier Scientific Publishing Company, Amsterdam - Oxford - New York, p. 129, 1976.