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GEOLOGY OF THE OIL SHALE DEPOSITS OF CANADA

G. MACAULEY

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Artwork by CARTOGRAPHY UNIT,
Institute of Sedimentary and
Petroleum Geology, Calgary

Author's address
274 Wildwood Drive
Calgary, Alberta T3C 3E1

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GEOLOGY OF THE OIL SHALE DEPOSITS OF CANADA

Abstract

Known 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. Deposits are reviewed on a geologic/geographic basis, including Ordovician and Devonian of Ontario and Quebec, Carboniferous of the Maritime Provinces, Jurassic of British Columbia, and Cretaceous of the Prairie Provinces and the Northwest and Yukon Territories. Each section contains an historic review of oil shales of the area and discussion of stratigraphy, lithology, thickness, distribution, mineralogy and economic geology, and includes a comprehensive annotated bibliography.

Lower Mississippian Frederick Brook Member oil shales of the Albert Formation in New Brunswick are the best known, most explored, and presently most significant of Canadian oil shale deposits. These lithologically resemble the Green River shales, being lacustrine dolomite beds. At Albert County, an area 2.6 km^2 contains oil shale to a depth of 615 m in a structurally expanded 300 m 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.

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 in the Pasquia Hills. Zone thicknesses are 40 and 20 m respectively over a large geographic area. These appear to be the second most significant of the Canadian oil shales.

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

Résumé

Les dépôts connus qui sont d'âge ordovicien à crétacé, se trouvent dans toutes les provinces et territoires du Canada, sauf l'Île-du-Prince-Édouard, et représentent toutes les catégories de milieux de sédimentation des schistes bitumineux. Les dépôts ont été examinés d'un point de vue géologique et géographique et comprennent l'Ordovicien et le Dévonien de l'Ontario et du Québec, le Carbonifère des provinces de l'Atlantique, le Jurassique de la Colombie-Britannique et le Crétacé des Prairies, des Territoires du Nord-Ouest et du Yukon. Chaque section contient un examen historique des schistes bitumineux de la région et une discussion de la stratigraphie, de la lithologie, de l'épaisseur, de la répartition, de la minéralogie, ainsi que de la géologie économique, et comprend une bibliographie annotée complète.

Les schistes bitumineux du niveau de Frederick Brook (Mississippien inférieur de la formation d'Albert au Nouveau-Brunswick) sont les mieux connus, les plus explorés et actuellement, au Canada, les plus importants des dépôts de schistes bitumineux. Ces derniers ressemblent lithologiquement aux schistes argileux de Green River, puisqu'ils sont formés de couches dolomitiques lacustres. À Albert County, une zone de 2,6 km^2 contient des schistes bitumineux jusqu'à une profondeur de 615 m dans un secteur structurellement élargi sur 300 m. Avec quelques intervalles produisant plus de 100 litres/tonne, cette région pourrait contenir plus de 47,4 millions de m^3 de réserves en place.

Le long de l'escarpement du Manitoba, dans les Plaines centrales, les deux zones crétacées de <<White Specks>> (formations de Boyne et de Favel) ont produit jusqu'à 100 litres/tonne dans les collines de Pasquia. L'épaisseur des zones, qui couvrent une surface considérable, varie de 40 à 20 m respectivement. Ces zones de schistes bitumineux semblent être les deuxièmes en importance au Canada.

À l'exception du cas du dépôt du Nouveau-Brunswick, trop peu de travaux ont été faits actuellement pour évaluer le potentiel économique des schistes bitumineux. Présentement, toute prévision sur les réserves en schistes bitumineux du Canada serait si conjecturale qu'elle s'avérerait, pratiquement, sans signification.

INTRODUCTION

Oil shales were first made known in Canada in 1847 by Abraham 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 Formation. This operation was discontinued in 1860 soon after 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 efforts reached commercial production, all failing financially, or by destruction of the plant by fire. Interest in Maritime oil shales was maintained and reinforced by their geological similarity, in age and lithologic character, to those oil shales being mined successfully in Scotland.

Geological interest in oil shales continued until approximately 1926, with many publications, both regional and local, outlining virtually all areas of currently known Canadian oil shale deposits; however, most of these descriptions were economically oriented, presenting many individual analyses of shale oil content, and repeating 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 derived from studies defining nomenclature and geologic sequences, whereas more recently, broader studies of regional correlation and subsequent analyses of the sedimentary and tectonic framework have been made. In some of the more remote areas, reconnaissance studies are still in progress, although any available data have been, in most cases, incorporated into regional concepts. Oil shales were identified but considered only incidental to the main purpose of such studies.

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

This study combines the data of the sources mentioned. 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 characteristics such as lithology, mineralogy and structural attitudes. Economic consideration is also given to shale oil content 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 presents a "state-of-the-art" review concerning oil shales in Canada.

The stratigraphic and geographic distributions of oil shales 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, subdivided into 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 the comments of the author.

Because of the cost and increasing difficulty of finding and developing additional conventional petroleum reserves, 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, confusion has existed, and still does within the geological community, as to the meaning of many geochemical terms. 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.

This study is not a new research effort, but is based primarily on previous publications, unpublished reports and basic data. It integrates the abundant available information with interpretation and estimates of the relative economic potential of known oil shale deposits.

Throughout the text, where Imperial and metric measurements appear side by side, units were originally recorded in Imperial measurements and have been converted to their approximate metric equivalents.

Acknowledgments

This study required the assistance and co-operation of many people in the Geological Survey of Canada, in the Energy Resources sections of the Provincial Governments, and on the staffs of oil companies. Several provincial government geologists provided important information for this study by making available all data, published and unpublished, within their files. Some data, still confidential to the petroleum companies involved, were released for this study. Such information is acknowledged specifically within the text.

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OIL SHALE: DEFINITIONS AND CONCEPTS

Geology is noted for imprecise terminology. This results from two factors: geology is as much interpretive as factual, an art as much as 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 when used within the range of general to restricted, descriptive terminology.

"Oil Shale" is one of the most inexact and ill-defined of all geological terms, partly because of usage long before understanding either of the geology of the deposits or of the chemistry of the included organic components. Only long-established usage, in conjunction with a present-day generally accepted definition, can justify continued use of "Oil Shale", a rock which does not contain oil and is not necessarily a shale.

Definition

For the purpose of this report, *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 (i.e. heating in a retort).*

"Significant amounts" is an open-ended phrase but several generalized concepts are implied. The temperature of pyrolysis 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 energy necessary to raise the rock temperature to 500°C is approximately 250 calories/gram of rock. The heat 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, ie. 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, a 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 consensus indicates 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 become graphite.

Kerogens vary in composition and character just like petroleums but kerogens, unlike oils within a reservoir, cannot become uniform across a deposit. Thus, the kerogen of an oil shale varies according to the initial character of the material from which it is derived and the degree of maturation of the sediment involved. Both the character of the initial kerogen and its maturation products 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 a great deal 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 shale 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 commercial process is far higher than that which occurs naturally in petroleum generation and the chemical mechanism is somewhat different. For this reason, *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 its 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. as in 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 liquid 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 could contain a liquid petroleum phase; bituminous rocks should contain soluble solid hydrocarbon; and kerogenous rocks should have an insoluble kerogen content. Their differentiation cannot be made without chemical analysis, 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 descriptive nomenclature, "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, are 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 sediments with visible organic content, becomes overly descriptive; the term "organic" is sufficient. Within this report, the following terminology will be used:

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 a 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 and 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%.

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 clay- 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 clay-size grains, as the dominant mineral. Clay is a second major type, whereas siliceous (quartz) and tuffaceous material constitute the third mineral type.

The kerogen-rich and kerogen-poor portions generally occur as alternating layers, creating a varved and/or laminated appearance. This appearance is the reason for use of the descriptive term "shale", although not all oil shales, 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 argillaceous, and 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 cover most of the world's oil shale deposits.

Probably best known is the continental lacustrine environment in which the Green River oil shales of the United States were formed. Lacustrine oil shales are finely varved, grey to black, and limestone and/or dolostone is the primary lithology. Halite and related minerals may be present since saline conditions were frequently prevalent.

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

A third distinctive type includes oil shales of limited geographic extent which were deposited in small lakes, bogs or lagoons associated with coal-productive swamps. These are the torbanite oil shales.

Reference Material

The above definitions and concepts of oil shales and related hydrocarbons have been gleaned from many articles but are generally not directly referable to any specific author. The most comprehensive single work is "Oil Shale", edited by T.F. Yen and L.V. Chilingarian, published in 1976. 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, the reader is advised to review these references. The discussion in the present report does not delve deeply into geochemical problems in the retorting and refining of oil shales. Chiefly, it is restricted to the geology of oil shales in Canada, but does touch on refining problems so that the complexity of oil shales can be appreciated more fully.

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Oil shales in Canada occur through much of the geologic column, including the 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 those of 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. The latter 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 reviewing the earliest attempts to produce from Canadian oil shales in Ontario, New Brunswick and Nova Scotia. Within the 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, repetition of data becomes evident. Although most papers added retort recoveries and new analyses, a detailed study of all the referenced literature is not worth the investigative efforts involved. Most of the bibliography cited for this section is chiefly of historic interest.

A disturbing problem became obvious during this review; namely that incorrect data and conclusions can become an integral part of the geological literature. Thus, Matveyev (1974), in a Russian analysis of world oil shale deposits, cites Canadian 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 and had never subsequently been retracted. Similarly, early unsubstantiated reports of oil shales in the Lytton area, British Columbia, were made in the Canadian literature, and thence found their way into Matveyev's review. Additionally, references to Canadian oil shales by the United Nations (1965), contain incorrect geological ages and present a potential oil shale reserves figure which is nowhere referenced or established. On the basis of this completely unconfirmed 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 the literature and by personal contacts with some of the geologists who have actively worked in the areas involved. Only those deposits considered valid 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, but excluding unverified potential oil shale zones. In the following descriptive list of oil shale areas, the numerical sequence corresponds to the locality numbers on 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 to the west.
3. Southampton Island; one, or possibly two, thin black shale zones between carbonates; possibly equivalent to Collingwood and Billings of southwestern 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 m 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 m black oil shale intercalated with grey 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; continental lacustrine deposits up to 100 m thick but expanded by deformation to possibly 300 m 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; probably not 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 m 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.

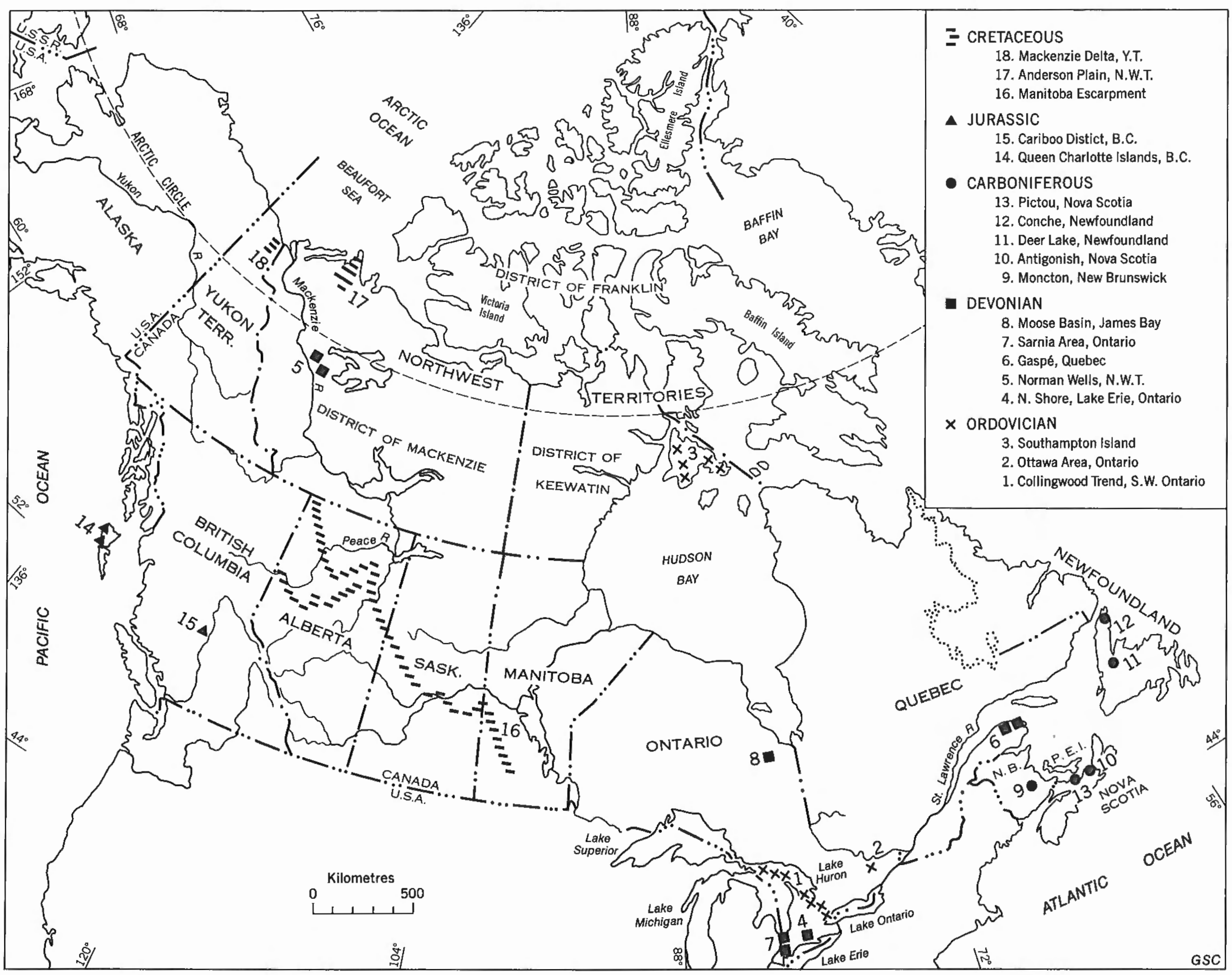

Figure 1. *Principal oil shale deposits of Canada.*

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 m 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 to the east.

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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).

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INTRODUCTION

Canada's first and only oil shale plant to achieve and maintain a continued period of operation was erected in 1859 at Craigleith, 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 at Craigleith, which continued until 1861, when it was 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, 3% of the rock volume; however, of the retorted products only 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 was some doubt that the Craigleith retort was actually operated on 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 probable source of the ore as the actual quarry site had not been located. Martison (1966, p. 23) reported that the quarry, some 9 to 10 m deep, is now a resort swimming pool, and he has presented oil yield analyses from samples of that location.

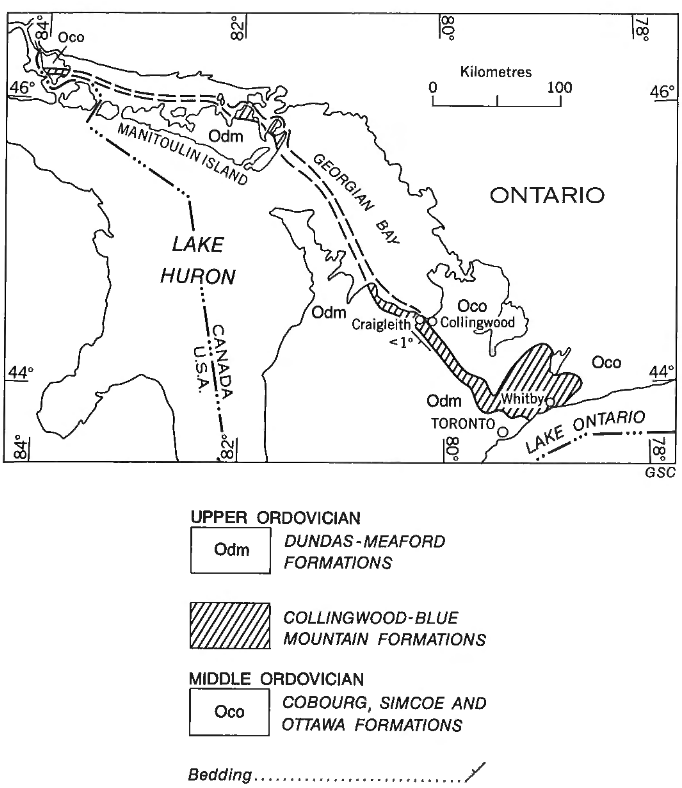

Figure 2. *Outcrop distribution of Collingwood beds, southwestern Ontario (from Ontario Geological Survey, 1979, Map 2441, Geological Highway Map of Southern Ontario).*

ST. LAWRENCE LOWLAND – GREAT LAKES AREA

Oil shale production at Craigleith was from the Upper Ordovician Collingwood Formation, which is recognized along a subcrop belt extending from Manitoulin Island in the west, through Collingwood and from 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 northeast of Montreal, the Mictaw shales of Gaspé, and the Utica shales of the Lake Champlain area (Fig. 3). The last three units 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 Formation. They overlie the Trenton limestones, and are in turn overlain by non-organic shales, arenaceous shales and sandstones of the Hudson River Formation. Paleontological data were presented for various outcrop areas, but Logan did not differentiate any of the Utica black shale exposures on the basis of age.

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 paleontological evidence for the use of the name Collingwood at a distance greater than 300 km from Collingwood and the Collingwood oil shale.

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

A more comprehensive 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 with 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, unpublished local terminology referred to the once-productive oil shales as Collingwood; hence Parks's 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. Wilson retained the terms Collingwood and Gloucester, near Ottawa, as time units.

Sanford (pers. comm.) states that the Eastview correlates with the Collingwood and the Billings with the Blue Mountain. This unpublished opinion is not shown in Figure 4.

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 colour is apparently not recognizable to the east in the Ottawa area. On Manitoulin Island, the

Collingwood is overlain by the Shequiandah Formation (Foerste, 1924), defined as interbedded layers of limestone and soft brownish shale. Figure 4 illustrates nomenclature and relationships. More complete stratigraphic data are available in the reference list.

The Lachine/Lotbinière formations represent the Collingwood equivalents 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 black shale appears sharp, thin stringers of black shale generally occur in the uppermost limestone beds, and limestone stringers 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 m) 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 transitional, with a decrease in organic content and interbedding 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 abundant graptolites. 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 lower beds in the Whitby area 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, but varies in amount. Liberty and Bolton state "the

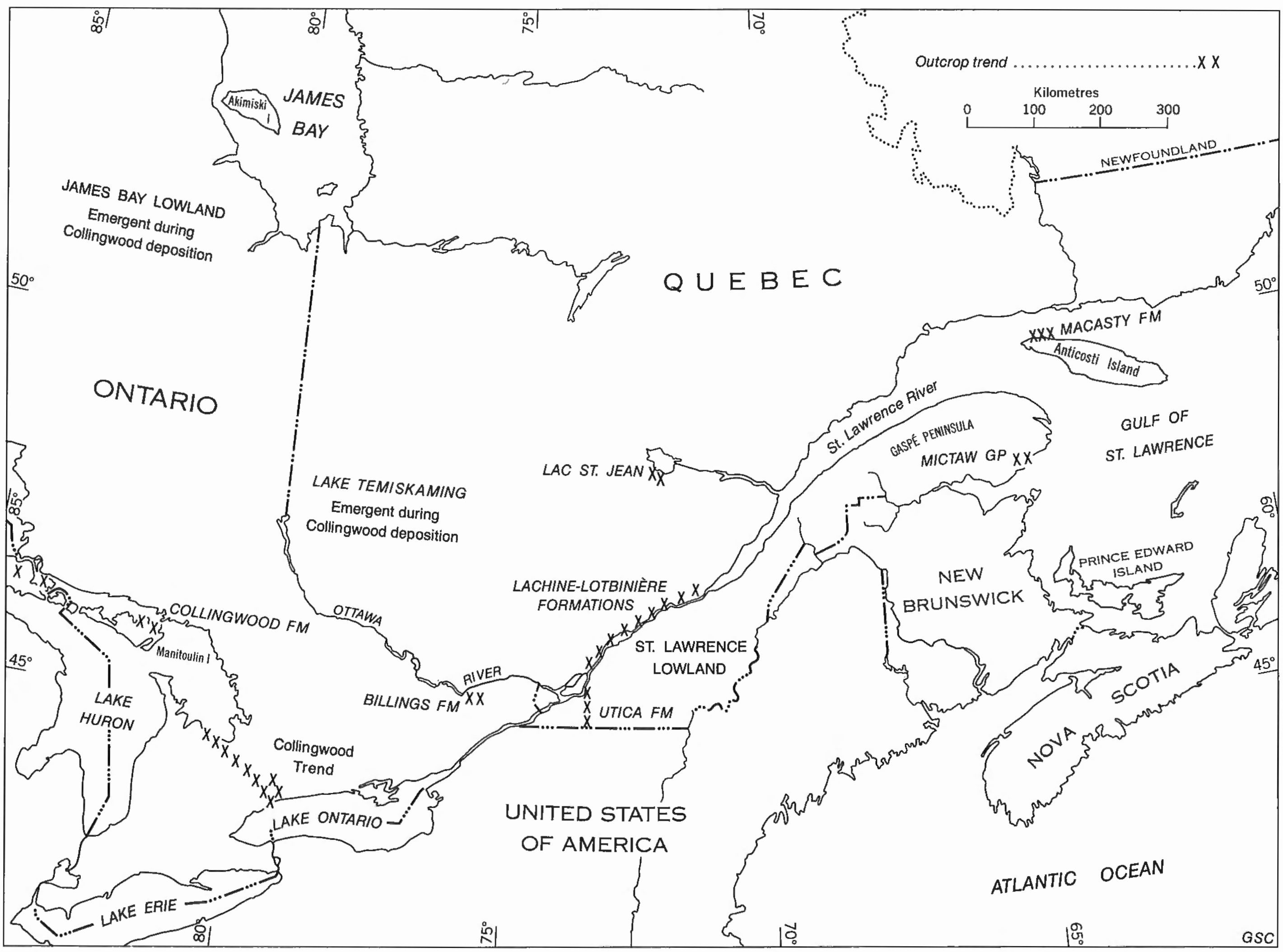

Figure 3. *Distribution of Ordovician oil shales and potential oil shales, Ontario and Quebec.*

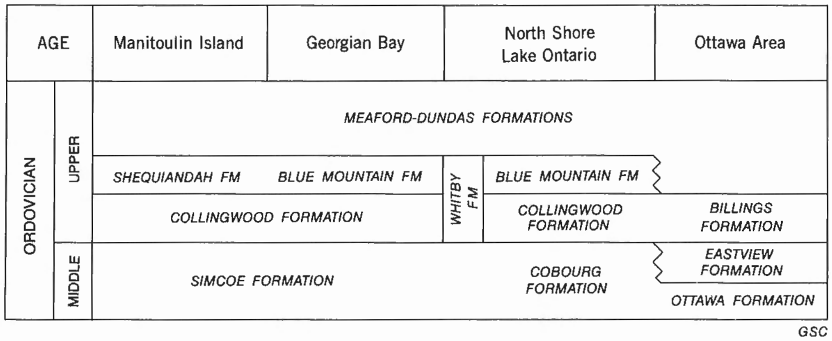

Figure 4. *Pertinent Ordovician correlations, west-east across southern Ontario, as interpreted from the literature.*

shale is petroliferous, but not bituminous as often described". Their definitions of these descriptive terms are not known; therefore, no interpretation of the type of organic content can be made. The limestone beds are grey to brownish grey, hard, brittle, sub-lithographic, and 2 to 5 cm thick. They comprise less than 15% of the zone. Liberty and Bolton also recognize a middle member of their Whitby Formation, occurring locally as soft brown shales transitional upward to the overlying bluish-grey shale equivalent of the Blue Mountain Formation.

Most of the descriptions of the 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 equivalent beds in Ontario.

The Collingwood and equivalent shales are all recessive weathering. Paper-shale weathering 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 strata are all younger than the Collingwood as this area was emergent during Collingwood deposition (Cumming, 1974). On the Ontario-Quebec border, at Lake Temiskaming, Ordovician carbonates, equivalent to the Cobourg 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 lithology between the Ordovician and Silurian: if present, the Collingwood equivalent would be in this interval. These interpretations require a major depositional and/or erosional break, not seen elsewhere, between Middle Ordovician and Silurian beds in the Lake Temiskaming area. The anomaly has been more rationally explained by Caley and Liberty (1957, p. 237) who identified the basal Ordovician carbonates of this area overlying Precambrian, 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 Shequiandah Bay, all at the east end of the Island (Liberty, 1957). Maximum thickness is about 7 m, overlain by 29 m of Shequiandah grey shale and limestone (Liberty, 1957). Williams (1937, p. 10) estimated the black shale thickness to range from 7 to 18 m from well records; these records may tend to over-estimate the thickness values. Surface thickness estimates are also in doubt as the total section is seldom exposed at any one place.

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

Within this same general area, Liberty and Bolton (1971) gave estimates of the Whitby Formation increasing northwards from 51 to 61 m. In the southerly, thinner, subsurface sections, the lower member (Collingwood) is 10 m thick and the upper unit (Blue Mountain) was estimated at 42 m.

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

Wilson (1946) estimated the thickness of Billings Formation black shale in the Ottawa area (Fig. 3) at 79 to 91 m, thicker than any of the other combined Collingwood-Blue Mountain intervals described. Several factors probably contribute to the thickening within this area: (1) facies change of Blue Mountain shale eastwards to Billings black shale; (2) the possibility that some of the Billings is also stratigraphically equivalent to part of the more westerly Dundas beds; (3) a downward thickening by facies change of both Billings and Eastview as lateral equivalents to more westerly Cobourg limestone and, finally; (4) in the Ottawa area these strata may be depositionally thicker through an increased rate of subsidence.

The last explanation is preferred, 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 m of Utica type shale at Trois-Rivières and 90 m on the island of Orleans near Montreal (Fig. 5). These data, essentially for the combined Lachine-Lotbinière section, confirm an eastwards regional thickening of the black shale beds, which were estimated by Caley and Liberty (1957) to attain thicknesses of 300 m in the Quebec section. Paleontologic data verify the general stratigraphic equivalence of these units, but the validity of the quoted thicknesses is in some doubt.

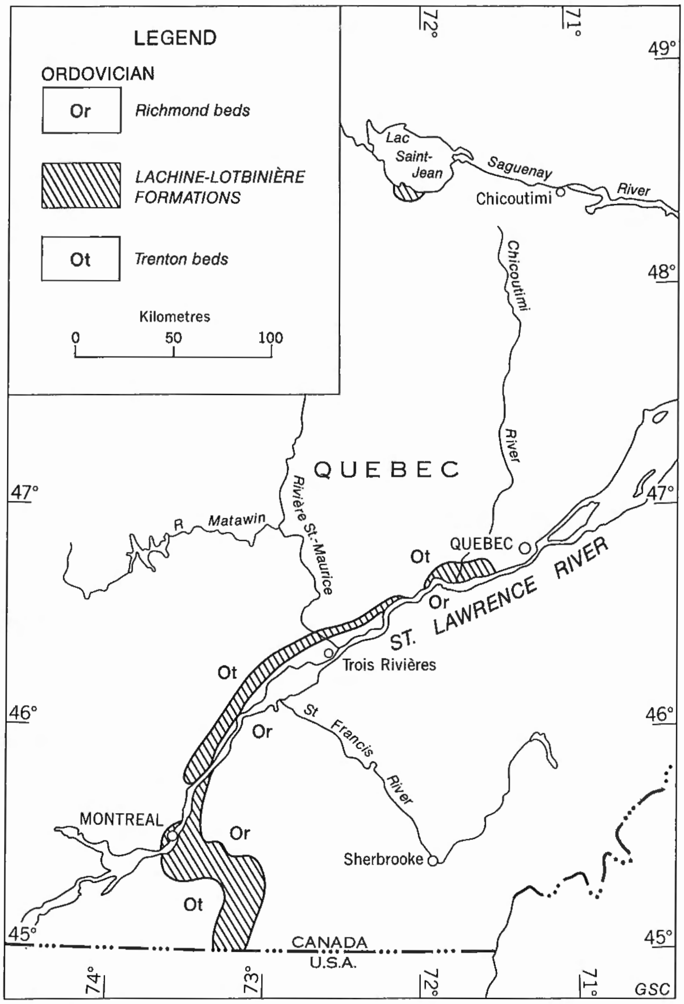

Figure 5. Outcrop distribution, Lachine-Lotbinière (Utica) shales, St. Lawrence Lowland (from Laurin, 1969).

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

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

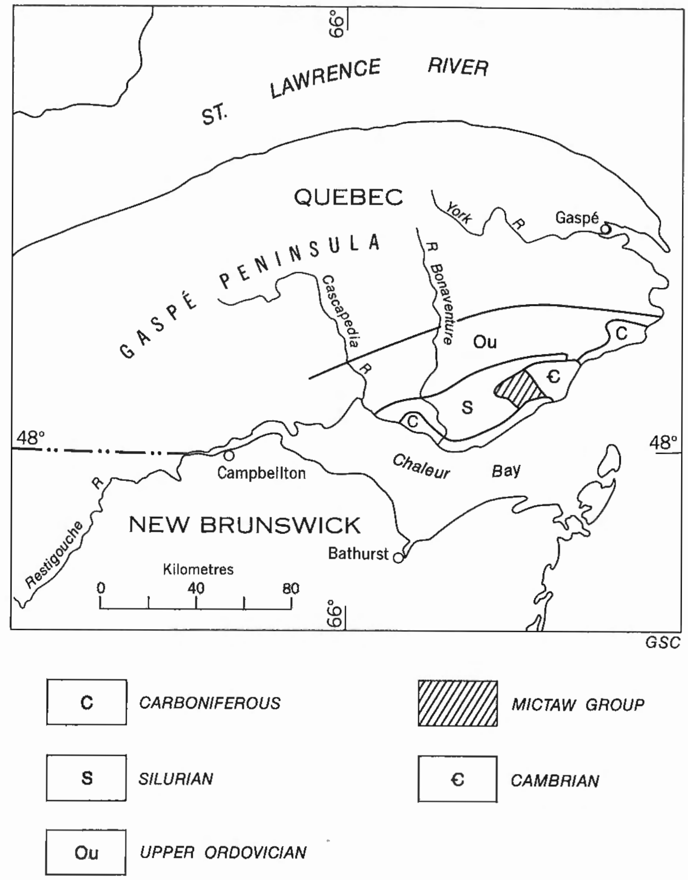

Figure 6. Outcrop distribution of Mictaw, Group, Gaspé, Québec (from McGerrigle, 1950).

Mineralogy

Almost no data are available on the mineralogy of the Ordovician organic shales of Ontario and Quebec. R.W. Ells (1909) gave the results from four scattered analyses of "Utica" shales, which ranged from 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.

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 with 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 ft 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 similar organic shales have been recognized south of Hudson 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 becomes 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 reiterating that the oil shale apparently occurs 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.

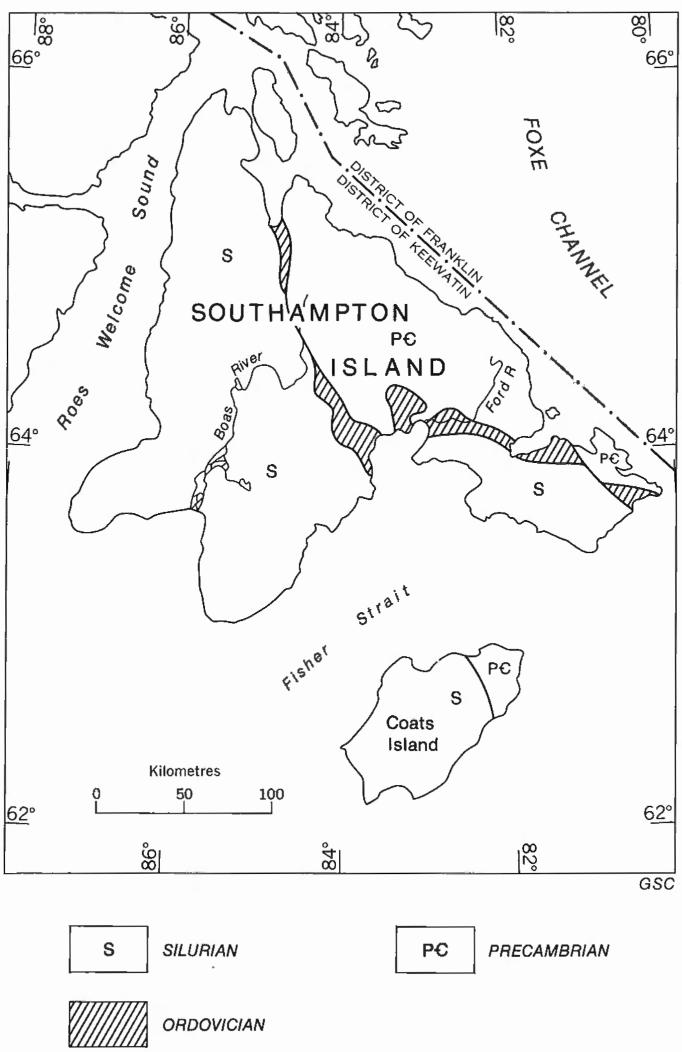

Figure 7. *Outcrop distribution of Ordovician strata, Southampton Island (from Nelson and Johnson, 1976).*

Nelson and Johnson 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 continuing through to the Precambrian surface. Heywood and Sanford (1976) have used Boas River shale to describe one of the two possible oil shale zones.

Lithology

Only brief descriptions of the lithologies were presented for the oil shale interval by the authors cited above. The shale was 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. Most data are from rubble so that precise outcrop boundaries are not known; however, a good understanding of the distribution is given by Nelson and Johnson (1976, p. 71, Fig. 1).

The interbedded oil shale and limestone were estimated to be 15 m thick, based on known carbonate outcrop and 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 m.

Mineralogy

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

ORDOVICIAN OIL SHALES – ECONOMIC POTENTIAL

There are inadequate shale oil recovery data to provide anything but generalized statements on the relative advantages and disadvantages of resource development of the various areas. 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 litres/tonne (L/t) are used herein. 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 common 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, nor on the degree of undersaturation and organic character of the shale oil.

Table 1

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

AREA Source	No. of Samples	Organic Content %	Oil Yields g/t			Yield l/t	Specific Gravity			Amm. Sulphate		Others	Potential Thickness
			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				
Ontario Geol. Surv. unpubl.	5	11.5-15.1											
COLLINGWOOD													
Logan, 1863	Prod'n.		6.9	8.3	7.6	38.1							10m
Martison, 1966	18		3.5	9.6	7.1	35.4	0.891	0.925	0.907				
Ontario Geol. Surv. unpubl.	4	0.5-10.15											
OTTAWA													80m
Martison, 1967	14		0.0	trace									
Ontario Geol. Surv. unpubl.	1	4.24											
LAC ST. JEAN													8m
Dresser and Denis, 1944	1				4.5	22.5			0.914	20.0	10.0		
PORT DANIEL													?
Swinnerton, 1933	2			0.6		3.0							
SOUTHAMPTON ISLAND													10m
Nelson and Johnson, 1976													
Rubble	71		2.1	33.9	12.7	63.6						U Va Z	
Core	4		4.6	7.3	6.3	31.5							

GSC

The thickness of the oil shale zone increases eastward from Manitoulin to the untested St. Lawrence Lowland section, from 7 m to a possible maximum 150 m. 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 Craigleith 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 recovery in the range of 83 to 100% of analyzed content. This would be an extremely high economic recovery rate, but Logan's production data must be regarded as estimates only.

Shale oil yields on Southampton Island (Nelson and Johnson, 1976) are higher in many cases 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 of 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 situ 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 interbedding with limestones. This will restrict the net pay available from the gross 15 m 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.

Control data are insufficient to present a reserve estimate which would have any validity.

INTRODUCTION

Four Devonian oil shale deposits have been recognized in Ontario and Quebec. Two are in the Middle Devonian beds of Gaspé and on the north shore of Lake Erie, with the other two in Upper Devonian strata of the Sarnia area in southwest Ontario and of the James Bay Lowland area (Fig. 8).

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

GASPÉ PENINSULA, QUEBEC

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

Stratigraphy and Lithology

Logan (1863) described over 2100 m of a 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 and shales appear to be of secondary importance.

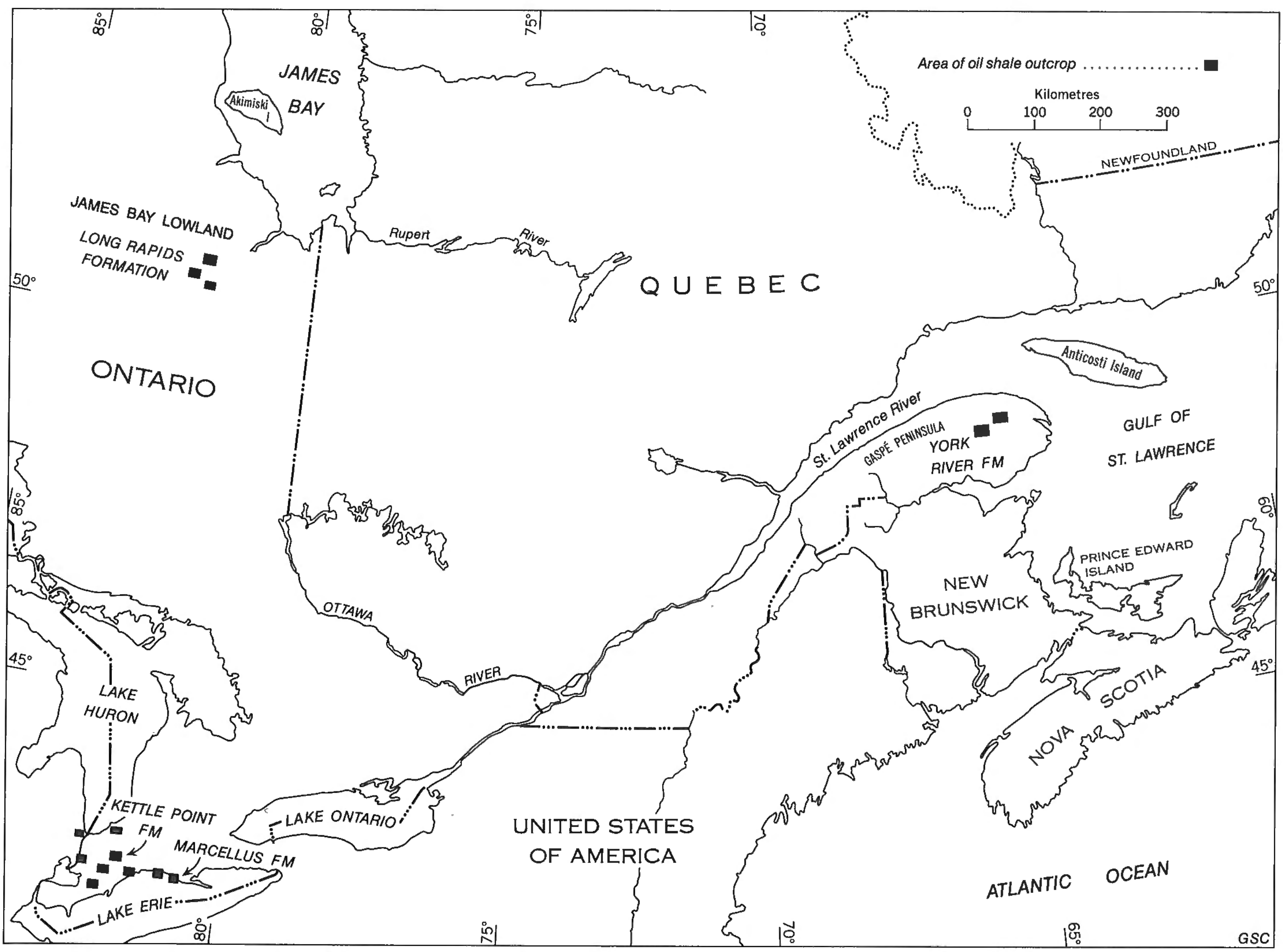

Figure 8. *Distribution of Devonian oil shales, Ontario and Quebec.*

Williams (1910) studied the "sandstones of York River", as used informally by Logan, and defined these as the York River beds. McGerrigle (1950) later defined the York River Formation to include all strata similar to the initially described York River beds. Figure 9, partly based on Williams (1973), outlines the present generally accepted stratigraphic nomenclature.

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 m 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.

Distribution and Thickness

York River strata occur in the Gaspé fold belt (Fig. 10) and reach a maximum thickness in excess of 1500 m, but thin northward to less than 1000 m at the northeast end of the fold belt.

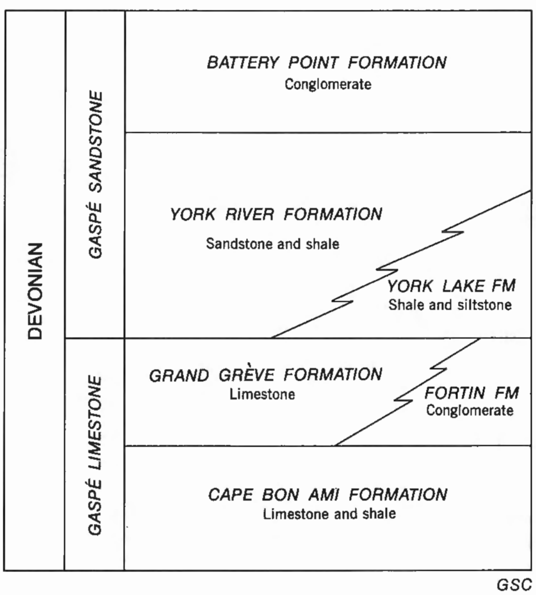

Figure 9. *Devonian oil shales, Ontario and Quebec.*

Table 2

Retorting analyses of York River oil shales

YORK RIVER BEDS Source of data	Recoveries		Specific Gravity	Amm. Sulphate	
	g/t	l/t		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

GSC

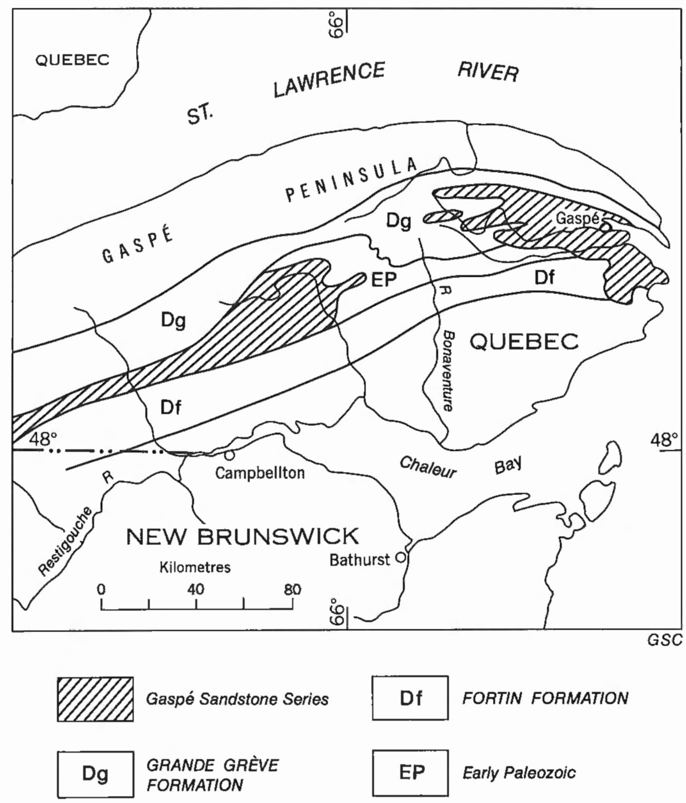

Figure 10. *Outcrop distribution of sandstone sequence, Gaspé, Quebec (from McGerrigle, 1950).*

QUEBEC DEVONIAN (YORK RIVER) - ECONOMIC POTENTIAL

Logan (1863) described the oil shale beds as containing resinous matter in irregular laminae up to 1/8 in. (0.3 cm) maximum thickness, with vitreous lustre, conchoidal fracture, translucent orange-red colour, and insoluble in organic solvents. This resinous material, locally called scleretinite or middletonite, contains 22.8 to 52.4% volatile matter.

R.W. Ells (1908) described the oil shale beds as 1 to 15 in. (2.5 to 38.1 cm) thick and Ells (1910) reported that the material, especially the oil sandstone phase, burns 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 oil sands and that some coal seams were present in the section involved. He also inferred that the oil occurrences had been overly emphasized by previous writers and were not so common as had been previously reported.

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 of minor distribution, the economic potential is limited; however, McGerrigle reported his analysis to be from a 5 m 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. Additional geological information will be necessary to determine the nature and economic potential of this unit.

LAKE ERIE – NORTH SHORE, ONTARIO

The Marcellus Formation is an erosional remnant edge 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 analogous to the previously described Ordovician interval containing the Collingwood.

The Marcellus occurs along the north shore of Lake Erie (Fig. 11) and has been penetrated in wells. A maximum thickness of about 9.1 m is known.

No analyses have been made for shale oil from any samples of the Marcellus; the potential of this zone as an oil shale is speculative, but is considered to be good by comparison with 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 100 m, over much of the outcrop area. This may preclude any possibility of open-pit mining.

SARNIA-CHATHAM 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 that these two units are stratigraphic equivalents.

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 Port Lambton section (Sanford, 1969, and Winder and Sanford, 1972).

Logan (1863) first proposed the Kettle Point. Williams (1919) described two subdivisions of the Ohio strata; a lower unit, the Huron shales, characterized by kettles, and an upper Cleveland shale, barren of kettles. Both zones yielded shale oil on retorting. In 1943, Caley resurrected "Kettle Point" to include all the oil shale beds as well as the Port Lambton, but this definition was later restricted by Sanford and Brady (1955) to include only the black shales and excluded the Port Lambton beds.

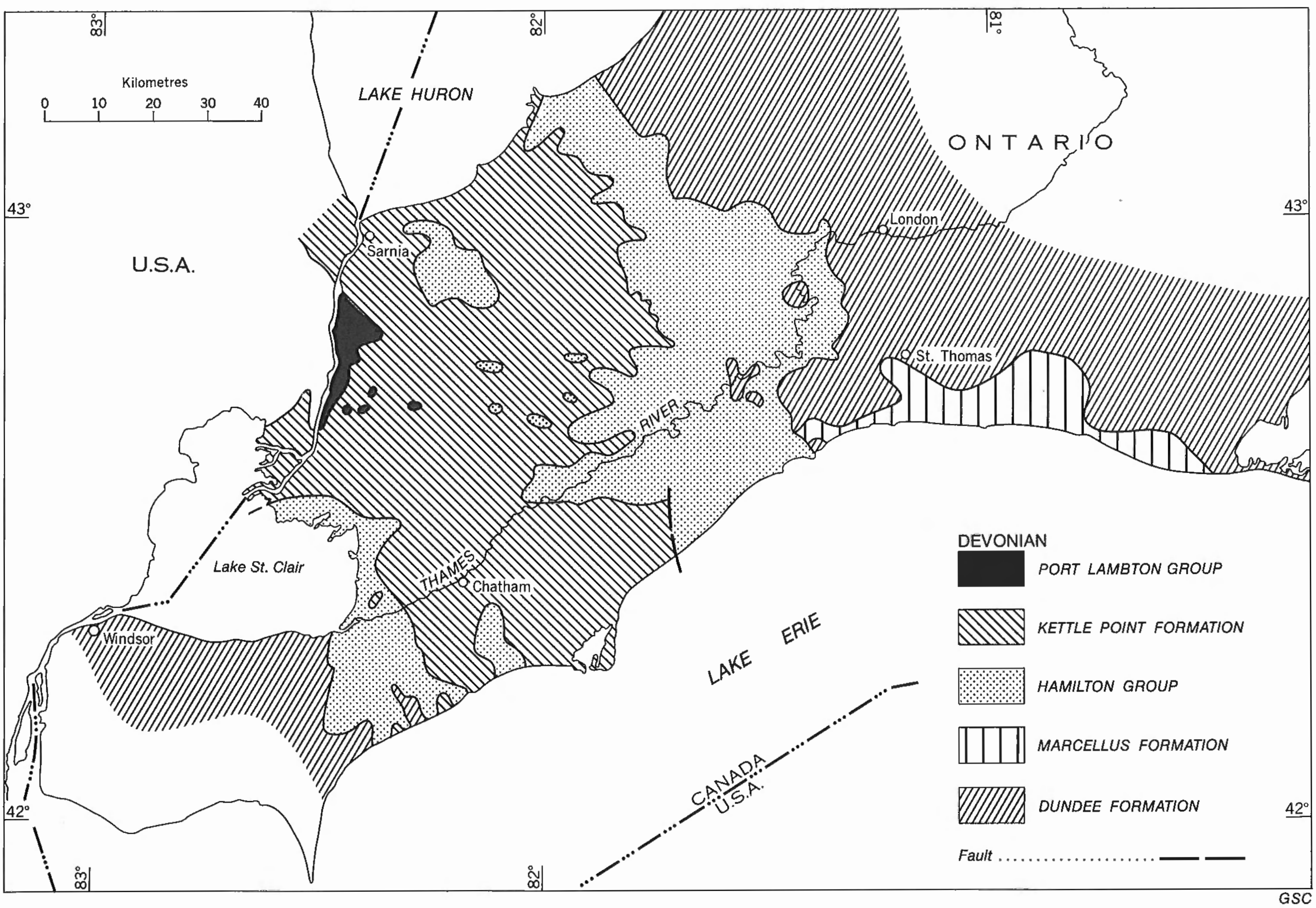

Figure 11. *Outcrop distribution of Devonian Marcellus and Kettle Point Formations, southwestern Ontario (from Sanford, 1969).*

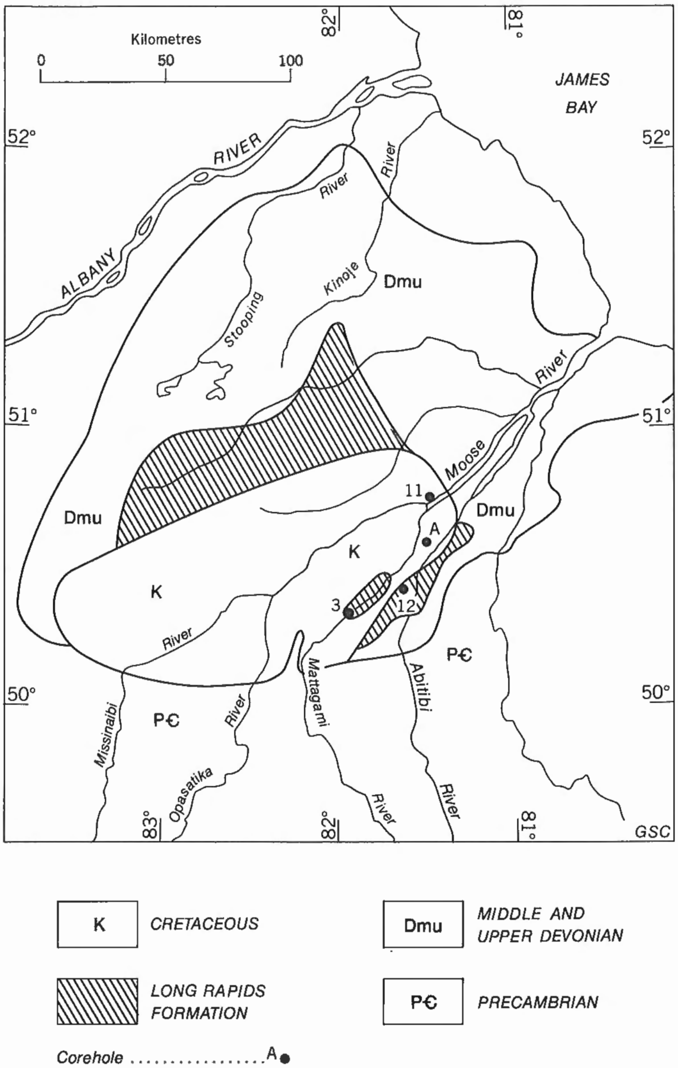

Figure 12. *Outcrop distribution of Devonian Long Rapids Formation, James Bay Lowland (from Sanford, Norris and Bostock, 1968).*

In 1946, Caley stated the equivalence of the Kettle Point-Port Lambton (Port Lambton should be excluded) to the Antrim shales of Michigan and to a sequence of Devonian black shales in the western Appalachian Basin trending north-south through Ohio, West Virginia and Kentucky. These latter shales are also being investigated for oil shale potential (Schmoker, 1980).

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 is always present over the contact, so the conformability of the formation is not known. The oil shale interval is overlain by Cretaceous and or Jurassic strata, and although this contact is also covered, an erosional unconformity must occur between these units (Sanford and Norris, 1975).

Lithology

Kettles were described in the Sarnia-Chatham area by Caley (1946) as "composed of radiating fibres of impure carbonate of lime extending from an amorphous shaly center, and occurring in zones divided by concentric amorphous bands". Caley also stated, "shale bedding occurs above and below the concretions". These concretions range in size from 6 to 38 cm in diameter. Within the Long Rapids, Sanford and Norris (1975) described "clay ironstone nodules up to 1.5 ft (46 cm) maximum diameter .... These nodules are analogous to the 'kettles' in the Kettle Point Formation".

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

A description of the Long Rapids Formation 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 colour-organic content relationship encountered in the Kettle Point section. This interbedding of lithologies is the basis of Caley's inclusion of the Port Lambton in the Kettle Point because 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 m 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 m in the equivalent American sections. From the scattered outliers of Port Lambton and inliers of Hamilton beds, the outcrop pattern can be interpreted to indicate an irregular thickness distribution for Kettle Point strata. Investigation of black versus greenish-grey shales will be necessary to define the oil shale potential of this unit, although Sanford (pers. comm.) considers the green shale beds to be much less significant than indicated by Satterly.

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

Table 3

Analytical results from Devonian strata in Ontario

AREA Source	No. of Samples	Organic Content %	Oil Yields g/t			Yield l/t	Specific Gravity			Amm. Sulphate	
			Min.	Max.	Avge.		Min.	Max.	Avge.	lb/t	kg/t
KETTLE POINT											
Logan, 1863	1				10.0	50.0					
Williams, 1919	2		3.0	4.0	3.5	17.5	0.868	0.887	0.878	6.0	3.0
	3				10 est.	50.0				13.0	6.5
Ells, 1923	9				7.8	39.1				20.6	10.3
Ontario Geol. Surv. unpubl.	6	7.44-11.9									
LONG RAPIDS											
Ells, 1912	?		7.0	16.0						16.0	8.0
Williams, 1919	3		3.5	12.0						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		

GSC

Mineralogy

Data are lacking on the clay minerals of these shales. Calcite is 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 these shales are described as non-calcareous, and dolostone beds are mentioned. Dolomite and siderite may be the dominant carbonate components. Pyrite nodules are common.

ONTARIO DEVONIAN OIL SHALES – ECONOMIC POTENTIAL

Few analyses are available for the Upper Devonian oil shales of Ontario (Table 3). They 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 lower than Martison's (1953) data for the Long Rapids. Martison reported a gas yield of 515 to 730 ft^3/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 evaluate potential net oil shale thicknesses, an important factor when considering the areally large outcrop distribution. Although Williams (1919), using 13 m as an average shale thickness, estimated 116 000 000 000 tons (105 billion tonnes) in round numbers for 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.

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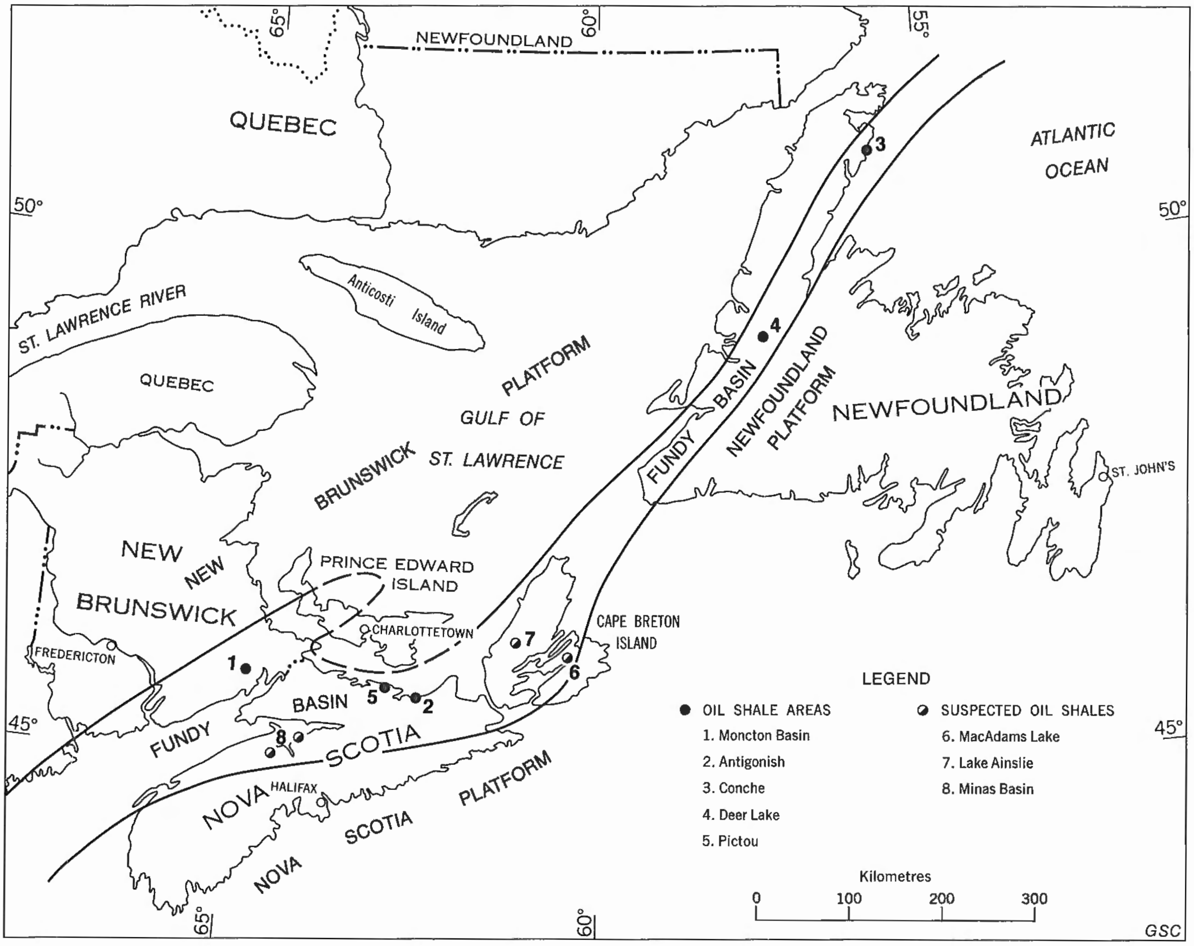

Figure 13. ***Major tectonic elements and potential oil shale areas, Maritime Provinces (tectonic elements interpreted from Poole, 1967, and Belt, 1968a, 1968b).***

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. Downwarping and sedimentation recommenced during the Upper Devonian and continued through the ensuing Carboniferous and Permian. The downward phase was accompanied by tectonic activity. With the exception of a Middle Mississippian marine incursion, a thick series of terrigenous clastics was deposited along a complex depositional trend, the Fundy Basin (Fig. 13), which represents 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 Permian age are thick in the basinal downwarps, but are only gently warped and/or faulted in contrast to the more severely deformed earlier Devonian and Mississippian strata. Initially the basin was narrow, but widened with time by encroachment onto the bordering platform areas, which seems to be a realistic assessment of the changing tectonics.

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 Basin. 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 Basin.

Virtually the entire Carboniferous sequence of Nova Scotia and New Brunswick was subdivided and named between 1921 and 1929 by W.A. Bell: most of his nomenclature is still in use today, although some significant modifications have been made. Bell's initial units were called "Groups", but were based primarily on paleontological boundaries; as such, they were actually "Series" rather than lithologically defined groups. Bell believed that disconformities separated all his units. Additional knowledge of the area has established the local extent of his disconformities (Poole, 1967), 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 redefined (see Kelley, 1967) as lithologic groups, removing the initially inferred time connotation.

Because of the continental depositional environment, macro-paleontological data are sparse; most of the recent age dating and correlation are dependent upon miospores.

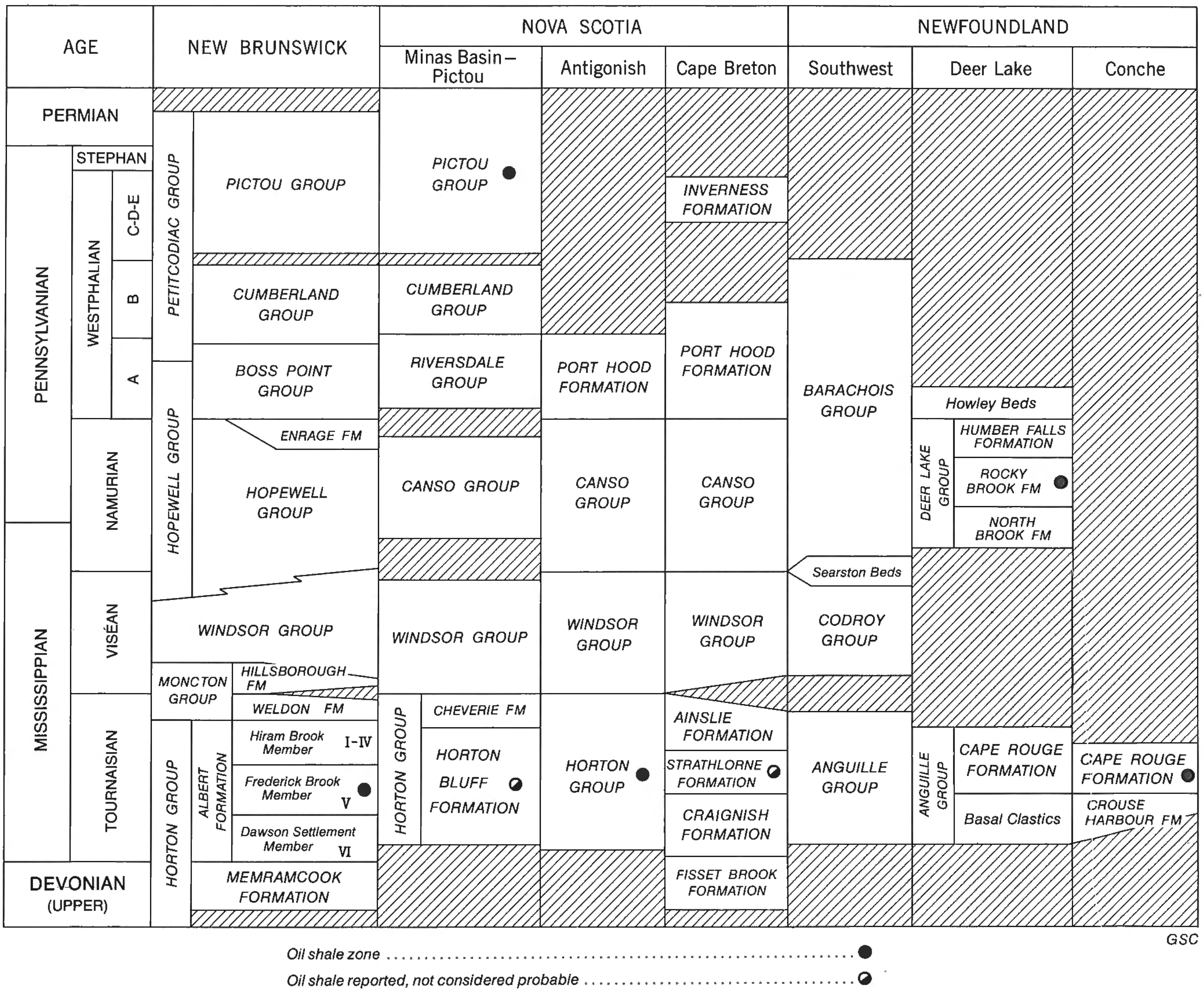

***Figure 14.** Carboniferous correlations, Maritime Provinces.*

Figure 14 is a generalized correlation chart of the Maritimes Upper Devonian-Carboniferous section. Although the oil shales could be described without this regional stratigraphic-tectonic background, an appreciation of the sedimentary framework aids in understanding the origins of the individual oil shales indicated on the correlation diagram.

More specific references and detail will be made as each oil shale area is reviewed. The following reference list provides a basis for this summary. Of the selected publications, the reader should definitely review Kelley (1967) for stratigraphic detail, Poole (1967) for a tectonic history, and Hacquebard (1972) for the sedimentary framework.

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INTRODUCTION

Interest in the oil shales of New Brunswick began, not with the shales themselves, but with a black, vertical vein of albertite, 0.3 to 5 m thick, that intersected the associated oil shale strata. In the 1852 court case of Gesner vs. Cairns, 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. Cairns owned the mining rights to coal.

Albertite was then mined during the years 1863-1874, and 154 800 tons were shipped to the United States. The vein was mined to a depth of 335 m at which time the major reserves had been exhausted. Sold at $20.00/ton, the albertite yielded 100 gallons shale oil and 14 500 cubic ft of gas per ton. Because the albertite was defined as coal, coal royalties applied, yielding only slightly over $8000 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 litres/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 off and on for 9 months in 1921-1922, retorting oil shale mined from various outcroppings in the area. The final result of the operation was reportedly 37 gallons shale oil and 60 lbs. ammonium sulphate per ton (185 litres and 30 kilograms/tonne respectively).

During the same period, Wright (1922) published the first detailed study of the Albert Mines area, where the albertite had been mined. In this report, he proposed 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 boreholes to that date and included 47 analyses of surface samples, most of which fell well below the yields indicated by previous work. This was the first publication to include maps whereon the sample locations and drillhole sites were located. 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 provided the first firm data basis for the prospect.

In 1927, the Maritime Reduction Co. Ltd. erected a plant near Rosevale, but closed due to 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 7468 m (24 500 ft) in three areas, with 36 holes near Rosevale (3167 m, 10 380 ft), 36 at Albert Mines (4001 m, 13 128 ft) and 7 at Taylor Village (321 m, 1052 ft). The relative geographic distribution of these areas is illustrated on Figure 16. From the results (Timm et al., 1948), Albert Mines was considered to have 90 700 000 tonnes (100 000 000 tons) of oil shale to a depth of 122 m (400 ft) with an average yield of 53.1 litres/tonne (10.6 gallons/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 recently been released by the company, several years prior to the expiry of confidential status, and are included herein.

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

Gussow (1953) published the first comprehensive study of Carboniferous geology of New Brunswick, creating continued interest in structure, stratigraphy and 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).

Since preparation of this paper, a comprehensive report on the Albert oil shales, based on 11 corehole sections, has been available. Macauley and Ball (1982) described the stratigraphy, lithology, mineralogy, organic geochemistry, and economic geology in much greater detail than presented herein. The reader is referred to their report for a more extensive geological analysis of these strata.

Stratigraphy

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

The Horton Group is divisible into 3 distinct colour 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), Memramcook Formation of present terminology (Fig. 14), are composed of conglomerate, sandstone, siltstone and shale, commonly red, commonly 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 colour types, the contact has been defined in the subsurface by drillers at the top of the uppermost redbed. The contact has arbitrarily been placed where either red or grey becomes dominant. Hacquebard (1972) indicates 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 glauberite salt sequence occurs in the uppermost part of the 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 four 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 use this subdivision beyond the field limits, the rapid lateral facies changes have prevented this nomenclature supplanting that of Greiner. The grey colour 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 redbed, but can also be arbitrarily chosen at the change of colour 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 Horton Group to range from possible late Upper Devonian (Fammenian) through Tournaisian 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 with the biostratigraphic unit defined by Bell, but are now locally removed from the Horton under the general redefinition of that group (McCutcheon, 1978).

Within the Albert Formation, both Greiner's and the driller's subdivisions are based on recognition of the oil shale facies, but this facies laterally gives 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 aggregates, 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. The reader should review Gussow (1953), Howie (1980), and Pickerill and Carter (1980) if further detail is desired. The lithology discussed in this section is entirely that of the Frederick Brook Member, more commonly referenced as the Albert oil shales.

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 detail, including the distribution of kerogen.

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

These laminae are not glacial varves, but appear to be related to the seasonal growth of surface algae. Algae, utilizing CO_2 from the water, reduce the solubility of calcium and magnesium by destruction of the soluble HCO_3 ion, thus causing precipitation of 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 anhydrite 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 interbedded 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 dolostones 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 interbedded bituminous shale, grey shale, and sandstone.

Distribution and Thickness

Exposures of the Albert Formation, and consequently of the Frederick Brook oil shale member, occur entirely within the Moncton sub-basin (Fig. 15). The sub-basin is bounded on the northwest by the Kingston uplift, beyond which deposits of the New Brunswick platform are recognized. The sub-basin is limited on the southeast by the Caledonia uplift and northeast by the Westmorland uplift, and also by deepening into a possible area of successor basin 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-southeast of the Caledonia Arch. Most writers conclude that deposition of the Horton Group was discontinuous across the Caledonia Arch, the present geographic distribution resembling the initial depositional extent. Environmental patterns of sedimentation have been mapped based 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 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 northeast 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

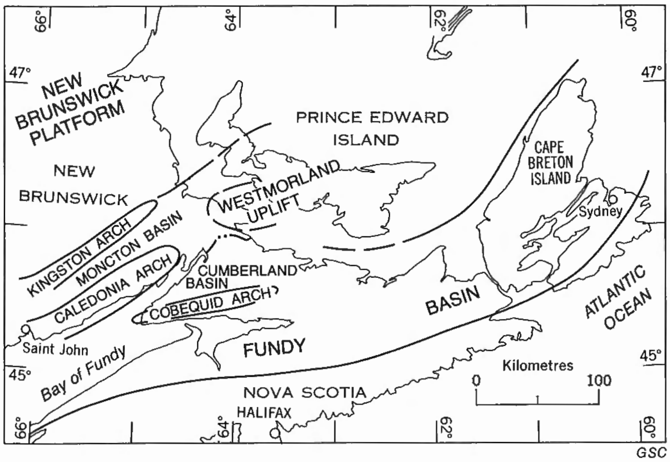

***Figure 15.** Tectonic elements of the Fundy Basin, New Brunswick and Nova Scotia (as interpreted from Poole, 1967, and Belt, 1968a, 1968b).*

present Minas Basin. The recognition of different source areas probably signifies discontinuity of uplift along the Caledonia Arch during Horton time.

Although the Albert Formation is described in recent reports (Greiner, 1962, 1974; Howie, 1980; McCutcheon, 1978; McLeod, 1980; McLeod and Ruitenberg, 1978; Pickerill and Carter, 1980; and St. Peter, 1974), two publications provide most of the data to map the surface distribution of the oil shale zone. The paper by Bailey and Ells (1878) is generalized, without maps, but gives good geographic description; the other by Carter and Shaw (1979) offers an excellent map of the Albert outcrop. Figure 16 illustrates the distribution of the Albert Formation, with an attempt to outline oil shale areas from interpretation of the published data.

Albert (Frederick Brook) oil shales outcrop along east-northeast trends across the southern 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 area (Turtle Creek, Prosser Brook, Baltimore, Weldon Creek), the Albert Mines deposit, and Taylor Village (Dorchester, upper Dorchester and Boudreau). The more northerly trend,

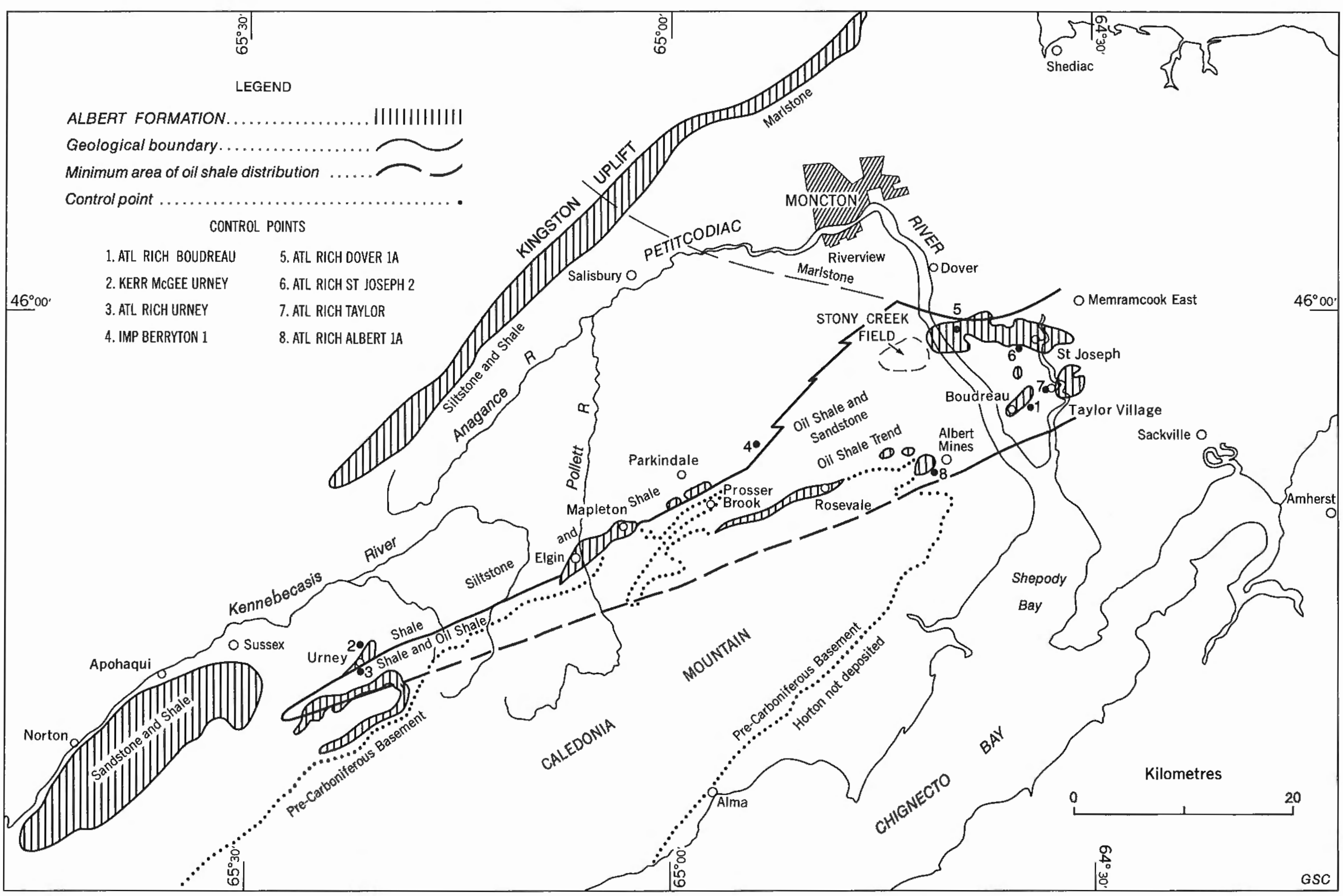

***Figure 16.** Outcrop areas of Albert Formation, New Brunswick, with interpreted lithologies of the Frederick Brook Member (as interpreted and geologically modified from Greiner, 1962; Howie, 1980; and Pickerill and Carter, 1980, original cartography).*

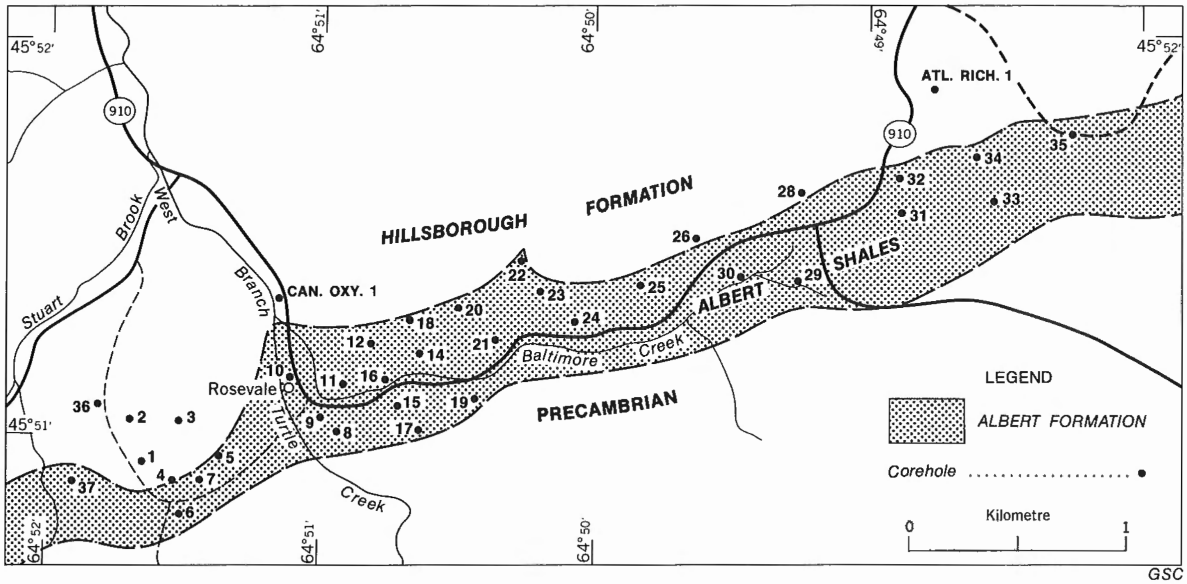

Figure 17. *Corehole distribution, Rosevale area, New Brunswick (after Ells, S.C., 1948).*

also described west to east, includes Urney (Sussex, Proctor Brook), Mapleton (Elgin, Pollett River, 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 belt 8.8 km long and averaging 335 m wide. 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 m of oil shale zone; most cores were encountered between 61 and 85 m of the zone and two penetrated about 113 m. Considering that the deepest boreholes may have partly followed dip, the zone thickness is probably less than 91 m (300 ft). There is no evidence of extreme folding or repetition of section in this area. Figure 17 is a map showing the distribution of the coreholes. Howie (1970) reported that the Atlantic Richfield Rosevale no. 1 directional corehole, located centrally on the outcrop trend, penetrated the Moncton Group (Hillsborough), 172 m of the Hiram Brook Member, 61 m of Frederick Brook oil shale, and bottomed in Dawson Settlement. This may indicate that the possible 100 m average thickness estimated from the Rosevale cores may be excessive; an average net thickness may be closer to 60 m.

Albert Mines

Oil shales at Albert Mines outcrop over a small geographic area (Fig. 18) of about 1.6 km by 1.6 km (2.6 km^2 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 interbedded sandstone and shale (Zone 3), the same subdivisions later defined by Greiner (1962). Wright estimated the total thickness of the oil-bearing zone at approximately 244 m. 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 m may be locally useable for reserves estimates, this thickness is composed of repeated intervals resulting from the extremely complex structural uplift. Atlantic Richfield Albert no. 1A, located on the southeastern flank of the feature, penetrated oil shale to a depth of 515 m.

Taylor Village

Scattered oil shale outcrops occur in an inlier of Albert Formation crossing the Memramcook River from Taylor Village in the west to Dorchester in the east. The net surface area of oil shale is estimated by St. Peter (1974) at 5 km^2 (2 square miles). Three kilometres west of Taylor Village, a small outcrop of Albert Formation is present at Boudreau, on the Petitcodac River. The structure here is a northeast trending anticline, one limb having a slight northwest 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 m (Alcock, 1948). The Atlantic Richfield Boudreau hole, between the outcrop areas, penetrated 198 m (650 ft) of oil shale in the log interval 306-504 m (1003-1653 ft), 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 to indicate a maximum possible Frederick Brook thickness.

Urney

In the Urney area (Fig. 16), only a few outcrops of oil shale are mapped. Most surface rocks of the Albert Formation are sandstones, calcareous sandstones and shales, dominantly of the Hiram Brook Member. On Prosser Brook, a thin 1.5 m bed of oil shale has been reported, but no significant sections are present to establish thickness values. Just north of the outcrop area, Kerr McGee Urney no. 1 penetrated 186 m of probable Frederick Brook Member, as

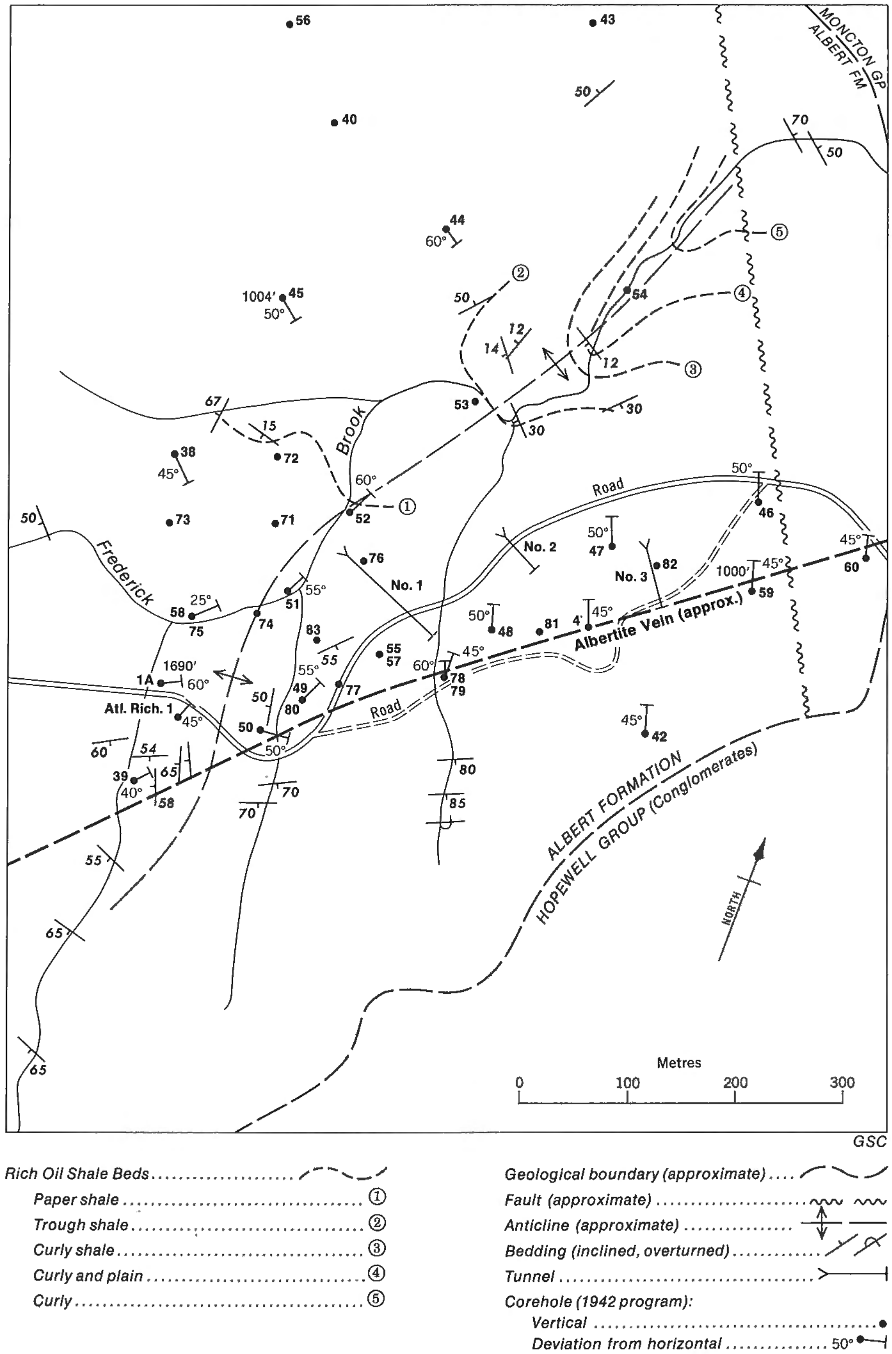

***Figure 18.** Corehole distribution and general surface geology, Albert Mines, New Brunswick (modified from Wright, 1922, and Alcock, 1948).*

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 corehole did not penetrate any significant oil shale zones to a total depth of 383 m (1257 ft), excepting one narrow interval of 1.3 m (4 ft) which yielded 38 litres/tonne (6.4 gallons/ton).

This outcrop area is essentially continuous westward to the Apohaqui area (Fig. 16) where the Albert Formation is exposed. No oil shales were mapped in the Apohaqui exposures, which consist primarily of shales, sandstones and 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 in this western area due to a facies change, or, if present, may not be exposed as the section does contain covered intervals.

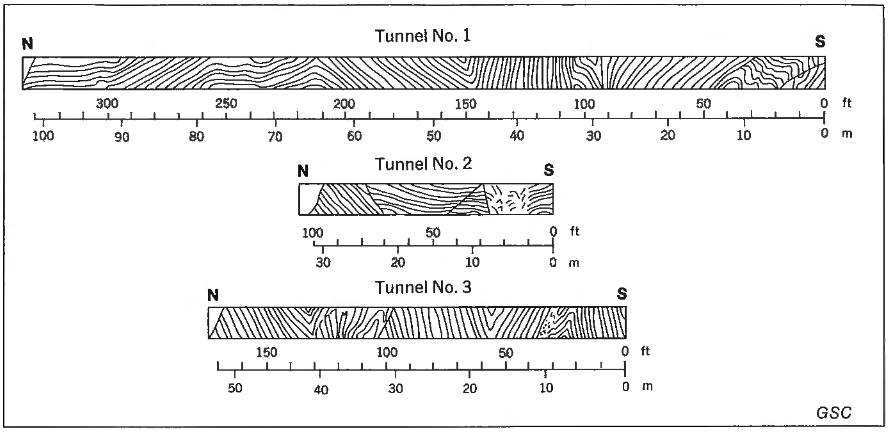

***Figure 19.** Structural attitudes of oil shale beds in tunnels at Albert Mines, New Brunswick (after Wright, 1922).*

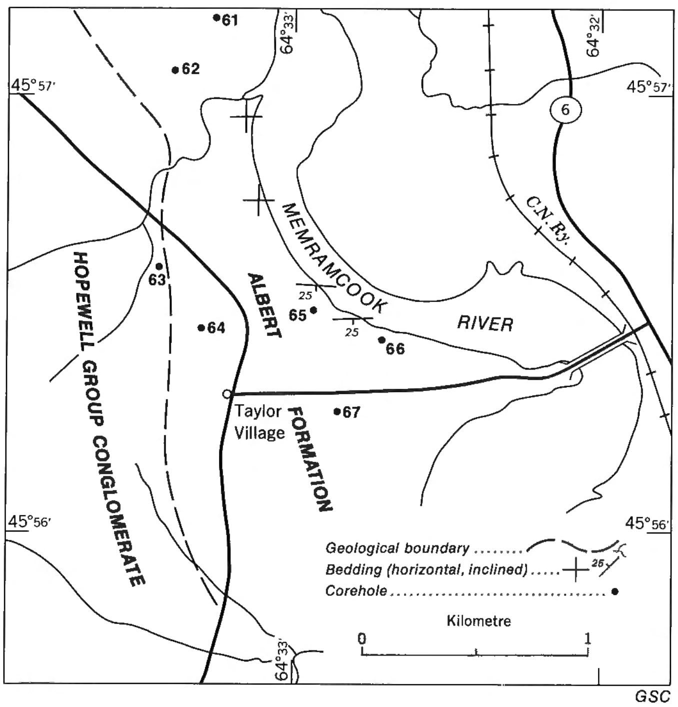

***Figure 20.** Corehole distribution, Taylor Village, New Brunswick (after Alcock, 1948).*

Mapleton

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

Three kilometres east along the Mapleton trend, and 2.5 km north of the Rosevale area, Imperial Berryton no. 1 hole penetrated a full section of Albert without encountering any significant oil shale beds.

Dover

In the Stony Creek oilfield (Norman, 1932; Hume, 1932), wells located west of the Petitcodiac 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 m maximum. Not all of this interval is organic shale, as sandstones are also present (Howie, Fig. 5). Howie gave a maximum thickness of 107 m for zone V, comprised of bituminous shale, non-bituminous shale, and siltstone. The proportion of sandstone increases from east to west across the Petitcodiac 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.

Subsurface well control is present in the Dover-St. Joseph area (Dover near river, St. Joseph at east end of outcrop trend) north of 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 m and St. Joseph no. 2 to 778 m. 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 no. 2, but again oil shale thickness is not known.

Kingston Uplift

The Albert Formation, at the western end of the uplift, at Apohaqui (Fig. 16) is dominantly sandstone, siltstone, some conglomerates, and non-organic shale (McCutcheon, 1978). Greiner (1962) indicated the northeast 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) presented a generalized facies distribution for the Albert Formation. His, and some new data, are included in Figure 16 to show distribution of oil shale facies. This interpretation implies that some sediments of the Frederick Brook Member did encroach into the area of the present Caledonia Uplift. Subsequent uplift and erosion 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.

MINERALOGY

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

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

Abbott 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 section. Wright (1922) established that the shales of the Albert Mines area vary from oil-rich to barren, and that the richer shales are more resistant to weathering. This explained the "high grade" results of most previous analyses.

Albert Mines

Wright attempted a more comprehensive analysis by using the three tunnels (Fig. 19), taking samples where bedding character changed. In all, 43 samples were retorted, yielding shale oil from a maximum 160 litres/tonne (32.2 gallons/ton) to two samples with no recovery. An average of these samples is 70 litres/tonne (15.2 gallons/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 beds. The specific gravity of the recovered shale oil ranged from 0.812 to 0.880, with a 0.848 average value.

Detailed information on the Albert Mines was presented by Alcock (1948) in summarizing the 1942 Canada Department of Mines program. Log summaries from 36

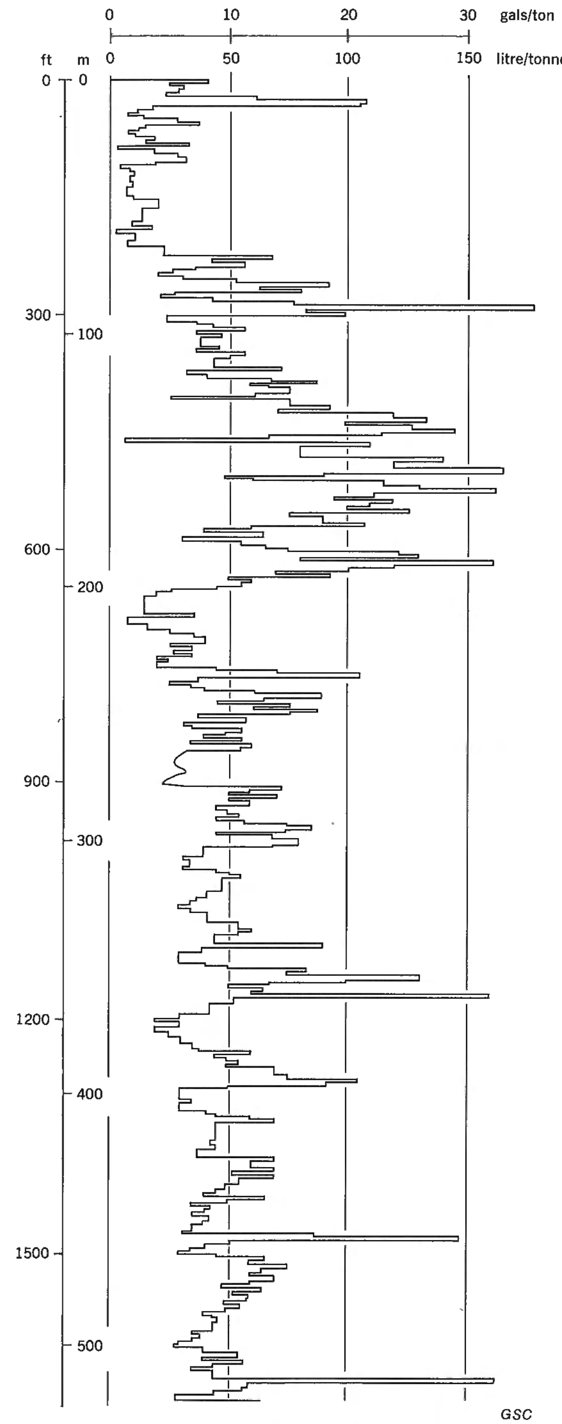

Figure 21. *Atlantic Richfield Albert Mines 1A – Shale oil recoveries.*

diamond boreholes, ranging in depth from 76 to 306 m (249 to 1004 ft), indicated average recoveries per hole ranging from 27.0 to 71.6 litres/tonne (4.4 to 14.3 gallons/ton). These holes were drilled at angles from vertical to 45°, depending on the location on the crest or flank of the anticline. Two deep holes exceeded 305 m (1000 ft) on the outer limbs of the feature. Only the thicknesses of various grades of oil shale were recorded; therefore, the degree of interbedding of rich and lean zones cannot be interpreted from the Alcock report.

Table 4

Analytical results of coreholes in the Albert Mines area

Hole No.	Footage of various grades g/t					Thickness and average 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. IA	272	746	382	148	132	1680	10.3	511.9	52

GSC

From the results of that program (Table 4 and Fig. 18), 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.

The Atlantic Richfield Albert Mines 1-A corehole penetrated oil shale to a depth of 515 m (1690 ft) and encountered good oil shale at 69 m through to 197 m for a total thickness of 130 m (428 ft) of relatively continuous high yield zone (Fig. 21). With analyses conducted over each 1.2 m (4 ft) of core, the total cored interval averaged 51 litres/tonne (11.2 gallons/ton). Data for this core have been prepared in a form comparable to those of Alcock and are presented at the end of Table 4. 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. Unfortunately, time did not permit 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 the accuracy of any such estimate. Data from the 1943 core program are available, in published form, only as gross interval values. In the Albert 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 be contained within the indicated high-grade interval, but the depth and distribution of this zone have not been mapped. Correlation of the core data and integration of dips into a structural interpretation have still to be undertaken.

In spite of the missing geological background, some rough estimates are possible. Alcock (1940) calculated 30 000 000 barrels of recoverable shale oil. He 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

Table 5

Analytical results of coreholes in Rosevale area

Hole No.	Footage of various grade g/t					Thickness and average oil content			
	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

GSC

walls. St. Peter (1974) disputed this estimate because of the impossibility of such pits, and because mining to 122 m (400 ft) would require diversion of Frederick Brook. St. Peter doubted that shale could be mined below 175 ft 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 pessimistic in view of today's increasing prices and product demand.

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 610 m (2000 ft) 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 6, 1981, p. B 36).

A few additional data (listed below under A and B) on the Albert Mines shale oil were cited by Alcock (1948):

A. 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:

Gallons/ton	litres/tonne	Specific gravity
6.4	32	2.37
9.1	46	2.23
11.4	57	2.22
20.6	103	1.97
36.5	183	1.83

B. Characteristics of Shale Oil

S.G. @ 60°F	0.861	API @ 60°F	32.8
Sulphur, % by wt.	0.75	Pour Point, °F	60

Approximate Summary

	% by volume	S.G.	Degrees A.P.I.	Saybolt Viscosity 100°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 no. 1 are added to the bottom of the table for comparison. A weighted average yield from 254 m (834 ft) of analyzed core at the Atlantic Richfield hole is 20 litres/tonne (4.06 gallons/ton).

In all of the test holes, only limited footages had yields exceeding 50 litres/tonne (10 gallons/ton). The shale oil recoveries of this area are considerably less than at Albert

Mines. Figure 17 illustrates the distribution of the corehole 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°, although none are horizontal.

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 part of a single lacustrine deposit, it is probable that a gross zonation could 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 correspondingly more viscous lubicants and residuum.

Taylor Village

Alc^ck (1948) summarized the Department of Mines drilling for this area. Table 6 and Figure 20 reproduce these data and locations.

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 no. 1 hole, to 132 m (432 ft), averaged 16 litres/tonne (3.1 gallons/ton), whereas the deeper 1A location averaged 17 litres/tonne (3.7 gallons/ton) to a depth of 275 m (903 ft). 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 no. 2, located just south of, and centrally along, the Dover St. Joseph outcrop area. This hole penetrated 3 significant zones, 362-372 m (1187-1220 ft) averaging 45 litres/tonne (8.9 gallons/ton), 491-500 m (1610-1640 ft) averaging 63.1 litres/tonne (12.5 gallons/ton), and the third zone, 736-779 m (2415-2555 ft), yielding 62 litres/tonne (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. Gas shows were reported in the lowermost interval (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 (0.860 to 0.910) and 0.865 (0.818 to 0.909).

Table 6

Analytical results of coreholes in Taylor Village area

Hole No.	Footage of various grade g/t					Thickness and average 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

GSC

Summary Statement

Additional study is 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 122 m (400 ft) 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 47.4 million cubic metres (300 million barrels) of in situ 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, valuable secondary minerals will be lost. Investigation into the distribution of trace elements must be continued as these may strongly influence recovery economics.

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Coal has long 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 1.52 m (5 ft) seam, of which 55.8 cm (1 ft 10 in) was stellarite, 40.6 cm (1 ft 4 in) bituminous coal and 55.8 cm (1 ft 10 in) 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 less inorganic mineral content (ash).

Seams of torbanite oil shales (often called "boghead coal"), with ash content greater than 35% of the rock, were encountered during the continuing exploration of the Pictou area.

How (1868) also described the oil shales of the Antigonish area, which he recognized as Lower Carboniferous and equivalent to the non-productive Coal Measures of Hants County (southside of Minas Basin). The early recognition of this equivalence to the Albert oil shales of New Brunswick stimulated examination of 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 coloured, clastic sequence, and the Cheverie Formation, an upper, greenish to reddish, clastic interval which is overlain by carbonate of the Windsor Group. Miospore correlations (Varma, 1969) showed the Cheverie to equate to the Hiram Brook Member of the Albert Formation in New Brunswick (Fig. 14). The basal Windsor beds of this Nova Scotia area are stratigraphically equivalent to Moncton redbeds of the Moncton sub-basin (Kelley, 1967). Black shales of the upper Horton Bluff, containing palaeonscid fish scales, were readily correlated with the Albert oil shales. These black shales were described in many early publications 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 coarse, red Craignish clastics, the fine grey Strathlorne and the upper, coarse, red Ainslie formations, in ascending order. Kelley (1967) stated that the sequences may be colour correlative with 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, McNeil (1948) considered the colour zones to be correlative. The organic matter in the dark grey to black shales of this area 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 53 m (175 ft), 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 preclude much oil shale potential, although Gilpin (1899) reported MacAdam Lake shales to be combustible, variably yielding 75-100 litres/tonne (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 attempts at retorting 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 ft in thickness, 20 ft of which may be regarded as good oil shale including 5 ft of curly cannel rich in oil. The upper band cannot be much short of 150 ft 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, shown on the geological map of Nova Scotia (Keppie, 1979) as Devonian-Carboniferous undivided. Potter (1974) reported that these shales occur about 457 m (1500 ft) 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, a name generally applied to 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 redbed 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 to the presence of a calcareous admixture in the shale was noted.

Lithologic descriptions are insufficient to define adequately the depositional environment; certainly many characteristics resemble those of 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 taken from an unpublished map of the unit prepared in 1974 by the Nova Scotia Department of Mines. From a series of diamond drillholes, the zone thickness was established as 102 to 122 m (335 to 400 ft) at Big Marsh and 76 m (250 ft) 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 made on the mineralogic content of Big Marsh oil shales, either for inorganic minerals, or to determine 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 20 to 115 litres/tonne (4.0 to 23 gallons/ton), averaging 44 litres/tonne (8.8 gallons/ton) 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 from these holes have been supplied for this study. Locations are shown on Figure 22.

At the most southerly outcrop area, borehole no. 5 penetrated 101 m (330 ft) of oil shale, yielding a maximum 36 litres/tonne (7.27 gallons/ton) and an average 17.7 litres/tonne (3.54 gallons/ton). Farther south on the outcrop trend, holes no. 8 and no. 9 encountered 119 m (390 ft) and 126 m (414 ft) respectively of oil shale zone, but the assays indicated minimal shale oil potential.

Borehole no. 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 92 m (303 ft). Borehole no. 6 also failed to encounter any oil shale section in this structurally disturbed area. West of these locations, drillhole no. 7 penetrated 42 m (137 ft) of oil shale interval, but no significant shale oil recoveries were made.

At Beaver Settlement, near St. George's Bay, hole no. 2 averaged 16.3 litres/tonne (3.26 gallons/ton) over 61 m (200 ft) gross zone with a maximum yield of 39 litres/tonne (7.87 gallons/ton). About 400 m farther to the west, hole no. 4 averaged 19.2 litres/tonne (3.84 gallons/ton) with a maximum 44 litres/tonne (8.82 gallons/ton). The better yields within the Big Marsh area are definitely in this northerly outcrop section, but are still much below presently defined economic levels.

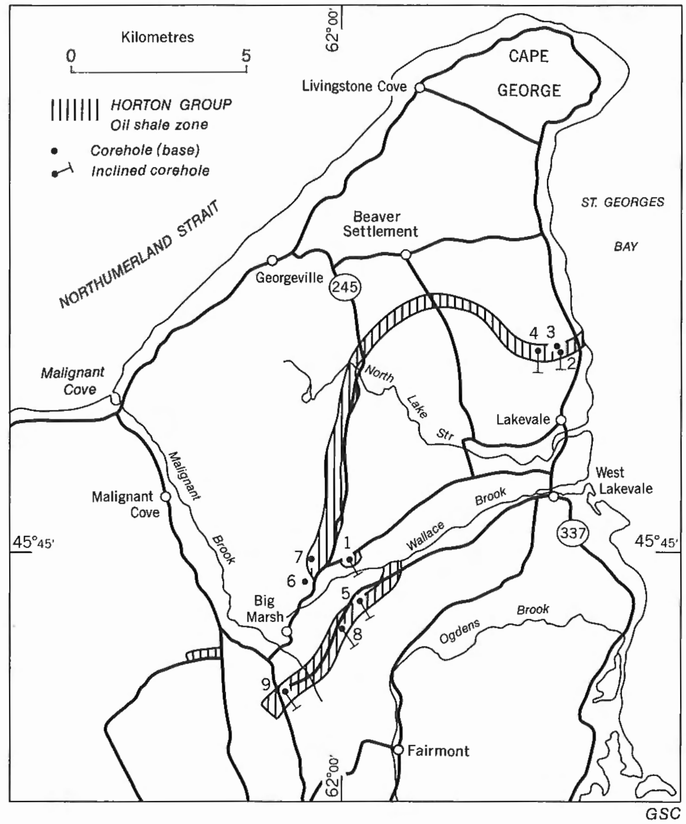

Figure 22. Surface distribution of Horton Group oil shales, Big Marsh area, Antigonish, Nova Scotia excerpted from Potter, unpublished maps, Nova Scotia Department of Mines and Energy.

PICTOU (McLELLAN BROOK)

The Stellarite band, known in Nova Scotia since before 1860, had a stope driven into the zone about 1856. Some of the oil shale was shipped to Scotland.

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 200 litres/tonne (40 gallons/ton), no further work was done at that time. The next year, Ells (1910a), added one further analysis, which yielded 224 litres/tonne (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 coreholes from the Nova Scotia Coal Company published by Bell (1924). None of these efforts resulted in any significant recoveries, and nowhere were the high yields 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 (1942) 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 coreholes 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 between 100-150 litres/tonne (20-30 gallons/ton); 45 between 50 and 100 litres/tonne (10-20 gallons/ton); and the remainder were below 50 litres/tonne (10 gallons/ton), the majority being under 25 litres/tonne (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 subsurface exposures of oil shales and torbanites, with structural attitudes at all outcrop locations. No attempt has been made to correlate individual zones or to integrate these data with the 1956 corehole program. This work provides 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 nonmarine 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 are locally interspersed with grey to red sandstone and shale.

As defined by Bell, the Pictou Series contained a Westphalian C and D flora; however, the general practice now assigns to the Pictou Group all Paleozoic above a regional unconformity within the Pennsylvanian (Fig. 14). Because of these 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 small inorganic influx, although generally the lake area will have a much higher sediment inflow than the rest of the swamp. As can be readily visualized, the amounts of humus, sapropel and inorganic sediment can vary between wide extremes. 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 and confirmed by strike and dip data shown by Potter (unpublished).

Indicated thicknesses of the oil shale beds and torbanites range from centimetres to less than 3 m, similar thicknesses to those shown for the coal beds. No attempt has been made to integrate the detailed surface data with the corehole 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 section study and analysis of the organic materials within the stellarites and torbanites.

The stellarite contains bright yellow organic particles, which are distorted commensurate 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, with 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

Unfortunately, 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 content is too high to include the torbanites as a coal resource.

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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. 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. 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.

D.M. Baird (1950, 1959, 1966), Newfoundland Geological Survey, prepared several reports, some of which remained unpublished, covering the Deer Lake region and Conche-Groais Island area (Fig. 23) near the northern extremity of the island. Significant work was completed by H.J. Werner (1956), who established the Deer Lake Group and the formational subdivision of the central Carboniferous area; oil shales were placed within the Rocky Brook Formation. Although the work was completed for a mining company, his nomenclature has been accepted. Copies of his report are on file and can be obtained from the Newfoundland Department of Mines and Energy.

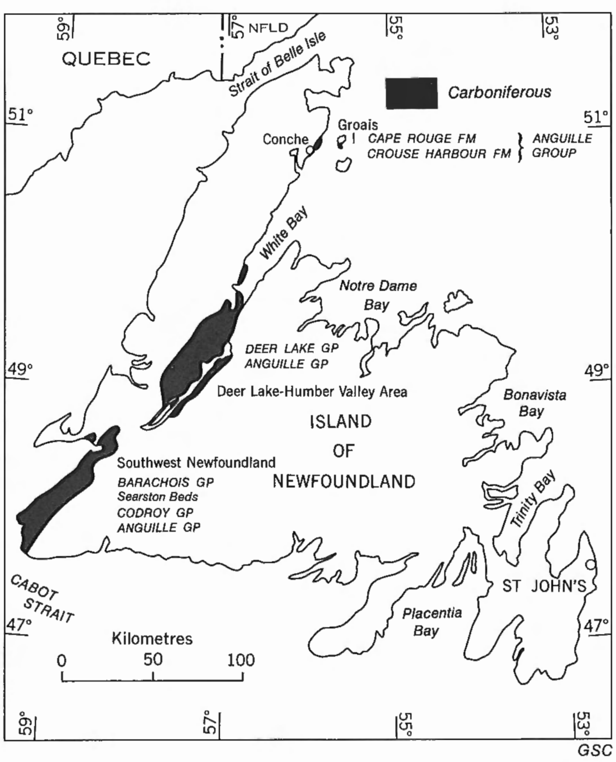

Figure 23. Outcrop distribution of Carboniferous strata, Newfoundland (excerpted from Williams, 1966, Map 1231A, Geology Island of Newfoundland).

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. Some reports are published and some data are still in map preparation. All of Hyde's work sheets were kindly supplied for this review.

The Ells report (1910) of possible oil shales at Port-au-Port Bay (Fig. 23) in southwestern Newfoundland may refer to the Middle Ordovician Table Head Group, the uppermost unit of which 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.

Matveyev (1974), in a Russian review of world oil shales, quoted deposits near 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 significant 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 important 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 rocks 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 (Tournaisian), 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 (see Johnson, 1918), bituminous beds were reported to be interbedded in thin layers, possibly as much as 15 m net in a gross 150 m 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 accentuated 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 m 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 successor basin (Fig. 13).

DEER LAKE – HUMBER RIVER – GRAND LAKE

Hyde (1979) in conjunction with Werner (1956), provides all the background geology for the present report.

Stratigraphy

Werner made the first subdivision of the section, establishing the Deer Lake Group with three formations. The lowermost, North Brook Formation, consists of red and grey arkose, greywacke, and conglomerate, grading upward to sandstone. 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 constitute oil shale intervals. The upper, Humber Falls, is a red, coarse clastic sequence. Initially Werner named it the Big Falls Formation, even though the term Humber Falls had been used informally. Later writers reinstated the name Humber Falls, and the term, Big Falls Formation, is no longer in use.

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 with 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 facies change from carbonate to clastics would be implied by this correlation. Later, Belt (1969) correlated the Deer Lake Group with the Canso Group of Nova Scotia, establishing that a significant Middle Mississippian (Viséan) hiatus occurs in the Deer Lake area. Hacquebard (1972) illustrated these correlations in a series of diagrams for the basic biostratigraphic intervals. Correlations on Figure 14 illustrate these last interpretations.

Nowhere in the region do rocks of the 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) 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 colouration 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 redbed 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 crosslaminations), 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, which resemble tilestone, are compact, hard and grey weathering. Hatch described the oil shales as both fissile and blocky, similar to Landell-Mills' type rocks. Hatch reported that the best beds 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 entire area is also faulted and structurally complex.

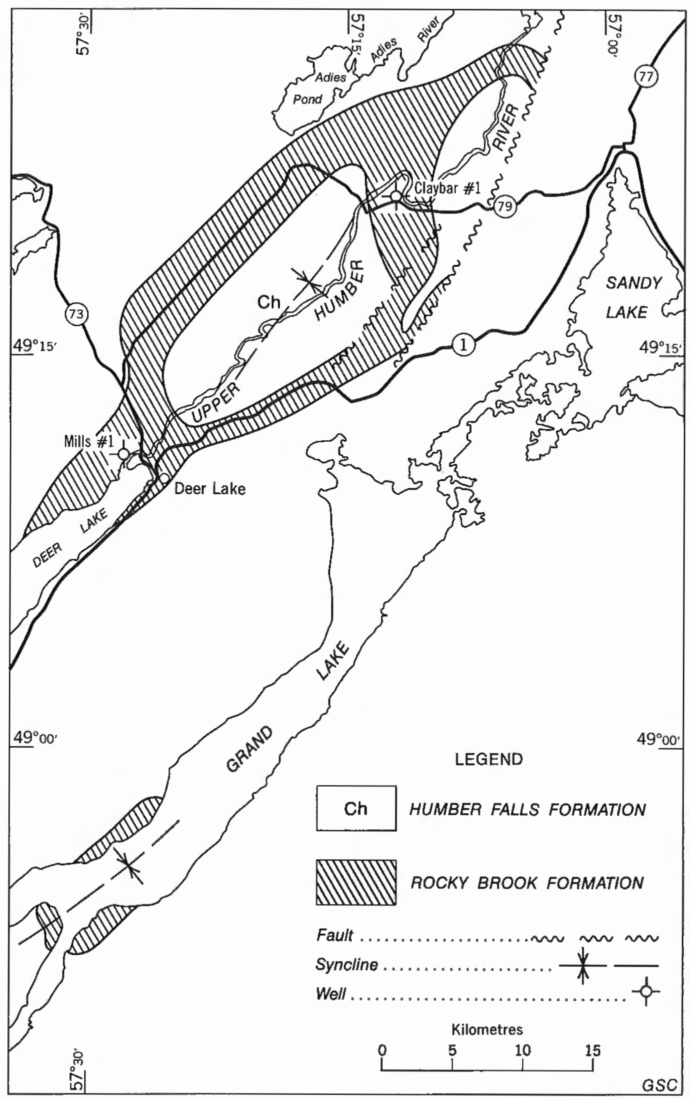

Figure 24. *Outcrop distribution of Rocky Brook Formation, Deer Lake-Humber Valley-Grand Lake area, Newfoundland (from Baird, 1959 and Hyde, 1980, 1981).*

Hatch (1919) has given the most detailed 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 difficult to ignite. Only beds over 1 m (3 ft) thick were considered.

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

Group II: medium heat; 4 beds on Rocky Brook; 1 to 1.76 m (3 to 5.8 ft).

Group III: hard to ignite; 6 beds on Rocky Brook; 1 to 1.8 m (3 to 6 ft).

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

Better quality 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 so 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 m (7 ft) thick, and are not likely to aggregate more than 15 to 30 m (50 to 100 ft) within the overall Rocky Brook Formation, which has a thickness range from possibly 500 to 1500 m.

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 as concretionary growths. The clay mineralogy is not known.

ROCKY BROOK FORMATION – ECONOMIC POTENTIAL

Only a few verified analyses are available for the Deer Lake oil shales.

Two shale oil recoveries were reported by Hatch (1919), one near Deer Lake at 37.5 litres/tonne (7.5 gallons/ton). 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 29.2 litres/ton (5.8 gallons/ton) 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 31 litres/tonne (6.19 gallons/ton). At Grand Lake, probably from high grade curly shale samples, 3 analyses averaging 10.84% volatile matter yielded 54 litres/tonne (10.8 gallons/ton).

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

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

25 in Seam, brownish black, 31.0 gallons/ton (155 litres/tonne), S.G. 0.884

Seam M, 4 ft (1.1 m), 10 in at 24 gallons/ton (120 litres/tonne) and 38 in at 6 gallons/ton (30 litres/tonne), 33 lb/ton (16.5 kg/tonne), ammonium sulphate.

Seam KPI, 2 ft 11 in at 7 gallons/ton (35 litres/tonne), 6 ft at 17 gallons/ton (85 litres/tonne) and 7 in at 26 gallons/ton (130 litres/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 no. 1, an analysis of 0.15 m (0.5 ft) oil shale at a depth of 61.1-61.3 m (200.5-201 ft) yielded 20 litres/tonne (4 gallons/ton). A shallower test at 24.4-24.8 m (80-81.5 ft) retorted 30 litres/tonne (6 gallons/ton).

The individual oil shale beds are thin and widely dispersed in a thick unit. The ore is structurally complicated and generally the shale oil yields are poor. These factors combine to eliminate the Deer Lake region as a significant oil shale area at the present time. Even though some beds do yield in excess of 100 litres/tonne, they are not sufficiently thick to offset the higher recovery values.

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INTRODUCTION

From historic accounts, Richardson (1874) was probably the first to see the Queen Charlotte Islands oil shales, although at that time he mistook the carbonaceous surfaces on crushed and slickensided zones for coal. Although Dawson (1880) described the interval, 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 instead of Jurassic because of erroneous paleontological interpretations.

In the British Columbia Department of Mines annual reports, published in 1904 and 1905, Robertson mentioned four other oil shale areas, with a 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 (25 litres/tonne). No further data have since been reported in this area. The writer has interpreted the probable oil zone from a comparison of the published data with GSC Map 3-1961 (Campbell, 1961).

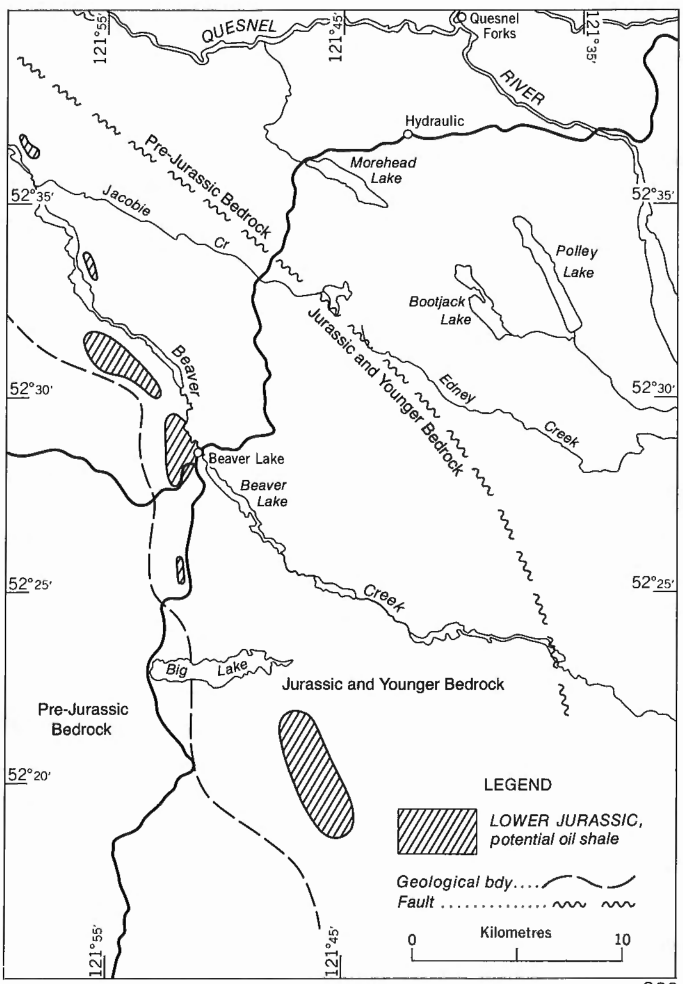

Figure 25. *Outcrop distribution of potential oil shale, Beaver Creek, Cariboo District, B.C. (excerpted from Campbell, 1961, Map 3-1961, Quesnel Lake, west half).*

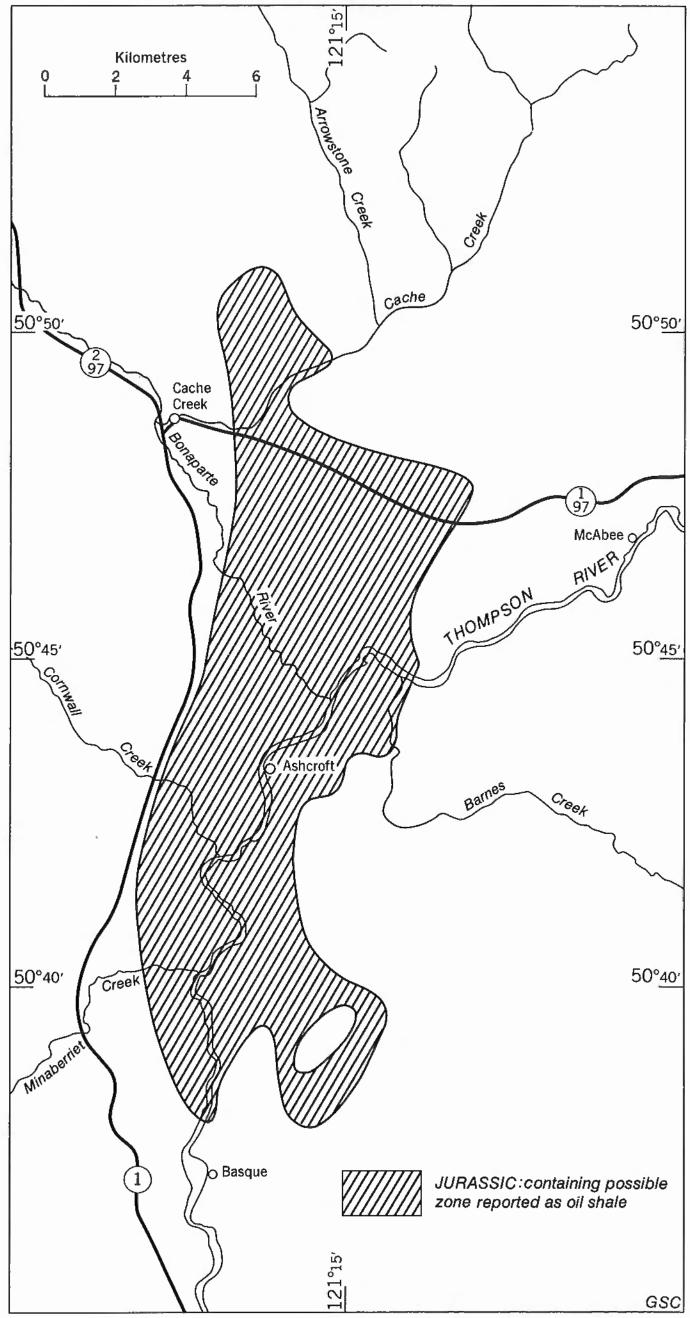

Figure 26. *Outcrop distribution of carbonaceous shale unit, Ashcroft, B.C. (excerpted from Duffell and McTaggart, 1952).*

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 G.S.C. Map 1010A (Duffell and McTaggart, 1952) is probably the suspected oil shale. These shales are black, metamorphosed, quite brittle, and contain ammonite fragments which establish a Jurassic age. Map unit 19 of the

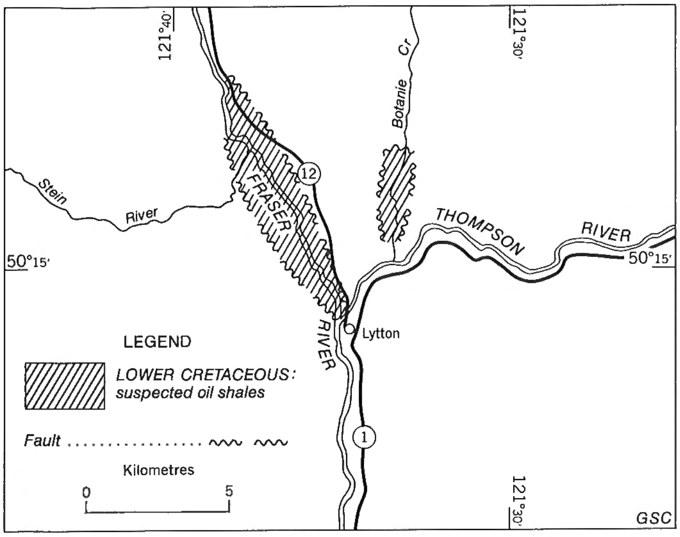

Figure 27. *Outcrop distribution of questionable oil shale, Lytton, B.C. (excerpted from Duffell and McTaggart, 1952).*

same map is a Cretaceous arkose, conglomerate, shale and greywacke (Fig. 27), which might contain suspected oil shale beds in the Lytton area.

A fourth area, in the Flathead Valley of southeastern British Columbia, has not been examined since the early report of oil shales.

QUEEN CHARLOTTE ISLANDS

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

Stratigraphy

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

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

Sutherland-Brown (1968), in his comprehensive report, 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 clastic rocks, and separated the underlying argillite-limestone Kunga Formation as a distinct unit. Under this classification, all oil shale beds occur 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.

A three-fold subdivision of the Kunga Formation was also established by Sutherland-Brown. A lower zone of 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 few specific data are available. Chamney noted that the three unit subdivision occurs laterally as well as vertically; the black argillite member thickens northwards at the expense of the underlying massive grey carbonate, and grey limestone-black bedded limestone-black argillite can also be projected as a south to north facies relationship. The 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 cm to 3 m) to massive. The fresh surface is 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 member 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 cm thick, with inconspicuous internal lamination which locally become fissile.

The black argillite member somewhat resembles the black limestone, except that argillite dominates, and commonly looks like "ribbon chert". Beds are also 2.5 to 10 cm 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. Geological mapping has not been done in sufficient detail 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 member weathers to multi-coloured 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 can 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), the area east of the Sandspit fault has been moved into its 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; pre-Jurassic basement rocks were penetrated. Farther south, the carbonate equivalent of the Kunga is understood to be present at the Sockeye well location.

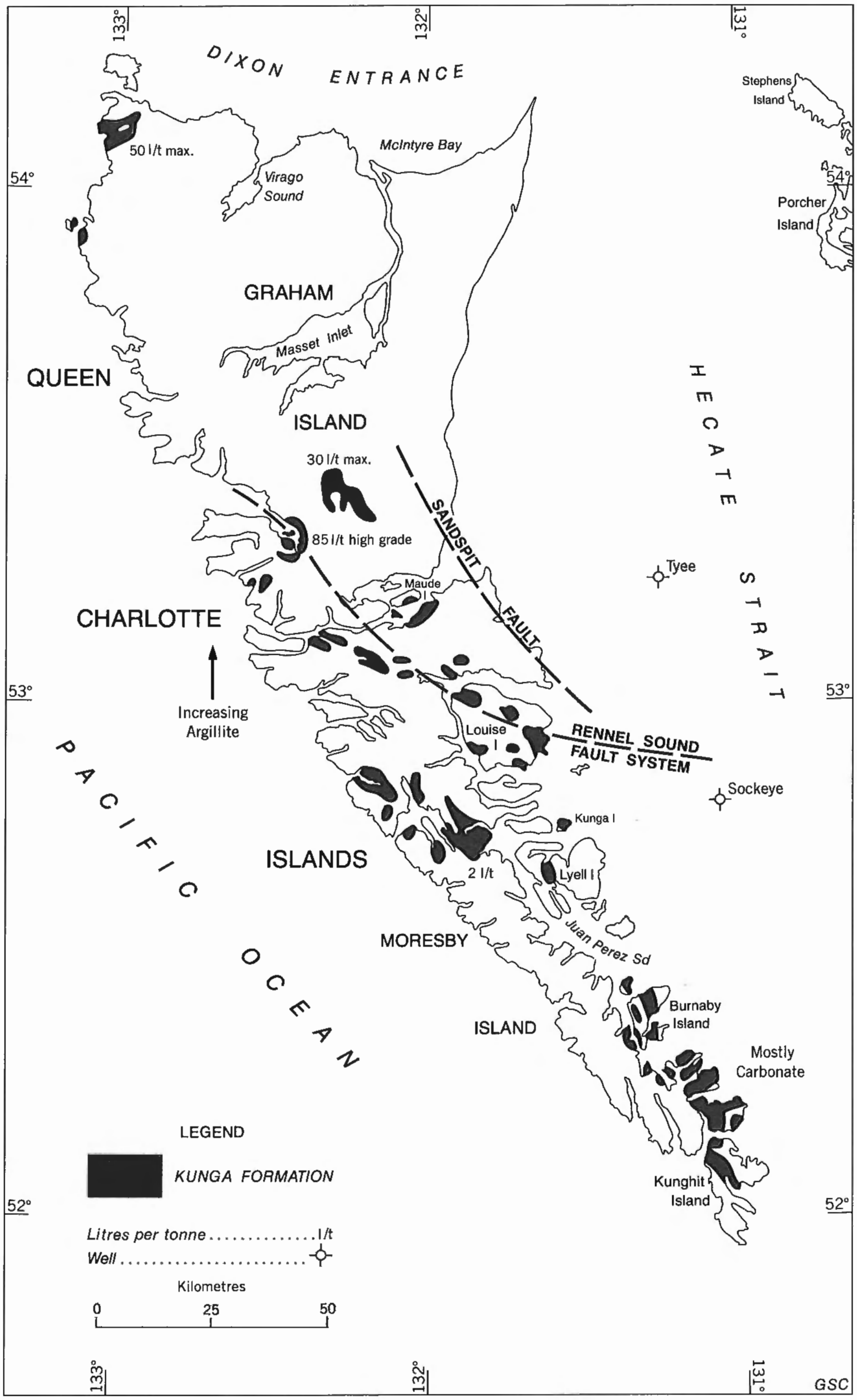

Figure 28. *Outcrop distribution of Kunga Formation modified from Sutherland-Brown, 1968 (assay data from Petro-Canada Exploration Inc.).*

Thicknesses of the argillite member are also difficult to project, as the entire area has been very much deformed structurally. 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 structure at Albert Mines, New Brunswick.

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

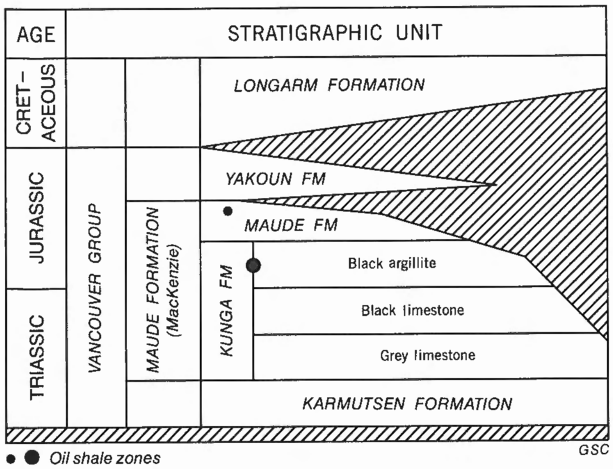

Figure 29. *Triassic-Jurassic stratigraphic section, Queen Charlotte Islands, B.C. (excerpted and modified from Sutherland-Brown, 1968).*

Mineralogy

Both the argillites and black limestones are mineralogically similar with the calcite decreasing as the fine rock fragments increase and the rock grades from limestone to argillite. Beds are commonly composed of fine sand to silt size grains of volcanic rock fragments, with much plagioclase and virtually no quartz. Calcite varies in amount as does finely disseminated pyrite. Opaque ground mass (volcanic?) may 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 further 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 supplied 13 analyses, from three areas (Fig. 28).

On Moresby Island, one analysis yielded 2.5 litres/tonne (0.5 gallons/ton) with 0.920 specific gravity. Six analyses from the outcrop area of central southern Graham Island ranged from 6.5 to 31 litres/tonne (1.3 to 6.1 gallons/ton), averaging 16 litres/tonne (3.2 gallons/ton). No change was noted in specific gravity from the more southerly area analyzed. At the northwest end of the island, 6 analyses ranged from 4 to 4.8 litres/tonne (0.8 to 9.5 gallons/ton), averaging 25 litres/tonne (4.9 gallons/ton), with a specific gravity range of 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, have 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 a potential for recoveries beyond those of the Petro-Canada investigations.

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

Oil shale quality appears to increase northwards 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 suspicion 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.

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INTRODUCTION

Tyrrell (1892) was the first geologist to report the presence of oil shales along the Manitoba Escarpment on the basis of 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). The first significant comments came from S.C. Ells (1923), who stated, "Oil shales of New Brunswick and Nova Scotia were deposited under different conditions from those of Manitoba and Saskatchewan". Ells understood 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 into 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 upper Cretaceous 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 accounting for the white specks. The zones are traceable across the three Prairie Provinces, except for the central area of Saskatchewan where only one unit is present (Park, 1965) (Fig. 30).

Stratigraphy

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

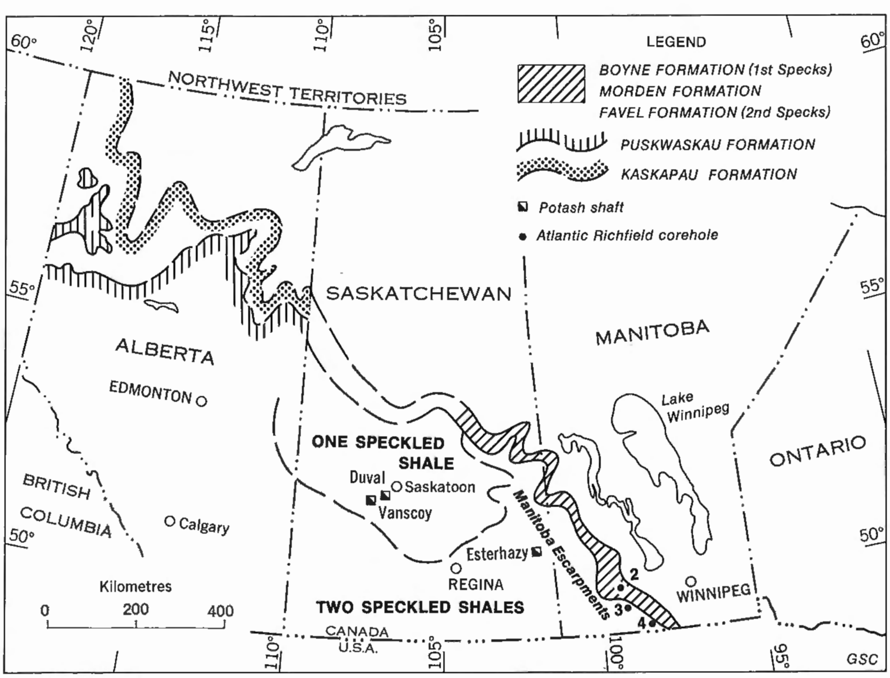

Figure 30. *Outcrop distribution of Upper Cretaceous oil shale zones, Prairie Provinces.*

Ells (1923) first used the term "Boyne" to refer to the white speckled shale zone which was faunally equated with 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 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 overlies 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 usage, 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 westwards thinning and eventual loss of the intervening Morden shale between the Boyne and Favel, until 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.

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

Some suggested unconformities may represent uplift and erosion, or even 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 the underlying salt from Middle Devonian prairie evaporite formations has created anomalous conditions throughout the overlying geological section. Many of the single well anomalies may be attributable to this cause.

One of the problems in evaluating oil shale potential at the surface is 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).

<table>
<tr><th colspan="3">Generalized present terminology</th><th>As used herein</th><th colspan="3">Proposed by McNeil and Caldwell</th></tr>
<tr><td colspan="3">RIDING MOUNTAIN FM</td><td>RIDING MOUNTAIN FORMATION</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 Specks</td><td>BOYNE FORMATION</td><td colspan="3">NIOBRARA FORMATION</td></tr>
<tr><td colspan="2">Morden Member</td><td>MORDEN FM</td><td colspan="3"></td></tr>
<tr><td rowspan="2">FAVEL FORMATION</td><td>Assiniboine Member</td><td rowspan="2">2nd Specks</td><td rowspan="2">FAVEL FORMATION</td><td rowspan="2">FAVEL FM</td><td>Assiniboine Member</td><td>Marco calcarenite</td></tr>
<tr><td>Keld Member</td><td>Keld Member</td><td>Laurier limestone</td></tr>
<tr><td colspan="3">ASHVILLE FORMATION</td><td>ASHVILLE FM</td><td colspan="3">Belle Fourche shale</td></tr>
</table>

GSC

Figure 31. *Pertinent Upper Cretaceous stratigraphy, Manitoba Escarpment.*

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 thick sequence of sediments, and equates approximately to the lower part of the Kaskapau Formation (Fig. 30).

Lithology

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

The shale may grade to beds of argillaceous limestone where the fossil debris becomes the dominant rock component. The limestone beds may reach several metres in thickness and 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 colour 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 colour to the hydrocarbon content. Along the southern part of the Manitoba Escarpment, where hydrocarbon content is considerably less than to the north, lighter colours are more prevalent. The shales 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 three 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 and the oil shales are also lighter coloured. Undoubtedly, there is sufficient organic content throughout the section below the Riding Mountain Formation to effect colour darkening in a northward direction.

Although the impure limestones, or calcarenites, are somewhat resistant to erosion, the white speckled oil shale beds are generally recessive. This is in marked contrast to the resistance of the Maritime Carboniferous oil shales to weathering.

Distribution and Thickness

The distributional pattern has already been fairly well outlined in discussing the stratigraphy of the two units. The Boyne (upper zone) generally averages 30 to 46 m (100-150 ft) in the outcrop area, thinning to approximately 18 m (60 ft) in central Saskatchewan, where only a single unit is present, and thickening again westwards to a range of 46 to 61 m (150 to 200 ft) in the Alberta subsurface.

Favel beds attain a general maximum thickness of 18 m (60 ft) along the escarpment, thinning to zero (or centimetres only) in central Saskatchewan and thickening westwards to 36 to 61 m, similar to the "First White Specks", in the subsurface of Alberta.

The intervening Morden shale thins westwards from as much as 45 m in the outcrop area to zero in central Saskatchewan, and from there thickens westwards to more than 100 m in the subsurface of the Alberta plains and up to 300 m along the Alberta Foothills.

There appears to be a general southeastwards 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 represents 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. 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, the sulphur content of which 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 m. The reservoir was probably in low porosity bands of limestone calcarenite; no sandstones are present in the formation at that depth. The field dropped from 33 to 23 lb/in^2 pressure between 1940 and 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 bed.

In addition to discussing the oil potential, Beck (1974) outlined tests made on the limestone beds to assess their potential as a cement source rock. Some equivalent beds in Manitoba are reportedly used for cement manufacture.

Beck also indicated some interest in uranium within the Pasquia Hills area. 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. The marlstones to pure carbonates were also virtually free 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. This additional cost might be overcome if the limestone could be used as a base for a cement by-product.

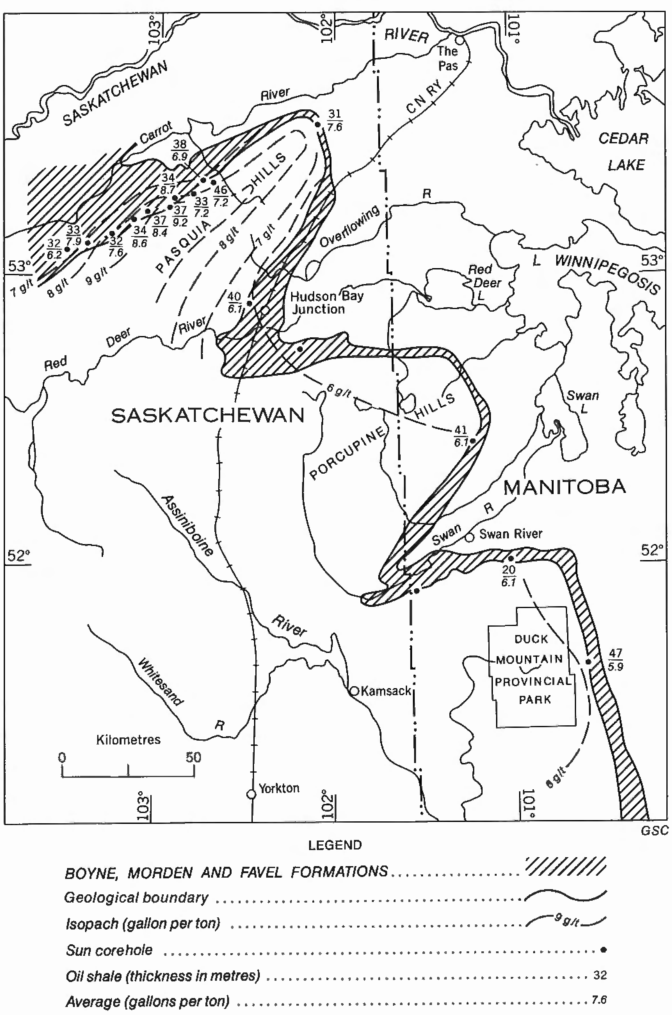

Figure 32. Outcrop distribution of oil shales on the Manitoba Escarpment, with generalized oil content data.

Table 7

Analytical results from Manitoba Escarpment coreholes

Hole No.	Oil Yield g/t		Avge.	Thickness		Specific Gravity		
	Max.	Avge.	l/tonne	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

GSC

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. Contacts appear to be gradational, with the initiation of kerogen preceding the influx of pelagic fossil debris and continuing to some degree 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 suggest 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 litres/tonne), but also 22.5 lb/ton (11.2 kg/tonne) of ammonium sulphate.

Table 7 is a summary of the analyses from the key locations penetrating nearly complete sections of the Boyne or Favel formations. 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 optimum area, in excess of an average 9 gallons/ton, over about 37 m, is mappable along the northwest edge of the Pasquia Hills. The regional southerly decrease in shale oil recoveries is indicated on Figure 32, which shows generalized average recovery isopachs prepared from borehole sections that partly penetrated 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 indicate a distribution similar to that of the Boyne.

Beck (1974) estimated that a zone, 1.6 to 19 km (1 to 12 miles) in width by 56 km (35 miles) in length, could be mineable along the northwest flank of the Pasquia Hills. Using an average thickness of 30 m, and with a 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 m (60 ft); the average gallons/ton seems quite realistic. A reduction of the average zone would bring the oil in place down to 1.6 billion barrels.

From a brief review of recovery distribution within the cored Boyne intervals, the basal 10 m is commonly very low grade; consequently, the average pay thickness may more realistically be reduced to about 14 m (45 ft), which would reduce oil in place to 200 million cubic metres (1.25 billion barrels).

The above figure is approximate only, as no detailed analysis was made 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. Fuglem (Geological Survey of Canada, Calgary; pers. comm.) stated that the two "White Specks" zones, when encountered in well cuttings in east-central to northwestern Alberta, can often be ignited in an alcohol flame. Equivalent beds in the United States northern Great Plains (Schulz et al., 1980) are also oil shales.

Because of their 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. These zones must be considered as primary oil shale targets.

Ells noted the geological difference between these oil shales and those of the Maritimes. These shales exude much greater odor, distill a much poorer gravity product (SG 0.95 to 0.98, API 11.5°), 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.

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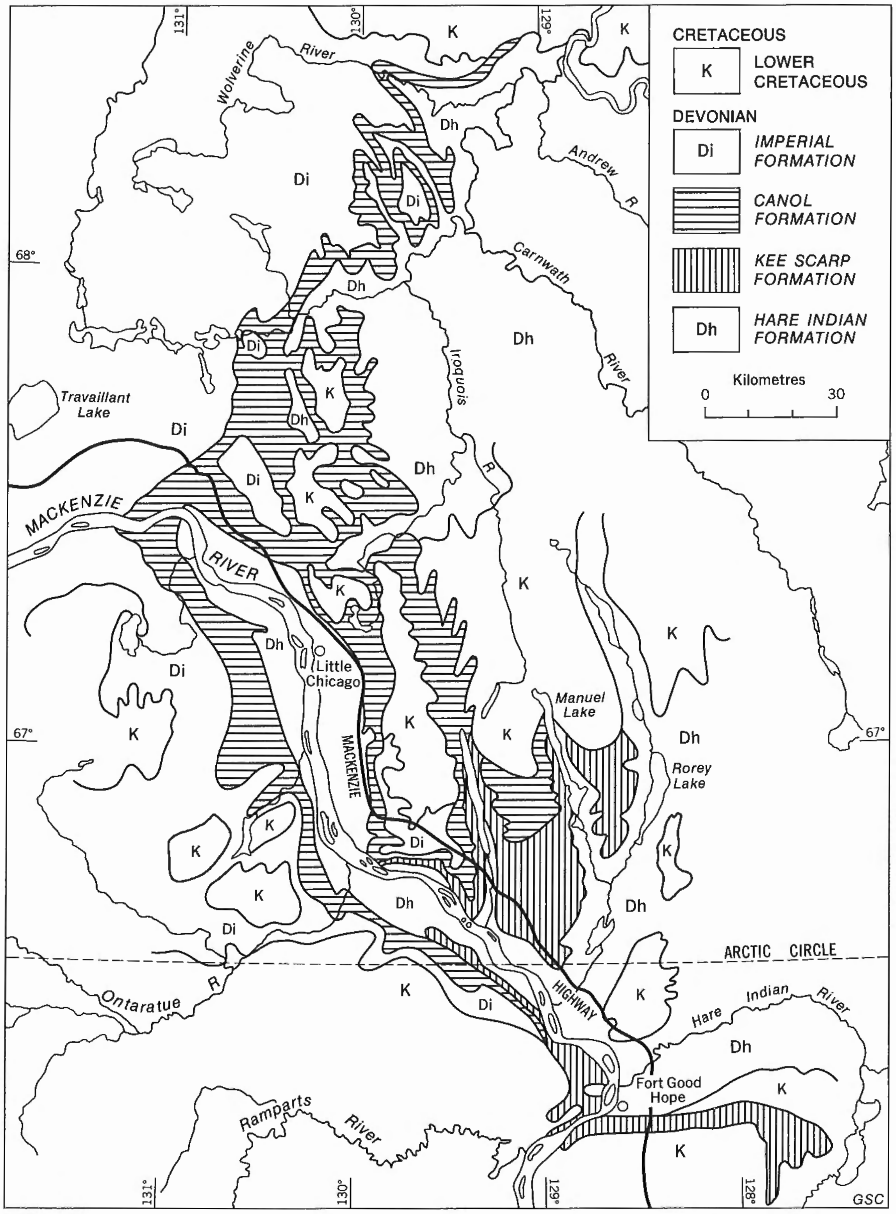

Figure 33. *Outcrop distribution of Canol Shale, lower Mackenzie River, N.W.T. (excerpted from Cook and Aitken, 1969).*

LOWER MACKENZIE RIVER AREA

Kindle and Bosworth (1921) named the Devonian 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, an age range that is still accepted.

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) taken from these maps.

Canol shales, generally about 30 to 40 m thick, are recessive, black, commonly 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. Pyrite is common, and oxidizes at the surface to form reddish brown hematite patches.

Oxidation of the pyrite certainly creates heat, but the burnt appearance probably relates also to ignition of the kerogen by the oxidizing pyrite. Samples can reportedly be ignited by a flame. Kindle and Bosworth (1921) indicated

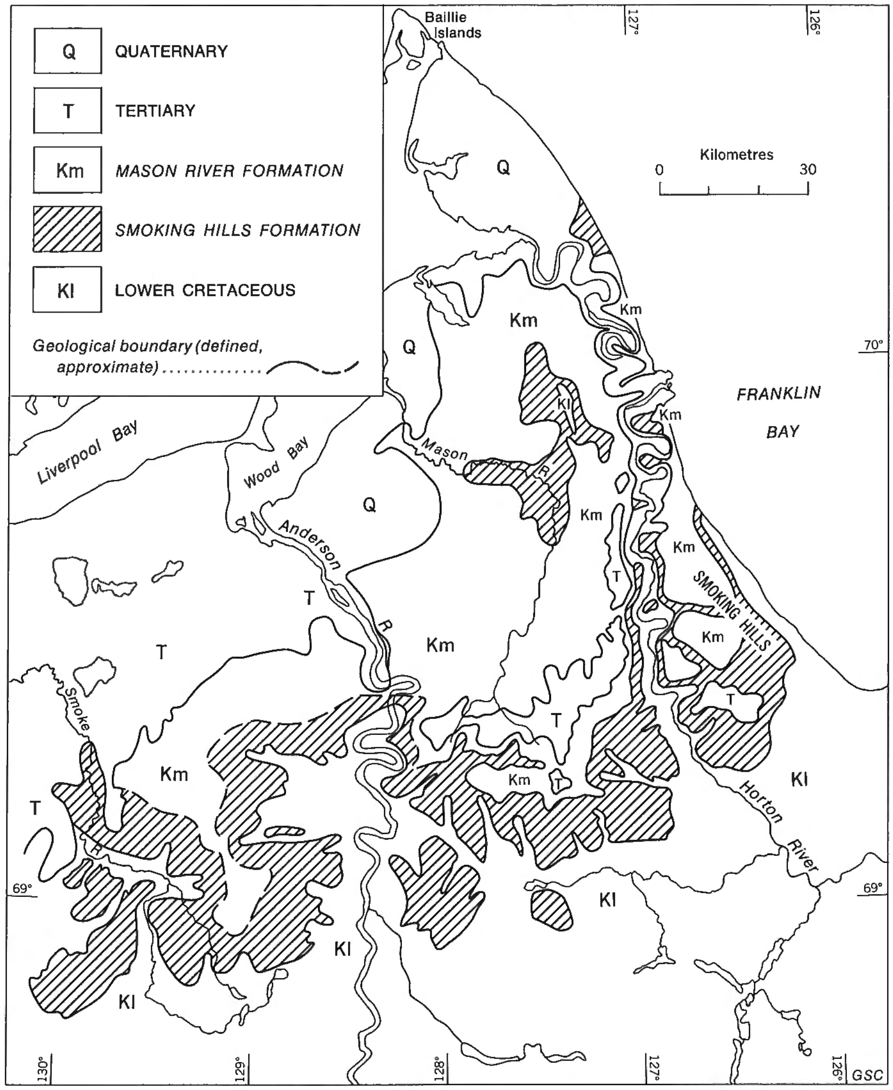

***Figure 34.** Outcrop distribution of Smoking Hills Formation, N.W.T. (excerpted from Yorath, Balkwill and Klassen, 1969, Fig. 4).*

that the only attempted retorting of Canol shales was unsuccessful because of poor equipment. Although not proven, the Canol interval is very probably an oil shale zone.

Shales of the Canol Formation are shallow marine platform deposits which overlie and are in part equivalent to Kee Scarp carbonate beds. Where Kee Scarp carbonate is absent, Canol overlies non-organic grey shales of the Hare Indian Formation.

ANDERSON PLAIN – MACKENZIE DELTA

Within the Northwest and Yukon Territories, the greatest areal extent and greatest thickness of possible oil shale 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, 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 as the oxidation of pyrite in oil-free shales 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 in Saskatchewan.

Stratigraphy

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).

Farther west, at the south end and west side of the Mackenzie Delta, Jeletzky (1960) recognized upper Cretaceous strata, informally defined as the "upper

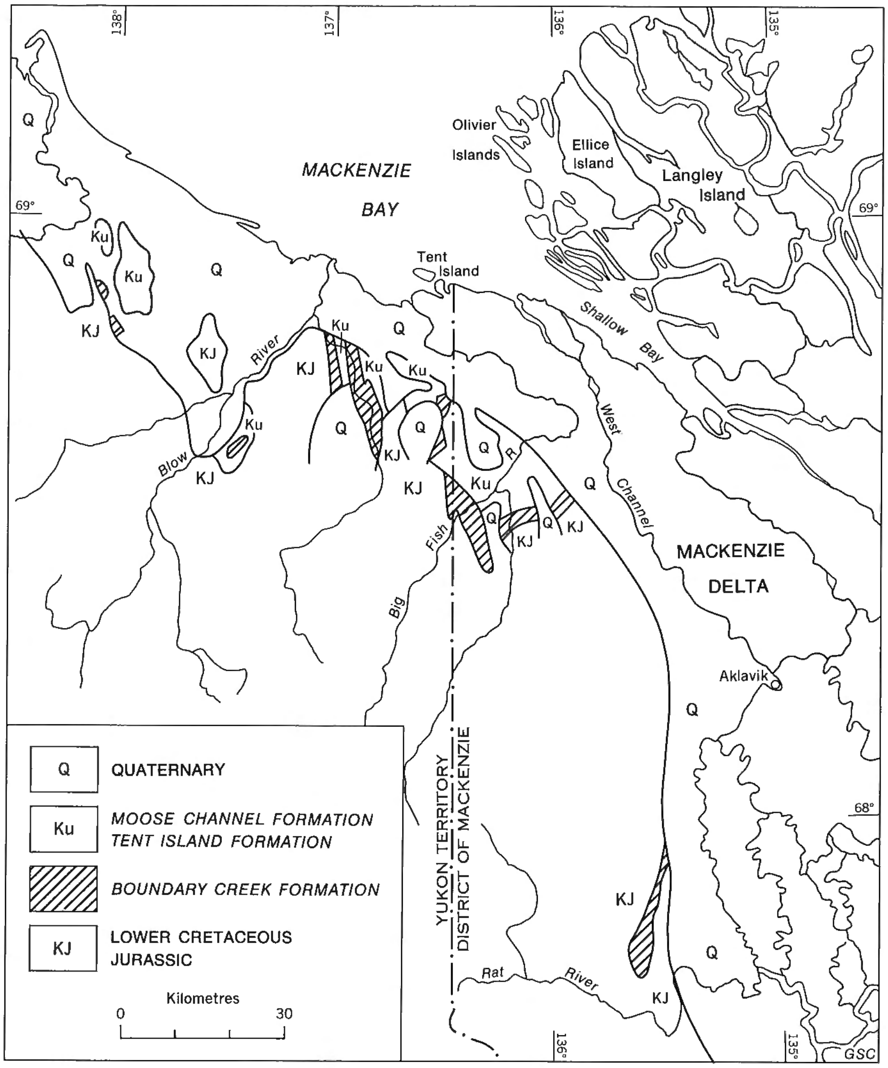

Figure 35. *Outcrop distribution of Boundary Creek Formation, Y.T. (excerpted from Young, 1975 and Jeletzky, 1960).*

Cretaceous shale division", which Young (1975) redefined by introducing the Boundary Creek and overlying Tent Island formations (Fig. 33). 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.

Young, Myhr and Yorath (1976) presented a regional paper covering the Beaufort – Mackenzie Basin. Here the Smoking Hills Formation 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. Westwards, in the Richardson Mountains, the Boundary Creek seems to represent most of Cenomanian through Campanian time, with a more complete sedimentary record. This is directly analogous to the Prairie Provinces situation where some of the record is missing in the Boyne-Favel area in the east, but 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 jarosite laminae. Basal conglomeratic sandstone is sporadic, indicating possible local erosional unconformity with 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 mahogany brown. Beds of bentonite are concentrated in zones with seams to 0.3 m. 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

These Upper Cretaceous strata are preserved as erosional remnants in broad to local synclinal features (Figs. 34, 35). 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) from a well section.

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

Sections of the Boundary Creek Formation vary from 165 to 240 m in thickness, 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 plentiful 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. 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 identified from lithologic descriptions, from the bocannes, and from direct comparison to those of the Manitoba Escarpment. Recovered shale oil is expected to have similar characteristics to that of the "White Specks" of the Prairie Region, including a high sulphur content because of the abundance of surface weathering sulphur-bearing minerals.

Studies have been conducted on the Boundary Creek Formation as a potential source rock. These were analyzed and summarized by Snowdon (1980) who concluded that the Boundary Creek is an excellent source rock, already identified as 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 their 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 similar Manitoba-Saskatchewan oil shale intervals.

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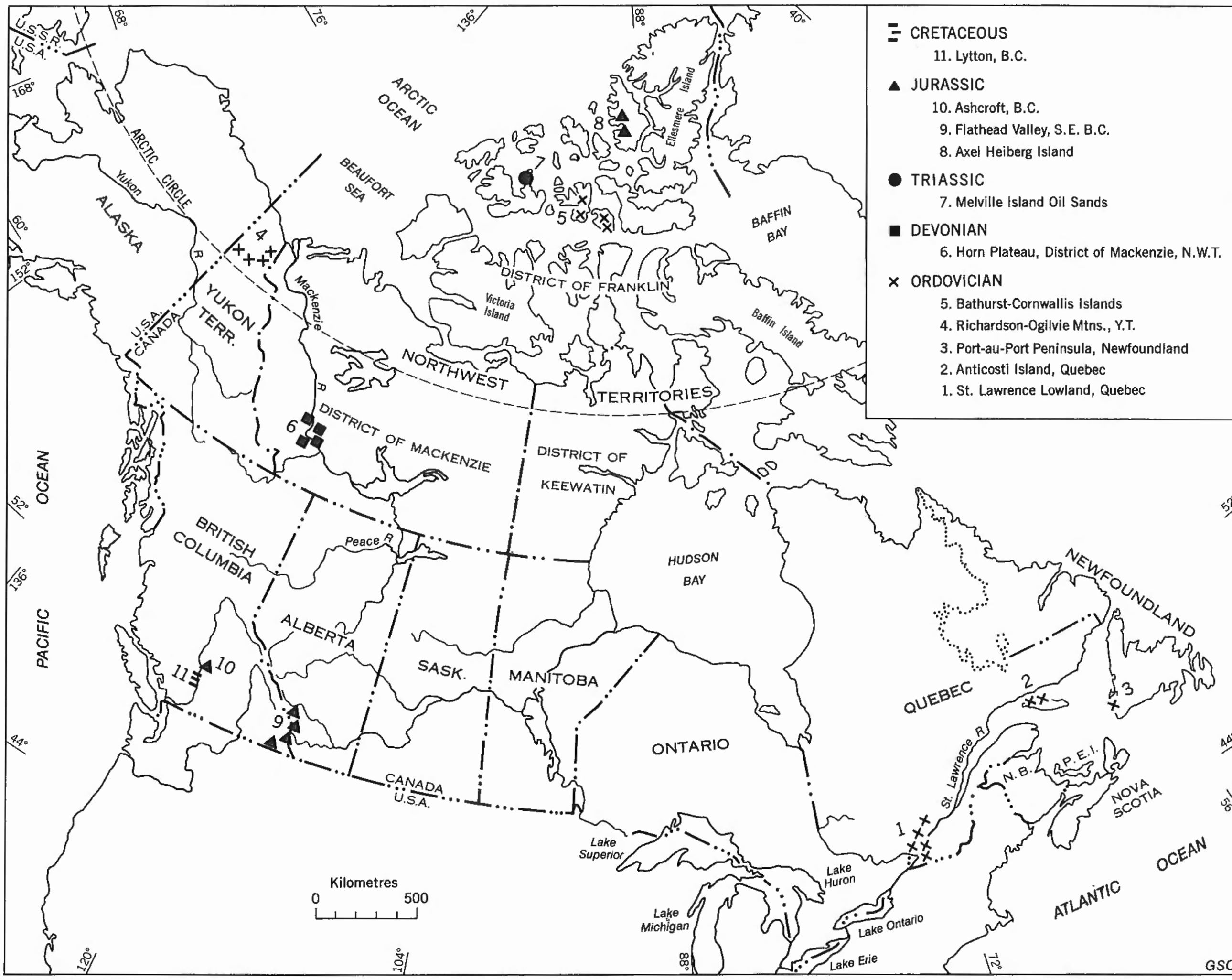

Figure 36. *Areas of possible interest for oil shales in Canada.*

Several areas of possible oil shales have already been mentioned in addition to the known oil shale deposits. A few additional areas seem to warrant consideration (Fig. 36).

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 Arctic Islands. 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 in the "Fort Creek Formation", an early term encompassing all dark shales in the Devonian of the Northwest Territory. Ranging from 15 to 70 m 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 Island 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 a 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 along the mountain fronts of Alberta and northeastern British Columbia, and are significant mappable units within the adjacent subsurface areas to the east. Within the subsurface of west-central Alberta, carbonate and sandstone facies of the Nordegg Member, a lower unit of the Fernie Formation, 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 as a source rock and for their 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 further sampling and analytical investigation may be justified to confirm the present conclusions.

Of all the known Canadian oil shale deposits, those of the Frederick Brook Member of the Albert Formation, at Albert Mines, New Brunswick, are the most thoroughly analyzed, and are the most economically attractive at the present time.

A possible minimum 100 m 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 oil 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 negative side of the economics, the deposit is structurally 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 reach a depth of almost 700 m 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, covering an area of the Pasquia Hills, are also of interest. Although of lesser average yield, with a maximum 45 litres/tonne (9 gallons/ton) average, the Boyne and Favel white speckled shale zones are significant because of their large subsurface as well as surface areal extent, and their excellent thicknesses, averaging 40 and 20 m for the upper and lower zones respectively along the Manitoba Escarpment. The shale oil quality is not as 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 degrees 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° 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 a low southwesterly dip. Strip mining may be more practical along the escarpment than the pit mining, which would be required 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 relevant 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 be more economical, as the shale oil contains up to 7% sulphur. 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 success or lack of success in one area cannot be automatically applied to the other.

Data are presently insufficient to rate the economic potential of the other known oil shales.

The potentials of the Smoking Hills and Boundary Creek formations of the Northwest and Yukon Territories are suspected to be significant because of their geologic similarity to the Boyne and Favel of the Manitoba Escarpment. Their geographic location currently restricts interest, but further knowledge of these deposits will be acquired with minimum effort by comparisons with research results from the similar Manitoba-Saskatchewan strata.

The few analyses available for 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, subsurface data are available from conventional oil and gas field development; consequently, the areas of greatest thickness are mappable.

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 and thicknesses are 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 in either area. From present knowledge, both areas are worthy of continuing investigation until firm data on thicknesses and oil contents have been obtained.

The torbanite and oil 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 m or more thick), some technique for the joint energy consumption of the three types should be feasible.

The oil shale deposits of Canada are all geologically different and 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 the various types of host rock. These rocks are all lithologically and mineralogically so different that reactions to any specific treatment will be extremely variable from deposit to deposit.

FUTURE ALTERNATIVES

"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.

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