Geological Survey of Canada
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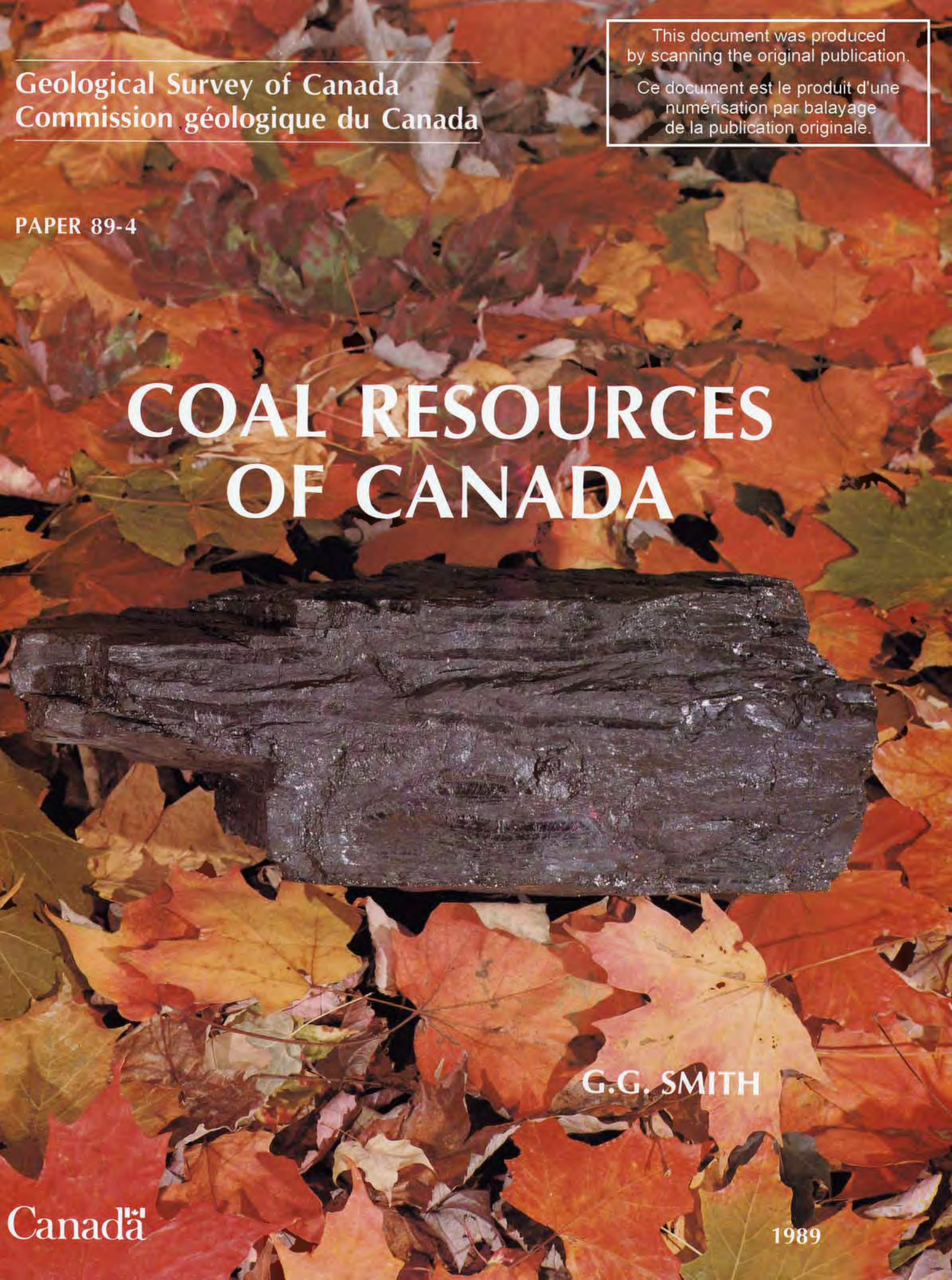
PAPER 89-4



COAL RESOURCES OF CANADA

G.G. SMITH

Canada

1989

GEOLOGICAL SURVEY OF CANADA
PAPER 89-4

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by G.G. Smith

Available in Canada through
authorized book store agents
and other book stores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Hull, Quebec, Canada K1A 0S9

and from

Geological Survey of Canada
601 Booth Street
Ottawa, Canada K1A 0E8

and

Institute of Sedimentary and Petroleum Geology
Geological Survey of Canada
3303 - 33rd Street, N.W.
Calgary, Alberta
T2L 2A7

A deposit copy of this publication is also available
for reference in public libraries across Canada

Cat. No. M44-89/4E
ISBN 0-660-13085-8

Price subject to change without notice

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Cette publication est aussi disponible en français

PREFACE

Canada is particularly well endowed with coal resources and exploitation and these resources has undergone unprecedented expansion in the past fifteen years. During this period, the Geological Survey of Canada accelerated its research activities in coal-related geoscience. This has resulted in the development of a world-class capability for assessing coal potential in terms that are relevant to the exploration, evaluation, development, utilization and management of this resource. Current studies are directed toward defining the nation's inventory of abundant yet diverse coal resources, in addition to providing a knowledge base from which informed choices related to effective coal development may be made and upon which national coal policy issues within Federal Government jurisdiction may be adequately addressed.

This compendium summarizes information pertaining to the distribution, geological context, estimated quantities, and characteristics of Canadian coals. Information has been compiled from published and unpublished records of the Geological Survey of Canada, provincial governments and coal companies. The report accommodates information made available up to the beginning of 1988. The regional breakdown selected reflects the various distinct geological, geographic and physiographic settings for the resources. The information provided in this report should prove to be of benefit to those interested in an overview of Canada's coal resources in terms of their potential for exploration and development.

Elkanah A. Babcock
Assistant Deputy Minister
Geological Survey of Canada
September 28, 1988

PRÉFACE

Le Canada possède des ressources en charbon relativement abondantes et leur exploitation a connu un essor remarquable au cours des quinze dernières années. Pendant cette même période, la Commission géologique du Canada a multiplié ses projets de recherche dans le domaine du charbon. Cette intensification des travaux a débouché sur l'élaboration de compétences de niveau mondial en ce qui a trait à la production d'estimations de potentiél tenant compte de l'exploration, su l'évaluation, l'exploitation, l'utilisation et la gestion des ressources en charbon. Les études en cours visent à établir l'inventaire des ressources canadiennes en charbon, fort abondantes mais aussi très diversifiées, ainsi qu'à élaborer un répertoire de connaissances permettant d'orienter les décisions relatives à la gestion de l'exploitation du charbon, grâce auquel pourront être abordés les aspects de politiques de compétence fédérale.

Le présent document offre un résumé des caractéristiques du charbon canadien, à savoir la répartition, le contexte géologique, les estimations et la qualité du combustible. Les renseignements sont tirés de rapports, publiés ou non,produits par la Commission géologique du Canada, les gouvernements provinciaux et les sociétés d'exploration. Le document a été rédigé à l'aide des informations disponibles au début de 1988. Sa division en différentes régions géographiques reflète les distinctions géologiques et géomorphologiques des environnements où se trouvent les ressources. Les renseignements présentés ici sauront intéresser quiconque désire obtenir une vue d'ensemble des ressources canadiennes en charbon en ce qui a trait à leur potentiel sur le plan de l'exploration et de l'exploitation.

Elkanah A. Babcock
Sous-ministre adjoint
Commission géologique du Canada
28 septembre 1988

ACKNOWLEDGMENTS

The author has drawn freely on the work of many people who have reported on Canada's coal resources. Various provincial government agencies and private companies have provided invaluable support for recent coal-related activities of the Geological Survey of Canada. Federal/Provincial agreements with the British Columbia Ministry of Energy, Mines and Petroleum Resources, Saskatchewan Department of Mineral Resources, and Nova Scotia Department of Mines and Energy have resulted in significant advances in coal geoscience in Canada. Coal resource information compiled by the Alberta Research Council and Alberta Energy Resources Conservation Board has been most useful. Geological data from well explored coal deposits, freely provided to the Geological Survey of Canada by private coal companies and electric utilities, are very useful for assessing coal potential in less explored areas with similar geological settings. These data also contribute significantly to a broader understanding of factors that affected coal distribution and coalification processes.

Numerous important contributions to the current knowledge base of Canada's coal resource potential have resulted from the activities of geoscientists in the Coal Geology Subdivision of the Geological Survey of Canada's Institute of Sedimentary and Petroleum Geology, located in Calgary. These geoscientists include A.R. Cameron, F.M. Dawson, D.W. Gibson, F. Goodarzi, J.D. Hughes, T. Jerzykiewicz, W.D. Kalkreuth, D.K. Norris and B.D. Ricketts. Each provided helpful advice during the planning and preparation of the report, in addition to pertinent unpublished information resulting from their most recent work. A.R. Sweet assisted in ensuring that the indicated ages of sedimentary units reflect current knowledge. The support and suggestions of D.K. Norris, both in the early phases of the project, and in critically reviewing and editing the draft manuscript, are gratefully appreciated. The able assistance of Mark Lewis, with extensive literature searches and reviews, and Ian deBie, with preparing all draft figures and in providing advice and direction on layout and production of the original draft manuscript, was extremely valued. C. Boonstra provided general assistance in preparing the draft manuscript. L. MacLachlan directed the production of the final report, and provided valuable advice on design and content throughout the entire final production phase. P. Greener supervised word processing and compugraphic activities. M. Jacobs was responsible for most of the layout on the Compugraphic and was assisted by H. King. B. Rutley was responsible for photography of the cover and elsewhere unless otherwise credited. B.H. Ortman and D.J. Walter were responsible for all the colour separation on the figures, modifying the illustrations in English and French and providing the final page negatives for printing. P. Côté directed the translation of the original English manuscript into French. To all of these persons the author expresses appreciation and thanks.

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COAL EXPLORATION

COAL EXPLOITATION (Greenhills Mine, B.C.; courtesy J.D. Hughes)

SUMMARY

Canada is richly endowed with coal. Its coal resources are widely distributed and have diverse characteristics. These resources occur in a variety of geological, geographical and physiographical environments, and include all coal ranks from lignite to meta-anthracite. They have been commercially exploited for more than 300 years; during the past 15 years, however, coal production in Canada has undergone unprecedented expansion. The diversity in the nation's coal resources puts Canada in a strong position to respond positively to coal development opportunities as national and international coal requirements change.

The term "coal" is generic for a rock that comprises mainly plant-derived carbonaceous material and can be applied to rocks having significantly different properties. Coal is formed from peat which, over time, is coalified by heat and pressure that are commonly associated with stratigraphic burial. The formation, accumulation, preservation and alteration of peat relate to geological, biological, ecological and geochemical factors associated with environments of deposition. The depth of burial and degree of thermal maturation of resulting coals relate to tectonic factors that control basin subsidence. Tectonism also causes structural deformation of stratigraphic successions, which can alter the present distribution and character of contained coals. The present distribution and character of coals in Canada reflect environments of deposition, original types of peat-forming vegetal debris, degree of organic maturation, structural deformation and mineralization.

Coal resources are found from coastal British Columbia in the west, to the Atlantic Provinces in the east, and in northern Canada. They occur within the following regions (Fig. 1.1):

- Coastal British Columbia.
- Intermontane British Columbia.
- Rocky Mountain Front Ranges and Foothills of British Columbia and Alberta.
- Interior Plains of British Columbia, Alberta, Saskatchewan and Manitoba.
- Hudson Bay Lowland of Ontario.
- Atlantic Provinces; New Brunswick, Nova Scotia and Newfoundland.
- Northern Canada: Yukon Territory and District of Mackenzie; Arctic Archipelago.

Each region is geologically, geographically and physiographically distinct. The nature of coal occurrences and coal characteristics vary from region to region. Correspondingly, coal exploration, evaluation, development and resource management must often consider the unique circumstances presented by the region within which the coal deposits occur.

In British Columbia, the low and medium volatile bituminous coal deposits that occur in the East Kootenay and Peace River regions of the Rocky Mountains and Foothills constitute more than two-thirds of Canada's measured and indicated metallurgical coal resource of immediate interest. Several intermontane basins in the interior regions of the province contain important thermal coal deposits, such as the lignitic deposits of the Hat Creek Coalfield, and anthracitic deposits of the Groundhog Coalfield. Other thermal coal deposits occur on Vancouver Island and in the Queen Charlotte Islands.

In Alberta, commercially significant coal resources occur throughout the Rocky Mountains, Foothills and Plains regions. Most coal resources of the Rocky Mountains and Inner Foothills are of metallurgical grade, like those of the adjacent East Kootenay and Peace River regions of British Columbia. High volatile bituminous coals, commonly containing less than one per cent sulphur, occur within the Outer Foothills region and are potentially exportable thermal coals. Virtually all of Canada's subbituminous coal resources, which are particularly suitable for mine-mouth power generation, occur within the Interior Plains of Alberta. Nearly 75 per cent of Canada's measured and indicated thermal coal resources of immediate interest are located in Alberta.

Coal deposits that are widely distributed throughout southern Saskatchewan contain most of Canada's lignitic resource inventory, an important source of fuel, particularly suitable for mine-mouth electric power generation.

A single extensive lignite coalfield in the Hudson Bay Lowland contains Ontario's only indigenous coal resources, which could become a viable source of fuel for a mine-mouth electric power generating plant.

Numerous seams of mainly high volatile bituminous thermal coals occur in New Brunswick, but they are generally thin and have high sulphur content. Although the resource base is relatively small, about 0.5 megatonnes are being mined annually.

Nearly 1.5 per cent of Canada's measured coal resources of immediate interest occur in Nova Scotia. These resources comprise high volatile bituminous coals of which about 75 per cent are thermal and 25 per cent are metallurgical grades.

The Geological Survey of Canada has been conducting coal geoscience studies for more than a century. Results have provided important information for the nation's public and

TABLE 1.1

SUMMARY OF CANADA'S COAL RESOURCES

Coal Region	Coal Rank	IMMEDIATE INTEREST (megatonnes) measured	indicated	inferred	FUTURE INTEREST (megatonnes) measured	indicated	inferred	speculative
COASTAL BRITISH COLUMBIA								
- Vancouver Island	h-mvb	35	80	200	-	-	300	-
- Queen Charlotte Islands	lvb-an	-	-	10	-	-	-	-
	h-mvb	-	15	10	-	-	-	-
	lig-sub	-	-	50	-	-	-	500
INTERMONTANE BRITISH COLUMBIA								
- Northern District	lvb-an	100	500	1000	-	-	-	4000
	h-mvb	30	50	100	-	-	-	100
- Southern District	sub-hvb	40	120	340	-	-	-	-
	lig-sub	450	320	270	-	-	-	-
ROCKY MOUNTAINS AND FOOTHILLS								
- Front Ranges								
- East Kootenay	h-mvb	1390	1320	4040	-	2700	-	-
- Crowsnest	m-lvb	265	140	510	-	200	-	-
	h-mvb	330	170	630	-	-	-	-
- Cascade	lvb-an	240	120	455	-	210	-	-
- Panther River-Clearwater	lvb-an	-	-	-	15	15	700	-
- Inner Foothills								
- Southern District	m-lvb	635	320	1145	-	245	-	-
	h-mvb	150	75	275	-	-	-	-
- Northern District	m-lvb	1115	2385	6270	-	100	-	-
- Outer Foothills	sub-hvb	830	740	1955	-	200	-	-
PLAINS								
- Mannville Group	lig-sub	-	35	100	-	-	30	-
- Belly River/Edmonton/Wapiti	sub-hvb	1240	585	1860	-	820	-	-
	lig-sub	11860	4935	16575	-	14115	-	-
- Paskapoo	sub-hvb	120	60	175	-	25	-	-
- Ravenscrag	lig-sub	1445	2680	3440	165	3910	23510	-
- *Deep coal*	sub-hvb	-	-	-	1200	4000	50000	85000
HUDSON BAY LOWLAND - Onakawana	lig-sub	170	10	-	-	(no available estimates)		-
ATLANTIC PROVINCES	h-mvb	345	365	770	-	1500	215	-
NORTHERN CANADA								
- Yukon Territory and District of Mackenzie	lvb-an	-	-	90	-	(no available estimates		-
	h-mvb	-	-	150	-	of resources of future interest		-
	sub-hvb	-	-	350	-	for this region)		-
	lig-sub	-	-	2290	-	-	-	-
- Arctic Archipelago	sub-hvb	-	-	-	-	500	550	4500
	lig-sub	-	-	-	-	7000	7500	31000
TOTALS	lvb-an	340	620	1555	15	225	700	4000
	m-lvb	2015	2845	7925	-	545	-	-
	h-mvb	2280	2075	6175	-	4200	515	100
	sub-hvb	2230	1505	4680	1200	5545	50550	89500
	lig-sub	13925	7980	22725	165	25025	31040	31500

commercial planning, and industrial development. Current studies are directed toward defining Canada's abundant but diverse coal resources to provide the basis of choice to respond effectively to future coal development opportunities, and to address associated national policy issues within the Federal Government's jurisdiction.

The Geological Survey of Canada conducts studies of the nation's coal resources. The Canada Centre for Mineral and Energy Technology (CANMET) assesses Canada's coal reserves.

Canada is ranked fifth among nations with respect to the distribution of the world's coal resources. It contains nearly 4 per cent of the world's coal resources, exceeded only by U.S.S.R., United States, People's Republic of China, and Australia. Although there are currently no means for comparing the reliability of the various national resource estimates included in world coal studies, Canada will always be among the nations that are particularly well-endowed with coal, by virtue of the size of the Canadian landmass that contains coal.

About 60 per cent of Canada's coal production is thermal coal of which nearly 90 per cent is used domestically for the generation of electricity, with the balance being exported to destinations around the world. Nearly 40 per cent of Canada's coal production is metallurgical coal of which the vast majority is exported to markets around the world.

Estimated coal resources of immediate and future interest in various parts of Canada, categorized by rank classes that reflect probable ultimate use, are summarized in Table 1.1. A

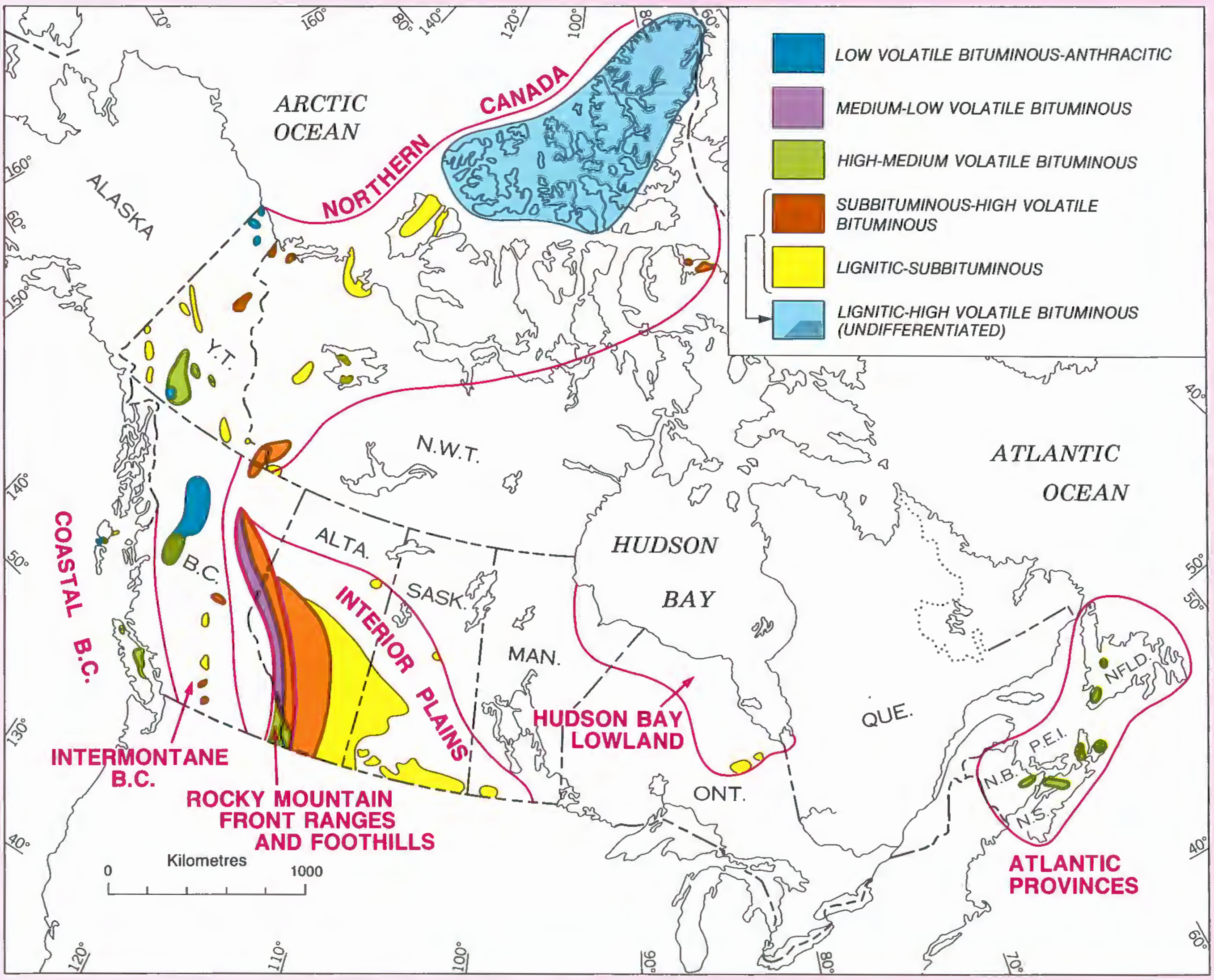


Figure 1.1. Distribution of coal in Canada.

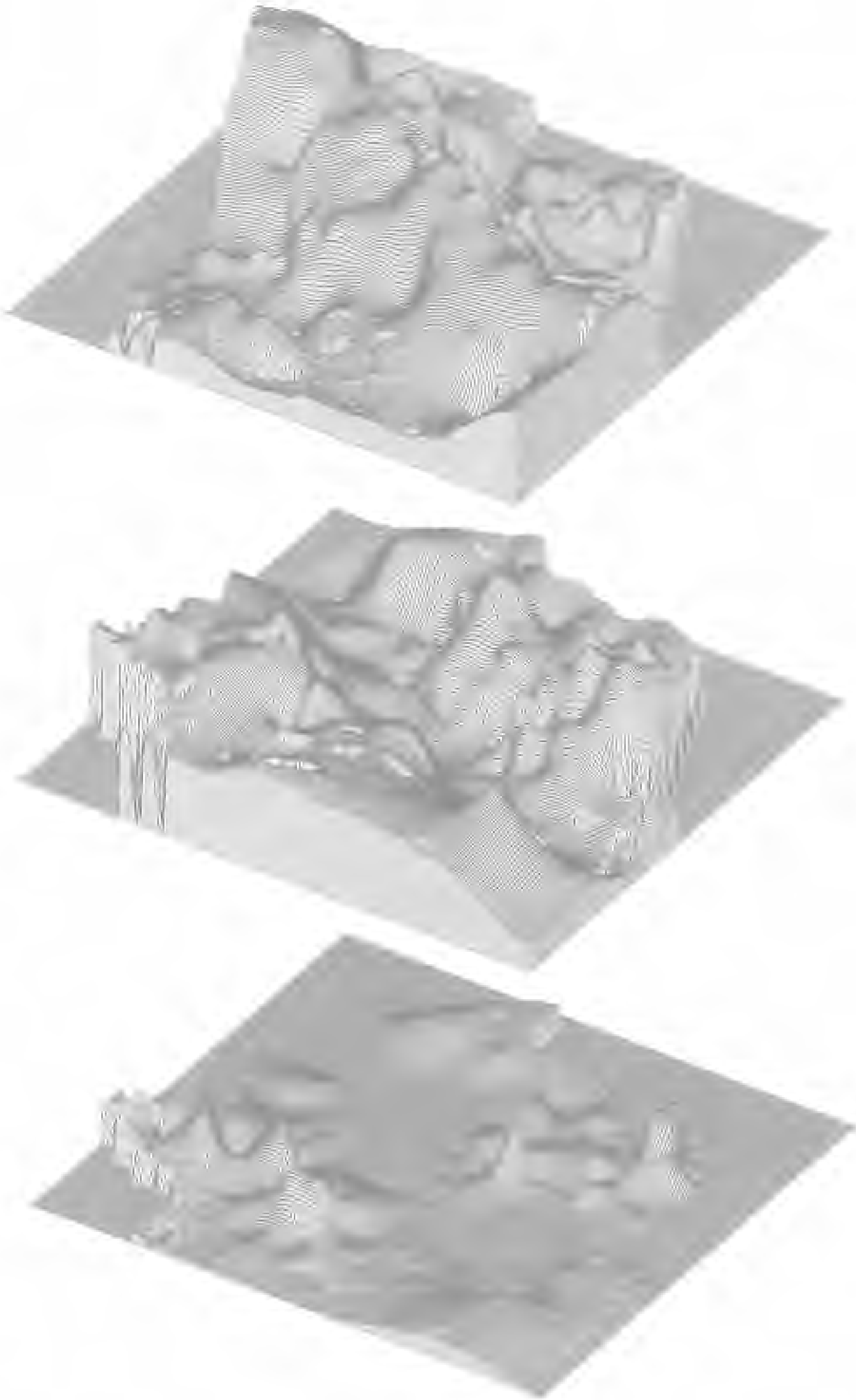
TABLE 1.2

SUMMARY OF CANADA'S COAL RESOURCES OF IMMEDIATE INTEREST, BY PROVINCE

Province	General Rank Class	measured	indicated (megatonnes)	inferred
British Columbia	lvb-an	100	500	1010
	m-lvb	1015	2285	5970
	h-mvb	1435	1445	4310
	sub-hvb	45	160	440
	lig-sub	450	320	320
Alberta	lvb-an	240	120	455
	m-lvb	1000	560	1955
	h-mvb	500	265	945
	sub-hvb	2185	1345	3890
	lig-sub	11860	4960	16655
Saskatchewan	lig-sub	1445	2690	3460
Ontario	lig-sub	170	10	-
New Brunswick	h-mvb	45	10	20
Nova Scotia	h-mvb	300	355	750
Yukon Territory and District of Mackenzie	lvb-an	-	-	90
	h-mvb	-	-	150
	sub-hvb	-	-	350
	lig-sub	-	-	2290
TOTALS	lvb-an	340	620	1555
	m-lvb	2015	2845	7925
	h-mvb	2280	2075	6175
	sub-hvb	2230	1505	4680
	lig-sub	13925	7980	22725

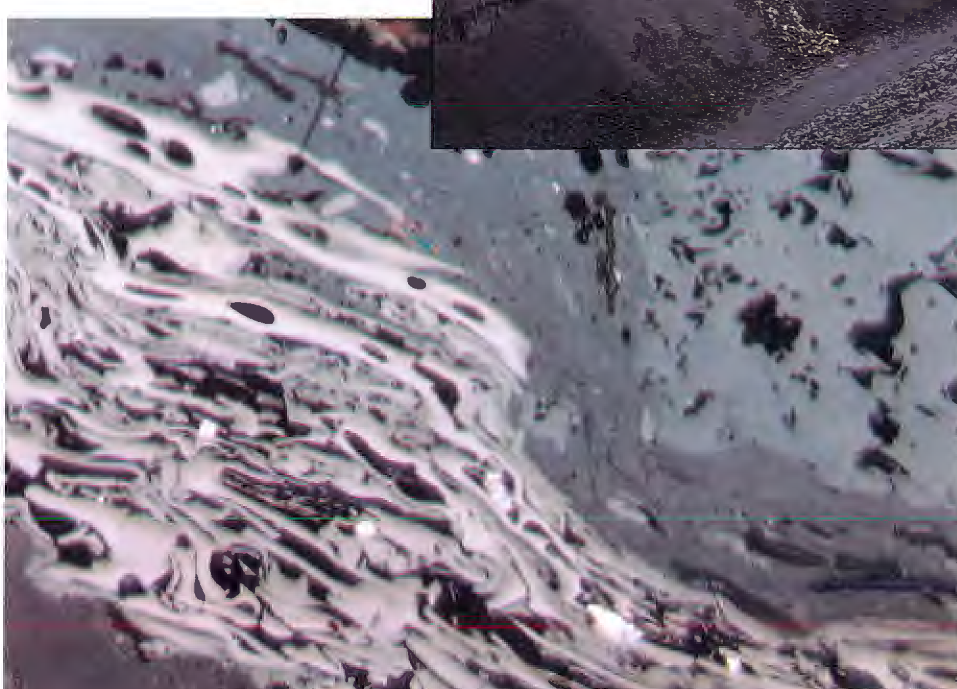
These coal resource estimates may differ from those of the respective Provincial Governments because of different resource estimating criteria and parameters used.

summary by province and territory, of the coal resources of immediate interest is provided in Table 1.2. Variations between these estimates and those produced by provincial government agencies reflect differences in criteria used for estimating coal resources and/or categories in which these estimates are reported.



MEGASCOPIC
(near Drumheller, Alberta)

MESOSCOPIC (Paintearth Mine, Alberta; courtesy J.D. Hughes)



MICROSCOPIC (subbituminous coal of Alberta; courtesy W.D. Kalkreuth)

CHAPTER 2

INTRODUCTION

FEATURES

INTRODUCTION

Coal is the most abundant fossil fuel in Canada and in the rest of the world. It currently represents about 14 per cent of Canada's primary energy economy. This is nearly the same as the combined contribution of hydro- and nuclear-generated electricity. In 1986, the value of coal production in Canada surpassed that of all other mineral commodities with the exception of petroleum and natural gas.

Coal is not a singular homogeneous substance — it comprises variable amounts of different components, which can give it diverse properties. The character of coal is related mainly to original types of peat-forming vegetal debris, environments of deposition, degree of organic maturation (rank), and mineralization.

The occurrence of potentially exploitable coal is related to a variety of geological factors. Although coal is abundant in Canada, deposits, which vary significantly in geological complexity, are widely distributed and contain coals of diverse rank, composition and properties. The Geological Survey of Canada is establishing a national inventory of coal resources in collaboration with coal companies, universities, and provincial and federal government agencies. This inventory provides the basis for the purposeful management of the nation's coal resources, and is essential for considering effectively Canada's future energy options.

This compendium is intended to reflect the Geological Survey of Canada's current knowledge of the nation's coal resources. It updates previous coal resource summaries published by the Government of Canada, with particular reference to **Coal Resources and Reserves of Canada** that was released in 1979 (Bielenstein et al., 1979). Unlike some previous publications, however, which summarized both national coal resource and reserve potential, this compendium focuses only on coal resources, with particular attention to the nation's presently undeveloped coal potential.

COAL GEOSCIENCE

Organic matter occurs in variable amounts in most sedimentary rocks. It originates as animal or vegetal debris, and is fossilized in appropriate geological and geochemical environments. Its presence is essential for the formation of coal and hydrocarbons (e.g. petroleum and natural gas). It undergoes progressive diagenesis under the influence of geothermal conditions that are mainly related to depth of burial. Hydrocarbons are generated during all phases of organic maturation.

Coal is a heterogeneous material that comprises an organic phase and mineral matter. The organic phase comprises a variety of altered plant tissues that originated from different types of vegetation and different parts of plants, such as cuticles, woody structure, spores, etc. Under appropriate conditions of preservation, plant debris can accumulate to form peat which, in turn, can undergo a progressive transformation commonly referred to as **coalification**. As organic matter is coalified, or is subjected to increasing heat and pressure, it is continually altered, both physically and chemically. This increasing maturation is characterized by a progressive loss of volatile matter and hydrogen, an increase in carbon content and latent heat value, and a decrease in porosity and inherent moisture content. Degree of organic maturation is commonly expressed as **coal rank**.

The inorganic phase of coal, or **mineral matter**, (often referred to as **ash**), originates mainly from the introduction of clastic sediments into peat-forming swamps, commonly as a result of flooding and from volcanic ash falls. Additionally, minerals can be postdiagenetically introduced into the fractures and pores of coal. The composition and properties of mineral matter within a coal deposit and between different deposits can vary significantly. The character of mineral matter influences the potential utility of a coal.

The types of vegetation that have resulted in coal have varied with time. The dominant coal-forming plant species of the Cretaceous Period, for example, were different from those of the Carboniferous Period. The types and proliferation of dominant coal-forming flora during any specific period was influenced by climatic and depositional environments. Interpretation of depositional environments (Fig. 2.1) and geological histories of possible coal-bearing stratigraphic sequences provides the basis for predicting coal resource potential.

Tectonism (crustal movements) controls both the development of sedimentary basins that might contain coal, and structural deformation of coal-bearing stratigraphic sequences. Coal deposits are often structurally deformed, particulary where situated in or near orogenic belts (mountainous regions). This deformation can significantly affect the present distribution and character of coals. Tectonism often causes movement within the extremely incompetent (weak) coal beds of a stratigraphic sequence, which can result in sheared surfaces and complex patterns of thickening and thinning of these beds. Tectonism also affects coal rank distribution patterns. An intimate knowledge of geological structures, both regionally and within deposits, is needed to evaluate coal potential in orogenic belts.

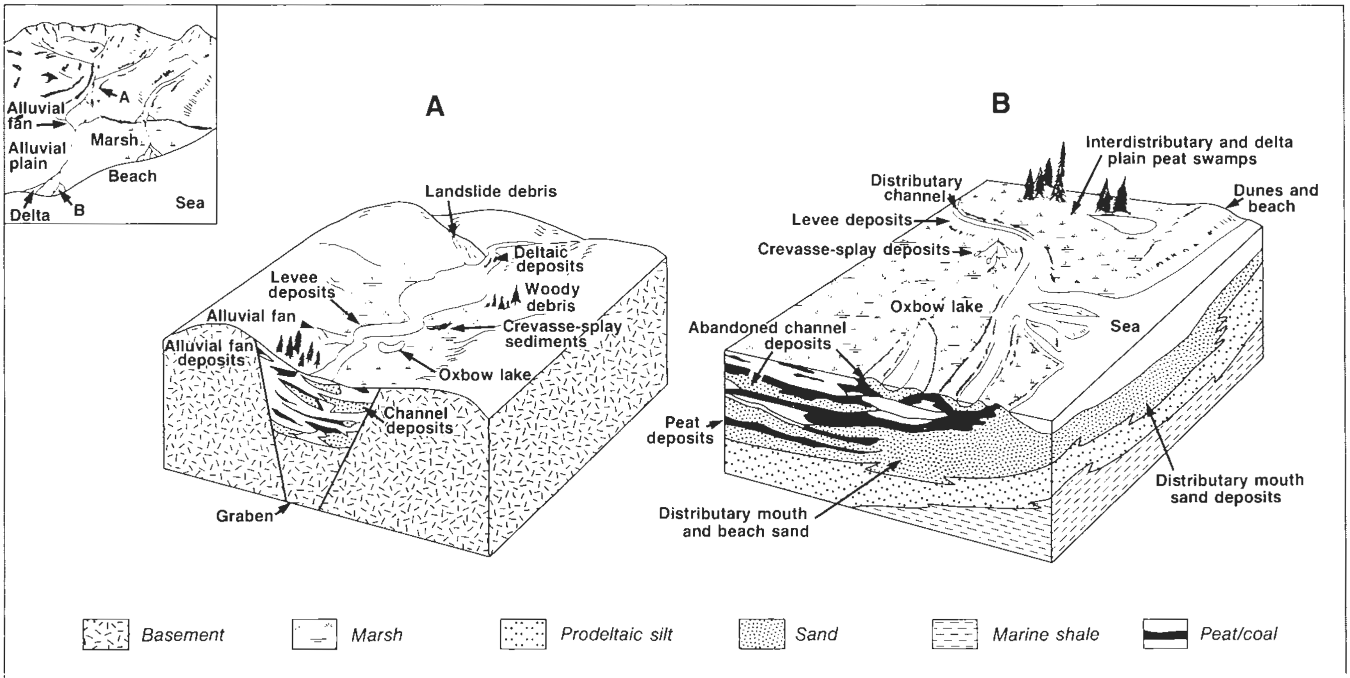


Figure 2.1. Depositional environments that are commonly associated with peat-forming swamps and marshes.

Information from surface exposures and subsurface exploration can be used to interpret depositional and tectonic paleoenvironments that controlled the distribution, composition and rank of coals. Stratigraphic and sedimentological studies provide the basis for interpreting paleogeographical conditions that controlled the original areal extent, thickness variation, lateral continuity and geometry of individual seams, and the nature of the associated rock masses. Studies in structural geology provide the basis for interpreting present distribution, structural geometry, and physical characteristics of coals and associated strata in deformed sedimentary basins.

The optical properties and morphology of coal constituents and dispersed organic matter in sedimentary rocks can reliably indicate both biological origin, from which syndepositional environments can be deduced, and thermal maturity of the material. The combination of microscopic (petrographic) and geochemical analyses of organic matter can provide critical information for deducing coal and hydrocarbon potentials within sedimentary basins, both in quantitative and qualitative terms.

Following the discovery of a potentially viable coal deposit, the evaluation of exploitation potential is based on several assumptions, many of which are geologically sensitive. The reliability of the geological model (i.e. interpreted spatial distributions of geological variables), upon which a feasibility study is based, is a function of both information input with respect to the complexity of the geological environment, and the integrity of interpretation.

COAL UTILIZATION

Although coals can be used to produce many useful derivatives (Fig. 2.2), most are consumed either by combustion to raise steam for electric power generation, or by carbonization to produce metallurgical coke. Lesser amounts are used in the production of cement and char, and for domestic and industrial space heating. Existing technologies are being upgraded for more efficient conversion of coals into synthetic liquid and gaseous fuels.

Modern markets demand coals that meet rigorous specifications. Although coals for electric power generation can often be used as-mined in mine-mouth generating stations, those required for other uses commonly need some form of processing to meet market specifications. This processing, referred to as **coal preparation**, is usually directed toward reducing impurities comprising mineral matter, sulphur, and moisture. It can also be required for producing a specified product size-grade.

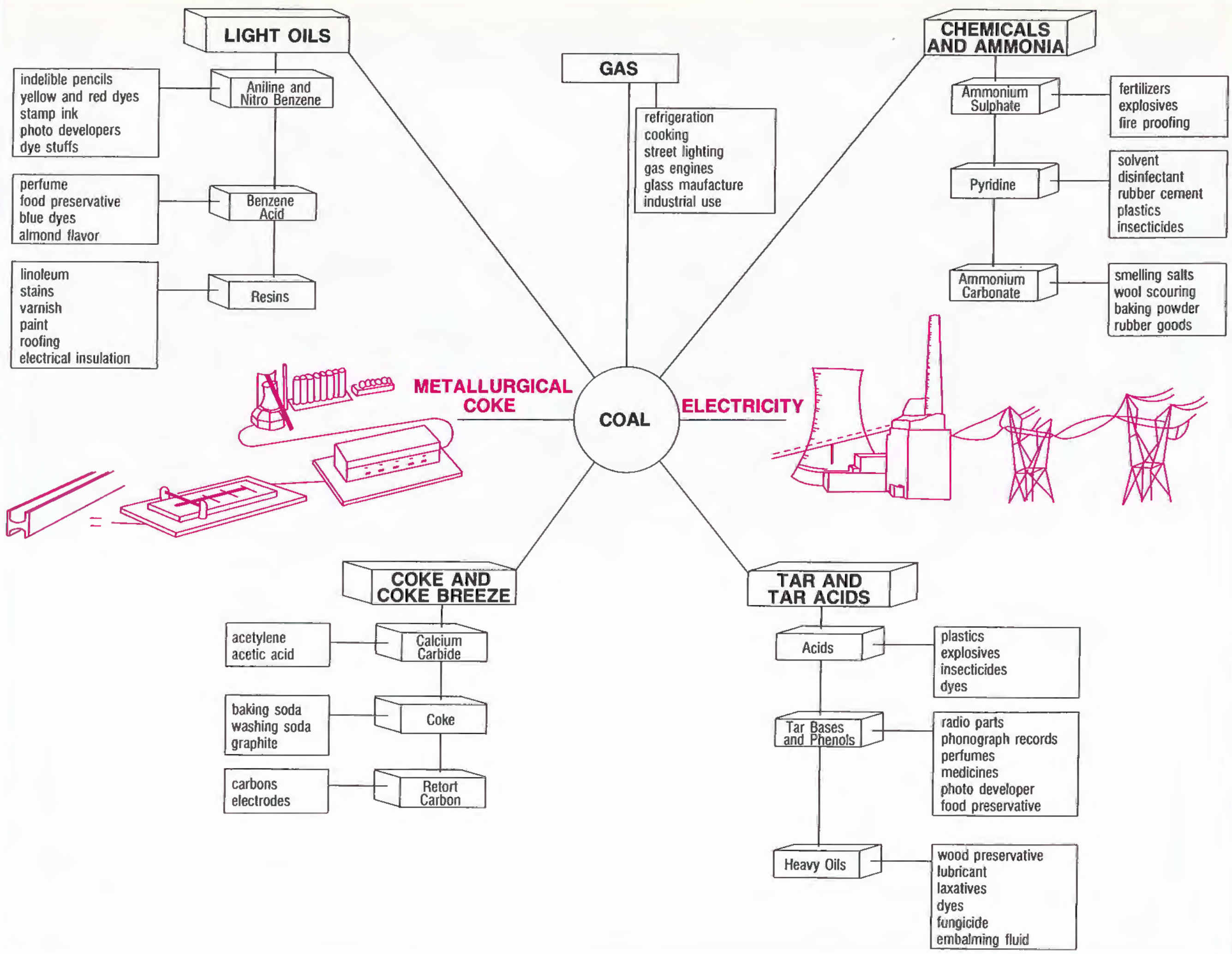


Figure 2.2. Coal-derived products.

The relative merits of a coal with respect to a particular use are determined from analyses and tests that define or allow prediction of one or more of the following characteristics:

- Rank and intrinsic properties.
- Diluents or impurities.
- Size grade.
- Rheological properties and other behavioral characteristics.
- Utilization impact on the environment, or on materials ultimately produced from the coal.

Coal for the production of metallurgical coke must yield a coherent coke, alone or in blends with other coals. It must be possible to carbonize the coals, or blends, without damaging the ovens or causing difficult operating problems. The coals must be low in ash, sulphur, and any other impurities that might have a deleterious effect on materials that are ultimately produced.

Coal for producing steam in the generation of electricity must have sufficient heat value to develop steam at a desired rate for which a boiler is designed. Ash behavior (fusion characteristics) with respect to clinkering must be satisfactory for the type of firing equipment and furnace design used. The grindability of the coal must be suitable for the available pulverizing capacity, where applicable.

In addition to having certain fundamental properties for particular applications, coals must meet rigorous specifications to insure optimum performance of a user's facilities.

Liquid fuels have been produced from coal for more than a century, and were used by the German air force during

World War II. In 1955, the Sasol plant in South Africa began operations and has subsequently undergone expansion in the production of liquids, chemicals, waxes and fuel gas from coal.

Gaseous fuels have been produced from coal for residential, commercial and industrial users for more than 100 years, although interest in this use declined following large discoveries of natural gas after World War II. Experiments are progressing to establish a viable means of recovering combustible gases from in situ coals. These experiments could make coals that are too deep for economical extraction, available for commerical use.

COAL RESOURCE TERMINOLOGY

Coal beds are relatively common in Canada's sedimentary basins. To qualify as a resource, however, the coals must have potential for endowing wealth to the nation. Meaningful estimates of Canada's coal resources must, therefore, be constrained within limits that reflect the coals' potential utility. Coals that occur in beds less than 45 cm thick, and in beds that occur at depths below about 600 m, are presently excluded from Canada's coal resources (with the exception of coals in Nova Scotia, where mining to a depth of 1200 m is currently planned). The transformation of the nation's coals to resources and reserves is, however, a dynamic process (Fig. 2.3) that proceeds on the basis of changing supply and demand circumstances.

A glossary of commonly applied coal-related terms is included at the end of the report. Some of these terms should be reviewed at the outset in order to appreciate fully their intended usage in following discussions.

In this report the term **coal resource** refers to coal deposits that occur within specified limits of thickness and depth from surface. These thickness and depth limits are intended to reflect limits of economic and/or technological feasibility for exploiting Canadian coals. Coal resource quantities are estimated and categorized with respect to relative **exploitation potential** and **assurance of existence** (Fig. 2.3), according to specified parameters. Resource estimates in this report generally reflect standards reported by Bielenstein et al. (1979). The Geological Survey of Canada, in collaboration with The Coal Association of Canada, has recently revised these standards as the basis for estimating and reporting Canada's coal resources and reserves in future (Hughes et al., in press).

Relative exploitation potential is expressed according to the notion of immediate interest and future interest, whereby coal **resources of immediate** interest for continuing exploration and possible development, have favourable combinations of thickness, depth, quality and location. Coal deposits having less favourable combinations of thickness, depth, quality and location contribute to **resources of future interest**, if they might reasonably be considered for possible exploitation in future, given moderate improvements to economic and/or technological conditions. Coal deposits that have no imaginable potential utility are excluded from the resource inventory, and contribute only to the nation's overall coal endowment.

Assessments of the relative assurance of existence of estimated resource quantities are made on the basis of spatial distribution of available data. It is assumed that resource definition near observation points, or control data, is more reliable than that which is more remote. Resource quantities are classified as **measured, indicated, inferred**, and **speculative** (Fig. 2.3) based on a notion of the confidence of the estimates according to criteria of distance from control data. The term **speculative resource** is applied to resource quantities that have been estimated on the basis of very limited or remote evidence to which reasonable, broad geological assumptions have been applied. Speculative resources are always classified as resources of future interest.

The term **coal reserve** refers to that portion of the resource which is anticipated to be mineable under technological and economic conditions prescribed by a feasibility study, and which has no legal impediment to mining. Coal reserves form a portion of measured and/or indicated coal resources of immediate interest (see Hughes et al., in press).

A common method of aggregating or comparing quantities of different coal-types involves converting tonnages to **tonnes coal equivalent**, which refers unit heat values of different coals to a standard 29.3 MJ/kg. Canada's inventory of coal resources of immediate interest comprises 14 000 measured megatonnes, 11 000 indicated megatonnes, and 32 000 inferred megatonnes, on a tonnes coal equivalent basis. Large quantities of deep coal (i.e. 300-500 m from surface), inferred from petroleum well information in the Interior Plains, along with potentially vast quantities of coal in northern Canada, and coals contained in thin beds throughout the country are considered resources of future interest. These coal resources of future interest comprise about 1000 measured megatonnes, 24 000 indicated megatonnes, 60 000 inferred megatonnes and 94 000 speculative megatonnes, on a tonnes coal equivalent basis. These resources represent only a small portion of Canada's overall coal endowment, which includes additional vast quantities of coals in beds that are deeper and thinner than are currently being considered in resource estimates.

On a tonnes coal equivalent basis, about 60 per cent of Canada's measured coal resources of immediate interest are located in the Interior Plains of western Canada, and nearly 35 per cent are located in the Rocky Mountain Front Ranges and Foothills.

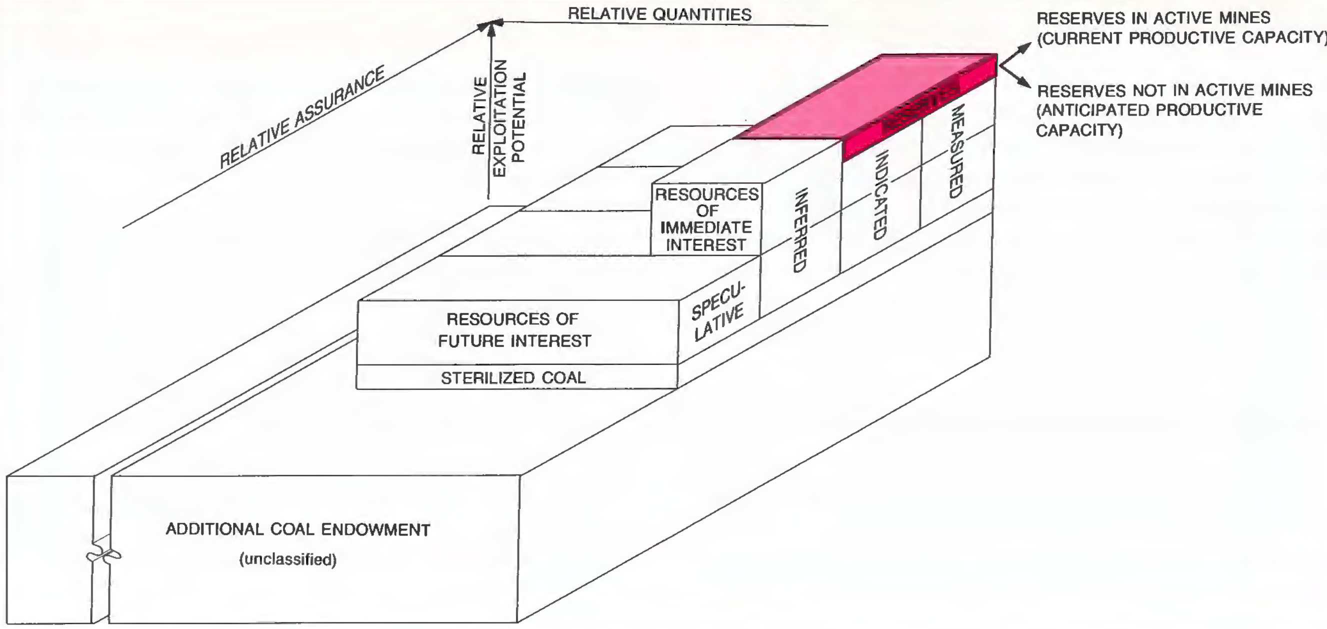


Figure 2.3. Classes of coal resources and reserves and their relationship to total coal endowment.

Canadian coals have diverse characteristics. It is inadequate, when evaluating a coal resource, simply to express quantitative potential without reference to the coal's intrinsic attributes that affect its value. The classification of coals by rank is a conventional means of inferring some of their relative fundamental qualities.

Different coal ranks have different intrinsic properties, which affect coal value in a commercial sense, relative to utilization potential. Most Canadian coals are used either as thermal coals for electric power generation, or as metallurgical coals for the production of coke.

Coals are classified (Fig. 2.4) according to degree of organic maturation in the continuous series that ranges from lignitic and subbituminous ranks through the high volatile, medium volatile and low volatile bituminous coal ranks, to anthracite and meta-anthracite.

Lignitic and subbituminous B/C coals (presented in this report as general rank class **lig-sub**) have been used mainly to fuel mine-mouth electric power generating stations, although some are also shipped trans-provincially for use mainly in electric power generation. Subbituminous A and high volatile B/C bituminous coals (presented in this report as general rank class **sub-hvb**) have been shipped to electric power generating plants throughout Canada and around the world. High volatile A bituminous, medium volatile bituminous, and many low volatile bituminous coals (presented in this report as general rank classes **h-mvb** and **m-lvb**, respectively) have been extensively used in steel mills in Canada and elsewhere for the production of metallurgical coke. Canada's higher rank low volatile bituminous coals and anthracitic coals (presented in this report as general rank class **lvb-an**) are not presently being exploited, although they might be good thermal coals for some combustion applications. The composition and properties of many Canadian coals appear to make them very suitable feedstocks for emerging processes to convert coals to liquid and gaseous substitutes for petroleum and natural gas derivatives.

Units of measurement in this report are the International System of Units (SI) as approved for official use by the Canadian Standards Association and Metric Commission, Canada (see inside back cover for conversion factors).

GEOLOGICAL SURVEY OF CANADA'S COAL PROGRAM

The mission of the Geological Survey of Canada is to ensure the availability of comprehensive geological, geophysical and geochemical knowledge, technology and expertise concerning the Canadian landmass, as required for effective exploitation of mineral and energy resources, estimation of the resource base of Canada, public safety and security, and formulation of policies.

VM%*	FC%*	CLASS	GROUP	GENERAL CLASSES USED IN THIS REPORT	CALORIFIC VALUE** BTU/lb.	CALORIFIC VALUE** MJ/kg	PRINCIPAL USES
2	98	ANTHRACITIC (1)	META-ANTHRACITE	lvb-an			Space heating Chemical production
8	92		ANTHRACITE				
14	86		SEMIANTHRACITE				
22	78	BITUMINOUS (2)	LOW VOLATILE BITUMINOUS	m-lvb			Metallurgical coke production Cement production Thermal electric power generation
31	69		MEDIUM VOLATILE BITUMINOUS				
			HIGH VOLATILE A BITUMINOUS	h-mvb	14 000	32.6	
			HIGH VOLATILE B BITUMINOUS		13 000	30.2	
			HIGH VOLATILE C BITUMINOUS	sub-hvb	11 500	26.7	
		SUBBITUMINOUS (4)	SUBBITUMINOUS A (3)		10 500	24.4	Thermal electric power generation Conversion to liquid and gaseous petroleum substitutes
			SUBBITUMINOUS B	lig-sub	9500	22.1	
			SUBBITUMINOUS C		8300	19.3	
		LIGNITIC (4)	LIGNITE A		6300	14.7	Thermal electric power generation Char production Space heating
			LIGNITE B				

* *Dry, mineral-matter-free basis*
** *Moist mineral-matter-free basis*
VM: *Volatile matter*
FC: *Fixed carbon*

(1) *Non-agglomerating; if agglomerating classified as low volatile bituminous*
(2) *Commonly agglomerating*
(3) *If agglomerating classified as high volatile C bituminous*
(4) *Non-agglomerating*

Figure 2.4. Classification of coals by rank (after A.S.T.M., 1977).

William Logan, the Geological Survey of Canada's first director pursued the Survey's mission with the following understanding (Zaslow, 1975):

> "Unless it can in some way be indicated that value will be returned to the country for the expenditures, it is vain to expect that the legislature will support the Survey for the sake of science".

Background. The Geological Survey of Canada (GSC) has conducted coal geoscience studies, to varying degrees, since its inception in 1842. Much of its early work focused on coal, an essential ingredient for industrial growth during the second half of the 19th century and early 20th century. Other studies by the GSC during this period, in areas of central Canada having unfavourable geological conditions for the occurrence of coal deposits, helped to discourage the futile expenditure of large sums of money in the search for coal, at a time when coal exploration, or prospecting, was being pursued with somewhat reckless abandon. Early coal studies were not only instrumental in establishing the Geological Survey of Canada as a national institution, but also helped to promote, throughout the world, the socioeconomic usefulness of the relatively new science of geology. The works of G.M. Dawson, D.B. Dowling and J.B. Tyrrell, among several others, are intimately tied to GSC's coal tradition. Results from GSC's coal studies profoundly affected the planning of transcontinental railways and ancillary developments that were essential to Confederation. They have assisted the establishment of effective coal exploration strategies, and have stimulated new mine developments in support of the nation's industrial growth.

D.B. Dowling (1913) published Canada's first national inventory of coal resources and 34 years later B.R. MacKay published a relatively comprehensive inventory of Canada's coal reserves, in support of a Royal Commission on Coal (MacKay, 1947). In the 1950's, P.A. Hacquebard began important studies of geological factors that influence the formation and preservation of coal precursors and subsequent character of coals. During the same period, D.K. Norris began studies of the structural geology of coal measures, having significant implications toward the safe and economical extraction of coal. During the past 15 years, the Geological Survey of Canada has developed more sophisticated capabilities of assessing coal potential in less explored sedimentary basins, and has accelerated studies of geological factors that influence coal characteristics. Results from these studies are relevant to efficient coal exploration, evaluation, development and utilization.

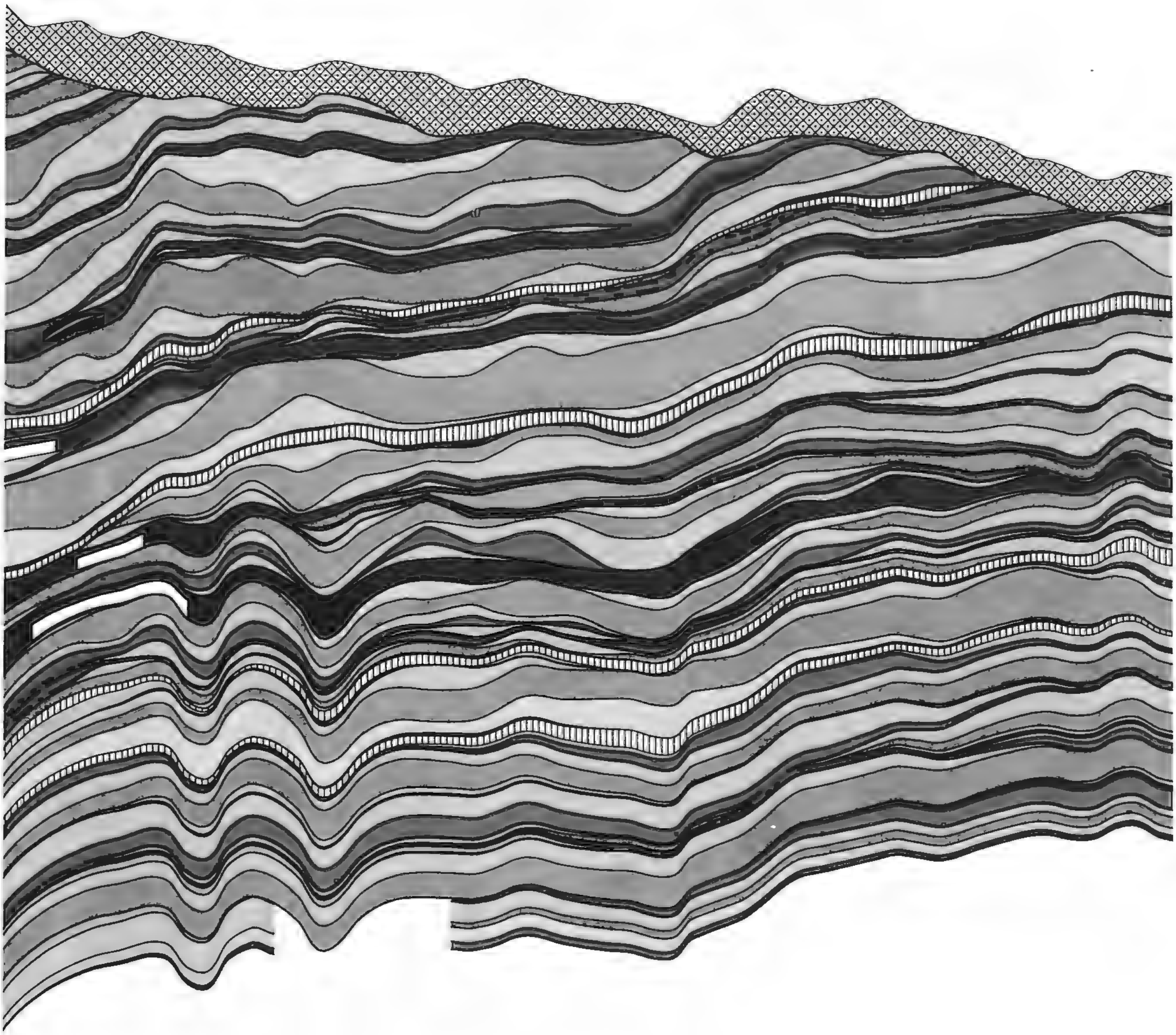
The geographic distribution of Canada's coal deposits has, to a large extent, been identified; the geological framework of many deposits has been established; and the composition and properties of many coals have been determined. In addition to the two previously published major national coal resource assessments (Dowling, 1913; MacKay, 1947), several interim updates and more generalized national and regional summaries have been prepared (e.g. Latour and Chrismas, 1970; Canada Department of Energy, Mines and Resources, 1977; Bielenstein et al., 1979). Results from numerous regional and local studies of the geology and coal potential of commercially significant coal measures have been published (e.g. Irvine et al., 1978). Results from many stratigraphic, sedimentological and structural studies of important coal-bearing formations are cited in following chapters. These results have provided a basis for considering regional coal potential, a prerequisite to the strategic planning of efficient coal exploration activities by coal companies. The Geological Survey of Canada has been involved in the development of important technologies for effectively modelling and evaluating coal resources, and for assessing the composition and properties of coals.

Current activities. The role of the Coal Geology Subdivision of GSC's Institute of Sedimentary and Petroleum Geology is to provide comprehensive geological knowledge, technology and expertise pertaining to Canada's coal deposits. The Subdivision's scientists determine their geological distribution, origin and potential abundance to facilitate exploration, land-use planning and policy formation. They also provide understanding of the characteristics of coals for the commercial use in a national and international context.

Specialized studies are being conducted to establish the geological framework of important coal measures in terms of stratigraphy, sedimentology and structure; to determine composition and properties of coals, in addition to regional rank distributions and coalification patterns; and to evaluate Canada's coal potential in quantitative terms, according to a variety of criteria, such as coal bed thickness, depth from surface, geological complexity, location, and other factors that have socioeconomic implications.

A capability is being developed and maintained for providing authoritative advice to senior governments officials, and to scientists and engineers in government and industry, on the resource potential of Canada's coal deposits.

Objectives. GSC's coal program is directed mainly toward defining the nation's diverse inventory of coal resources. This inventory provides the basis of choice for responding effectively to future coal development opportunities. The program focuses mainly on Canada's undeveloped coal potential, whereby results might assist possible future exploration and development. The program is being conducted on the premise that the expanded use of Canadian coals, both nationally and internationally, can only be considered fully in the light of available coal resource possibilities. Additionally, the degree to which Canada might supply feedstocks for nonconventional coal uses can only be considered effectively with knowledge of the nation's coal resource base.



PAST

PRESENT (coal loadout, Natal Ridge, B.C.)

FUTURE (GSC's coal characterization by image analysis)

CHAPTER 3

COAL IN CANADA

FEATURES

COAL IN CANADA

INTRODUCTION

Canada's abundant coal resources are widely distributed and diverse in character. Although commercial production of these coals dates back to the 17th century, most coal deposits are undeveloped. Future exploitation of the nation's undeveloped coal potential can be considered effectively only in the light of available coal resource possibilities. Geological and geographical diversity of Canada's coal resources directly influences coal mining, processing, transportation and utilization possibilities. An understanding of the nation's coal resource inventory, in view of this diversity, is essential for comparing and evaluating new development options.

DISTRIBUTION AND GENERAL CHARACTERISTICS OF CANADIAN COALS

Coal-bearing strata are found in many areas of Canada, from coastal British Columbia to the Atlantic Provinces, and in northern Canada (Fig. 1.1). These strata range in age from Devonian to Tertiary, and the coals range in rank from lignitic to anthracitic.

Major coal deposits in Canada occur in the following distinct geological, geographical and physiographical regions (Fig. 3.1):

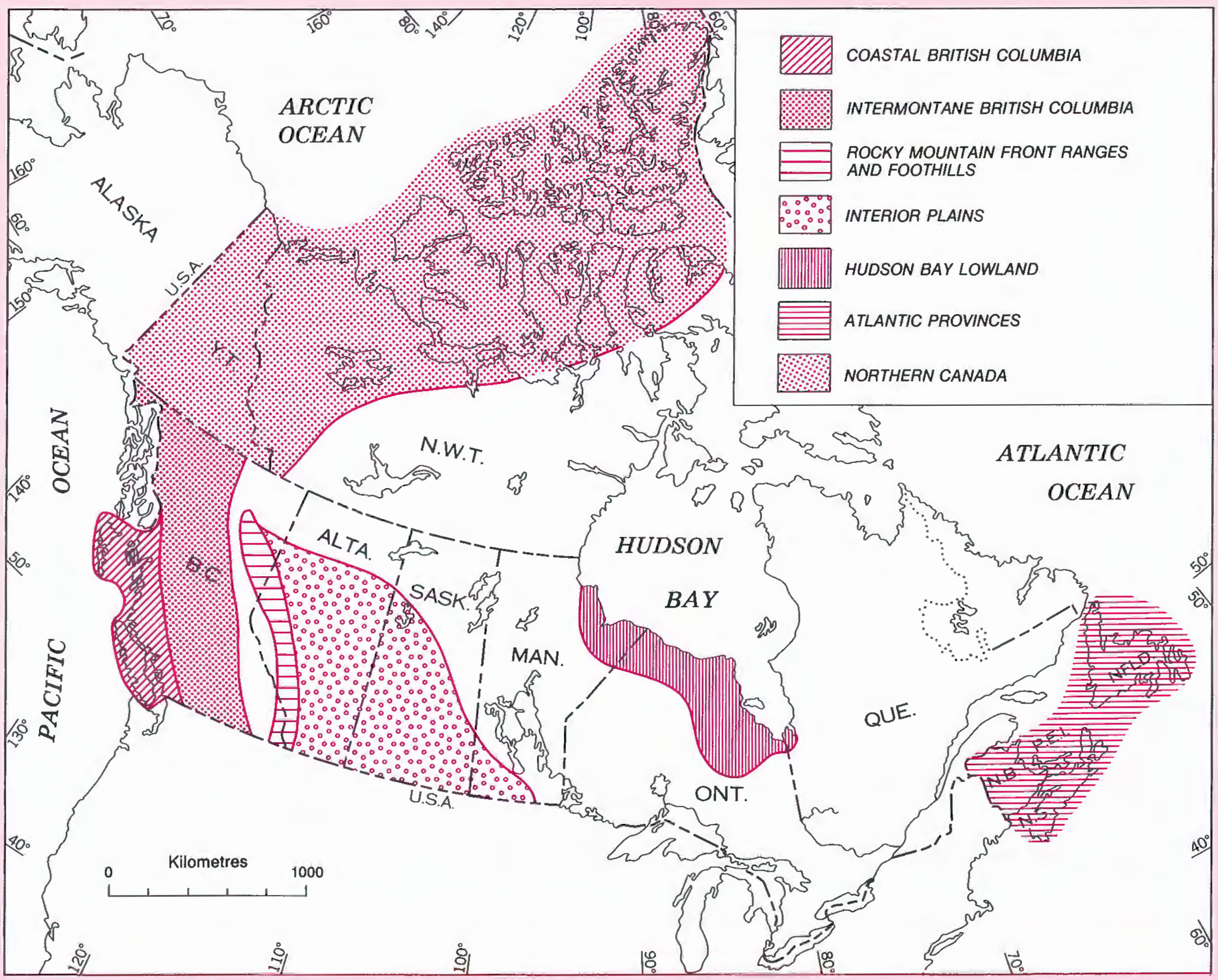


Figure 3.1. Coal regions of Canada.

- Coastal British Columbia.
- Intermontane British Columbia.
- Rocky Mountain Front Ranges and Foothills of British Columbia and Alberta.
- Interior Plains of British Columbia, Alberta, Saskatchewan and Manitoba.
- Hudson Bay Lowland of Ontario.
- Atlantic Provinces: New Brunswick, Nova Scotia and Newfoundland.
- Northern Canada: Yukon Territory and District of Mackenzie; Arctic Archipelago.

Coal deposits within each region commonly have some geological and geographical similarities. The following chapters summarize coal resource information by region and highlight some of the distinct characteristics of the coal deposits. The largest commercially significant deposits occur within the physiographic regions of the Appalachians in eastern Canada, and in the eastern Cordillera and Interior Plains of western Canada.

The major coal deposits in eastern Canada are of Late Carboniferous age (Fig. 3.2), like those of western Europe and

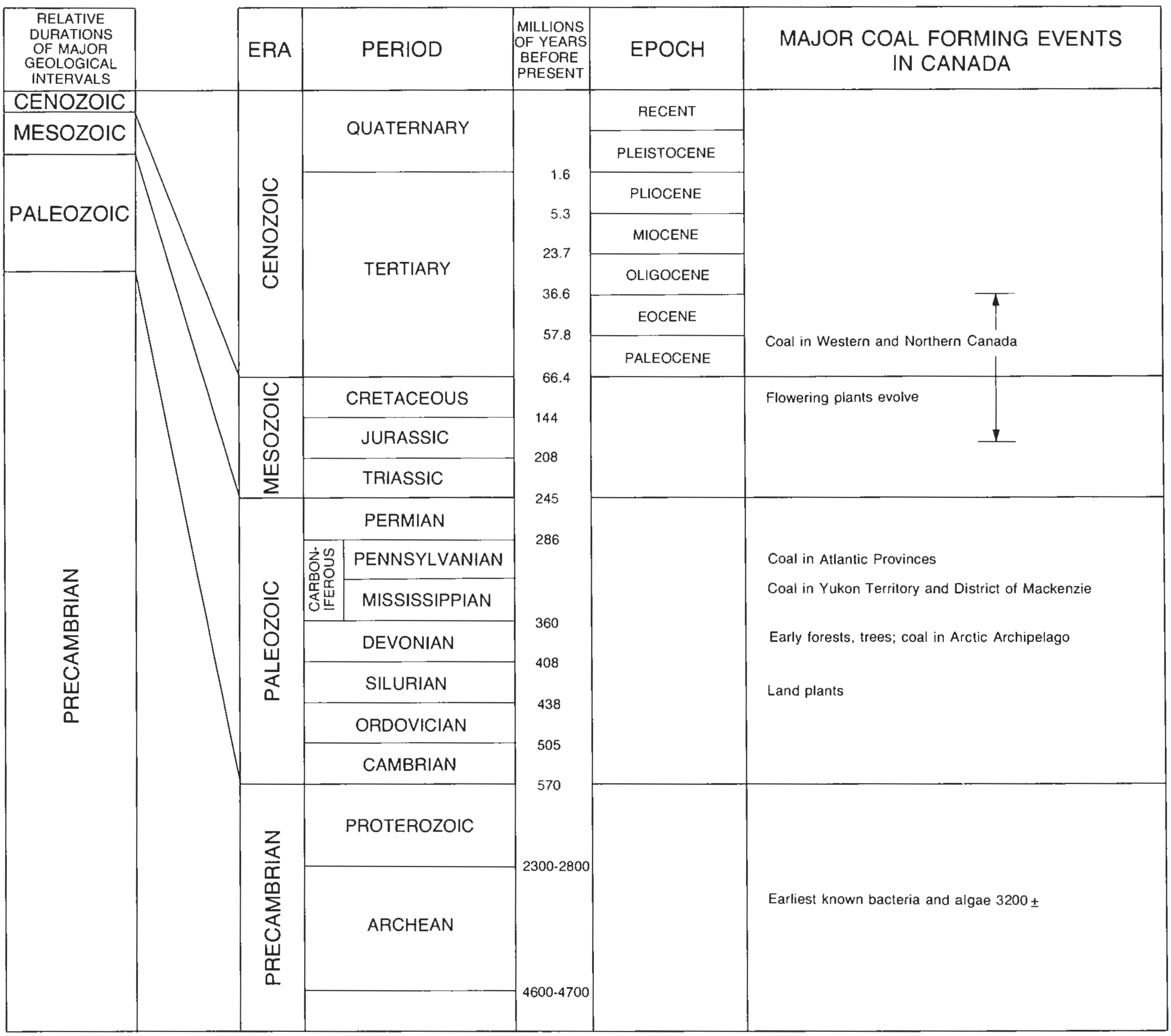


Figure 3.2. Geological time scale (after Geological Society of America, 1983).

in the Appalachian region of the United States. In western Canada, the major coal deposits are younger, ranging in age from Late Jurassic to Tertiary, and characteristically different from those in the east.

Coal deposits originated as peat-forming materials that accumulated at or near their place of growth, within swamps and marshes occurring in deltaic, alluvial and lacustrine environments. Canada's major coal-bearing sedimentary basins are shown in Figure 3.3.

The oldest significant coal beds in Canada occur in the Middle-Upper Devonian clastic wedge, that extends from Ellesmere Island to Banks Island in the Arctic Archipelago. Coal beds in slightly younger Mississippian strata occur in the Yukon Territory and District of Mackenzie. A major seam of anthracite (about 5.5 m thick), containing low ash and low sulphur was recently discovered in the Mississippian Kayak Formation, in northern Yukon (Cameron et al., 1986). High volatile bituminous coal deposits that occur in the Mississippian Mattson Formation, in the Liard-South Nahanni region, in southern District of Mackenzie, have been explored but not yet developed.

The Pennsylvanian coal measures of eastern Canada form part of the Appalachian mountain system that is situated on the eastern side of the North American continent. Carboniferous sedimentation was largely controlled by tectonism that constituted the final phase of deformation of the Appalachian Geosyncline. Mountain building resulted in the formation of a series of connected troughs and intermontane basins that are collectively referred to as the Maritimes Basin (Hacquebard, 1972). The major coal measures of the Atlantic Provinces were deposited within or near the margins of this basin (Fig. 3.3).

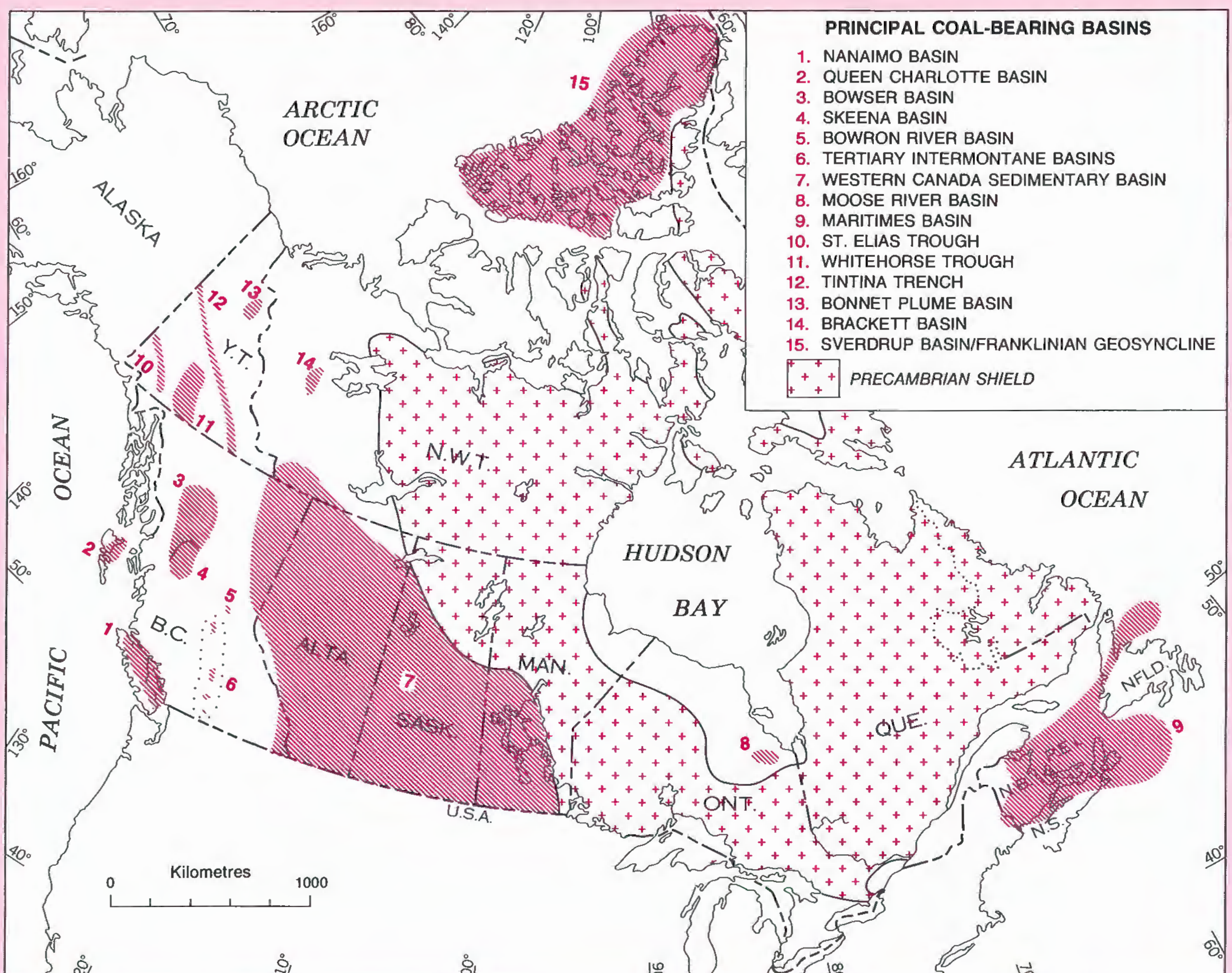


Figure 3.3. Major coal-bearing sedimentary basins in Canada.

During the Jurassic and Cretaceous periods, most of what is now the Cordillera of western North America was a landmass flanked to the east and west by seas (Fig. 3.4; and Williams and Stelck, 1975). The Pacific Ocean extended eastward over a large portion of the region that is presently the interior of northern British Columbia. During Late Jurassic and Early Cretaceous time the southward incursion of boreal seas (Fernie and Clearwater-Moosebar) covered the present-day eastern Yukon and western Northwest Territories (District of Mackenzie), along with much of eastern British Columbia, Alberta and northern Saskatchewan (Fig. 3.4a, 3.4b). During the Late Cretaceous Epoch, seas (Pakowki and Bearpaw) extended north from the Gulf of Mexico to the Arctic, transgressing, at various times, much of Alberta, Saskatchewan and Manitoba (Fig. 3.4c, 3.4d). Many of the commercially significant coal deposits of western Canada originated near the margins of these seas while mountain building in the Cordillera was taking place.

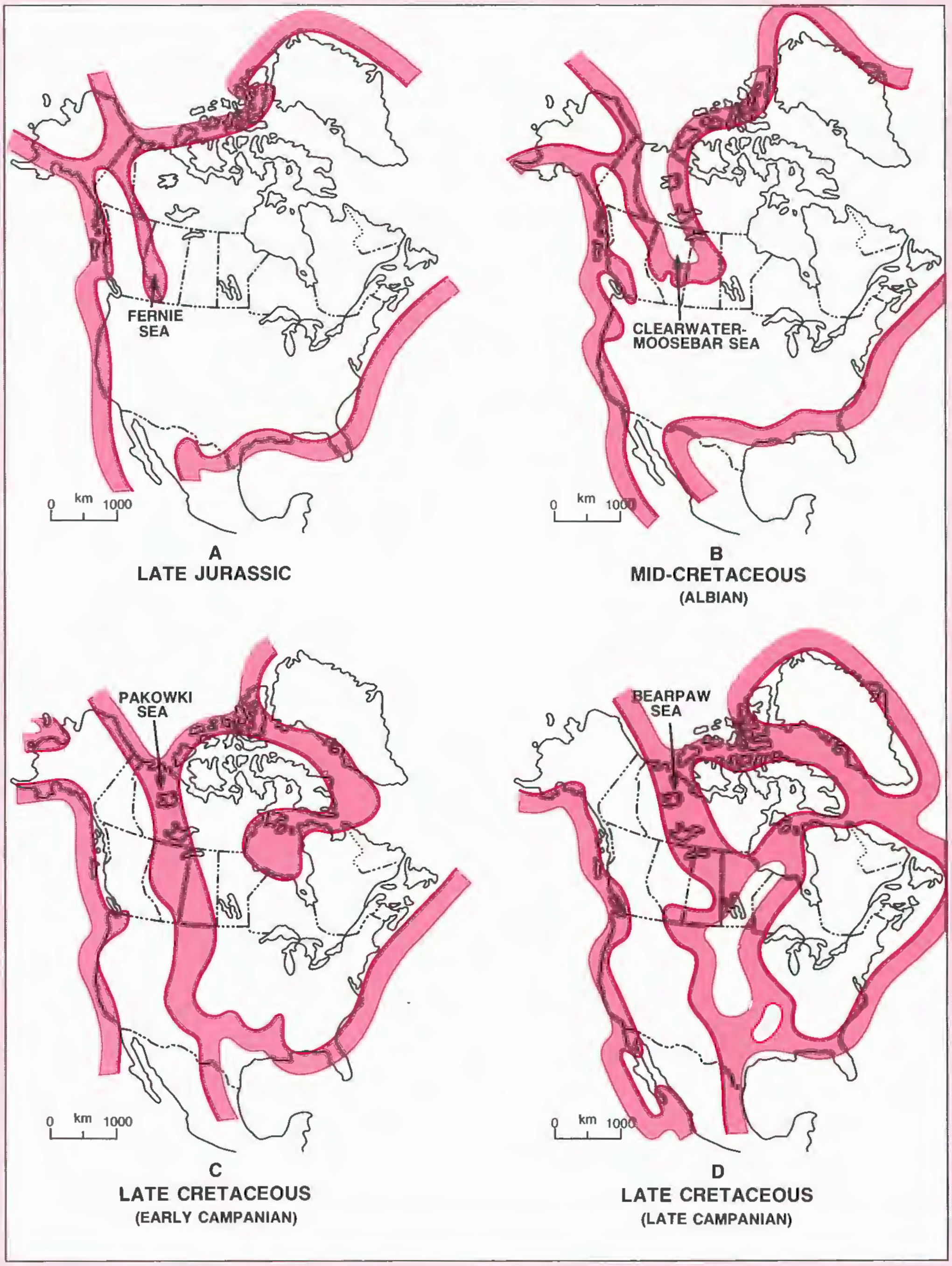


Figure 3.4. Extent of some Late Jurassic and Cretaceous seas in North America (modified from Williams and Stelck, 1975; Koke and Stelck, 1984).

In Late Cretaceous and Tertiary time, tectonic episodes resulted in the development of fault controlled intermontane basins in the interior of British Columbia and Yukon Territory, which often sustained environments that were suitable for the accumulation of peat. Extensive Late Cretaceous and Tertiary coal deposits in the Interior Plains of western Canada, and in mainland northern Canada (Yukon Territory and District of Mackenzie) developed during the final regressions of the epicontinental sea.

The major coal-bearing stratigraphic units in Canada are shown according to region and age in Figure 3.5.

Most Canadian coals are consumed either by carbonization to produce metallurgical coke, or by combustion to raise steam for electric power generation. Coals that are suitable for the production of metallurgical coke are referred to as **metallurgical coals**. Coals that are used to fuel electric power generating plants are referred to as **thermal coals**.

Most of Canada's metallurgical coal resources are located in the Rocky Mountain Front Ranges of southeastern British Columbia and southwestern Alberta, and in the Inner Foothills Belt of northeastern British Columbia and west-central Alberta.

Most of Canada's thermal coal resources are located in the Interior Plains of Alberta and Saskatchewan, and in the Outer Foothills Belt of Alberta. Other major thermal coal deposits occur in the coastal and intermontane regions of British Columbia, and in northern Canada.

Most coal resources of the Atlantic Provinces range in rank between high volatile C bituminous and high volatile A bituminous. Many of these coals are suitable as both thermal and metallurgical coals.

In addition to its extensive resources of conventional thermal and metallurgical coals, Canada has large quantities of coals, such as anthracite, that do not meet the major current conventional thermal and metallurgical market requirements (i.e. for electric power generation and metallurgical coke-making). Availability of these nonconventional coals could ultimately be a critical factor in influencing the degree to which Canada might take advantage of nonconventional coal utilization technologies that may be developed in future. Many Canadian coals show good liquefaction and gasification potential, and some may be ideally suited for in situ gasification. Advancing technologies in coal uses pertaining to combustion, carbonization, conversion to synthetic fuels, and petrochemical feedstocks, could result in increasing demands for the current nonconventional coals.

	COASTAL BRITISH COLUMBIA		INTERMONTANE BRITISH COLUMBIA		ROCKY MOUNTAINS AND FOOTHILLS			INTERIOR PLAINS	HUDSON BAY LOWLAND	ATLANTIC PROVINCES	NORTHERN CANADA	
	VANCOUVER ISLAND	QUEEN CHARLOTTE ISLANDS	NORTHERN	SOUTHERN	FRONT RANGES	INNER FOOTHILLS	OUTER FOOTHILLS				YUKON AND DISTRICT OF MACKENZIE	ARCTIC ARCHIPELAGO
TERTIARY		SKONUN FM.		FRASER RIVER FM. KAMLOOPS GP. PRINCETON GP.			PASKAPOO FM. COALSPUR FM.	PASKAPOO FM. RAVENSCRAG FM. SCOLLARD FM.			AMPHITHEATRE FM. REINDEER FM. SUMMIT CR. FM.	EUREKA SOUND GP.
UPPER CRETACEOUS	NANAIMO GP.		SUSTUT GP.				BELLY RIVER FM.	WAPITI GP. HORSESHOE CANYON FM. BELLY RIVER GP.			WAPITI GP. BONNET PLUME FM. LITTLE BEAR FM.	
LOWER CRETACEOUS		HAIDA FM.	SKEENA GP.			BOULDER CR. FM. GATES FM. GETHING FM.		SWAN RIVER FM. MANNVILLE GP.	MATTAGAMI FM.		LANGTON BAY FM.	HASSEL FM. ISACHSEN FM.
JURASSIC		YAKOUN FM.	CURRIER FM. LABERGE GP.		MIST MOUNTAIN FM.	MINNES GP.					DEZADEASH GP. TANTALUS FM. LABERGE GP.	
TRIASSIC PERMIAN												HEIBERG GP.
CARBONIFEROUS										MORIEN GP. PICTOU/ STELLARTON GP. CUMBERLAND GP. RIVERSDALE GP.	MATTSON FM. KAYAK FM.	

Figure 3.5. Principal coal-bearing stratigraphic units in Canada according to region and age.

Large deposits of anthracitic coals occur in the northern Intermontane region of British Columbia, and in the Yukon Territory. Smaller deposits occur in the Rocky Mountain Front Ranges and Inner Foothills of Alberta.

Peat bogs have been found to be highly enriched in metals and rare earths. Although little is known of the factors that might have caused peats to be enriched in elements such as iron, manganese, nickel, copper, cobalt, uranium, vanadium, platinum, beryllium and germanium, anomalous concentrations might be indicative of the presence of mineralization, and possibly orebodies, in nearby rocks (Usik, 1969). It is conceivable that coals, which are enriched in some rare elements, might provide a source for the commercial recovery of these elements in future. However, anomalous concentrations of some elements can affect the present commercial use of coals. Studies of elemental concentrations in Canadian coals are continuing (cf. Goodarzi et al., 1985; Goodarzi, 1987; Goodarzi, 1988).

The distribution and character of coals and coal resources in each of the major coal-bearing regions of Canada is discussed separately in the following chapters.

HISTORY OF CANADIAN COAL SUPPLY AND DEMAND

Canadian coals have been exploited since pre-Confederation for both domestic and international consumption. Competition from oil began to affect the coal industry after 1910, and international trade declined. Domestic coal consumption declined during the Depression and rejuvenated only with increased demands that resulted from World War II. A marked and continuous decline began in 1950 and continued until 1963 (Fig. 3.6). The decline resulted from the discovery of major reserves of oil and natural gas, and the gradual replacement of coal by these alternative fuels. The most significant negative impact on coal demand occurred when diesel-electric locomotives replaced coal-fired steam locomotives on Canadian railways.

Although coal's portion of the primary energy balance continued to decline throughout the 1950's and 60's, demand by thermal electric power stations steadily climbed, with significant annual increases recorded in the years following 1961. Increased domestic coal demands in the 1960's were largely offset by increased coal imports and, consequently,

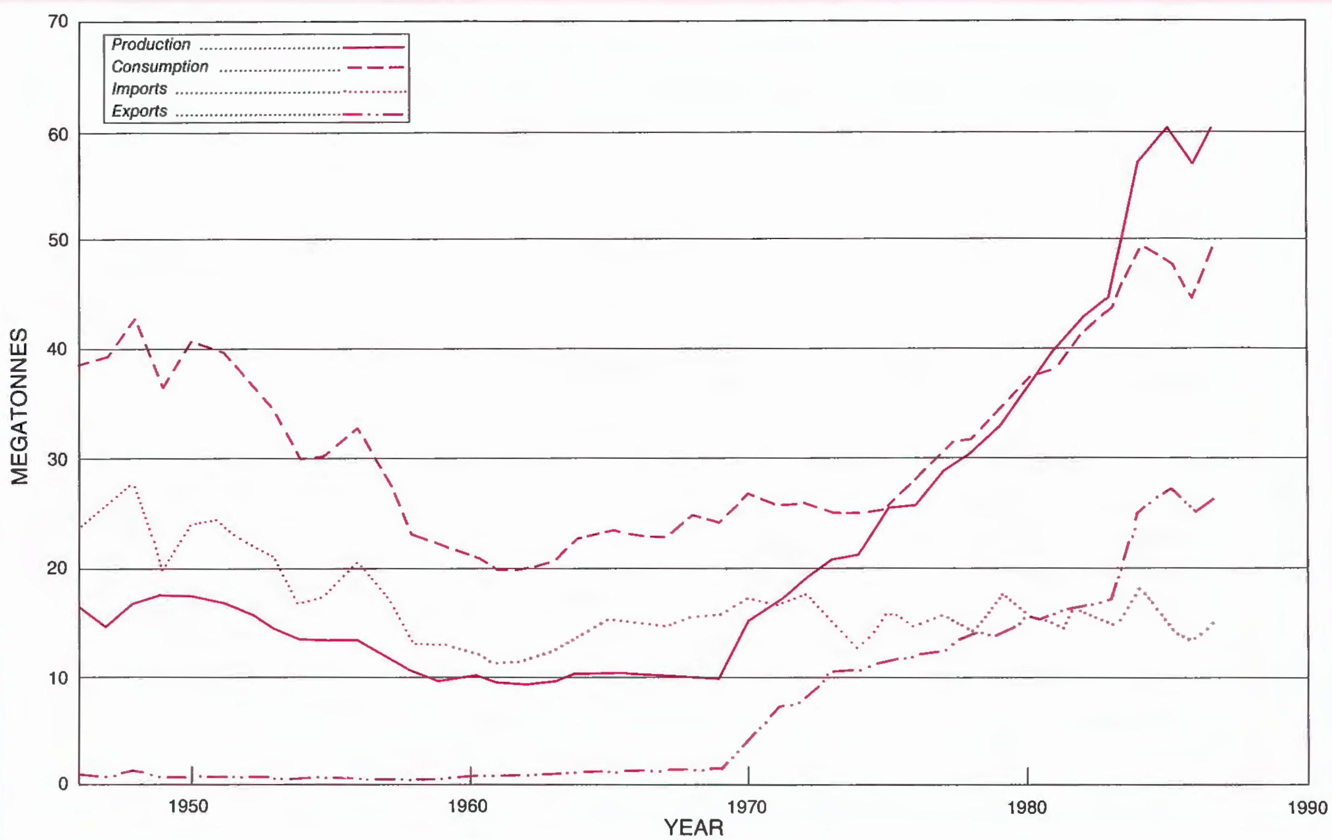


Figure 3.6. Canadian coal supply and demand, 1946-1987.

Canadian coal production did not expand during this period. During the mid-1960's, however, Canadian coal producers began to respond to increasing demands for high-grade metallurgical coals from a rejuvenating post-war Japanese steel industry. By 1970, Canadian coal production capacity was sufficiently established to allow vigorous participation in global coal markets. A new era for Canadian coal production had begun (Fig. 3.6).

The world energy crisis that began in 1973 caused many countries to reassess their energy supply options. Significantly higher international oil prices made coal an attractive fuel option in global markets. Canadian coal producers, electric utilities, and federal and provincial governments began to respond to expanding opportunities for coal. In this climate of international reassessment of energy demands and supplies, the Government of Canada began to increase initiatives directed toward managing effectively the future utilization of Canadian coal resources. The role of the Federal Government was recognized as one of predominantly research and development on technical and economic problems that constrain the coal industry, and one of providing assessments of national coal potential.

PRODUCTION AND UTILIZATION OF COAL IN CANADA

Nearly 39 megatonnes of thermal coal and 23 megatonnes of metallurgical coal were produced in Canada, in 1987, mainly from 26 principal coal mines (Fig. 3.7). The value of

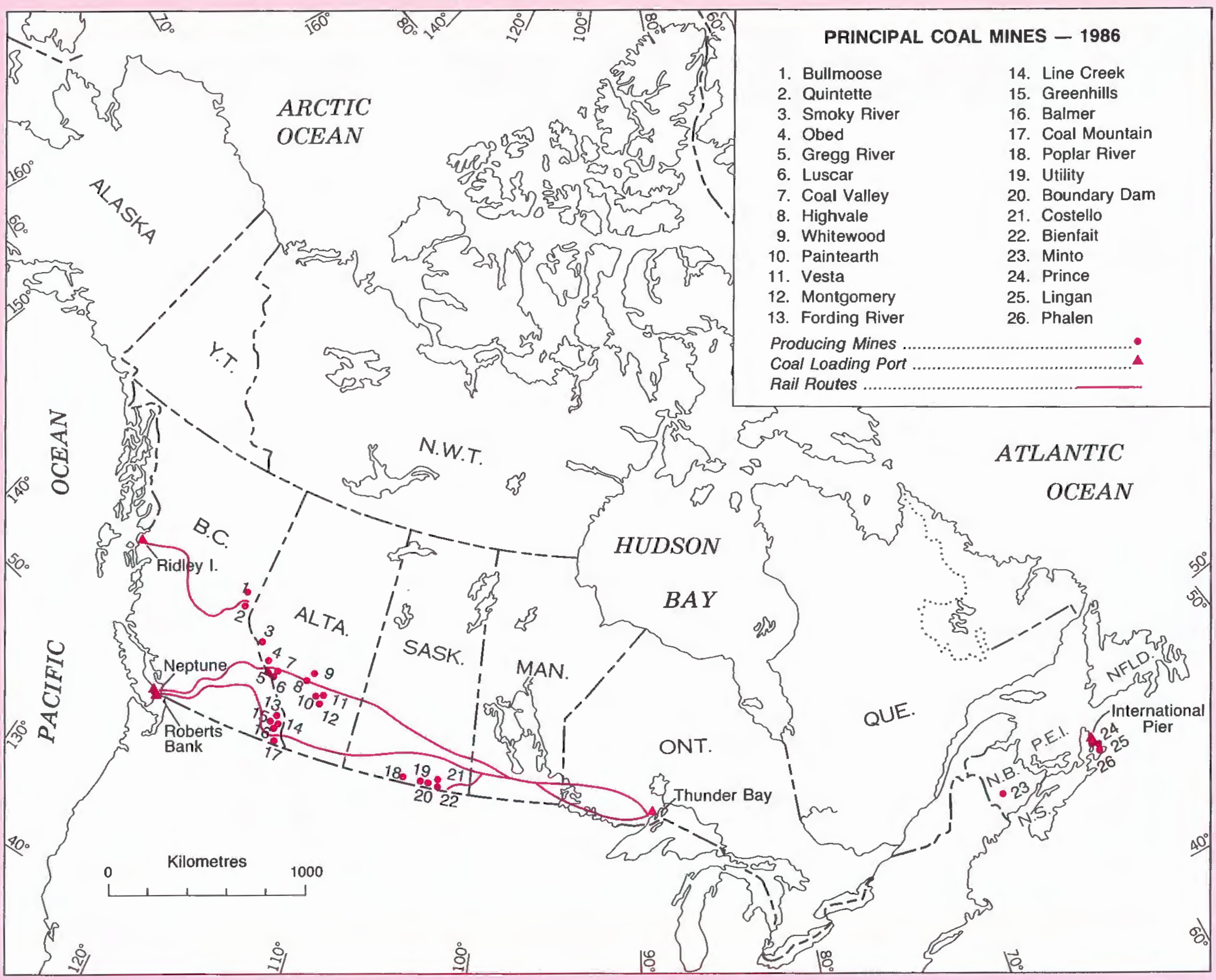


Figure 3.7. Principal Canadian coal mines — 1986 (from the Coal Association of Canada, 1987).

this coal production exceeded $1600 million, surpassing all other mineral commodities with the exceptions of petroleum and natural gas (Fig. 3.8).

During the 12-year period between 1976 and 1987, annual coal production in Canada increased from about 25 megatonnes to more than 61 megatonnes. Annual value of this production rose from nearly $600 million to more than $1600 million (f.o.b. minesite). During this period, domestic coal consumption increased from about 28 megatonnes to about 50 megatonnes. Coal exports increased from approximately 12 megatonnes to nearly 28 megatonnes (Canada Department of Energy, Mines and Resources, 1988).

Canadian coal supply and demand patterns over the past 40 years are illustrated by Figure 3.6. Coal's contribution to the total domestic primary energy demand is illustrated in Figure 3.9. Coal represents about 14 per cent of Canada's primary energy economy, which is nearly the same as the combined share of hydro- and nuclear-generated electricity. More than 90 per cent of the electricity produced in Alberta, and about 75 per cent of that produced in both Saskatchewan and Nova Scotia is derived from coal. Ontario produces about 26 per cent of its electricity from coal.

Currently established reserves of mineable coal in Canada total approximately 8500 megatonnes (Table 3.1), of which about one-third is metallurgical grade, with the balance being suitable for combustion applications.

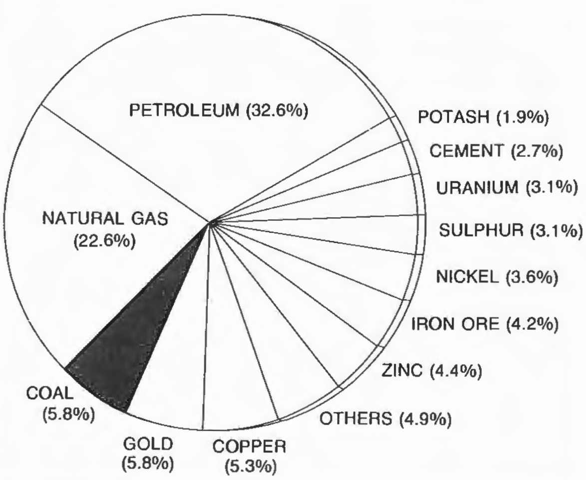


Figure 3.8. 1986 mineral production in Canada (based on statistics from Canada Department of Energy, Mines and Resources, 1987).

TABLE 3.1

ESTIMATED COAL RESERVES IN CANADA — (December, 1985)

(Romaniuk and Naidu, 1987)

Province / Region / Coalfield	Predominant Rank	Coal in Mineable Seams (megatonnes)	Recoverable Coal
British Columbia			
Vancouver Island			
Nanaimo	hvb	3	2
Comox	hvb	16	15
Southern Intermontane			
Hat Creek	lig-sub	739	566
Rocky Mountain Front Ranges			
Fernie/Flathead	m-lvb	540	436
Elk Valley	m-lvb	1133	1069
Northern Inner Foothills			
Peace River	mvb	710	476
(sub-totals - British Columbia)	m-lvb	2383	1981
	hvb	19	17
	lig-sub	739	566
Alberta			
Inner Foothills			
Cadomin-Luscar	mvb	161	77
Smokey River	lvb	420	163
Outer Foothills			
Coalspur	hvb	449	316
McLeod River	hvb	387	330
Plains			
Obed Mountain	hvb	197	154
Alix	sub	4	3
Ardley	sub	2	1
Battle River	sub	136	76
Drumheller	sub	42	11
Mayerthorpe	sub	3	2
Morinville	sub	13	8
Sheerness	sub	192	134
Thorhild-Abee	lig	2	1
Tofield-Dodds	sub	1	1
Wabamun	sub	642	480
Wetaskiwin	sub	250	155
(sub-totals - Alberta)	m-lvb	581	240
	hvb	1033	800
	lig-sub	1287	872
Saskatchewan			
Cypress	lig	(published data on separate coalfields are not available)	
Willow Bunch	lig		
Wood Mountain	lig		
Estevan	lig		
(sub-totals - Saskatchewan)	lig	2088	1670
New Brunswick			
Minto	hvb	10	9
Beersville	hvb	13	12
(sub-totals - New Brunswick)	hvb	23	21
Nova Scotia			
Inverness	hvb	3	1
Sydney	hvb	567	413
(minor reserves in Inverness and Springhill coalfields)			
(sub-totals - Nova Scotia)	hvb	570	415
TOTALS — CANADA	m-lvb	2964	2221
	hvb	1645	1253
	lig-sub	4114	3108

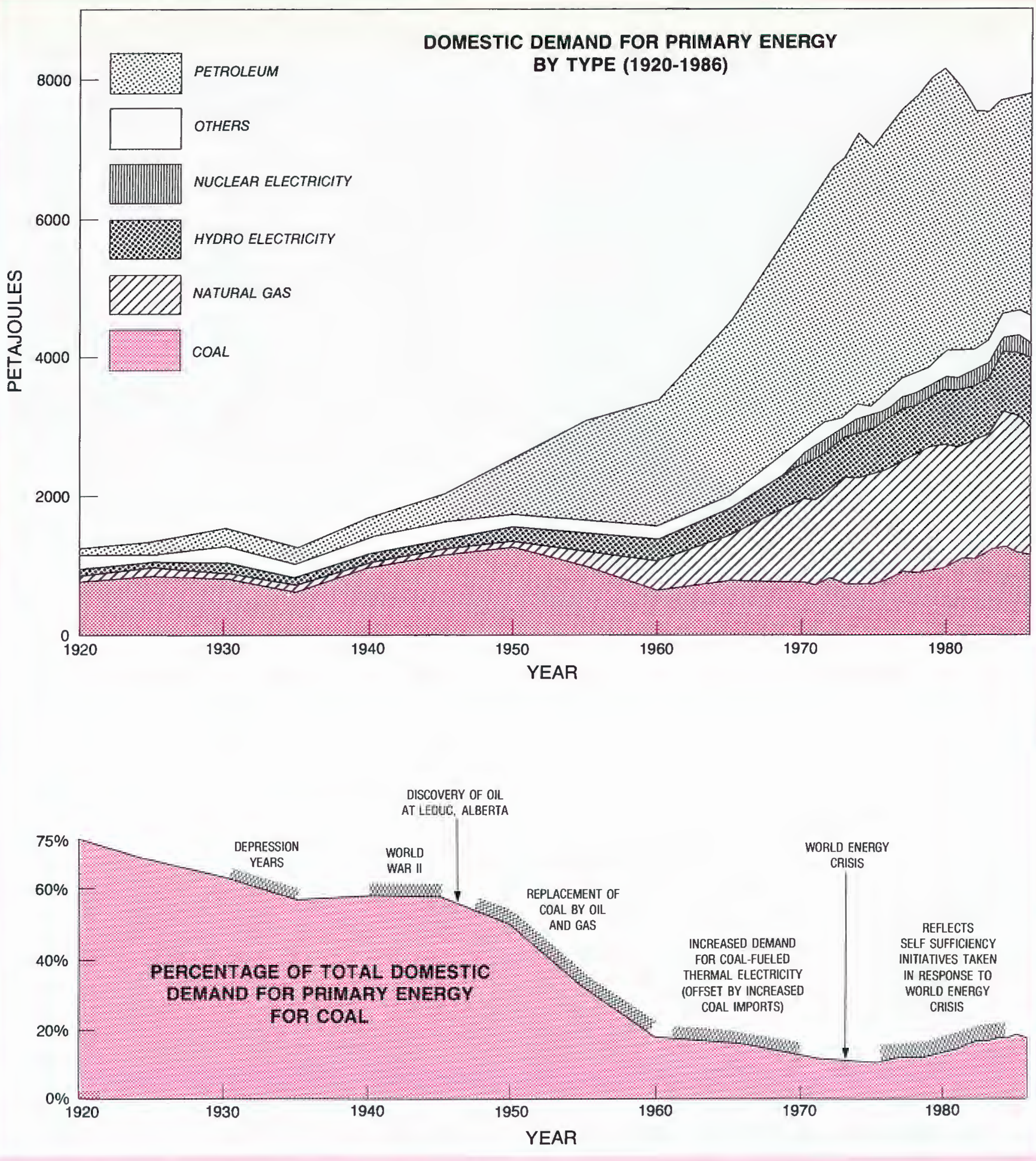


Figure 3.9. Contribution of coal to Canada's primary energy demand, 1920-1986 (based on statistics from Canada Department of Energy, Mines and Resources, 1987).

CANADA'S COAL RESOURCES IN A GLOBAL CONTEXT

In 1981 Canada became a net exporter of coal (Fig. 3.6). In 1987, about 27 megatonnes, or 44 per cent of the nation's coal production, were exported to destinations around the world (Fig. 3.10). Nearly 15 megatonnes were imported, mainly for the production of electricity and steel in Ontario.

According to the results of a world coal study, Canada is ranked seventh among world coal exporting countries and twelfth among world coal producing countries (Grossling, 1981). The study showed Canada ranked fifth among countries with respect to total estimated coal resource quantities, exceeded in descending order by U.S.S.R., U.S.A., People's Republic of China and Australia (Fig. 3.11). Canada was reported to contain nearly 4 per cent of the world's coal resources. Although there are no means of comparing the reliability of the various national estimates, Canada will always be among the nations that are particularly well-endowed with coal, by virtue of the size of the Canadian landmass that contains coal.

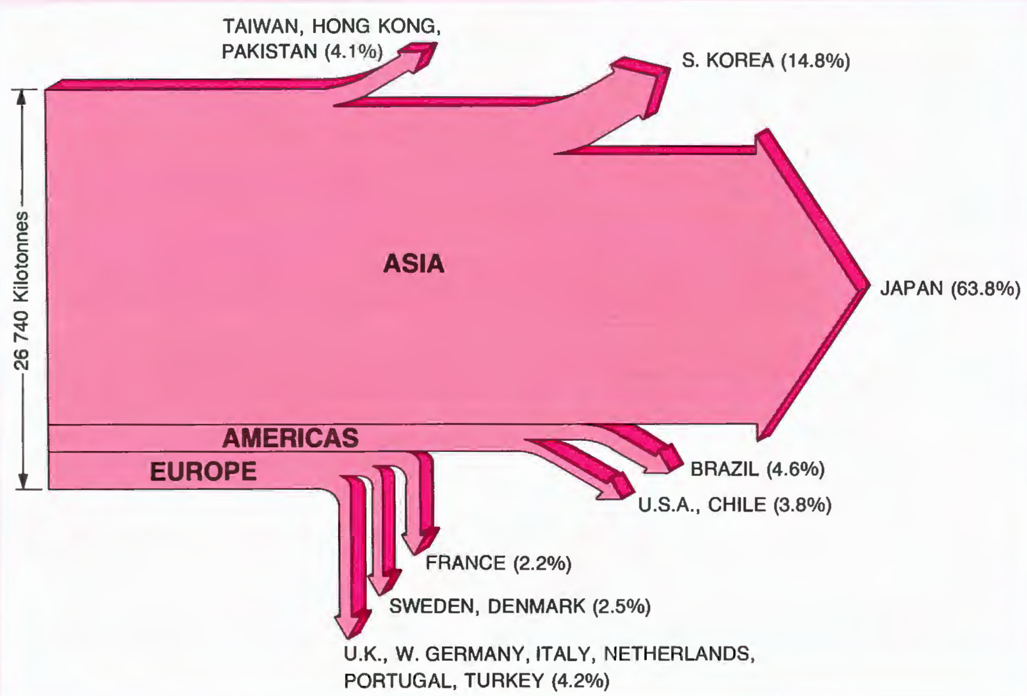


Figure 3.10. Canadian coal exports — 1987 (based on statistics from Canada Department of Energy, Mines and Resources, 1988).

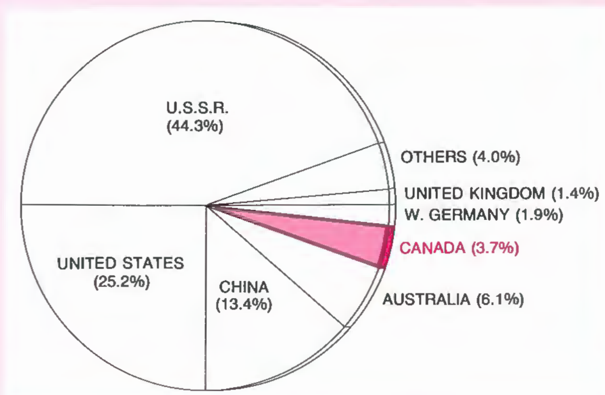
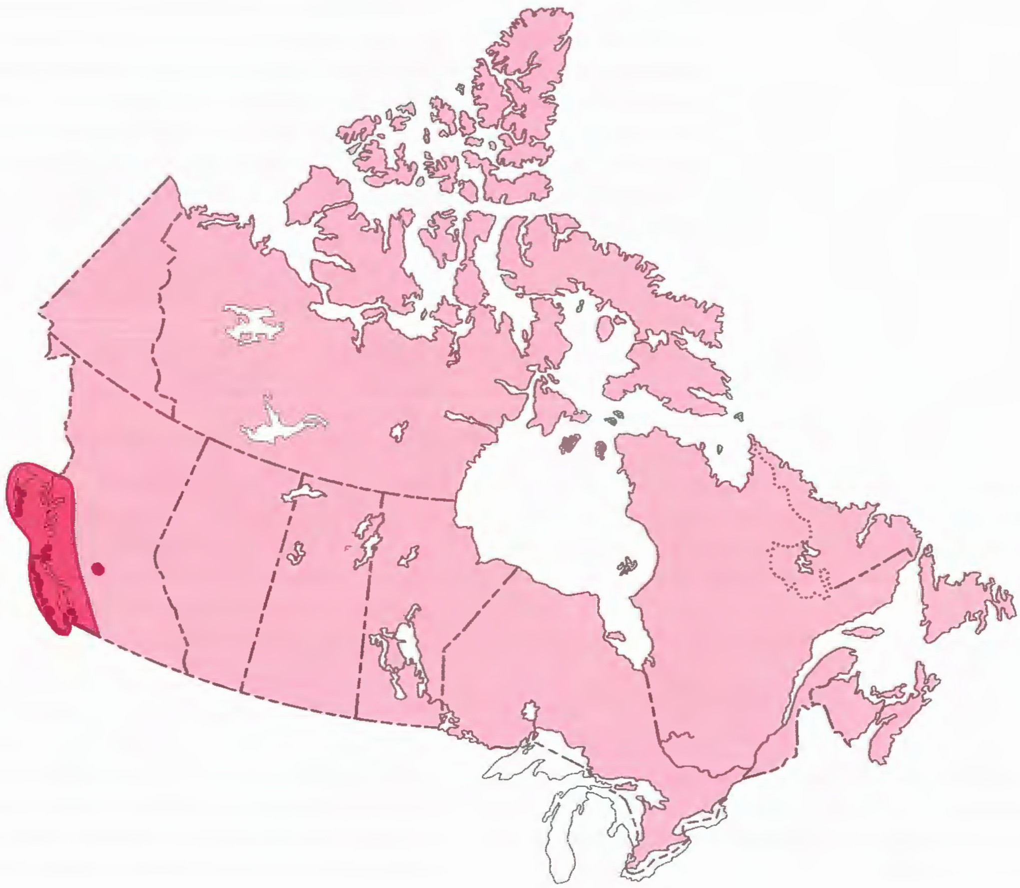


Figure 3.11. Proportionate distribution of the world's coal resources by country (according to Grossling, 1981).

EAST COAST OF VANCOUVER ISLAND (courtesy L. MacLachlan)

CHAPTER 4

COAL RESOURCES OF COASTAL BRITISH COLUMBIA



FEATURES

COAL RESOURCES OF COASTAL BRITISH COLUMBIA

INTRODUCTION

Coals that vary in rank from lignitic to anthracitic occur in Late Mesozoic and Tertiary strata on Vancouver Island, Queen Charlotte Islands and the coastal mainland of southwestern British Columbia (Fig. 4.1). The most promising resource potential is within the Upper Cretaceous Nanaimo Group, which is exposed along the east coast of Vancouver Island. High volatile bituminous coals have been mined from these strata since about 1850. The general absence of mining and exploration activities in other coal-bearing areas within the region makes assessment of resource potential tenuous. In 1915, the Geological Survey of Canada summarized available knowledge of significant coal occurrences of the coastal British Columbia region (Dowling, 1915b). Deposits with the least commercial potential are not discussed in the present report. There are currently no operating mines in the region.

Low rank Tertiary coals occur in several locations, but most notably on Graham Island in the Queen Charlotte Islands, and in the Fraser Basin on the coastal mainland. Although large quantities may exist in both areas, they are much too deep for economical surface mining (Clapp, 1912; Sutherland Brown, 1968). Furthermore, socioeconomic and environmental considerations for large scale extraction of low rank coals could be prohibitive in the areas of greatest mining potential, such as Skonun Point on Graham Island.

Minor Eocene lignite and carbonaceous sandstone deposits in the Lang Bay area of the coastal mainland (Fig. 4.1) are not commercially significant in the context of conventional coal exploitation. However, some contain high concentrations of germanium and gallium. The commercial recovery of these rare metals, which are primarily contained in the vitrinite fraction of the lignite, is presently being investigated (Queneau et al., 1986).

Coal deposits occur in Lower Cretaceous strata at the north end of Vancouver Island. These deposits are essentially unexplored and are not well understood. Jurassic-Cretaceous strata on Graham Island contain coal deposits that have been explored, and one mine operated until 1872.

VANCOUVER ISLAND

BACKGROUND AND GEOLOGY

Coal was first reported on Vancouver Island in 1835. Mining began in the Suquash Coalfield in 1849, the same year that coal was reported to occur at Nanaimo (Fig. 4.2). By 1852, mining of the poor quality coal in the Suquash Coalfield failed and miners were transferred to the extremely profitable coal mines at Nanaimo. In 1888, production from the Cumberland deposit, near Comox, commenced.

Coals from the Suquash Coalfield were exploited mainly for bunker use by British naval ships, whereas coals from the Nanaimo Coalfield were largely exported to California. By 1910, export trade to California declined following discoveries of indigenous oil. Although production was sustained for many years through improved domestic markets, exhaustion of the most easily mined deposits, and discoveries of oil and gas in British Columbia and Alberta resulted in the rapid decline of coal mining activities on Vancouver Island. Approximately 67 megatonnes of coal were produced from the coalfields between 1849 and 1968 (James, 1969). Production by coalfield was approximately as follows:

Coalfield	Production (megatonnes)	Period
Nanaimo	49	1852-1953
Comox	18	1888-1967
Suquash	(<1)	1849-1852

The Nanaimo Group is a 2000 m thick stratigraphic succession of Late Cretaceous age, comprising mainly sandstones, siltstones, shales and conglomerates. It has been preserved in six discontinuous erosional remnants, which are often referred to as basins, along the east coast of Vancouver Island. Segmenting of the original depositional basin was apparently controlled by post-Cretaceous block faulting and tilting (Muller and Atchison, 1971). The distinguishable remnants are named Suquash, Comox, Quinsam, Alberni, Nanaimo and Cowichan basins. No commercially significant coal deposits have been discovered in the Cowichan and Alberni basins. The Comox, Quinsam and Nanaimo basins have the most promising resource potential and have been the most intensely investigated (Fig. 4.2). Relatively small quantities of high ash, high volatile B/C bituminous coals occur in the Suquash Basin.

Deposition of the Nanaimo Group occurred during a series of four or five cycles of marine incursions and retreats. Each cycle is characterized by progressively deeper water sedimentation. Facies generally progress upward from fluvial, to lagoonal and/or deltaic, to marine, although not all facies are necessarily found in a single cycle. The lagoonal facies of the first and second cycles are coal-bearing (Muller and Jeletzky, 1970).

Coal seams of the Nanaimo Group were apparently deposited in coastal lowlands, or lagoons, separated from the sea by sandbars (Buckham, 1947). Lagoonal coal-bearing facies have been identified in the first transgressive depositional cycle in the Comox Basin (Comox Formation), and in the second cycle in the Nanaimo Basin (Extension-Protection Formation). Coal distribution in the Comox Basin was controlled by the significant paleotopographic relief of the underlying pre-Cretaceous erosion surface. Lower seams originated in peat-forming swamps of limited areal extent that recurred at about the same geographic positions. Upper seams of the Comox Basin and seams in the Nanaimo Basin were not affected by the same physiographic controls and

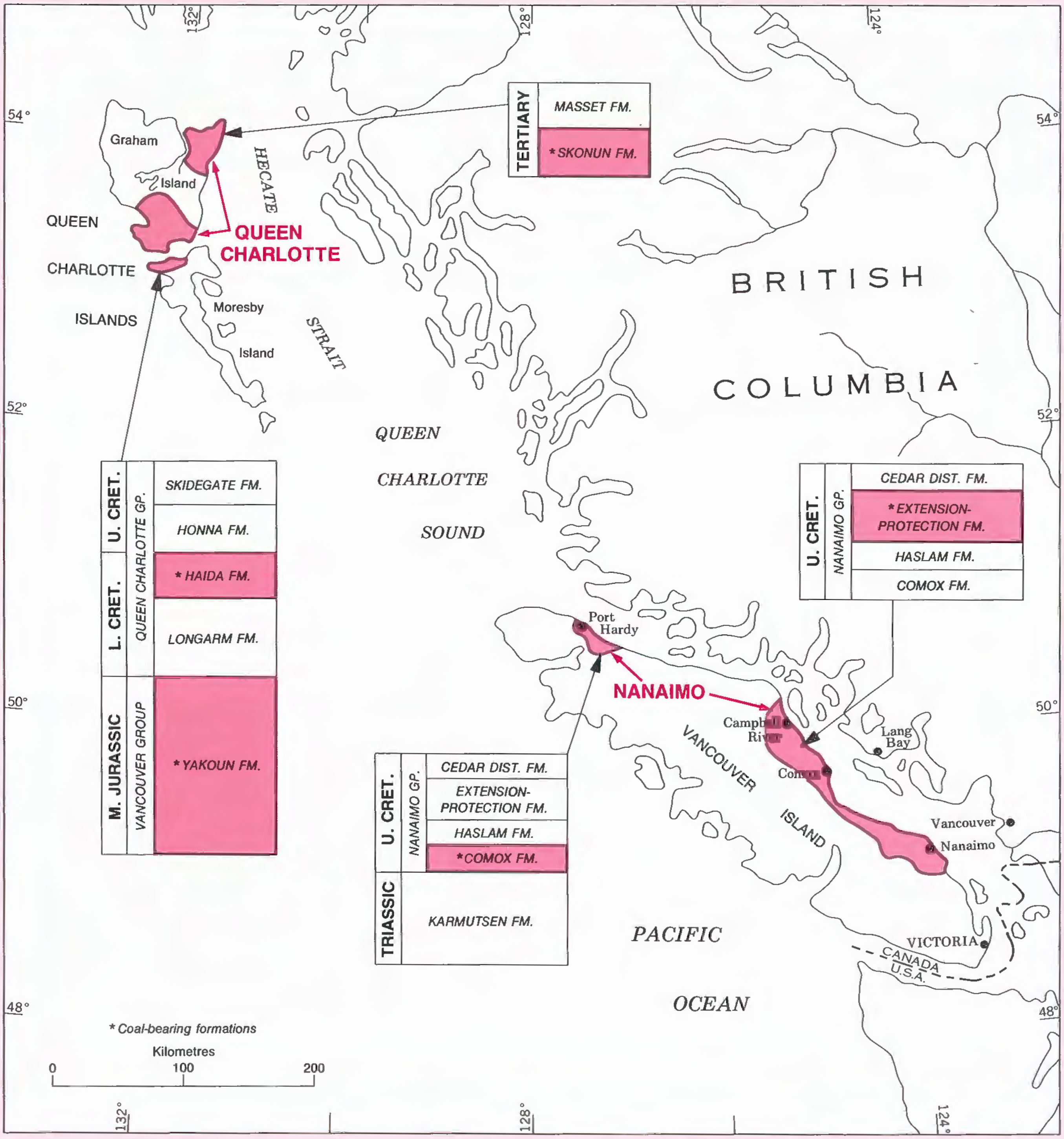


Figure 4.1. Major coal-bearing sedimentary basins of Coastal British Columbia.

are laterally more continuous. Highly variable thickness and gas content are characteristic of coal seams in the Nanaimo Basin (Muller and Atchison, 1971). Diverse petrographic composition of coals of the Nanaimo Coalfield apparently reflects the variation in groundwater level in peat bogs caused by fluctuations of sea level (Hacquebard et al., 1967).

Faults, which are the dominant structural features in the Nanaimo Group, have resulted in tilted fault blocks. Coal-bearing strata are usually gently homoclinal toward the northeast, except near fault zones where they may approach vertical. Faults often strike northwesterly with subsidiary cross-faults striking north to northeasterly (Muller and Atchison, 1971).

The most commercially attractive coal potential is apparently in the Quinsam Basin, where three zones of high volatile B bituminous coals occur within a stratigraphic interval of about 300 m in the Comox Formation. They have been relatively extensively explored during the past 15 years (Barnstable, 1980; and Eastwood, 1984). The lower No. 1 zone contains an aggregate coal thickness of approximately 2 to 4 m, in addition to some minor partings. The No. 2 zone, which is about 15 m stratigraphically higher than the No. 1 zone, contains up to about 1.5 m of coal with one parting. The No. 3 zone, which occurs nearly 35 m above the No. 2 zone, contains up to 3 m of coal and three partings. Intrusives have increased both the rank and inorganic sulphur content (attaining a maximum of 5 per cent) of coals in the southern part of the area (Barnstable, 1980)

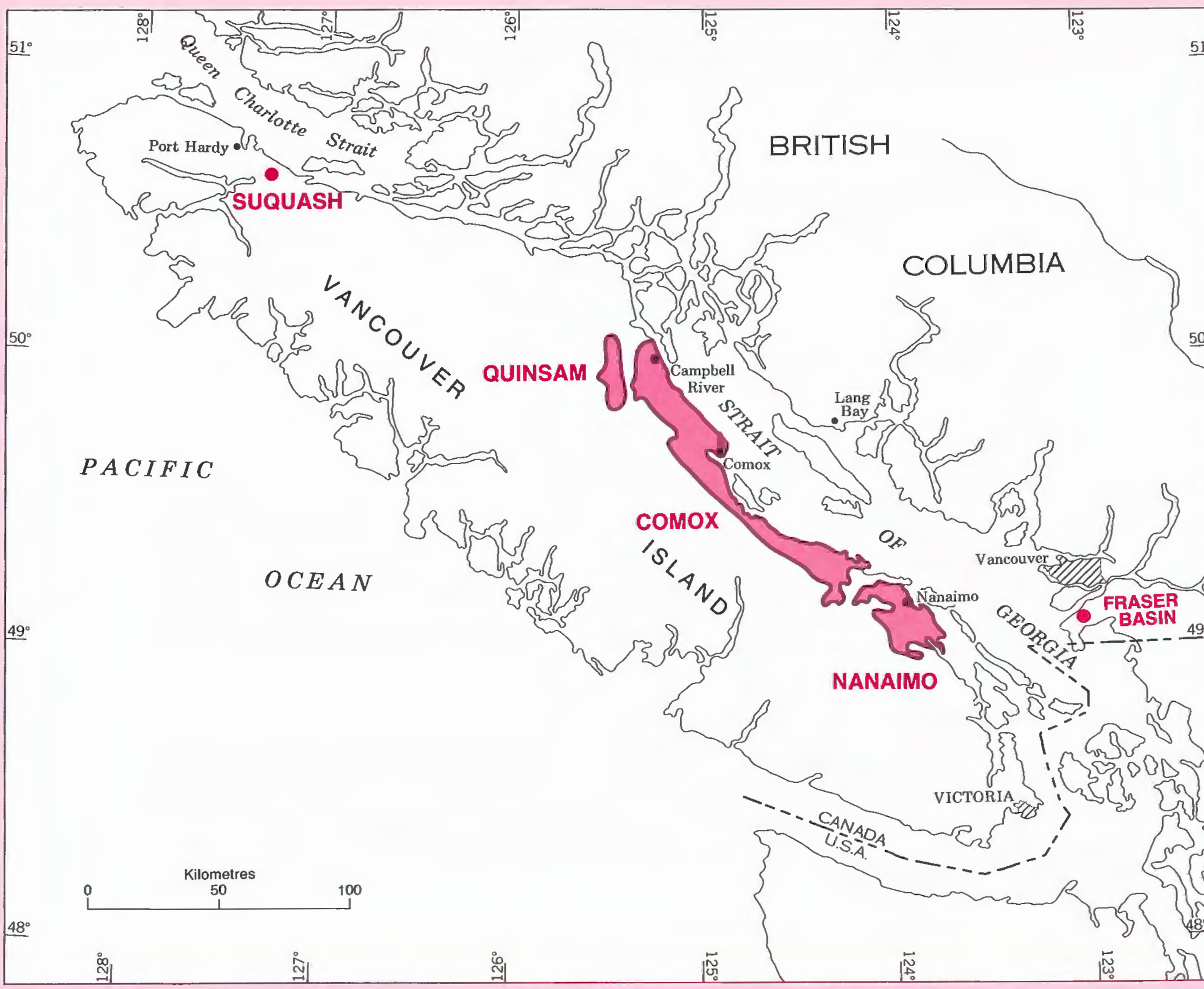


Figure 4.2. Coal districts of Vancouver Island.

RESOURCE QUANTITIES

Assessments of coal resource potential have been made on the basis of available company and government reports, including records from previous mining operations. General geological reports such as those of Muller and Jeletzky (1970) and Muller and Atchison (1971), provide the basis for considering the stratigraphic, sedimentological and structural context of the coal measures. Estimated coal resource quantities are shown in Table 4.1.

TABLE 4.1

COAL RESOURCES OF IMMEDIATE INTEREST VANCOUVER ISLAND

Coalfield	Predominant Rank*	measured	indicated (megatonnes)	inferred
Nanaimo	hvb	-	-	10
Comox	hvb	10	50	100
Quinsam	hvb	25	30	50
Suquash	hvb	-	-	40
TOTALS	h-mvb	35	80	200

*totals by general rank class

Estimated coal resource quantities are based mainly on information from the British Columbia Geological Survey Branch (W. Kilby, pers. comm., 1987), Dolmage Campbell and Associates Ltd. (1975) and MacKay (1947).

COAL QUALITY

The coals of Vancouver Island are generally classified as high volatile A/B bituminous rank (Table 4.2). Their characteristics are similar to those of other coals used to fuel conventional thermal electric generating plants in Canada and in other parts of the world.

TABLE 4.2

GENERAL COAL QUALITY CHARACTERISTICS VANCOUVER ISLAND

	Nanaimo	Comox	Quinsam
Proximate analysis (per cent by weight)			
moisture (as received)	5	4	6
ash (dry)	14	14	17
volatile matter (d.a.f.)*	41	38	42
fixed carbon (d.a.f.)	59	62	58
Heat value (d.a.f.) MJ/kg	34.5	34.5	33.5
Ultimate analysis (dry, ash-free) (per cent by weight)			
carbon	83.0	83.0	-
hydrogen	5.5	5.5	-
nitrogen	1.5	1.2	-
sulphur	0.5	1.5	1.1
oxygen	9.5	8.8	-
Analysis of ash (per cent by weight)			
SiO_2	37.5	30.0	-
Al_2O_3	20.5	18.5	-
Fe_2O_3	6.5	14.5	-
CaO	21.0	17.5	-
MgO	5.0	2.0	-
MnO	0.1	-	-
Na_2O	1.1	0.5	-
K_2O	0.9	0.6	-
P_2O_5	0.8	0.5	-
TiO_2	1.1	1.0	-
SO_3	4.0	13.0	-
undetected	1.5	1.9	-
Properties			
free swelling index	1-6	6-8	-
caking index (Gray)	45-63	65	-
grindability index (Hardgrove)	67	65	-
ash softening temp. (reduced) °C	1265	1160	-
Rank classification (ASTM)	hvbA/B	hvbA/B	hvbB

*dry, ash-free

These generalized coal characteristics result from the synthesis and consideration of information from Stansfield and Nicolls (1918), Nicolls (1952), Swartzman (1953) and Romaniuk and Naidu (1987). Values do not necessarily result from representative sampling of deposits and, therefore, are intended only as an indication of general coal characteristics that might be expected in the major coal deposits.

QUEEN CHARLOTTE ISLANDS

BACKGROUND AND GEOLOGY

Both Mesozoic and Tertiary coals occur on Graham Island, in the Queen Charlotte Islands (Fig. 4.1). The first discovery of Mesozoic bituminous and anthracitic coals near Cowgitz, on the south side of the island (Fig. 4.3), triggered some subsurface exploration and limited mining activities between 1865 and 1914. Although Tertiary lignites are exposed at several localities on the island, the most significant occurrence is at Skonun Point. Subsurface exploration of this coalfield has been minimal and no lignites have been commercially exploited.

The coal-bearing formations in the Cowgitz Coal District have not been conclusively differentiated and could be both the Middle Jurassic Yakoun Formation and the Lower Cretaceous Haida Formation (Sutherland Brown, 1968). Coals originated in relatively small, shallow, coastal estuarine basins. The sea periodically inundated the freshwater marshes causing deposition of sandy and shaly partings within coal zones. Coalification was influenced in places by nearby intrusives. Waters heated by the intrusives may have resulted in the development of anthracitic coals. The structures of coal measures are generally complex and seams are characteristically faulted and folded (MacKenzie, 1916).

Significant lignite deposits occur in the lower nonmarine member of the Tertiary Skonun Formation. In the Skonun Coalfield, thirteen beds of woody lignite having an aggregate thickness of 6 m occur within 60 m of shale. The thickest reported bed is 1.8 m. These beds occur in a faulted, west-plunging, moderately appressed anticline (Sutherland Brown, 1968).

RESOURCE QUANTITIES

The estimated coal resources of Graham Island are shown in Table 4.3. These estimates are based on limited data collected mainly from the areas near old coal exploration camps (Fig. 4.3).

COAL QUALITY

The general characteristics of coals on Graham Island are indicated in Table 4.4. The values shown were derived from several analyses reported by MacKenzie (1916) and Clapp (1914), from coals sampled mainly near the old exploration camps (Fig. 4.3). More recent analyses have not been published. Although most of these coals can be considered thermal quality, the high volatile bituminous coals also form coherent coke. The variability of characteristics between deposits is notable, and coal rank variations may be indicative of complex geothermal patterns.

TABLE 4.3

COAL RESOURCES OF IMMEDIATE INTEREST GRAHAM ISLAND, QUEEN CHARLOTTE ISLANDS

District / Coalfield	Predominant Rank*	measured	indicated (megatonnes)	inferred
Cowgitz	sa-an	-	-	10
	hvb	-	15	10
Skonun	lig	-	-	50
TOTALS	lvb-an	-	-	10
	h-mvb	-	15	10
	lig-sub	-	-	50

*totals by general rank class

Estimated coal resource quantities are based mainly on information from Dolmage Campbell and Associates Ltd. (1975), and MacKay (1947).

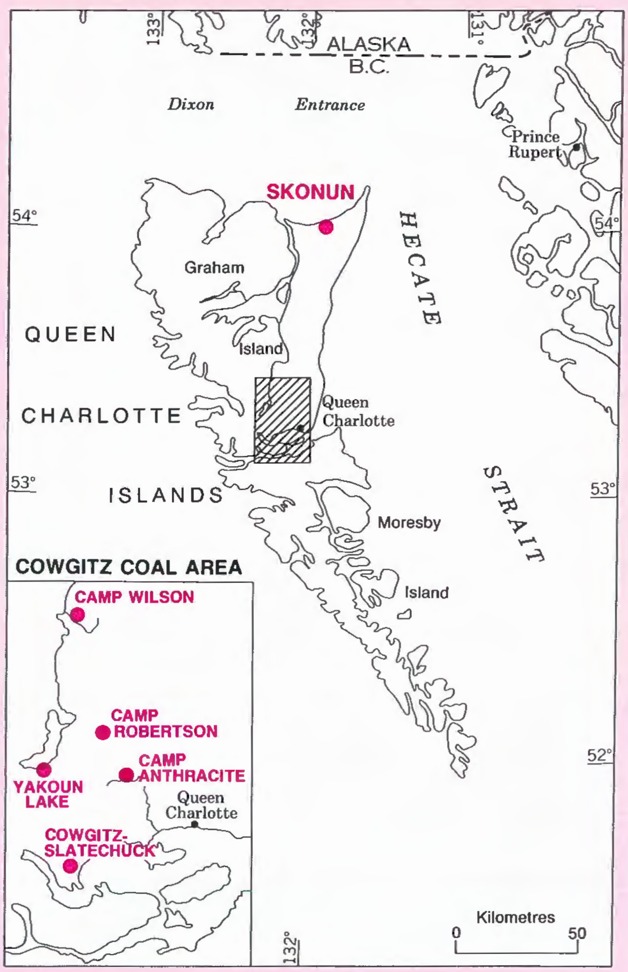


Figure 4.3. Coalfields of Graham Island.

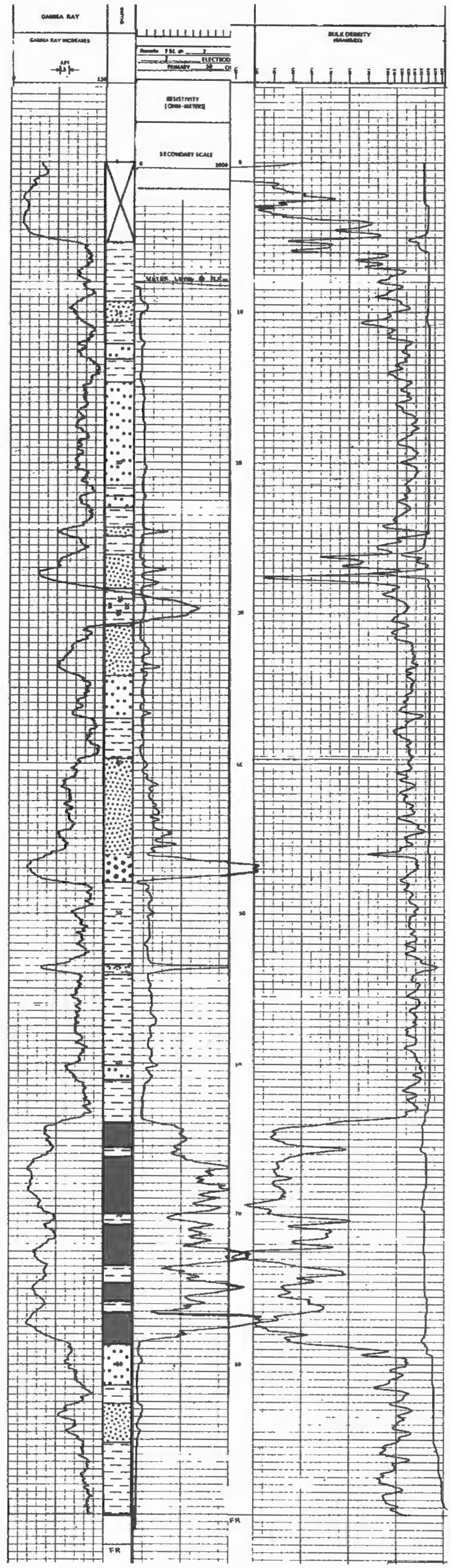
TABLE 4.4

GENERAL COAL QUALITY CHARACTERISTICS GRAHAM ISLAND, QUEEN CHARLOTTE ISLANDS

	Cowgitz 1	Cowgitz 2	Cowgitz 3	Cowgitz 4	Skonun 5
Proximate analysis (per cent by weight)					
moisture (as received)	6	1	3	2	19
ash (dry)	20	25	25	15	5
volatile matter (d.a.f.)*	7	36	11	41	55
fixed carbon (d.a.f.)	93	64	89	59	45
Heat value (d.a.f.) MJ/kg	-	-	-	-	-
Ultimate analysis (dry, ash-free) (per cent by weight)					
carbon	85.5	-	-	82.5	58.7
hydrogen	2.6	-	-	5.5	6.2
nitrogen and oxygen	11.5	-	-	11.0	34.8
sulphur	0.4	1.0	-	1.0	0.3
Rank classification (ASTM)	an	hvb	sa	hvbB	lig

*dry, ash-free

1 Cowgitz-Slatechuk deposit
2 Camp Robertson deposit
3 Camp Anthracite deposit
4 Camp Wilson deposit
5 Skonun deposit

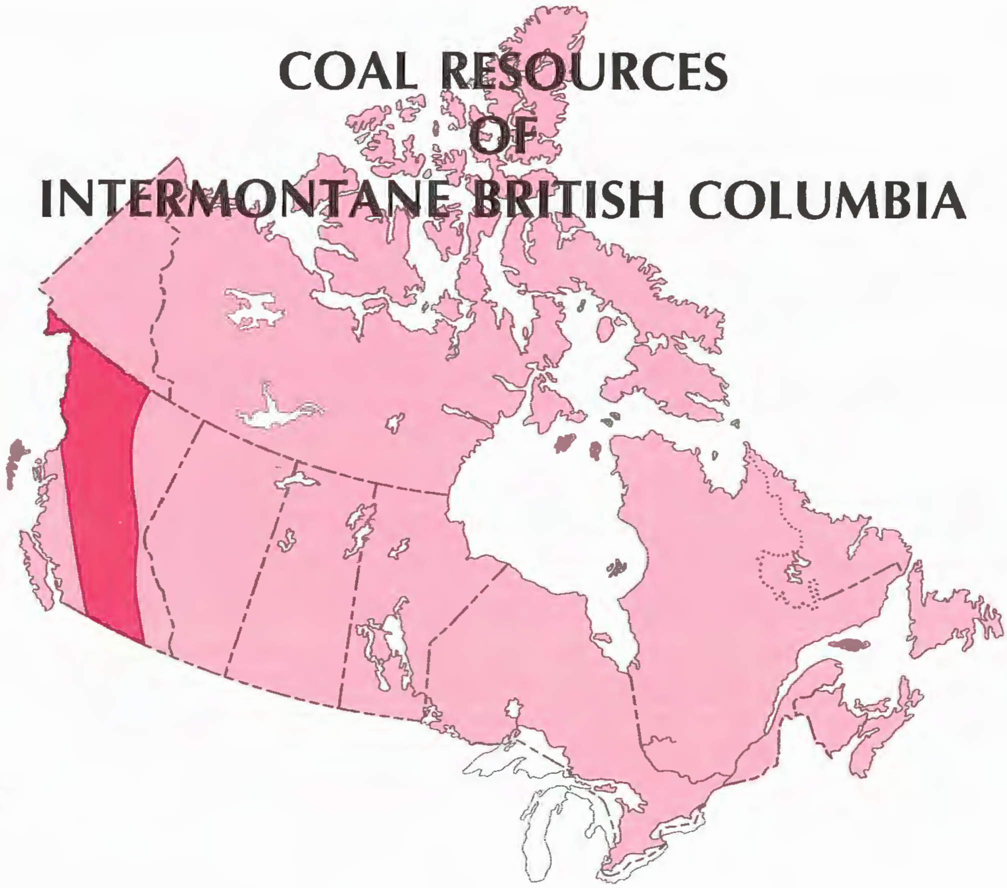


GAMMA RAY
GAMMA RAY INCREASES
API
150
ELECTROD
PRIMARY
RESISTIVITY
(OHM-METERS)
SECONDARY SCALE
0
2000
BULK DENSITY
10
20
30
FR
FR

COAL EXPLORATION CAMP NEAR MT. KLAPPAN (courtesy B.D. Ricketts)

CHAPTER 5

COAL RESOURCES OF INTERMONTANE BRITISH COLUMBIA



FEATURES

COAL RESOURCES OF INTERMONTANE BRITISH COLUMBIA

INTRODUCTION

Several significant coal deposits are located in the Intermontane Belt of the western Canadian Cordillera, in the interior of British Columbia (Fig. 5.1). The diversity of age, composition, rank, thickness and areal extent of these deposits reflects a variety of depositional environments and basin evolution histories. The major coal measures in the region were deposited in successor basins associated with tectonic development of the Cordillera (Gabrielse, 1976). Tectonic events associated with the evolution of the Canadian Cordillera substantially controlled the establishment of coal-forming environments and the subsequent maturation of coals.

For the purposes of discussing coal resources of Intermontane British Columbia, the area has been informally divided into a northern and southern region. In the northern region, coal deposits occur in strata ranging from Lower Jurassic to Lower Tertiary. The most commercially significant of these deposits are within Upper Jurassic and Lower Cretaceous strata. These coals vary in rank from bituminous to anthracitic. No high quality coking coals have been identified (Latour, 1976a). In the southern region, all major coal deposits are Tertiary in age and have ranks ranging between lignitic and high volatile bituminous.

NORTHERN INTERMONTANE REGION

INTRODUCTION

The most promising coal potential of the northern Intermontane Region of British Columbia is within the Groundhog and Telkwa coalfields (Fig. 5.2). Coal deposits of the Sustut River Coalfield, however, have been explored recently and could ultimately prove to be commercially significant. The most extensive deposits are within the Groundhog Coalfield, an area of about 3500 square kilometres underlain by Upper Jurassic-Lower Cretaceous rocks that contain major deposits of anthracitic coals (Bustin, 1984). Although these deposits have attracted serious commercial interest in the past, their relative inaccessibility has discouraged exploitation. Recently, relatively large-scale mining operations near Mount Klappan have been considered. Bituminous coal has been mined from Early Cretaceous strata of the more accessible Telkwa Coalfield in central British Columbia. Renewed interest in the coal potential of the northern Intermontane Region over the past 15 years, and improved access to the deposits, has encouraged exploration in the area, for example, in the Sustut River Coalfield (Schroeter and White, 1985).

Some successor basins in the Canadian Cordillera probably resulted from orogenic movements within the Intermontane Belt between the Columbian and Pacific orogens (Eisbacher, 1974a). The evolution of these basins was largely controlled by the interaction of distinct crustal blocks which collided (Eisbacher, 1981). Depositional environments during the evolution of these basins were often suitable for the accumulation and preservation of peat. The Bowser, Sustut, Sifton and Laberge basins are four successor basins within the northern Intermontane Belt that contain coal-bearing strata (Fig. 5.1).

GROUNDHOG COALFIELD

The existence of coal in the Groundhog area was first reported by Dawson (1901). He discussed deposits of anthracitic coal in the region and predicted that "large and important coal-fields will be available when required". Coal exploration in the area was active until 1913 when it became evident that a railway to the coalfield was needed prior to considering possible coal exploitation (Malloch, 1914; and Buckham and Latour, 1950). Renewed commercial interest in the coal deposits in recent years has resulted in fairly intense exploration in the Mount Klappan area, in the northwestern part of the coalfield, near the partially completed British Columbia Railway line between Prince George and Dease Lake (Fig. 5.2).

The Groundhog Coalfield is located within the northeastern part of the Bowser Basin, a Middle Jurassic to Early Cretaceous successor basin. Coal deposits in the northeastern Bowser Basin are associated with strata deposited in deltaic and alluvial fan environments during the gradual southward regression of the sea that covered much of the basin during the Middle Jurassic (Eisbacher, 1974b). Anthracite and meta-anthracite occur within the 400 to 600 m thick Late Jurassic transitional marine and nonmarine Currier unit (Fig. 5.1). This unit is considered to include marginal marine, deltaic and fluvial sediments within the overall regressive sequence which underlies the region (Bustin and Moffat, 1983).

The coal-bearing sequence and associated strata have undergone two major phases of deformation. Northwest-trending folds and minor thrusts that developed in the early phase were subsequently deformed by broad, open, northeast-trending folds and flat-lying thrusts in the later phase (Moffat and Bustin, 1984).

TELKWA COALFIELD
(Bulkley River District)

Commercially significant coal deposits have been known to exist in the Telkwa area since the early years of this century (Dowling, 1915). They have been explored and exploited somewhat continuously since that time. The coalfield is located in the Bulkley River District in west-central British Columbia, near the towns of Smithers and Hazelton (Fig. 5.2). The nearby Canadian National Railway line which runs between Prince George and the port at Ridley Island (370 km west), near Prince Rupert, has encouraged commercial interest in the coal deposits. About 300 000 tonnes of coal were produced from mines in the Goathorn Creek area

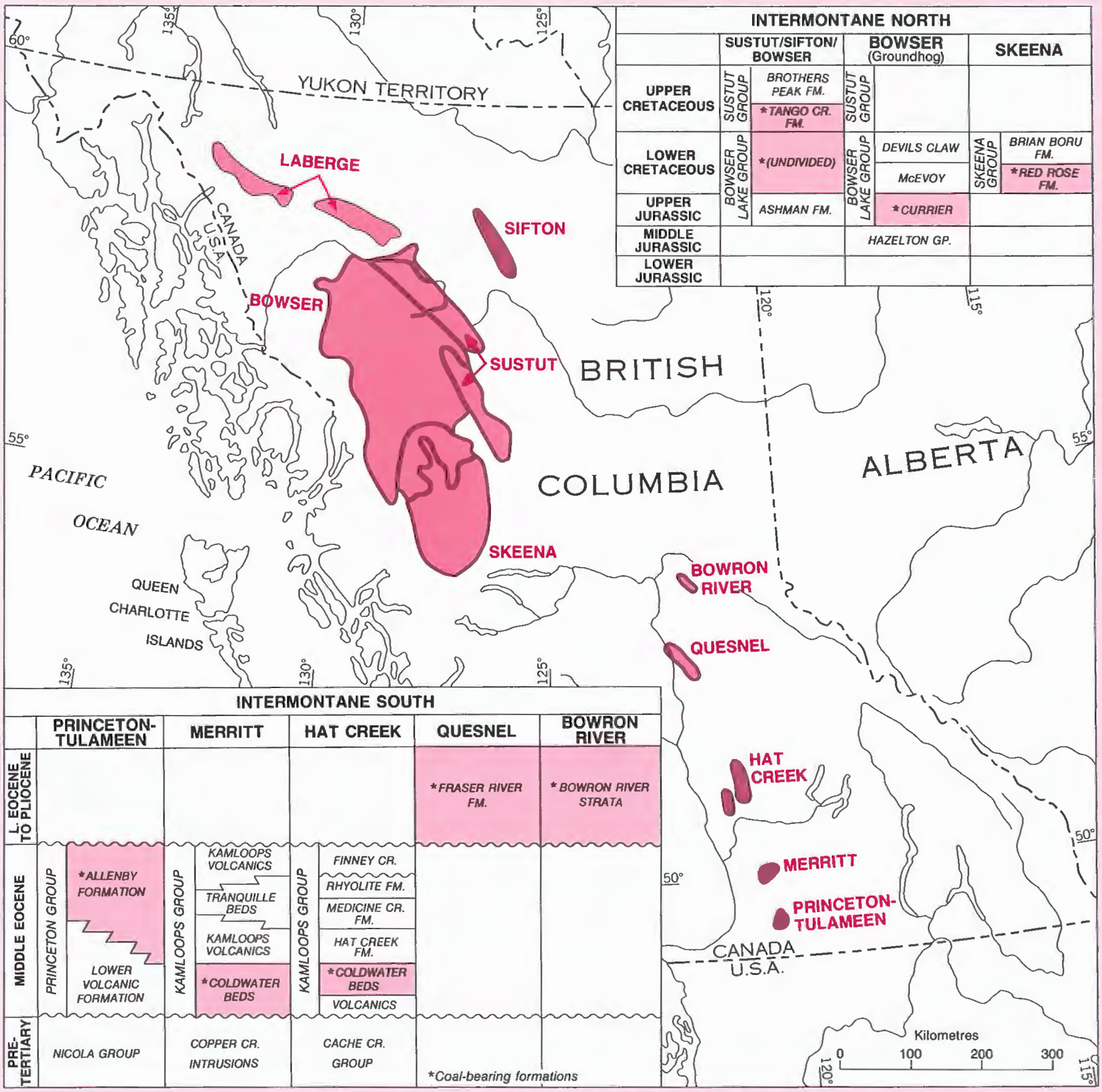


Figure 5.1. Coal-bearing sedimentary basins of Intermontane British Columbia.

between 1918 and 1980. The medium to high volatile bituminous coals were used mainly for domestic heating, although some have been used industrially in Prince Rupert.

The Telkwa Coalfield is located at the southern margin of the Bowser Basin. Coal deposits occur in the Lower Cretaceous (Hacquebard et al., 1967) Skeena Group, which comprises a distinct assemblage of interbedded marine and nonmarine sedimentary and volcanic rocks (Fig. 5.1). The sediments in the lower part of the Skeena Group were deposited in a different basin (i.e. depocenter) than the older Bowser Lake Group (Tipper and Richards, 1976). Therefore, although the Skeena Group is underlain by strata of the Bowser Basin, it is considered to be contained within the younger basin referred to as the Skeena Basin. The coal-bearing Red Rose Formation and overlying, mainly volcanic, Brian Boru Formation (Sutherland Brown, 1960) are the two current subdivisions of the Skeena Group (Tipper and Richards, op. cit.). Numerous coal seams ranging in thickness from 1 to 7 m are widespread throughout the coalfield and often occur near the surface.

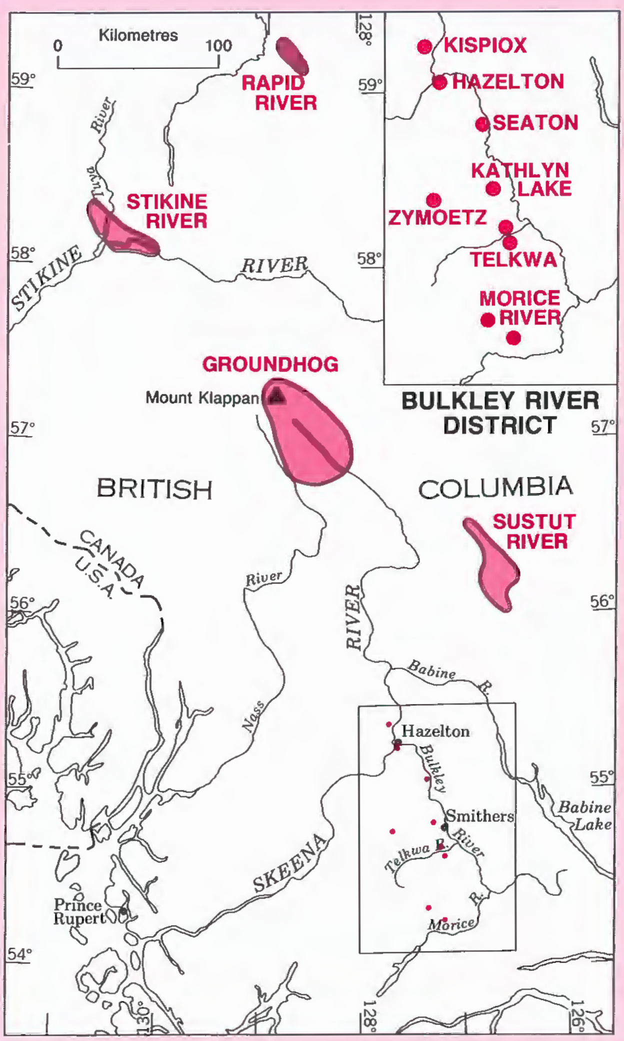


Figure 5.2. Coal districts and coalfields of the northern Intermontane Region of British Columbia.

The type of clastic sediments and the megascopic and microscopic nature of the coal seams in the Telkwa River area indicate that coal originated in a swamp-marsh environment associated with a lake basin (Hacquebard et al., 1967).

Northerly- to northwesterly-trending high angle normal and reverse faults commonly disrupt the coal measures. Younger northeasterly- to easterly-trending faults further complicate the geology. Strata generally dip gently to the northeast and southwest, and broad open folds have developed (Koo, 1984). A major Upper Cretaceous intrusion (Bulkley Intrusion) cuts the coal measures at the north end of the coalfield (Koo, 1983).

The following seven coal deposits in the Bulkley River District (Fig. 5.2) apparently occur within erosional remnants of the original Skeena Basin, and have been explored and exploited to varying degrees (Domage Campbell & Associates Ltd., 1975). No mines are currently operating in the coalfield:

1. Telkwa River (Goathorn Creek and Pine Creek)
2. Zymoetz River (or Coal Creek)
3. Morice River (Chisholm Lake, Clark Fork, Goldstream)
4. Kispiox (Skeena, Shegunia Creek)
5. Hazelton (Cedar Creek)
6. Seaton
7. Kathlyn Lake

SUSTUT RIVER COALFIELD

The occurrence of lignitic coal seams along the Sustut River was first reported by Malloch (1914). Low to high volatile bituminous coals, and some of subbituminous rank, near the Sustut River, have recently been explored (Fig. 5.2). Coal deposits in the Jurassic-Cretaceous strata of the upper Bowser Lake Group and the Upper Cretaceous Tango Creek Formation (Fig. 5.1) have potential economic significance in the area (Schroeter and White, 1985).

The coalfield is located at the eastern margin of the Bowser Basin where strata of the Sustut Group overlie those of the Bowser Lake Group (Fig. 5.1). The coal-bearing strata were probably laid down in deltaic and alluvial plain environments while marine strata of the Skeena Group were deposited (Eisbacher, 1974c). These strata have been intensely folded and faulted.

SUSTUT AND SIFTON BASINS

The Sustut and Sifton basins are two parallel basins located on the eastern side of the Bowser Basin (Fig. 5.1). The Sustut Basin is located in the narrow belt between the Skeena and Omineca Mountains. It contains Upper Cretaceous nonmarine clastic deposits within which thin seams of relatively low rank coal occur. The Sifton Basin, which contains strata of Tertiary age, is preserved in, or near, the Rocky Mountain Trench, northeast of the Omineca Mountains. A major southwesterly-dipping thrust fault that strikes across the northeast corner of the Sustut River Coalfield is probably a continuation of the Omineca and Pinchi fault zones (Gabrielse and Wheeler, 1961). It delimits the southwestern border of the Sustut Group to the north.

The nonmarine clastic sequences were deposited in these basins during the uplift of the Columbian and Pacific orogens. Folding and thrust faulting of the strata reflect the interaction between the two orogenic belts. Although several occurrences of coal within the Sustut Group and correlative units have been reported, and deposits near the Sustut River have been recently explored, the thin seams of poor quality (i.e. high ash content) coals are not considered commercially significant. A single analysis of coal from the Sifton Basin, reported by Hedley and Holland (1941, p. 43), indicates a rank of high volatile B bituminous. An analysis of coal from the Tuya River area, in the Stikine District to the north (Fig. 5.2), indicates a similar rank and quality (Dowling, 1915b, p. 325).

TABLE 5.1

COAL RESOURCES OF IMMEDIATE INTEREST NORTHERN INTERMONTANE BRITISH COLUMBIA

Coalfield / Deposit	Predominant Rank	measured	indicated (megatonnes)	inferred
Groundhog				
Mt Klappan				
Evans Creek				
Panorama				
Groundhog				
	lvb-an	100	500	1000
Bulkley River				
Telkwa				
Zymoetz				
Morice				
Kispiox				
Seaton				
Kathlyn Lake				
	h-mvb	30	50	100
TOTALS	lvb-an	100	500	1000
	h-mvb	30	50	100

Estimated coal resource quantities are based mainly on information from the British Columbia Geological Survey Branch (W. Kilby, pers. comm., 1987), Dolmage Campbell and Associates Ltd. (1975), and MacKay (1947). Coal resource information for separate deposits is often proprietary and confidential and, therefore, only totals by coalfield are shown.

LABERGE BASIN

The sedimentary sequence preserved in the Laberge Basin of northwestern British Columbia comprises mainly Lower and Middle Jurassic shelf-slope marine deposits referred to as the Laberge Group (Fig. 5.1; Souther, 1971). The Lower Jurassic deposits that contain minor coal represent nearshore facies. The Middle Jurassic strata represent offshore facies (Dolmage Campbell & Associates Ltd., 1975). Toward the end of Laberge deposition, return to a quiet, shallow marine environment is indicated by the presence of "calcareous shales, argillaceous limestone and a few beds of resinous coal" (Eisbacher, 1974a). No commercially significant coal occurrences have been reported within these deposits.

RESOURCE QUANTITIES

Coal resource quantities have been estimated for some deposits in the Groundhog and Telkwa coalfields (Table 5.1). Information regarding several other known coal occurrences is insufficient to speculate on potential resource quantities.

COAL QUALITY

The rank of coals in the northern Intermontane Region ranges from lignitic to anthracitic. The coals that have potential commercial significance, however, are classified in the range of high volatile bituminous to anthracitic. General coal characteristics for some of the deposits are indicated in Table 5.2.

In their report on the Groundhog Coalfield, Buckham and Latour (1950) tabulated 108 proximate analyses of coals sampled from surface and adit exposures throughout the coalfield. They commented on the need to wash any potential run-of-mine coal to yield a saleable product, and on the tendency of the coals to size-degrade seriously when handled. Although mainly anthracites were sampled, rank extremes range between low volatile bituminous and meta-anthracite.

The rank of most coals in the Telkwa Coalfield is in the range of high to medium volatile bituminous. Anthracitic coals, however, occur in the Kathlyn Lake deposit (Kindle, 1940; Nicolls, 1952).

Dowling (1915b) reported the analyses of coal samples from many deposits in the northern Intermontane Region of British Columbia, including those from the Groundhog, Telkwa and Sustut areas. The partial proximate analyses indicate general characteristics of the coals and variations of the analyzed attributes between deposits. The coal characteristics shown in Table 5.2 provide an indication of coal attributes for general regional considerations.

TABLE 5.2

GENERAL COAL QUALITY CHARACTERISTICS NORTHERN INTERMONTANE REGION OF BRITISH COLUMBIA

	Groundhog	Telkwa
Proximate analysis		
(per cent by weight)		
moisture (as received)	4	4
ash (dry)	24	10
volatile matter (d.a.f.)*	10	30
fixed carbon (d.a.f.)	90	70
Heat value (d.a.f.) MJ/kg	35.0	34.5
Ultimate analysis (dry, ash-free)		
(per cent by weight)		
carbon	-	86.7
hydrogen	-	4.8
nitrogen	-	0.9
sulphur	0.8	1.1
oxygen	-	6.5
Analysis of ash		
(per cent by weight)		
SiO_2	-	60.0
Al_2O_3	-	25.0
Fe_2O_3	-	4.0
CaO	-	3.0
MgO	-	1.0
MnO	-	-
Na_2O	-	0.5
K_2O	-	0.5
P_2O_5	-	0.5
TiO_2	-	1.0
SO_3	-	3.0
undetected	-	1.5
Properties		
free swelling index	-	1-2.5
caking index (Gray)	-	13
grindability index (Hardgrove)	-	70
ash softening temp. (reduce-°C)	-	1450
Rank classification (ASTM)	sa-an	h-mvb

*dry, ash-free

Values shown for the Groundhog Coalfield are an approximate average of analyses reported by Buckham and Latour (1950). Values shown for the Telkwa Coalfield are from Swartzman (1953) and Nicolls (1952). All values are intended only as an indication of general coal quality characteristics that might be expected in these coalfields.

SOUTHERN INTERMONTANE REGION

INTRODUCTION

Commercially significant coal deposits occur within Tertiary strata of the southern Intermontane Region of British Columbia. Coal occurrences were reported by the early settlers who mined small amounts for local consumption. By 1910, annual production of coal in the Princeton area exceeded 10 000 tonnes (Shaw, 1952a). The principal coal deposits of potential commercial importance include the following (Fig. 5.3):

- Similkameen District
  - Princeton Coalfield
  - Tulameen Coalfield
- Nicola District
  - Merritt Coalfield
  - Quilchena Coalfield
- Hat Creek Coalfield
- Cariboo District
  - Quesnel Coalfield
- Bowron River Coalfield

Other coal deposits in the region, including those near Kamloops, White Lake and Chu Chua (Dowling, 1915b), are either substantially less extensive, or are insufficiently known to allow speculation of coal resource potential.

Development and evolution of the coal-bearing sedimentary basins in the region were largely tectonically controlled. Several of the coal occurrences were deposited within fault-controlled graben-like structures. Some coal measures exist as erosional remnants of larger sedimentary basins.

The rank of the Tertiary coals ranges from lignitic to high volatile bituminous. They are non-coking and might generally be considered suitable to fuel conventional thermal electric generating plants. Coal characteristics of the separate deposits, and within a deposit, can vary widely. A significant portion of the resource is surface mineable, although underground extraction techniques would likely have to be considered for mining some of the deposits.

The major coal measures of the region, are of middle Eocene age, with the exception of those in the Quesnel (Fraser River Formation) and Bowron River coalfields, which are late Eocene or younger (Fig. 5.1). The Allenby Formation, which comprises mainly fluvial and lacustrine sediments, hosts the coal measures of the Princeton and Tulameen coalfields in the Similkameen District (Shaw, 1952a, 1952b; Rice, 1960). The coal measures in the Nicola District and in the Hat Creek Coalfield are associated with the fluvial and lacustrine Coldwater Formation, although the upper coal-bearing succession at Hat Creek has been separately assigned to the

Hat Creek Formation. Coal deposits of the Bowron River Coalfield are contained within the lower portion of a younger sequence of shale, sandstone and conglomerate beds, which may be age-equivalent to the Sifton Formation in the Rocky Mountain Trench (Graham, 1979). The youngest significant coal deposits of the region occur within the Fraser River Formation (Oligocene-Miocene) in the Quesnel Coalfield.

Many of the coal deposits of the region, including those in the Hat Creek, Quesnel, Chu Chua and Bowron River areas, originated in strike-slip controlled fault basins. Favourable environments for the accumulation of peat often formed near the distal fringes of fan systems and shallow lacustrine settings. Tectonics not only controlled syndepositional basin development, but also postdepositional deformation and coalification history of the coal measures (Long, 1981).

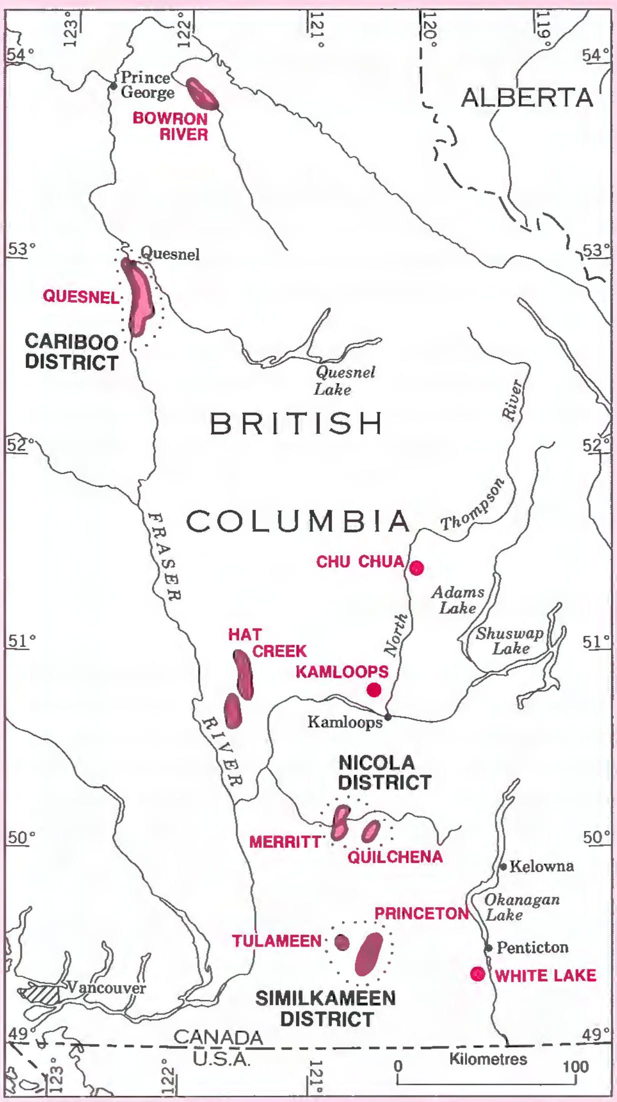


Figure 5.3. Coal districts, coalfields and coal deposits of the southern Intermontane Region of British Columbia.

PRINCETON COALFIELD
(Similkameen District)

The Princeton Coalfield is located in the readily accessible region of southern British Columbia centred about the town of Princeton (Fig. 5.3). Coal was first reported in the area in 1860. Mining began in 1909, and in 1942 the annual production rate peaked at about 112 000 tonnes. Since 1951 there has been virtually no mining and only limited exploration in the coalfield.

The coal-bearing Allenby Formation is preserved in a northerly-elongated basin, which underlies an area of 170 square kilometres. The thickest coal seams occur near the middle of the formation within the southern half of the basin. Four coal zones exist within a 520 m thick stratigraphic interval. Each zone contains beds of coal separated by clastic sediments. The lowest zone has been the most productive. Although seams up to 15 m thick have been recorded, there is considerable lateral thickness variability (Shaw, 1952a; Graham, 1979).

Coal seam correlations within the coalfield are uncertain because of the lateral variability of associated facies and the structural complexity of the basin. Previous mining activities were often complicated by rapid lateral variations of seam thickness, bentonite partings within mining horizons, folding and faulting of strata, and weak roof and floor strata enclosing the seams (Hughes, 1947).

Ranks within the coalfield range from lignitic to high volatile B bituminous. Previous mining operations exploited coals classified between subbituminous A and high volatile C bituminous (Rice, 1960). It has been reported that the coal is particularly susceptible to spontaneous combustion (Shaw, 1952a). Some of the general coal characteristics are shown in Table 5.4.

TULAMEEN COALFIELD
(Similkameen District)

The Tulameen Coalfield is located 20 km northwest of Princeton in a northwesterly-elongated basin which underlies an area 5 km long and 3 km wide (Fig. 5.3). It has been suggested, on the basis of dating and micro-flora similarities, that strata in the Tulameen Basin are correlative with those of the Princeton Basin (Camsell, 1913, p. 97-98; Hills, 1965). Although occurrences of coal in the region were known since 1885, they were not commercially exploited until 1919. Except in 1954, when about 210 000 tonnes of coal were extracted from an old mine pillar by surface mining, there has been essentially no coal production since 1940 (Dolmage Campbell & Associates Ltd., 1975). Annual production from the coalfield prior to 1940 reached a maximum of about 165 000 tonnes in 1928 (Rice, 1960). A total of about 2.1 megatonnes of coal have been produced from the coalfield.

The sedimentary succession within the Tulameen Basin had a predominantly fluvial-lacustrine origin and is assigned to the Allenby Formation (Fig. 5.1). It comprises three distinguishable units within a total interval of 840 m. The lower unit is about 200 m thick and comprises mainly sandstones interbedded with thin bands of shale. Within the middle unit the coal-bearing member is about 140 m thick and is readily identifiable by its characteristic assemblage of fine-grained, mainly shaly, sedimentary rocks (Shaw, 1952b). The upper unit is composed mainly of sandstone with thin shale bands and conglomerate beds.

Two coal zones occur in the middle unit. The upper zone averages 15 to 20 m thick and the lower averages 7 to 8 m thick. Coal beds range in thickness from a few centimetres to more than 9 m. In the Blakeburn Strip Mine, the coal zone is greater than 27 m thick (Donaldson, 1973). Descriptions of faulting, folding and sheared coal (Shaw, op. cit.) indicate that the zone has probably been tectonically thickened in this area. Partings of bentonite, shale and mudstone separate these beds within the coal zones. In the northern end of the basin the upper zone is interbedded and intruded by igneous rocks. This has resulted in locally charred coal and precipitation of minerals, including pyrite, in the coal. Bedding-plane thrust faults have complicated the zone and possibly exaggerated its thickness in the southern end of the basin (Williams and Ross, 1979).

The general structure of the coalfield is a southeasterly-plunging syncline with both limbs dipping about 45°. Toward the southeast, the syncline is asymmetrical with the southwest limb flattening to a dip of about 20°. The extent to which the basin is faulted is uncertain but conjugate northwesterly- and northeasterly-trending surface lineaments are believed to be high angle faults (Evans, 1978). Previous underground mining encountered faults that offset the coal beds. Coal has been mined only along the shallower dipping southwestern margin of the coalfield.

The rank of Tulameen coals ranges from high volatile C bituminous to high volatile B bituminous. The overall higher rank of these coals, with respect to other coals of similar age in the region, has been attributed to an abnormally high geothermal gradient caused by volcanic activity. Rank variations within the coalfield are due to variable depths of burial in conjunction with the relatively high geothermal gradient (Donaldson, 1973). Like other coals of similar age in the region, potentially mineable coal zones tend to be high in ash content. The coals have often been described as "crushed". Table 5.4 indicates some general characteristics of these coals.

MERRITT COALFIELD
(Nicola District)

Coal occurrences in the vicinity of Merritt (Fig. 5.3) were first reported by Dawson (1878). The deposits have been extensively explored and mined. About 2.4 megatonnes of coal were produced from the Merritt Coalfield between 1906 and 1963.

The Tertiary coal-bearing sedimentary rocks, which are assigned to the Coldwater Formation (Fig. 5.1), occupy a northeasterly-trending depression underlain by Triassic volcanics, 11 km in length and 5 km in width. Correlation of strata within the succession is difficult because of rapid lateral variations in rock types and faulting and folding (White, 1947). Reliable definition of the coal measures requires relatively closely spaced geological data. Thick till covers much of the area, resulting in only sparse exposures of the coal-bearing strata. Tight folds and steeply dipping strata characterize the structure of the measures at the western margin of the coalfield where mining took place (Cockfield, 1944).

Several small outliers of Coldwater beds south of Merritt have been reported (Cockfield, op. cit.). Also, coal-bearing strata that are probably age-equivalent to the Coldwater beds near Merritt, occur in the Quilchena Creek area, 20 km to the east.

The rank of coal in the Merritt Coalfield ranges from high volatile C bituminous to high volatile A bituminous. Coal quality is variable among the deposits and seams of the southern Intermontane Region (Dolmage Campbell & Associates Ltd., 1975). Some of the general coal characteristics are indicated in Table 5.4.

HAT CREEK COALFIELD

Thick beds of coal along Hat Creek in south-central British Columbia (Fig. 5.3) were first reported in 1879. Intensive exploration of the coalfield in recent years indicates the existence of in excess of 2 billion tonnes of lignitic to subbituminous coal. The Hat Creek Coalfield contains the world's thickest known coal deposit, and probably the greatest concentration of coal (Campbell et al., 1977).

The northerly-trending upper Hat Creek valley is underlain by Tertiary sediments and volcanic rocks contained within a graben that measures about 25 km long and 4 km wide.The fault-bounded intermontane depression within which the coal measure originated is similar to other Tertiary basins in the southern Intermontane Region, such as the Bowron River Coalfield (Church, 1977). The coal measure is a 350 to 550 m thick succession named the Hat Creek Formation. It is situated above the mainly fluvial sediments of the Coldwater Formation and below the mainly lacustrine sediments of the Medicine Creek Formation (Fig. 5.1). Although the Hat Creek Formation comprises predominantly low rank coals, about 30 per cent of the succession consists of clastic sediments that range from claystones to pebble conglomerates (Campbell et al., op. cit.) Two areas of the coalfield, referred to as No. 1 Deposit (original discovery area) and No. 2 Deposit (centred 8 km south of No. 1), have been recently explored.

The thick accumulations of coal apparently originated in limnic environments that must have been generally favourable for the accretion of peat throughout a period of about 1.7 to 2.5 million years (Long, 1981). Equilibrium conditions between deposition and basin subsidence, required to maintain suitable peat-forming environments, were probably controlled by downfaulting movements of the hosting graben. Periodic imbalances in these conditions resulted in the deposition of clastic sediments on the coal-forming swamps.

The graben is bounded by northerly-trending oblique-slip faults. These faults were locally offset by younger northwesterly- and northeasterly-trending wrench faults. Although the No. 1 and No. 2 deposits are within somewhat different structural domains, the general configuration of the coal measure is characterized by gentle, open folds (Church, 1977). Block faulting and associated structures within the coalfield limit the degree to which geological data can be reliably extended.

The rank of Hat Creek coals varies from lignitic to subbituminous A. Coal rank indicators show that most coalification took place after folding, resulting in sub-horizontal isoranks within the coalfield (Marchioni, 1985). Quality, as expressed by proximate analysis, varies significantly throughout the coal measure. The values shown in Table 5.4 provide an indication of some of the coal characteristics.

QUESNEL COALFIELD
(Cariboo District)

Coals that range in rank between lignitic and subbituminous B occur in the Tertiary (Oligocene-Miocene) Fraser River Formation (Fig. 5.1) that is exposed along the Fraser River between Prince George and Alexandria Ferry, about 38 km south of Quesnel (Fig. 5.3).

These occurrences were first reported by Dawson (1877); they have been subsequently explored in a reconnaissance fashion only, and no mining has been recorded. In 1979, the Geological Survey of Canada drilled three continuous core holes in the coal-bearing strata near Quesnel (Graham, 1979). The most commercially promising coal potential appears to be restricted to the area south of Quesnel (Graham, 1978).

TABLE 5.3

COAL RESOURCES OF IMMEDIATE INTEREST SOUTHERN INTERMONTANE BRITISH COLUMBIA

District Coalfield	Predominant Rank*	measured	indicated (megatonnes)	inferred
Similkameen District				
Princeton	sub-hvb	-	10	100
Tulameen	sub-hvb	20	60	160
Nicola District				
Merritt	hvb	10	20	40
Quilchena	sub-hvb	-	-	10
Hat Creek Coalfield	lig-sub	440	300	200
Cariboo District				
Quesnel	lig-sub	10	20	70
Bowron River	hvb	10	30	30
TOTALS	sub-hvb	40	120	340
	lig-sub	450	320	270

*totals by general rank class

Estimated coal resource quantities are based mainly on information from the British Columbia Geological Survey Branch (W. Kilby, pers. comm., 1987), Dolmage Campbell and Associates Ltd. (1975), and MacKay (1947).

The Fraser River Formation comprises deposits that originated mainly in fluvial, lacustrine and alluvial fan environments. It consists of a lower member (Oligocene) and upper member (Miocene) that are separated by an angular unconformity of commonly less than 20°, but up to 55°. The lower member, exposed along the Fraser River south of Quesnel, contains the major coal zones within a 360 m succession of mainly claystone with lesser amounts of sandstone and conglomerate. The coal zones are lenticular, highly variable in thickness over short distances, and commonly contain many clay partings (Graham, 1978). One zone is reportedly 21.9 m thick. The upper member, exposed along the Fraser River north of Quesnel, comprises at least 200 m of weakly indurated massive conglomerates and sandstones grading up to siltstones and claystones with occasional diatomaceous clay, and coal (Graham, op. cit.). Poorer coal development in the upper member might be attributable to a change in climatic conditions during its deposition, from conditions that prevailed during deposition of the lower member.

The lower member of the Fraser River Formation is characterized by broad folds with beds generally dipping between 10° and 30°. The upper member of the formation is relatively undeformed, with characteristic dips of less than 4° that are apparently related to depositional paleoslope rather than tectonism (Graham, 1979).

BOWRON RIVER COALFIELD

Coal occurrences along the Bowron River, approximately 45 km east of Prince George (Fig. 5.3), were first reported by Dawson (1878). The coalfield has been explored to varying degrees, and two small mines resulted in limited coal production.

Coal deposits of the Bowron River Coalfield occur in the lower portion of an unnamed Tertiary sequence (late Eocene or younger; A.R. Sweet, pers. comm., 1987). It comprises shale, sandstone and conglomerate beds that may be up to 700 m thick (Klein, 1978). The coal zone, which is up to 35 m thick and comprises variable proportions of coal and claystone, appears to be restricted to the lower part of the succession.

The coal measure was deposited in a northwesterly-elongated graben that measures about 25 km long and 2.5 km wide. Coal beds, which are often lenticular and attain thicknesses of 1.5 to 3.5 m, have an aggregate thickness of up to 12 m. Coal probably originated in limnic swamps near the shores of a shallow lake.

The basin is generally asymmetric with strata dipping moderately to the northeast (Holland, 1949). The coal measure is significantly faulted and folded (British Columbia Ministry of Energy, Mines and Petroleum Resources, 1976, 1978). The depth of the coal deposits indicates that extraction by underground mining methods would appear to be necessary.

Although analyses of coals in the Bowron River Coalfield indicate a high volatile C bituminous rank, slightly higher ranks (high volatile B bituminous) have recently been reported. Highly variable ash contents within coal zones are attributed to numerous clay and shaly layers up to 20 cm thick (Holland, op. cit.). Table 5.4 indicates general characteristics of the coals.

TABLE 5.4

GENERAL COAL QUALITY CHARACTERISTICS SOUTHERN INTERMONTANE REGION OF BRITISH COLUMBIA

	1	2	3	4	5	6
Proximate analysis* *(per cent by weight)						
moisture (as received)	20	10	6	25	25	6
ash (dry)	10	10	15	30	30	13
volatile matter (d.a.f.)*	42	38	40	51	51	41
fixed carbon (d.a.f.)	57	62	60	49	49	59
Heat value (d.a.f.) MJ/kg	30.6	32.0	32.5	27.0	27.0	31.3
Ultimate analysis (dry, ash-free)* *(per cent by weight)						
carbon	76.0	84.5	80.0	71.5	-	-
hydrogen	5.0	5.0	5.5	5.0	-	-
nitrogen	2.2	1.8	1.9	1.7	-	-
sulphur	0.8	0.5	0.6	1.0	0.5	1.5
oxygen	16.0	8.2	12.0	20.8	-	-
Properties						
free swelling index	0	0	0	0	-	-
caking index (Gray)	0	0	0	0	-	-
grindability index (Hardgrove)	39-45	39-45	57-59	-	-	-
ash softening temp. (reduce-°C)	1200	1200	1450+	1500+	-	-
Rank classification (ASTM)	subB/A	hvbC	hvbC/B	ligA/ subC	ligA/ subC	hvbC

*dry, ash-free

1 Princeton Coalfield (Similkameen District)
2 Tulameen Coalfield (Similkameen District)
3 Merritt Coalfield (Nicola District)
4 Hat Creek Coalfield
5 Quesnel Coalfield (Cariboo District)
6 Bowron River Coalfield

These generalized coal characteristics result from the synthesis and consideration of information from Holland (1949), Nicolls (1952), Swartzman (1953), Williams and Ross (1979) and Graham (1979). Values do not necessarily result from representative sampling of deposits and, therefore, are intended only as an indication of general coal characteristics that might be expected in the major coal deposits.

RESOURCE QUANTITIES

Resource quantities have been compiled for those coalfields that have sufficient available information (Table 5.3). These coalfields probably have greatest commercial potential in the region.

COAL QUALITY

The rank of coals in the southern Intermontane Region ranges from lignitic to high volatile bituminous. The quality of the coals varies significantly among the deposits and within each deposit. Graham (1979) compiled available coal quality information for most major deposits in the region. This compilation, supplemented by additional information, is the primary basis for values provided in Table 5.4, which indicates some general characteristics of coals within the major coalfields.

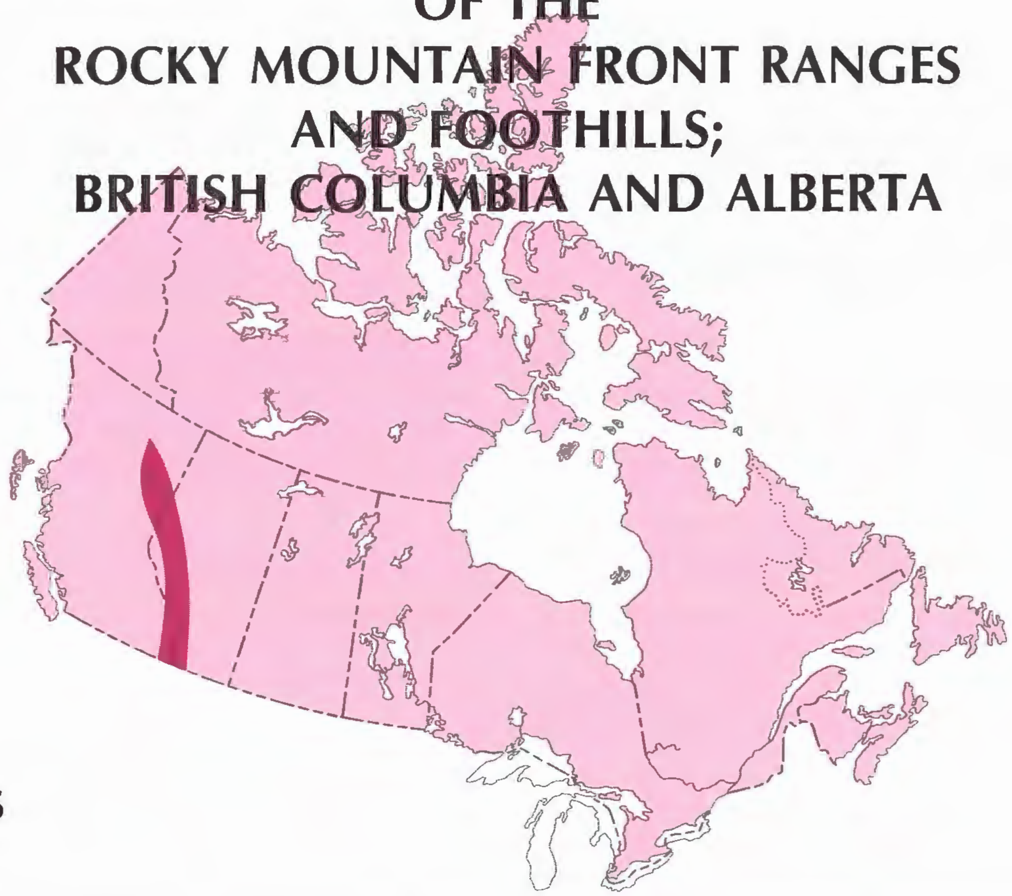
FRONT RANGES
(Line Creek Mine, B.C.)

INNER FOOTHILLS
(Luscar Mine, Alberta)

OUTER FOOTHILLS
(Coalspur, Alberta)

CHAPTER 6

COAL RESOURCES OF THE ROCKY MOUNTAIN FRONT RANGES AND FOOTHILLS; BRITISH COLUMBIA AND ALBERTA



FEATURES

COAL RESOURCES OF THE ROCKY MOUNTAIN FRONT RANGES AND FOOTHILLS; BRITISH COLUMBIA AND ALBERTA

INTRODUCTION

More than 95 per cent of Canada's bituminous coal resource is contained within the Rocky Mountain Front Ranges and Foothills of British Columbia and Alberta. Coal deposits have long been known to exist in the belt that extends almost 1200 km northwestward along the eastern side of the Rocky Mountains, from just north of the United States border to about latitude 58° North (Fig. 6.1). Nearly 50 per cent of the nation's total coal production, including 97 per cent of its metallurgical coal, is currently (1987) produced in the region.

The region is divisible into three geologically, physiographically and geographically distinct coal-bearing subdivisions (Fig. 6.1) — Rocky Mountain Front Ranges, Inner Foothills Belt and Outer Foothills Belt. The Rocky Mountain Front Ranges are characterized by thrust sheets of mainly Upper Paleozoic carbonates bounded by faults that extend for tens of kilometres in length and have displacements up to several kilometres. Subsidiary thrusts, tear faults and folds have further deformed individual sheets (Dahlstrom, 1970). Jurassic-Cretaceous coal measures occur in the Rocky Mountain Front Ranges of southeastern British Columbia and southwestern Alberta.

Deformed Mesozoic and some Cenozoic clastic rocks that extend from the Front Ranges to the eastern edge of the Disturbed Belt constitute the Rocky Mountain Foothills. The belt of relatively high relief along the western Foothills, produced by resistant sandstones of Early Cretaceous age, has been referred to as the Inner Foothills (MacKay, 1947; Dahlstrom, 1970). Lower Cretaceous coal measures are contained within the Inner Foothills Belt of northeastern British Columbia and west-central Alberta.

East of the Inner Foothills, the topographically distinct belt of relatively low relief, produced by the more shaly Upper Cretaceous and Tertiary rocks, has been referred to as the Outer Foothills (MacKay 1947; Dahlstrom, 1970). Upper Cretaceous and Tertiary coal measures underlie the Outer Foothills Belt of west-central Alberta.

Coal-bearing strata throughout the region were deposited in deltaic and alluvial plain environments near the western margin of the Western Canada Sedimentary Basin. The Jurassic-Cretaceous Kootenay Group, which contains major coal deposits in southeastern British Columbia and southwestern Alberta, was deposited during the first of two major episodes of the Columbian Orogeny. The Lower Cretaceous Bullhead and Fort St. John groups of northeastern British Columbia, and Luscar Group of west-central Alberta, contain the major coal deposits in the Inner Foothills Belt, and partially represent a second pulse of the orogeny. Deposition of the Belly River Formation and Saunders and Wapiti groups, which contain major coal deposits of the Outer Foothills Belt, began during the Late Cretaceous early phase of the Laramide Orogeny (Stott, 1983).

Tectonism associated with the mountain building has often resulted in highly faulted and folded coal measures within the Rocky Mountain Front Ranges and Inner Foothills Belt. The coals are mainly medium and low volatile bituminous in rank, generally suitable for producing a high quality metallurgical coke. In the Outer Foothills, coal deposits are usually less deformed and commonly contain high volatile bituminous thermal coals.

SOUTHERN ROCKY MOUNTAIN FRONT RANGES

INTRODUCTION

About half of Canada's measured medium and low volatile bituminous coal resources occurs in the Jurassic-Cretaceous Kootenay Group within the East Kootenay, Crowsnest, Cascade and Panther River-Clearwater coal districts in the Rocky Mountain Front Ranges of southeastern British Columbia and southwestern Alberta (Fig. 6.2). Some of the resources of the Kootenay Group also occur in the Inner Foothills of southwestern Alberta (e.g. Beaver Mines Coalfield); however, for convenience in this report, they are discussed with coals of the Crowsnest District in the Rocky Mountain Front Ranges. Coal deposits were observed on the eastern flanks of the Rocky Mountains by European trappers in the early 1800's. Although word of immense coal reserves resulted from the prospecting of coal outcrops by a Hudson Bay Company employee in 1873 and 1874 (Newmarch, 1953; Crabb, 1962), geological examinations did not begin until 1883 (Dawson, 1886). Within a few years, construction of the transcontinental railway branches through both the Kicking Horse and Crowsnest passes provided both access to the coal and a ready market. The first mining operations began in 1884, in the Cascade Coal District near Banff. Coal mining in the district continued until 1979 when the last operations ceased near Canmore. Coal mining in the Crowsnest Coal District began in the vicinity of Blairmore and Coleman in 1899 and continued until closure of operations at Coleman Collieries in 1981. Coal was first mined

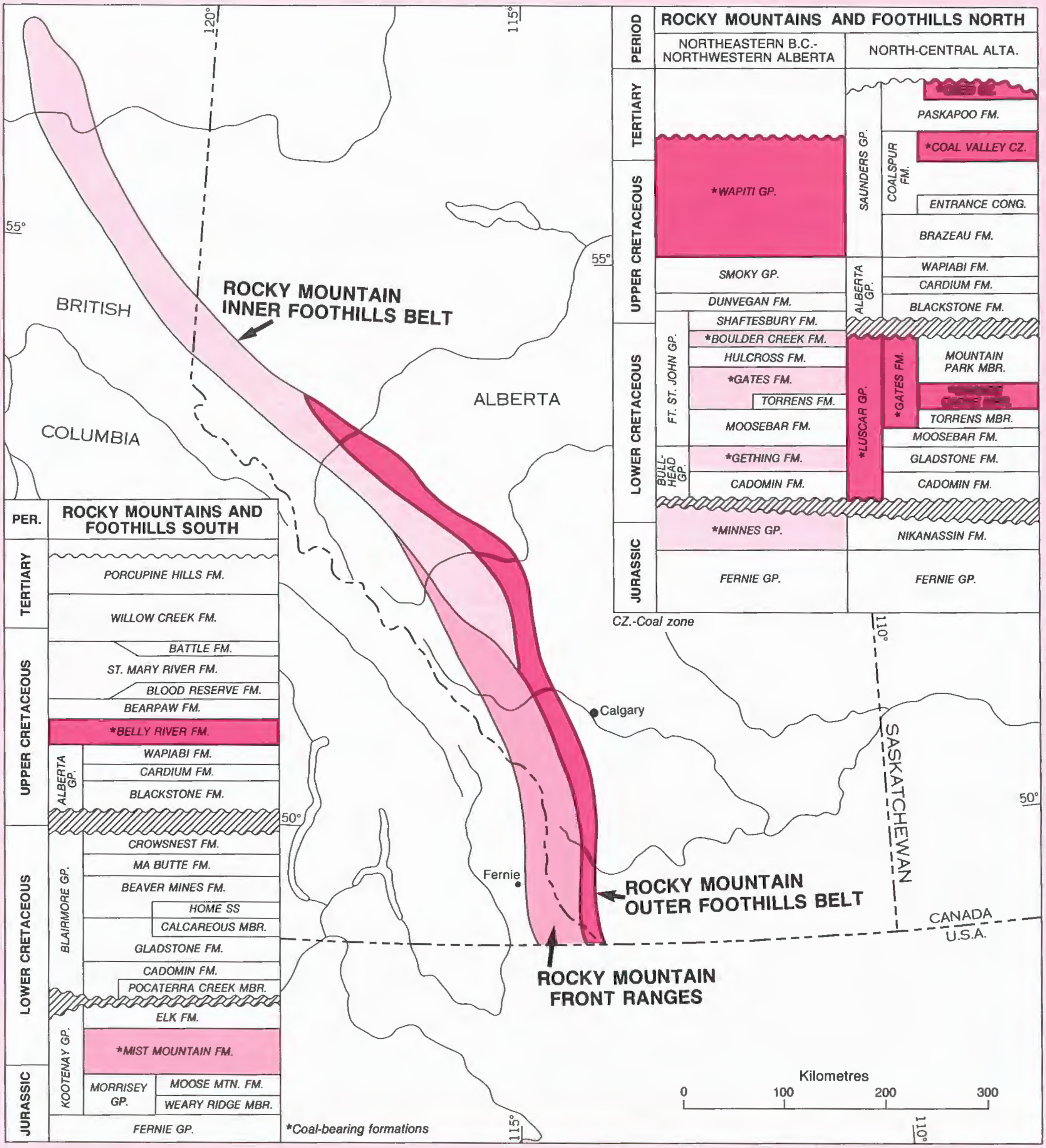


Figure 6.1. Regional subdivisions for major coal-bearing formations in the Rocky Mountain Front Ranges and Foothills of British Columbia and Alberta.

in the East Kootenay Coal District in 1898, at Coal Creek near Fernie, and all current mining operations in the region are within this district (Fig. 3.7). In 1986, the five operating mines (Balmer, Greenhills, Fording River, Line Creek and Coal Mountain) produced nearly 13 megatonnes of saleable coal, of which about 11 megatonnes represented nearly one-half of Canada's total metallurgical coal production. Nearly 2 megatonnes of saleable thermal coals were produced. Although mining in the past has been by both surface and underground means, only open pit mines are currently operating.

The Kootenay Group, which is up to 1112 m thick, is believed to have been deposited within a broad coastal plain as part of a northerly- to northeasterly- prograding clastic wedge along the western margin of the Jurassic-Cretaceous epicontinental Fernie Sea (Fig. 3.4a; Gibson, 1985a). It comprises the Morrissey, Mist Mountain and Elk formations, of which the Mist Mountain is the most important (Fig. 6.1). Coal beds within the Mist Mountain Formation are up to 18 m thick and generally vary in rank between high and medium volatile bituminous in the south, and between low volatile bituminous and semianthracite in the north. Thinner and less persistent beds of generally lower rank coal occur in the Elk Formation, and no commercially significant coal beds occur in the Morrissey Formation (Gibson, op. cit.).

During the Laramide Orogeny in Late Cretaceous and early Tertiary time, geological formations were faulted and folded as the Rocky Mountains were uplifted. The deformation segmented the Kootenay Group into the distinct domains of the East Kootenay, Crowsnest, Cascade and Panther River-Clearwater coal districts (Fig. 6.2). The East Kootenay Coal District is mainly within southeastern British Columbia. It is in the hangingwall of the Lewis thrust plate and extends about 175 km northward from near the U.S. border. The Crowsnest Coal District is entirely within southwestern Alberta. It lies between the Lewis and Livingstone thrusts, and extends 150 km northward from Beaver Mines (Fig. 6.2). The Cascade Coal District is also entirely within southwestern Alberta. It is in the immediate footwall of the northwest-trending Rundle Thrust, and extends about 35 km northwest and southeast from Canmore. Several remnants of Kootenay Group are exposed north of the Cascade Coal District. Coal-bearing units occur in the Panther River-Clearwater Coal District, although none has been commercially exploited.

Faulting and folding have profoundly influenced the mineability and quality of the coal (Norris, 1966). The deformation has resulted in shearing, pinching, swelling and imbrication of coal beds, and thickening of coal in the cores of some flexures (Norris, 1958). Major faults have resulted in the repetition of the Kootenay Group and have brought coal measures within access of modern mining methods. They have greatly increased the economic potential of the Kootenay Group (Gibson et al., 1983). In some cases, thrust plates increased burial depths of coals, which may have resulted in significantly higher coalification levels (ranks) than would otherwise exist (Hughes and Cameron, 1985). Coal ranks increase with stratigraphic depth in the Mist Mountain Formation (Hilt's law), and there is a general tendency for coal rank within correlative strata to increase northward through the region.

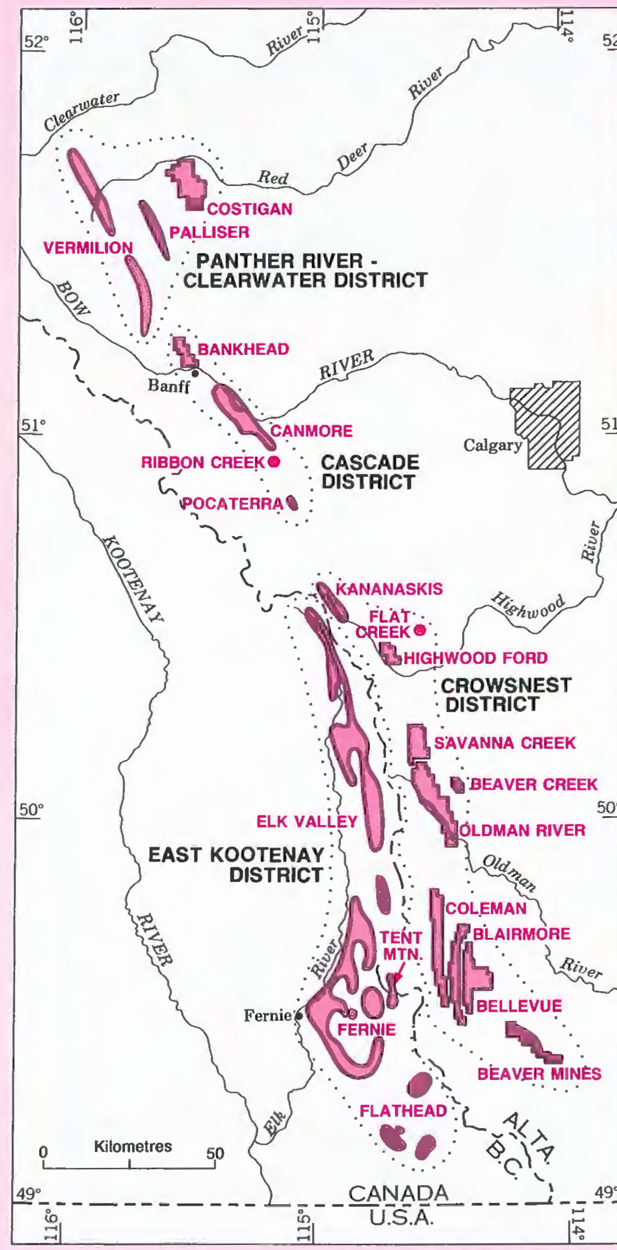


Figure 6.2. Coal districts and coalfields of the southern Canadian Rocky Mountain Front Ranges.

EAST KOOTENAY COAL DISTRICT

All current mining operations in the southern Rocky Mountain Front Ranges are within the East Kootenay Coal District. This district comprises three structurally separate coalfields named Flathead Coalfield, Fernie Basin (often referred to by others as 'Crowsnest Coalfield') and Elk Valley Coalfield (Fig. 6.2). Individual deposits within the coalfields are limited by geological, physiographic or legal (lease ownership) factors; the terms 'deposit' and 'property' have often been used synonymously. Coal exploration and mining activities in the district have been continuous since the late 1800's. During the mid-1960's, major expansions in coal production began in response to increasing demands for high quality coking coals from a rejuvenating post-war Japanese steel industry.

Commercially significant coal occurs within the interstratified sequence of siltstone, silty shale, mudstone, sandstone and conglomerate that constitute the Mist Mountain Formation (Gibson, 1977a). Stratigraphic thickness of the Mist Mountain Formation ranges from less than 240 m to nearly 1000 m, with an average thickness of 500 to 600 m (Grieve, 1985). Coal beds comprise 8 to 12 per cent of the total stratigraphic thickness (Grieve, op. cit.) and attain thicknesses in excess of 18 m. Substantially greater coal thicknesses, such as those of the Mammoth Seam near Corbin (The Big Showing, up to 120 m thick), have been reported in structurally deformed areas (MacKay, 1931; Grieve, 1985). Of at least 14 coal beds which have been mined, most occur in the lower part of the formation where the beds tend to be thicker and more persistent (Gibson, 1977a).

The East Kootenay coalfields are structurally and/or erosionally discontinuous remnants of the coal-bearing Mist Mountain Formation within the Lewis thrust plate. The coal-bearing strata are preserved within the structurally depressed areas of synclines, synclinoria and down-dropped fault blocks (Ollerenshaw, 1981; Grieve, 1985). The extensive deformation of these strata by folding, thrust (contraction) faulting and normal (extension) faulting of various magnitudes has both enhanced the economic potential of the district, and complicated exploration and mining. Faulting has segmented the district into structural domains of varying styles and complexities whereby establishment of reliable geological models for resource assessment and mine planning requires relatively detailed investigation. Each of the different structural domains presents a distinct challenge toward developing optimum coal extraction methods. Coals within 34 deposits contribute to the overall resources of the district (Table 6.1).

Tectonism has often resulted in movement within the extremely incompetent beds of coal. Sheared surfaces have produced very friable coal, and complex patterns of thickening and thinning within coal beds (Norris, 1958; Gibson and Hughes, 1981). Much of the coal maturation appears to have taken place prior to tectonic deformation and, therefore, coal rank often varies as a function of stratigraphic position (Norris, 1971; Hacquebard and Donaldson, 1974). Coalification levels, however, were also influenced by additional burial because of thickening of the sedimentary succession on the numerous thrust faults that characterize the structural style of the region (Hughes and Cameron, in prep.). Ash distributions, washability characteristics, weathering (oxidation) patterns and other coal characteristics have been affected by shearing (Bustin, 1980; 1982).

Composition, rank and other properties of East Kootenay coals vary widely. The ratio of vitrinite to total semifusinite-fusinite (inertinite), which are the most important macerals in the Kootenay coals, increases systematically upward in the stratigraphic section. This pattern might reflect a

TABLE 6.1

COAL RESOURCES OF IMMEDIATE INTEREST
EAST KOOTENAY COAL DISTRICT

Coalfield Deposit	Predominant Rank*	measured	indicated (megatonnes)	inferred
Flathead				
Lillyburt				
Cabin Creek				
Sage Creek				
Harvey Creek				
Hollebeke Mtn				
	mvb	70	150	200
Fernie				
Michel South				
Sparwood Ridge				
Leach Creek				
Taylor E and S				
Byron Creek				
McGillivray				
Hosmer Wheeler				
Martin Ridge				
Martin Creek				
Corbin-Coal Mtn.				
- Parcel 73				
- Parcel 82				
Lodgepole				
McEvoy Creek				
	mvb	700	300	1000
Elk Valley				
Crown Mtn				
Bare Mtn				
Burnt Ridge Ext				
Fording				
Line Creek				
Line Creek Ext.				
Greenhills				
Elk River				
Horseshoe Ridge				
Ewin Pass				
Ewin Creek				
Chauncy Ridge				
Mt Bannner E				
Teepee Mtn				
Mt Michael				
	mvb	600	850	2800
Tent Mtn Alberta	mvb	20	20	40
TOTALS	h-mb	139	1320	4040

*totals by general rank class

Estimated coal resource quantities are based mainly on information from the British Columbia Geological Survey Branch (W. Kilby, pers. comm., 1987), Domage Campbell and Associates (1975) and MacKay (1947). Coal resource information for separate deposits is often proprietary and confidential and, therefore, only totals by coalfield are shown.

systematic variation in plant-types that proliferated in different parts of the original delta plain, from the lower to upper delta plain environments (Cameron, 1972). This variation in maceral composition influences the carbonization and combustion properties of the coals (Pearson, 1980). Although degrees of coalification that occurred before and after initial compressional tectonism are variable, the significant proportion of post-deformation coalification has resulted in rank distribution patterns that are related to geological structures (Pearson and Grieve, 1985). Coal rank varies between low and high volatile bituminous in the district, and can change within individual beds both along strike and down dip. The average ash content of currently mined East Kootenay coals ranges between 15 and 25 per cent (Grieve, 1985). The diversity of composition and rank has resulted in coals ranging from high quality coking varieties to coals that have no caking capacity (Pearson and Grieve, op. cit.). Table 6.2 indicates some general characteristics of these coals.

CROWSNEST COAL DISTRICT

The Crowsnest Coal District is characterized by a series of imbricated northerly- and northwesterly- trending, subparallel, westward and southwestward dipping thrust plates whereby the commercially significant coal-bearing Kootenay Group recurs near surface in the region east of the Lewis Thrust. At least eight separate bands of Kootenay strata transect an east-west line drawn through the town of Frank, over a distance of about 35 km (Clow and Crockford, 1951). Major repetitions of the coal measure provide three important coalfields named after the towns of Coleman, Blairmore and Bellevue (Fig. 6.2).

Coal mining in the region started in 1899, and rapidly expanded in response to the needs of the Crowsnest Branch of the Canadian Pacific Railway which passes through the district. By 1910 the region was the largest producer of bituminous coal in Alberta (MacKay, 1933). Although most early coal production was from mines within 25 km of the railway, more than 40 mines were ultimately developed throughout the entire district. These mines ranged from the Beaver Mines Coalfield to the south, to the Kananaskis Coalfield, about 150 km to the north (Campbell, 1967a).

Within the Crowsnest Coal District the coal-bearing Mist Mountain Formation ranges in stratigraphic thickness from 67 m at the Adanac strip mine south of Blairmore, to about 380 m at Mist Mountain (Gibson, 1985a). Up to 11 beds or zones containing coals of greater than 1.3 m in thickness, and having an aggregate coal thickness in excess of 17 m, can occur within the formation (e.g. Mist Mountain section, in the Front Ranges west of Calgary). However, not more than five coal zones attain either adequate thickness or quality to be commercially significant within any particular deposit (Gibson, 1983, 1985a). The coal occurs within an

TABLE 6.2

GENERAL COAL QUALITY CHARACTERISTICS
EAST KOOTENAY COAL DISTRICT

Proximate analysis	
(per cent by weight)	
moisture (as received)	3-6
ash (dry)	15-35
volatile matter (d.a.f.)*	20-35
fixed carbon (d.a.f.)	65-80
Heat value (d.a.f.) MJ/kg	33-38
Ultimate analysis (dry, ash-free)	
(per cent by weight)	
carbon	87.5
hydrogen	5.5
nitrogen	1.5
sulphur	0.5
oxygen	5.0
Analysis of ash	
(per cent by weight)	
SiO_2	55.0
Al_2O_3	25.0
Fe_2O_3	4.0
CaO	4.0
MgO	1.5
MnO	-
Na_2O	0.1
K_2O	1.0
P_2O_5	1.0
TiO_2	1.0
SO_3	2.0
undetected	5.4
Petrographic indices	
(per cent by weight)	
mean max. reflectance ($R_o$max)	1.05-1.50
total reactives	55-80
total inerts	20-45
Properties	
free swelling index	5-8
caking index (Gray)	45-55
grindability index (Hardgrove)	100+
ash softening temp. (reduce-°C)	1260+
maximum dilatation	-10 to 100
maximum fluidity (ddpm)	3 to 1500
ASTM coke strength	40-62
Rank classification (ASTM)	hvb-mvb-lvb

*dry, ash-free

These generalized coal characteristics result from the synthesis and consideration of information from several sources, including Nicolls (1952), Swartzman (1953), Romaniuk and Naidu (1984), and Pearson and Grieve (1985). Values do not necessarily result from representative sampling of deposits and, therefore, are intended only as an indication of general coal characteristics that might be expected in the East Kootenay Coal District.

interstratified sequence of mainly non-marine siltstone, sandstone, mudstone and shale. The sections at Grassy Mountain and Mist Mountain have been described in detail by Norris (1959) and Gibson (1979) respectively.

Deformation of the coal measures within the district has both enhanced and decreased their economic potential. Imbrication and flow of coals, in addition to intricate patterns of faulting and folding have resulted in local thickening of coal, and destruction of the primary depositional fabric of coal beds (Norris, in press). Structural thickening of a 6 to 9 m coal zone at Grassy Mountain, to more than 25 m in the No. 2 Pit, indicates the degree to which coal potential can be enhanced (Gibson et al., 1983). In other cases, bedding plane slippages within coal zones have spoiled economic possibilities of coal (Norris, 1958). Ten coalfields within the district (Alberta Energy Resources Conservation Board, 1985) represent distinct structural and erosional remnants of the coal-bearing Mist Mountain Formation. One or more potentially mineable coal deposits occur within each field. Remnants of the coal-bearing Kootenay Group, such as those east of the Highwood Range (Rose, 1920), are not commercially significant, and thus have not been considered in the coal resource estimates for the district in Table 6.3.

Quality of coals in the Mist Mountain Formation of the Crowsnest Coal District varies widely. Coal rank within the commercially significant seams varies between high and low volatile bituminous. Moreover, excellent coking coals exist in some areas and, in other areas, coals within the same measure can have no caking capacity. An indication of some general characteristics of coals within the district is provided in Table 6.4.

TABLE 6.3

COAL RESOURCES OF IMMEDIATE INTEREST CROWSNEST COAL DISTRICT

Coalfield / Deposit	Predominant Rank*	measured	indicated (megatonnes)	inferred
Beaver Mines	h-mvb	10	5	20
Bellevue	h-mvb	80	40	140
Blairmore	h-mvb	130	70	250
Coleman	mvb	110	55	220
Oldman River	mvb	155	80	285
Beaver Creek	mvb	25	15	55
Savanna Creek**	m-lvb	40	20	80
Highwood Ford**	m-lvb	20	10	40
Kananaskis**	lvb	20	10	45
Flat Creek**	lvb	5	5	5
TOTALS	m-lvb	265	140	510
	h-mvb	330	170	630

*totals by general rank class

**Kananskis Country - Coal exploration and development will not be approved by the Government of Alberta, according to its 1986 Sub-Regional Integrated Resource Plan

Estimated coal resource quantities are based mainly on information from the Alberta Energy Resources Conservation Board (1987). This information has been modified to reflect the Geological Survey of Canada's coal resource classifications, including the classification of ERCB's "underground - thin" coal as coal resources of future interest, and a division of the balance of ERCB's "established resources" to measured, indicated and inferred categories.

TABLE 6.4

GENERAL COAL QUALITY CHARACTERISTICS CROWSNEST COAL DISTRICT

	Beaver Mines	Bellevue / Blairmore / Coleman	Highwood Ford
Proximate analysis			
(per cent by weight)			
moisture (as received)	3	2	2
ash (dry)	15	15	15
volatile matter (d.a.f.)*	37	30	19
fixed carbon (d.a.f.)	63	70	81
Heat value (d.a.f.) MJ/kg	34.5	35.0	35.5
Ultimate analysis (dry, ash-free)			
(per cent by weight)			
carbon	85.0	87.0	91.0
hydrogen	5.1	5.2	4.8
nitrogen	1.2	1.3	1.5
sulphur	1.0	0.7	0.7
oxygen	7.7	5.8	2.0
Analysis of ash			
(per cent by weight)			
SiO_2	-	52.0	-
Al_2O_3	-	31.0	-
Fe_2O_3	-	4.0	-
CaO	-	4.0	-
MgO	-	1.0	-
Na_2O	-	0.5	-
K_2O	-	0.5	-
P_2O_5	-	0.5	-
TiO_2	-	2.0	-
SO_3	-	2.5	-
undetected	-	2.0	-
Petrographic indices			
(per cent by weight)			
mean max. reflectance ($R_o max$)	0.91-0.94	0.88-1.34	1.57-1.70
total reactives	-	53-60	-
total inerts	-	40-47	-
Properties			
free swelling index	-	1-5.5	0-3
caking index (Gray)	-	27-40	0-27
grindability index (Hardgrove)	-	60-78	98
ash softening temp. (reduce-°C)	1200	1565+	1565+
Rank classification (ASTM)	hvbA	mvb	lvb

*dry, ash-free

These generalized coal characteristics result from the synthesis and consideration of information from several sources, including Stansfield et al. (1925), Stansfield and Lang (1944), Nicolls (1952), Swartzman (1953), and Horachek (1985). Values do not necessarily result from representative sampling of deposits and, therefore, are intended only as an indication of general coal characteristics that might be expected in the Crowsnest Coal District.

CASCADE COAL DISTRICT

Coals of the Cascade Coal District differ from those of the East Kootenay and Crowsnest coal districts both in quality and geological context. The highest rank coals in the eastern Canadian Cordillera are contained within the lower Mist Mountain strata of the Kootenay Group. This high rank has rendered all but the stratigraphically highest seams unsuitable for conventional production of metallurgical coke. Its exploitation, therefore, should be considered in the context of thermal coal production. The coal measure is preserved virtually continuously in a belt 75 km long and about 4 km wide (Fig. 6.2) in the Mount Allan Syncline in the immediate footwall of the northwest-trending Rundle Thrust. Small scale faults and folds have complicated the geological framework (Norris, 1971). The synclinorial form of the Kootenay Group provides few potentially favourable locations for possible open pit exploitation, unlike the Crowsnest Coal District where the measures are exposed in several parallel bands (Crockford, 1949).

Most coal production from the Cascade Coal District was in response to the needs of the Canadian Pacific Railway. Several mines have been developed since the completion of the railway in 1885, and virtually all areas underlain by accessible coal-bearing strata have been leased at some time. The coal resources of the district are contained within four areas named, from south to north, Pocaterra Coalfield, Ribbon Creek Deposit, Canmore Coalfield and Bankhead Coalfield (Alberta Energy Resources Conservation Board, 1987). There has been no mining to date in the Pocaterra Coalfield. The northern one-third of the district, including the entire Bankhead Coalfield, lies within Banff National Park. Except for the area in the immediate vicinity of Canmore, the remaining southern portion of the district is within the Provincial recreation region of "Kananaskis Country". Provisions pertaining to current federal and provincial land classifications allow exploration and development only within part of the Canmore Coalfield. Almost all past mining in the district has been by underground methods, and extraction of remaining resources would generally have to be considered in the context of underground mining.

A complete 400 m thick, unfaulted section of the coal-bearing Mist Mountain Formation is exposed on Mount Allan, 12 km southeast of the town of Canmore. It comprises an interstratified sequence of siltstone, sandstone, claystone and coal deposited within deltaic systems. These deltaic systems were established by accumulations of clastic sediments transported from uplifted source areas in south-central British Columbia (Hughes, 1987). Ten coal seams ranging in thickness from 0.5 to 9 m occur in this section (Hughes and Cameron, 1985), whereas 15 seams between 0.5 and 4.3 m thick occur 10 to 15 km northwest in the mining area of Canmore (Norris, 1971). Although 13 seams have an average thickness of greater than 1.5 m near Canmore, only about 10 have been mined (Norris, op. cit.). Some of these beds have been traced up to 10 km laterally (Hughes, op. cit.).

The Kootenay Group was folded into the asymmetrical to overturned (southwest dipping axial surface) Mount Allan Syncline in conjunction with the development of the major, overriding, Rundle thrust plate during the Laramide Orogeny. This tectonism resulted in considerable small-scale faulting, folding and shearing within the incompetent coal-bearing sequence (Norris, 1957, 1958). It has also resulted in significant additions to readily accessible coal (Norris, 1971), and may have contributed to the abnormally high coalification levels (Hughes and Cameron, 1985). Much of the tectonically induced movement was along bedding. Jointing, bedding slip surfaces, and extension, contraction and wrench faulting

TABLE 6.5

COAL RESOURCES OF IMMEDIATE INTEREST CASCADE COAL DISTRICT

Coalfield / Deposit	Predominant Rank*	measured	indicated (megatonnes)	inferred
Pocaterra	lvb	35	15	65
Ribbon Creek	lvb	5	5	10
Canmore	lvb-sa	180	90	350
Bankhead	lvb-sa	20	10	30
TOTALS	lvb-an	240	120	455

*totals by general rank class

Estimated coal resource quantities are based mainly on information from the Alberta Energy Resources Conservation Board (1987). This information has been modified to reflect the Geological Survey of Canada's coal resource classifications, including the classification of ERCB's "underground - thin" coal as coal resources of future interest, and a division of the balance of ERCB's "established resources" to measured, indicated and inferred categories.

TABLE 6.6

GENERAL COAL QUALITY CHARACTERISTICS CASCADE COAL DISTRICT

	Pocaterra / Ribbon Creek	Canmore	Bankhead
Proximate analysis (per cent by weight)			
moisture (as received)	2	2	2
ash (dry)	10	10	10
volatile matter (d.a.f.)*	20	15	11
fixed carbon (d.a.f.)	80	85	89
Heat value (d.a.f.) MJ/kg	35.0	35.8	35.8
Ultimate analysis (dry, ash-free) (per cent by weight)			
carbon	90.0	90.0	92.0
hydrogen	4.0	4.5	4.0
nitrogen	1.4	1.8	1.2
sulphur	0.6	0.7	0.8
oxygen	4.0	3.0	2.0
Analysis of ash (per cent by weight)			
SiO_2	-	60.0	-
Al_2O_3	-	25.0	-
Fe_2O_3	-	7.5	-
CaO	-	1.6	-
MgO	-	1.4	-
Na_2O	-	0.1	-
K_2O	-	1.4	-
P_2O_5	-	0.5	-
TiO_2	-	1.0	-
SO_3	-	1.5	-
undetected	-	-	-
Petrographic indices (per cent by weight)			
mean max. reflectance ($R_o$max)	-	1.33-2.65	-
total reactives	-	-	-
total inerts	-	-	-
Properties			
free swelling index	-	-	-
caking index (Gray)	-	-	-
grindability index (Hardgrove)	-	70-90	-
ash softening temp. (reduce-°C)	1510+	1390+	-
Rank classification (ASTM)	lvb-sa	lvb-sa	sa

*dry, ash-free

These generalized coal characteristics result from the synthesis and consideration of information from several sources, including Stansfield et al. (1925), Stansfield and Lang (1944), Nicolls (1952), Swartzman (1953), and Horachek (1985). Values do not necessarily result from representative sampling of deposits and, therefore, are intended only as an indication of general coal characteristics that might be expected in the Cascade Coal District.

have been recognized as the fundamental fabric elements within some commercially significant coal beds (Norris, 1966).

About 16 megatonnes of low volatile bituminous to semianthracitic coals were mined from the Canmore Coalfield between 1891 and 1979. The only other relatively major mining operations in the district were in the Bankhead Coalfield where about 3 megatonnes of low volatile bituminous coals were mined between 1888 and 1953 (Alberta Energy Resources Conservation Board, 1985). Table 6.5 lists the estimated remaining coal resources of immediate interest in the district, including some tonnages within lands where coal exploration and development is presently prohibited. The general quality characteristics of these coals are indicated in Table 6.6.

PANTHER RIVER—CLEARWATER COAL DISTRICT

Remnants of coal-bearing Kootenay Group strata occur within the structurally complex region north of the Cascade Coal District, near the eastern boundary of Banff National Park, about 40 km north of Banff (Fig. 6.2). Although significant quantities of technologically extractable coal might exist within the Vermilion and Palliser ranges (MacKay, 1947), deposits are within the national park and have not been well explored. Immediately east of the park boundary, a complete section of the Kootenay Group is exposed on the east side of Barrier Mountain (Gibson, 1985a), in the area referred to as the Costigan Coalfield (Alberta Energy Resources Conservation Board, 1985). Although this area has been explored more intensely than areas within the park, it is in a current Provincial land use category that does not permit coal exploration or development.

Published information pertaining to the coal potential of the district is mainly the result of work conducted by the Geological Survey of Canada during the first decade of this century (Dowling, 1907a, 1907b; Malloch, 1908). Coal-bearing strata exposed along the east side of the Vermilion Range were considered to be the northern extension of the Cascade Coal District. A total of 24 coal seams with an aggregate thickness of nearly 35 m was identified within about 430 m of coal-bearing strata. Fifteen of these seams are between 1.3 and 3.3 m thick. The coals range in rank between medium and low volatile bituminous, and apparently yield "firm cokes" (Malloch, 1908).

Six seams have been identified within the coal measure exposed along the eastern slopes of the Palliser Range. Analyses of samples from two of the seams, 0.5 and 1.5 m thick, indicate the coals to be semianthracite and non-coking, like those of the Cascade Coal District to the south (Malloch, 1908).

The Costigan Coalfield represents a remnant of coal-bearing Kootenay Group strata preserved within a synclinal structure on the east side of Barrier Mountain. The Mist Mountain Formation comprises nearly 410 m of the total Kootenay Group, which is about 840 m thick at Barrier Mountain (Gibson, 1985a). Although the formation contains several coal beds, only three attain significant thickness (1.5 to 3.0 m). Rank of coals varies between semianthracite and low volatile bituminous. Some of the coals yield "firm coherent coke" and others are non-coking (Malloch, 1908). A 2 m thick seam of low volatile bituminous coal exists in the overlying Elk Formation (Gibson, op. cit.). Within the eastern limb of the syncline only five coal beds, having an aggregate thickness of about 5.5 m, have been reported (Dowling, 1915b).

To the north of these Kootenay Group remnants, commercially significant coal deposits occur within the Lower Cretaceous Luscar Group of the Inner Foothills Belt.

Estimated coal resource quantities that are shown in Table 6.7 are all considered coal resources of future interest because the present classification of associated lands, including Banff National Park, prohibits coal exploration and development. The general quality characteristics of these coals, indicated in Table 6.8, are based on the limited information reported by Malloch (1908).

TABLE 6.7

COAL RESOURCES OF FUTURE INTEREST PANTHER RIVER-CLEARWATER COAL DISTRICT

Coalfield Deposit	Predominant Rank*	measured	indicated (megatonnes)	inferred
Vermilion	lvb	-	-	300
Palliser	sa	-	-	100
Costigan	lvb	15	15	300
TOTALS	lvb-an	15	15	700

*totals by general rank class

These estimates are based on information from MacKay (1947) and the Alberta Energy Resources Conservation Board (1987).

TABLE 6.8

GENERAL COAL QUALITY CHARACTERISTICS PANTHER RIVER-CLEARWATER COAL DISTRICT (based on information reported by Malloch, 1908)

	Vermilion	Palliser	Costigan
Proximate analysis (per cent by weight)			
moisture (as received)	2	1	2
ash (dry)	5	5	5
volatile matter (d.a.f.)*	22	12	16
fixed carbon (d.a.f.)	78	88	84
Rank classification (ASTM)	lvb	sa	lvb

*dry, ash-free

INNER FOOTHILLS BELT

INTRODUCTION

About one-half of Canada's measured medium and low volatile bituminous coal resource is contained in Lower Cretaceous strata that extend more than 800 km northwestward along the Inner Foothills of the Rocky Mountains, from the Clearwater River in west-central Alberta, to north of the Peace River in northeastern British Columbia (Fig. 6.3). Like the coal-bearing region in the southern Rocky Mountain Front Ranges, the Inner Foothills Belt is characterized by generally high relief. It can be conveniently divided into northern and southern coal districts according to distinct lithostratigraphic distributions of major coal beds. Northwest of the Kakwa River, near the Alberta-British Columbia

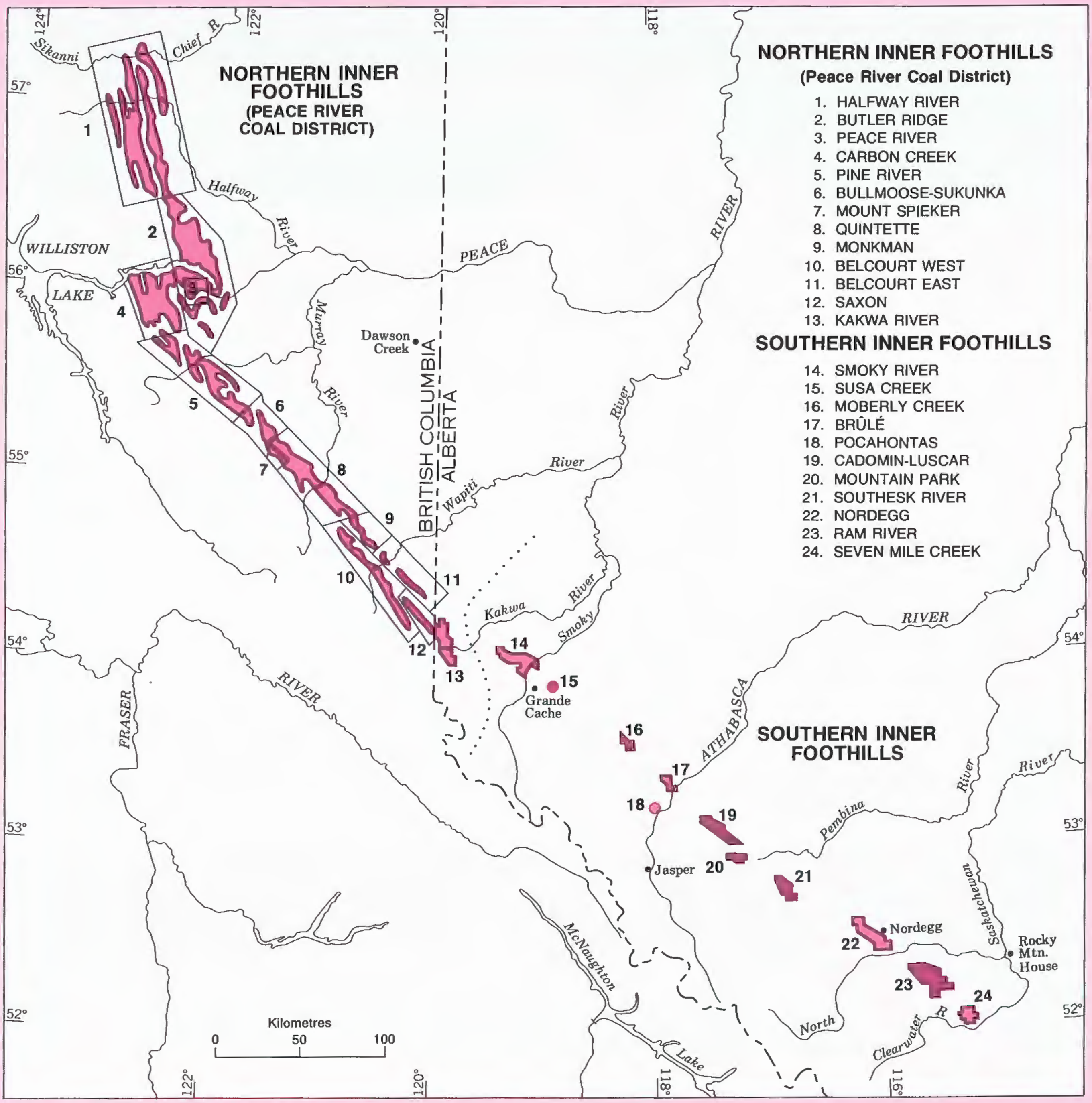


Figure 6.3. Coal districts and coalfields in the Inner Foothills Belt of the Rocky Mountains.

boundary, major coal beds occur in the Gething Formation of the Bullhead Group, and in the Gates Formation of the Fort St. John Group. To the southeast, the commercially important coal measures are within the Gates Formation of the Luscar Group (Fig. 6.1; Langenberg and McMechan, 1985). The Gladstone Formation of the Luscar Group is correlative with the Gething Formation in the northern district, and contains only minor coal beds.

Sir Alexander Mackenzie, the first European explorer in the region, observed coal in the Peace River Canyon during the winter of 1792-93. However, it was not until the 1870's, during exploration for a transcontinental railway route, that the coal potential of the northern part of the region was seriously investigated (Stott, 1968, 1973). The Canadian Pacific Railway completed a survey of the Yellowhead Pass, near Jasper, in 1876. It subsequently chose to develop southern transcontinental routes through the Kicking Horse and Rogers passes, west of Banff, and through the Crowsnest Pass near the United States Border. The Geological Survey of Canada continued exploration in the region between the Peace and Athabasca rivers, but exploitation of the vast coal resources was not seriously considered until the early 1900's, when the Grand Trunk Pacific and Canadian Northern Railways decided to traverse the Rocky Mountains through the Yellowhead Pass. Beginning in 1906, Dowling (1907b, 1910) discovered and examined coal areas between the Bow and Yellowhead passes. Coal deposits in the Bighorn Basin near Nordegg subsequently became important fuel sources for the railways. All major mines in the region, except those started within the past 20 years, were developed mainly in response to the needs of the railways. The conversion from steam to diesel driven locomotives during the 1950's brought a temporary end to coal mining in the region. By the late 1960's and early 1970's, however, coal exploration and development rejuvenated in response to increasing demands in international markets for metallurgical coals.

All currently operating mines within the Inner Foothills Belt were developed within the past 20 years to exploit mainly high quality metallurgical coals for export markets (Fig. 3.6). In 1986, these five mines (Luscar, Gregg River, Smoky River, Quintette and Bullmoose) produced a total of 11 megatonnes of metallurgical coal, about one-half of Canada's total metallurgical coal production. Nearly 0.7 megatonnes of thermal coal were also produced. Although several underground mines were developed in the past, current mining is by surface methods, with the exception of one of the Smoky River mines near Grande Cache.

Prior to 1930, the major coal-bearing stratigraphic sequence of the southern Inner Foothills was considered to be an extension of Kootenay strata of the Rocky Mountain Front Ranges to the south. MacKay (1930) recognized the distinction between the Kootenay and coal-bearing Luscar sequence to the north. He was also one of the first to recognize the persistence of the conspicuous Cadomin conglomerate throughout the region, which provides a clear basis for distinguishing Luscar from Kootenay coal measures.

Progressive south to north changes in depositional environments, from Late Jurassic to at least Early Cretaceous times, significantly affected the stratigraphic distribution of major coal deposits to the north and south of the Clearwater River (Holter and Mellon, 1972). Lithostratigraphic transitions resulted in the major coal-bearing Jurassic-Cretaceous Kootenay Group strata, to the south, being progressively replaced to the north by the Nikanassin Formation, within which coal beds are uncommon (Gibson, 1978). Commercially significant coal measures northwest of the Clearwater River occur in the younger Lower Cretaceous Luscar Group.

The Luscar Group is correlative with the non-coal-bearing Blairmore Group south of the Clearwater River, and with the important coal-bearing Bullhead Group and part of Fort St. John Group, northwest of the Kakwa River (Fig. 6.4). The widespread and readily mappable Cadomin Formation is a common base to each of these Lower Cretaceous groups and is one of the most useful stratigraphic markers in the region (McLean, 1977).

Typically, the Lower Cretaceous coal measures of the Inner Foothills are complexly folded and faulted. Regionally, the surface structural expression tends to be fold-dominated towards the northwest, and fault-dominated towards the south and southeast, including the coal-bearing region of the southern Rocky Mountain Front Ranges (McMechan, 1985). The basic structural forms include thrust faults, concentric folds, tear faults and late normal faults (Dahlstrom, 1970). Thrust faults and fold axes commonly trend northwesterly and persist over long distances. Thrust faults usually dip southwesterly and have resulted in displacements from a few centimetres to hundreds of metres within the coal measures. As in the coal region of the southern Rocky Mountain Front Ranges, tectonism has both improved and complicated coal mining possibilities. In some cases it has brought large quantities of coal within access of modern mining techniques. Coal-bearing strata are commonly steeply inclined, although some relatively large areas of nearly flat-lying strata occur, such as in the crests of box anticlines. Conventional room and pillar underground mining at the Smoky River operations near Grande Cache is used to exploit relatively flat-lying coal deposits. Longwall mining techniques might also be suitable for exploiting similar deposits.

Several tectonically-thickened coal deposits have been, or continue to be mined, and the search for others has attracted serious exploration (Hoffman and Jordan, 1984; Langenberg et al., 1987). Tectonism has also resulted in movement within coal beds, causing shearing of coals and irregular pinching and swelling of seams (Norris, 1958). The structural complexities within the coal measures commonly require

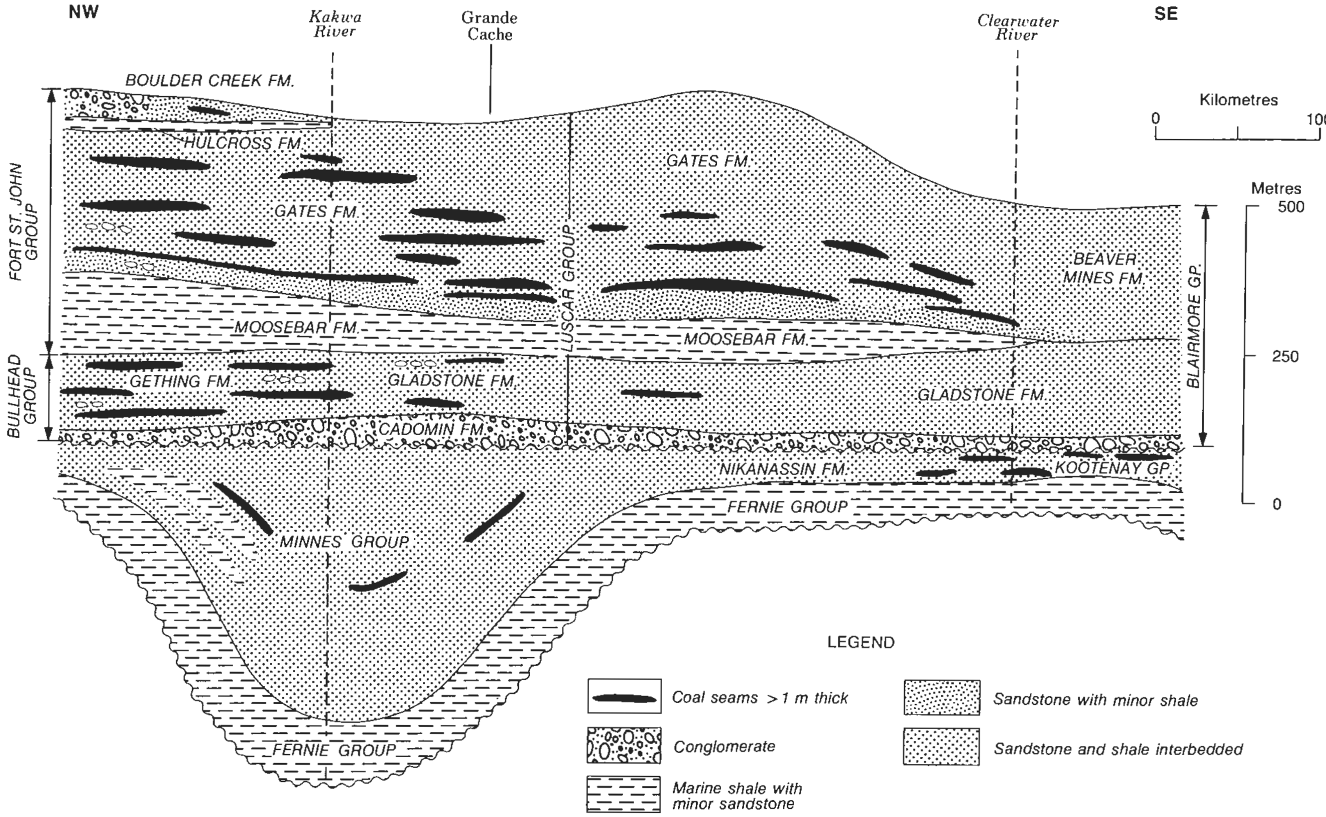


Figure 6.4. Schematic cross section illustrating the stratigraphic relationships of Jurassic-Cretaceous and Lower Cretaceous sequences in the Rocky Mountain Front Ranges and Inner Foothills Belt of British Columbia and Alberta (after Stott, 1984; Langenberg and McMechan, 1985).

relatively closely spaced data for the development of reliable geological models in advance of production planning. Structural and/or erosional dissection of the coal measures commonly limit the extent of individual deposits or coalfields.

Studies of thermal maturation in the region north of Grande Cache indicate that rank of the Lower Cretaceous coals was controlled mainly by pre-deformational depth of burial (Kalkreuth and Langenberg, 1986). A progressive eastward increase in depth and duration of burial of the coal beds resulted in increasingly higher coalification levels across the Inner and Outer foothills toward the core of the Alberta Syncline (Kalkreuth and McMechan, 1984). In contrast, a significant portion of coal maturation in the Jurassic-Cretaceous Kootenay Group of the southern Rocky Mountain Front Ranges was post-orogenic (Pearson and Grieve, 1985; Hughes and Cameron, 1985).

The commercially significant coals of the Inner Foothills Belt are mainly medium to low volatile bituminous, and commonly have coking properties desirable in international metallurgical coal markets. Where oxidized, these coals are usually suitable for thermal coal markets. Typically, these coals can be characterized as inertinite-rich, with sulphur contents of usually less than one per cent, and ash contents ranging between 10 and 30 per cent by weight (Pearson, 1980). All current mining operations in the region have associated coal preparation facilities for producing market-specified coals from the run-of-mine.

SOUTHERN INNER FOOTHILLS

Several coal occurrences, including major deposits and coalfields, and three operating mines occur within the southern Inner Foothills Belt that extends about 375 km northwestward from the Clearwater River in west-central Alberta, to the Kakwa River near the British Columbia boundary in northwest Alberta (Fig. 6.3). Two mining operations (Luscar and Gregg River) currently exploit coal within the Cadomin-Luscar Coalfield, and one operation (Smoky River) is mining within the Smoky River Coalfield. Several mines had been developed previously in the Nordegg, Mountain Park and Brûlé coalfields, mainly to service the needs of the railways. These mines eventually closed as locomotives became predominantly diesel-powered.

The coal measures are within the Gates Formation of the Lower Cretaceous Luscar Group. The Grande Cache Member of the Gates Formation hosts the major coal seams and all mining to date has exploited these coals (Langenberg, 1984). It comprises an interstratified sequence of coal, carbonaceous mudstone, siltstone and subordinate sandstone (McLean, 1982). Between the Clearwater and Smoky rivers, the Grande Cache Member ranges in thickness from about 70 m to nearly 150 m and contains up to 7 coal beds between 0.8 m and 13 m thick (McLean, op. cit.). It is part of a progradational sequence that includes marine deposits represented by the Moosebar Formation, which were overlain by beach deposits represented by the Torrens Member. These, in turn, were overlain by the coal-bearing Grande Cache Member, which was deposited within a coastal or delta plain environment. The Mountain Park Member overlies the coal-bearing Grande Cache Member, and contains only minor coal beds. It is characterized by strata deposited mainly within fluvial channels, or on floodplains (McLean, 1982). The distinct sandstone and conglomerate beds of the Torrens Member provide an extensive and important marker horizon for those exploring the coal measures.

Tectonism resulted in compressive stresses that caused strata to yield mainly by northeasterly movement on thrust faults, and through folding. Irish (1965) has suggested that, although broad regional folds may have existed prior to the major thrust faulting, most folds originated subsequent to the initiation of major thrust faults, and "the two processes then proceeded contemporaneously". The coal-bearing strata are often complexly folded and faulted on both mesoscopic and macroscopic scales. These structures, combined with considerable variation of lithofacies, complicate the correlation of coal beds over long distances. Structural features and styles that have been reported in and near the Mountain Park, Cadomin-Luscar and Smoky River coalfields (Kilby, 1978; Wrightson, 1979; Hill, 1980; Langenberg, 1984; Langenberg et al., 1987) might provide important clues pertaining to coal potential in the adjacent and less studied areas. In describing the economic potential of coal deposits in the Bighorn Coal Basin, in the southern part of the district, Malloch (1911) discussed geological structures in the context of "obstacles they offer to the profitable extraction of coal from certain portions of the basin". In many parts of the district, however, geological structures have enhanced economic possibilities of coal exploitation.

Estimated resource quantities within the southern Inner Foothills are provided in Table 6.9.

TABLE 6.9

COAL RESOURCES OF IMMEDIATE INTEREST SOUTHERN INNER FOOTHILLS

Coalfield Deposit	Predominant Rank*	measured	indicated (megatonnes)	inferred
Seven Mile Creek	mvb	30	15	50
Ram River	mvb	105	50	195
Nordegg	lvb	75	40	130
Southesk River	mvb	15	5	25
Mountain Park	h-mvb	40	20	70
Cadomin-Luscar	h-mvb	110	55	205
Pocahontas	m-lvb	5	5	5
Brule	m-lvb	15	10	25
Moberly Creek	m-lvb	120	60	220
Susa Creek	m-lvb	5	5	5
Smoky River	lvb	265	130	490
TOTALS	m-lvb	635	320	1145
	h-mvb	150	75	275

*totals by general rank class

Estimated coal resource quantities are based mainly on information from the Alberta Energy Resources Conservation Board (1987). This information has been modified to reflect the Geological Survey of Canada's coal resource classifications, including the classification of ERCB's "underground - thin" coal as coal resources of "future interest" and a division of the balance of ERCB's "established resources" to measured, indicated and inferred categories.

TABLE 6.10

GENERAL COAL QUALITY CHARACTERISTICS SOUTHERN INNER FOOTHILLS

	Nordegg	Cadomin Luscar Mountain Park	Smoky River
Proximate analysis (per cent by weight)			
moisture (as received)	1	2	2
ash (dry)	10	15	10
volatile matter (d.a.f.*)	18	25	21
fixed carbon (d.a.f.)	92	75	79
Calorific value (d.a.f., MJ/kg)	36.0	35.7	36.0
Ultimate analysis (dry, ash-free) (per cent by weight)			
carbon	90.5	88.0	91.0
hydrogen	4.5	5.0	4.5
nitrogen	1.5	1.5	1.0
sulphur	0.5	0.5	0.5
oxygen	3.0	5.0	3.0
Analysis of ash (per cent by weight)			
SiO_2	55.0	57.0	58.0
Al_2O_3	30.0	26.0	25.0
Fe_2O_3	3.0	4.0	6.0
CaO	3.0	4.0	3.0
MgO	1.0	1.5	0.5
Na_2O	0.3	1.0	1.0
K_2O	0.8	0.7	0.3
P_2O_5	0.5	0.5	1.5
TiO_2	1.0	0.9	1.0
SO_3	1.5	2.5	0.7
undetected	3.9	0.9	3.0
Petrographic indices (per cent by weight)			
mean max. reflectance (R_0max)	-	0.90-1.5	1.45-1.65
total reactives	-	-	65-70
total inerts	-	-	30-35
Properties			
free swelling index	1	1.5-5.5	3-5.5
caking index (Gray)	27-30	20-50	-
grindability index (Hardgrove)	100+	80-90	90-100
ash softening temp. (reduce-°C)	1565+	1370+	1250-1400+
Rank classification (ASTM)	lvb	mvb	lvb

*dry, ash-free

These generalized coal characteristics result from the synthesis and consideration of information from several sources, including Stansfield et al. (1925), Stansfield and Lang (1944), Nicolls (1952) and Swartzman (1953). Values do not necessarily result from representative sampling of deposits and, therefore, are intended only as an indication of general coal characteristics that might be expected in the Grande Cache Member of the Gates Formation in the southern Inner Foothills.

Coals of the Luscar Group vary in rank from high volatile A bituminous to low volatile bituminous. They commonly have low sulphur contents ranging between 0.3 and 1.0 per cent. Although they generally have good coking properties, quality can vary throughout the district (Table 6.10) and within a particular stratigraphic section.

NORTHERN INNER FOOTHILLS

(Peace River Coal District)

The northern Inner Foothills Belt, referred to herein as the Peace River Coal District, extends 300 km between the Kakwa and Sikanni Chief rivers in northeast British Columbia (Fig. 6.3). Major Lower Cretaceous coal deposits occur in the Gething Formation of the Bullhead Group and in the Gates Formation of the Fort St. John Group (Fig. 6.1). Commercial interest in the resource potential of the coal deposits began in the 1960's, in response to increasing international demand for metallurgical coals, and accelerated through the 1970's. Several coalfields were extensively explored and two major mines (Quintette and Bullmoose) were established by the early 1980's. Several other properties (eg. Monkman, Sukunka, Carbon Creek, and Mt. Spieker) have reached advanced stages of exploration and feasibility study.

The main development of coal beds in the Gething Formation appears to be between Wolverine and Halfway rivers (Stott, 1974; Fig. 6.3). North of Sukunka River, these beds were intermittently exploited on a relatively small scale between 1908 and the 1960's, and they now constitute the primary coal exploration target in the northern half of the district.

The Gething Formation comprises an interstratified, mainly nonmarine, fluvial-deltaic sequence of sandstone, siltstone, mudstone, conglomerate and coal, deposited over the fluvial-alluvial fan strata of the Cadomin Formation (Gibson, 1985b). In the Carbon Creek Coalfield, the Gething Formation attains a thickness of at least 1036 m, and more than 100 coal beds, ranging in thickness from a few centimetres to 4.3 m have been reported within it (Gibson, op. cit.). Duff and Gilchrist (1981) reported the existence of "several extensive 2-metre seams" within the Gething Formation between the Alberta border and Sukunka River, and at least 20 coal beds that exceed 1 m in thickness northward from Sukunka River. Recent work (Gibson, in press) indicates that beds that exceed about 6 m in thickness are probably tectonically thickened.

In the southern half of the Peace River Coal District the coal beds within the Gates Formation constitute the primary exploration target (Fig. 6.4). Recent mine developments and coal exploration activities have focused on these coals.

The Gates Formation is an 80 to 280 m thick interstratified sequence of mainly nonmarine sandstone, conglomerate, coal, shale and mudstone (Leckie, 1983). It is separated from the underlying Gething Formation by interstratified fine grained marine deposits assigned to the Moosebar Formation (Fig. 6.4; McLean and Wall, 1981). Within the formation, 11 coal beds, having a maximum thickness of about 10 m, and an aggregate thickness of up to 46 m, have been reported (Stott, 1982). Four or five laterally extensive seams, ranging in thickness from 5 to 10 m, are common between Kakwa and Sukunka rivers (Duff and Gilchrist, 1981). The Peace River Arch apparently controlled the northern extent of alluvial-deltaic environments within which the major coal beds originated (Stott, op cit.).

Although several coal beds occur below the Cadomin Formation in the Minnes Group, and above the Gates Formation in the Boulder Creek Formation (Figs. 6.1 and 6.4), they are generally thin and appear to have limited areal extent (D.W. Gibson, pers. comm., 1987). Significant coal beds in the Gething Formation extend northward to Sikanni Chief River; however, commercially important coal beds may be limited to the area south of Halfway River (Stott, 1973). Between the Peace and Halfway rivers (Butler Ridge and Halfway River coalfields), only a few, relatively thin coal beds have been reported. A structurally thickened seam occurs, however, at the south end of Pink Mountain (Stott, 1972b). North of the Peace River, toward the fringe of the Gething Delta, influx of large amounts of clastic sediments and repeated flooding by marine waters did not favour peat accumulation (Stott, 1972b).

Structural deformation of the Cretaceous sequence in the district is characterized by en échelon, northwest-plunging anticlines and synclines, and by southwest-dipping low and medium angle thrust faults, which have repeatedly brought coal measures to the surface. Locally, the tectonism has resulted in a thickening of coal beds. At a mesoscopic scale, fault and fold structures can be complex and mining operations can be significantly complicated (Schiller et al., 1983; Bell, 1985; Rance, 1985).

Estimated coal resource quantities within the northern Inner Foothills (Peace River Coal District) are provided in Table 6.11. Approximately 70 per cent of the measured resources of immediate interest occurs within the Gates Formation, with the balance assigned to the Gething Formation.

Although the rank of coals that occur in the Gething and Gates formations ranges from high volatile A to low volatile bituminous (Kalkreuth and McMechan, in press.), most of the resource is classified as medium volatile bituminous. In some areas (e.g. Burnt River), mean maximum vitrinite reflectance values exceed 1.5 per cent, indicating a rank of semianthracite. The coals commonly have sulphur contents of less than one per cent and excellent coking properties (Table 6.12). Locally, upper seams in the Gething Formation can have sulphur contents up to about 2.5 per cent. Coals

TABLE 6.11

COAL RESOURCES OF IMMEDIATE INTEREST NORTHERN INNER FOOTHILLS

Coalfield, Deposit	Predominant Rank*	measured	indicated (megatonnes)	inferred
Kakwa River	mvb	100	100	300
Saxon	mvb	25	250	250
Belcourt E. and W.	mvb	40	800	220
Monkman	mvb	400	800	1480
Quintette	mvb	150	50	2100
Mt. Spieker	mvb	30	5	85
Bullmoose-Sukunka	mvb	245	155	370
Pine River	mvb	65	125	395
Carbon Creek	mvb	50	30	35
Peace River	mvb	10	70	510
Butler Ridge	mvb	-	-	450
Halfway River	mvb	-	-	75
TOTALS	m-lvb	1115	2385	6270

*totals by general rank class

Estimated coal resource quantities for deposits in British Columbia are based mainly on information from the British Columbia Geological Survey Branch (W. Kilby, pers. comm., 1987); estimates, however for Butler Ridge and Halfway River coalfields are based on information from MacKay (1947). Estimated tonnages for that part of the Kakwa River Coalfield, located in Alberta, are based on information from the Alberta Energy Resources Conservation Board (1987). All information has been modified to reflect the Geological Survey of Canada's coal resource classifications.

within both formations have similar characteristics, and coals within the Gates Formation of the Fort St. John Group are similar to those of the Luscar Group in the southern Inner Foothills (Kalkreuth, in press). Coal ranks, as in the southern Inner Foothills, were established mainly prior to major deformation, and thrusting has not had a significant impact on rank (Kalkreuth, op. cit.). Weathering of coals that occurs near surface has rendered a relatively small portion of the resource unsuitable for carbonization; these oxidized coals are generally considered to be thermal coals.

OUTER FOOTHILLS BELT

INTRODUCTION

Most of Canada's high volatile bituminous coal resources occur within the Outer Foothills of the Rocky Mountains. The commercially significant coal-bearing portion of the Outer Foothills Belt is entirely within the province of Alberta and extends approximately 750 km northwestward from near the United States border to about 50 km north of the Athabasca River (Fig. 6.5). It is best developed south of the Athabasca River, where the average width is between 10 and 30 km (measured across strike). It attains a maximum width of about 50 km between the Pembina and North Saskatchewan rivers. The belt borders the Interior Plains to the east and is characterized by generally low to moderate relief with rounded, timbered, northwest trending ridges interspersed with some open grassy areas and occasional extensive muskeg deposits in low lying areas. The commercially important coal beds occur within the Upper Cretaceous and lower Tertiary strata. The more than 200 mines that have operated in the belt since about 1889 are distributed throughout the region between the U.S. border and the Athabasca River (Campbell, 1967a). In 1986, the only operating mine (Coal Valley, Fig. 3.7) produced 1.6 megatonnes of high volatile C bituminous thermal coal. Although Alberta's Energy Resources Conservation Board considers the Obed Mine to occur within the Foothills region, it is assigned to the Interior Plains herein.

Early descriptions and discussions of coal occurrences in the Outer Foothills were provided by several geologists of the Geological Survey of Canada. Selwyn (1874) described thick

TABLE 6.12

GENERAL COAL QUALITY CHARACTERISTICS NORTHERN INNER FOOTHILLS (Peace River Coal District)

Proximate analysis	
(per cent by weight)	
moisture (as received)	1-8
ash (dry)	5-20
volatile matter (d.a.f.)*	21-26
fixed carbon (d.a.f.)	74-79
Calorific value (d.a.f.) MJ/kg	34.5-36.5
Ultimate analysis (dry, ash-free)	
(per cent by weight)	
carbon	90.0
hydrogen	5.0
nitrogen	1.5
sulphur	0.5
oxygen	3.0
Petrographic indices	
(per cent by weight)	
mean max. reflectance ($R_o$max)	1.0-1.5
total reactives	70
total inerts	30
Properties	
free swelling index	1-7
caking index (Gray)	-
grindability index (Hardgrove)	90+
ash softening temp. (reduce-°C)	1250+
Rank classification (ASTM)	m-lvb

*dry, ash-free

These generalized coal characteristics result from the synthesis and consideration of information from several sources, including Dickson (1941), McLearn and Kindle (1950), Nicolls (1952), Swartzman (1953), Hacquebard and Donaldson (1974), and Kalkreuth (in press). Values do not necessarily result from representative sampling of deposits and, therefore, are intended only as an indication of general characteristics that might be expected of Lower Cretaceous coals in the Peace River Coal District of the northern Inner Foothills.

beds of "apparently excellent coal" near the Brazeau River. He postulated the existence of a vast coalfield between the Red Deer and Athabasca rivers. Dawson (1883) reported on several coal deposits occurring between the Bow and Belly rivers. He described several coal exposures in the Outer Foothills and Plains of present day southern Alberta, to which he assigned an Late Cretaceous to Eocene age. He recognized the great economic potential of the apparently abundant fuel supply, with particular regard to possible railway development. Tyrrell (1887) explored the region between the Bow and North Saskatchewan rivers and reported on coal occurrences therein. Still further north, McEvoy (1900) reported on the geology and natural resources in the vicinity of the Yellowhead Pass. Although he described a 4 m thick coal seam in the bank of the Pembina River, he gave no indication of the great coal potential of the region that was later recognized by Dowling (1910). Ross (1974) noted that it was probably a result of Dowling's work that the Grand Trunk and Pacific Railway decided to construct a spur line south of Edson (later referred to as the Coal Branch) to the extensive coal deposits of the Coalspur and McLeod River coalfields (Fig. 6.5). The deposits of high volatile bituminous coals between the North Saskatchewan and Athabasca rivers have the greatest commercial potential, although several small mines throughout the Outer Foothills operated intermittently prior to the mid-1950's. In addition to the major mining operations at Coal Valley, feasibility studies for developing other relatively large mining operations have reached advanced stages (e.g. McLeod River Project, Mercoal Project, Coalspur Project, etc.).

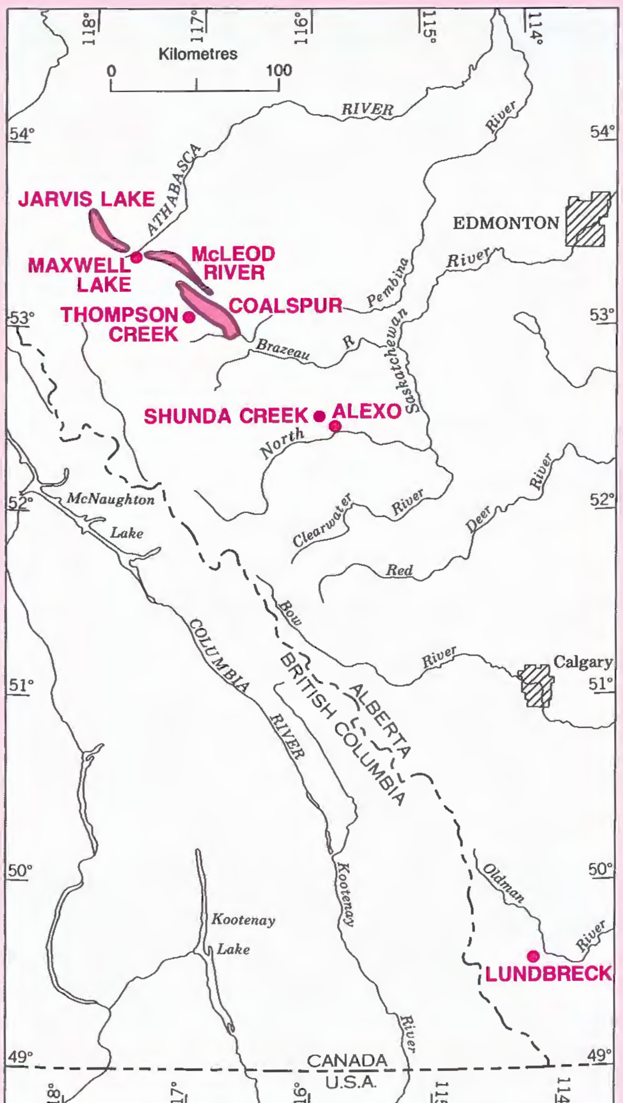


Figure 6.5. Coalfields and isolated coal deposits in the Outer Foothills Belt of the Rocky Mountains.

The coal-bearing units of the Outer Foothills are within the nonmarine Campanian to lower Paleocene strata that overlie the Upper Cretaceous nearshore strata and the marine Wapiabi Formation. Of the five formations that constitute post-Wapiabi strata in the southern Outer Foothills (Belly River, Bearpaw, St. Mary River, Willow Creek and Porcupine Hills; Figure 6.1), only the Belly River Formation contains appreciable coal. The entirely nonmarine post-Wapiabi stratigraphic sequence in the Outer Foothills of west-central Alberta is assigned to the Saunders Group (Allan and Rutherford, 1923). The most commercially significant coal deposits of the Outer Foothills Belt occur within the Paleocene Coalspur Formation of this group, between the North Saskatchewan and Athabasca rivers (Fig. 6.1). The Upper Cretaceous-Paleocene nonmarine Wapiti Group, which occurs mainly to the north of the Athabasca River, is correlative with pre-Paskapoo strata of the Saunders Group to the south. Although it is coal-bearing, the resources of the Wapiti are assigned to the Interior Plains.

The Upper Cretaceous-Paleocene coal beds were deposited in a foreland basin, in a series of cyclothems that accompanied orogeny in the Cordillera to the southwest (McLean and Jerzykiewicz, 1978; Jerzykiewicz and Sweet, 1986). Coal beds were deformed to varying degrees. On a regional scale, structures can generally be characterized as northwesterly-trending open folds and widely spaced southwest-dipping thrust faults. Locally, structures are commonly significantly more complex and, as elsewhere in the Cordillera, they have both complicated and enhanced coal mining possibilities. It has been suggested that structure is the principal factor in the development of mineable coal deposits in the Outer Foothills Belt, with particular reference to the Coal Valley area (Jerzykiewicz and Mclean, 1980). There, the interaction among structural elements has resulted in up to a twentyfold increase in the 6 m stratigraphic thickness of the Mynheer coal seam, and similar increases in the 8 m stratigraphic thickness of the Val d'Or coal seam (Alexander, 1977; Gagnon, 1982; Johnston 1985).

All Campanian to Paleocene coals within the belt are high volatile bituminous in rank. Coal quality is generally considered highly desirable in terms of fuelling conventional coal-fired thermal electric generating plants (Table 6.14). In addition to the large tonnages shipped annually to Ontario Hydro, coals from the Coal Valley Mine have been exported throughout the world.

BELLY RIVER COALS

The name Belly River was first used to include strata between the Colorado and Bearpaw shales (Dawson, 1883). The Belly River Formation and equivalent strata form an eastward-thinning wedge of clastic sediments (supplied from the rising Rocky Mountains to the west), which extends from the Foothills into southern Saskatchewan. In the Outer Foothills Belt it overlies the Wapiabi Formation (correlative with the Colorado Shales) where the transitional contact marks the end of a long period of marine sedimentation and the beginning of a long period of continental sedimentation (Rosenthal, 1984). The Belly River Formation is recognized in the Outer Foothills from the U.S. Border northward to about the Bow River where partly correlative beds are assigned to the Brazeau Formation (Stott, 1963). In the Interior Plains these Upper Cretaceous beds are divided into the Foremost and Oldman formations which constitute the Belly River Group. The Belly River Group contains the commercially significant Lethbridge and Taber coal zones. The undivided Belly River Formation of the Outer Foothills, however, contains only a few coal beds, intermittently mined on a small scale in the past and currently of little commercial significance.

The Belly River Formation is between 700 and 900 m thick in the Outer Foothills Belt south of the Bow River (MacKay, 1934; Hage, 1943; Douglas, 1951). Coal beds occur mainly in two zones of which the lower is about 120 m above the base of the formation, and the upper is within 45 m of the top of the formation. Although one seam in the lower coal zone attains a thickness of nearly 2 m between the Crowsnest and Oldman rivers, it is generally insufficiently thick throughout the Outer Foothills to suggest any commercial potential (MacKay, 1934). Some deposits, such as those near Morley, south of the Bow River, have supplied small amounts of coal for local domestic use (Beach, 1943).

Coal beds are best developed in the upper coal zone where they occur in nearshore sediments associated with the trangression of the Bearpaw Sea (Jerzykiewicz and Sweet, 1988). This coal zone is correlative with the Lethbridge Coal Zone in the Oldman Formation of the Belly River Group in the Plains. In the Outer Foothills, the coal beds appear to attain greatest thickness near the town of Lundbreck where a seam up to 3 m thick has been mined (Hage, 1943; Allan, 1943). Fifteen underground mines have exploited the coals near Lundbreck, producing a total of about 286 kilotonnes of high volatile bituminous coal between 1889 and 1954 (Alberta Energy Resources Conservation Board, 1985). Belly River coals have also been mined, on a relatively small scale, further north between Pekisko Creek and the Elbow River southwest of Calgary. Twenty-nine underground mines produced a total of about 205 kilotonnes of high volatile bituminous coal between 1896 and 1958 (Alberta Energy Resources Conservation Board, 1985). The mined seam varies in thickness from 1 m to nearly 3 m, and dips from nearly horizontal to more than 30° (Allan, 1943). There are currently no operating mines or "permitted" mine sites in the Belly River Formation in the Outer Foothills Belt.

The lack of commercially significant coal in the Belly River Formation might be attributable to unfavourable syndepositional climatic conditions as indicated by the presence of well-developed caliche deposits (Jerzykiewicz and Sweet, 1988). An unstable tectonic environment at the time of deposition might also have resulted in fluctuating conditions that were not conducive to the development of thicker and more continuous coal deposits (MacKay, 1947). Some of the thicker coal deposits are steeply dipping, thereby complicating their mining potential.

COALSPUR COALS

Post-Wapiabi strata in the central Foothills of Alberta are assigned to the Saunders Group, which includes the Brazeau, Coalspur and Paskapoo formations (Fig. 6.1). Malloch (1911) first applied the name Brazeau to nonmarine beds above the Wapiabi Formation where the tongue of Bearpaw shales is absent. The distinction between strata of the Belly River and Brazeau formations is not clear without reference to the Bearpaw Formation. The name Brazeau Formation is currently

TABLE 6.13

COAL RESOURCES OF IMMEDIATE INTEREST OUTER FOOTHILLS BELT

Coalfield Deposit	Predominant Rank*	measured	indicated (megatonnes)	inferred
Lundbreck	hvb	-	5	-
Alexo	hvb	5	5	5
Shunda Creek	mvb	-	5	-
Thompson Creek	hvb	5	10	25
Coalspur	hvb	230	115	430
McLeod River	mvb	500	550	1310
Maxwell Lake	hvb	-	5	-
Jarvis Lake	hvb	90	45	185
TOTALS	sub-mvb	830	740	1955

*totals by general rank class

Estimated coal resource quantities are based mainly on information from the Alberta Energy Resources Conservation Board (1987). This information has been modified to reflect the Geological Survey of Canada's coal resource classifications, including the classification of ERCB's "underground - thin" coal as coal resources of future interest, and a division of the balance of ERCB's "established resources" to measured, indicated and inferred categories.

TABLE 6.14

GENERAL COAL QUALITY CHARACTERISTICS
OUTER FOOTHILLS BELT

	Belly River Coals	Coalspur Coals
Proximate analysis		
(per cent by weight)		
moisture (as received)	4-7	8-10
ash (dry)	10-20	10-15
volatile matter (d.a.f.)*	40-45	37-42
fixed carbon (d.a.f.)	55-60	58-63
Calorific value (d.a.f.) MJ/kg	32-34	30-31
Ultimate analysis (dry, ash-free)		
(per cent by weight)		
carbon	78.0-82.0	78.5
hydrogen	5.5-6.5	5.0
nitrogen	1.5-2.0	1.3
sulphur	1.0-2.0	0.2
oxygen	7.5-14.0	15.0
Analysis of ash		
(per cent by weight)		
SiO_2	-	55.0
Al_2O_3	-	20.0
Fe_2O_3	-	4.0
CaO	-	12.0
MgO	-	1.5
Na_2O	-	1.0
K_2O	-	0.5
P_2O_5	-	0.1
TiO_2	-	0.7
SO_3	-	2.5
undetected	-	2.7
Petrographic indices		
(per cent by weight)		
mean max. reflectance ($R_o$max)	0.6-0.8	0.6-0.8
total reactives	90-93	63-66
total inerts	7-10	34-37
Properties		
grindability index (Hardgrove)	45-50	45-60
ash softening temp. (reduce-°C)	-	1150-1250
Rank classification (ASTM)	hvbB	hvbC

*dry, ash-free

These generalized coal characteristics result from the synthesis and consideration of information from several sources, including Stansfield et al. (1925), Stansfield and Lang (1944), Nicolls (1952), Swartzman (1953), Swartzman and Tibbetts (1955), and Bonnell and Janke (1986). Values do not necessarily result from representative sampling of deposits and, therefore, are intended only as an indication of general coal characteristics that might be expected of Upper Cretaceous-Paleocene coals in the Outer Foothills Belt.

applied to post-Wapiabi strata of the central Alberta Foothills, in the vicinity and north of the Bow River. It was deposited prior to the conspicuous bed named Entrance Conglomerate (Lang, 1947; Jerzykiewicz and McLean, 1980). The total thickness of the formation, measured along the Blackstone River, is about 950 m, of which the upper 400 m contains some coal beds (Jerzykiewicz and Sweet, 1988).

The Coalspur Formation which overlies the Brazeau Formation is the principal coal-bearing unit of the Saunders Group. It is correlative with the Scollard Formation of the central Plains of Alberta, which contains the important Ardley Coal Zone (Jerzykiewicz, 1985). The Entrance Conglomerate forms the base of the Coalspur Formation. The top of the main coal-bearing sequence, referred to as the Coalspur Coal Zone, coincides with the top of the formation (Jerzykiewicz, op. cit.).

The Paskapoo Formation lies unconformably on the Coalspur Formation. It mainly comprises a thick sequence of sandstones, which contains the Obed Coal Zone in the Interior Plains north of the Athabasca River. It does not host commercially significant coal beds in the central Alberta Foothills.

The Brazeau and Coalspur formations were deposited in a series of five cyclothems, each consisting of a lower part, comprising mainly channel sandstones, and an upper part, comprising mainly mudstone with coaly shale and/or coal seams and lacustrine rhythmites (Jerzykiewicz and Sweet, 1988). Relatively thin coal beds occur in the upper part of the second, third and fourth cyclothems. The thickest beds are associated with alluvial deposits in the upper part of the fifth cyclothem, which constitutes the Coalspur Formation.

The Coalspur Formation contains the vast majority of coal resources in the Outer Foothills, and the only currently operating mine. Coal beds are best developed between the Athabasca and Brazeau rivers, although some mines have exploited these coals further south near the North Saskatchewan River. The first coal bed, which marks the base of the Coalspur Coal Zone, is about 170 m above the Entrance Conglomerate (Jerzykiewicz and Sweet, 1988). The Cretaceous-Tertiary boundary is, coincidentally, at the base of this first coal bed which has been named the Mynheer seam in the Coalspur and Coal Valley areas (Jerzykiewicz and Sweet, 1986). Development of the Paleocene Mynheer coal follows a pattern of deposition that began in the underlying Brazeau Formation. The seam is much thicker and more laterally continuous than the underlying Maastrichtian coal beds.

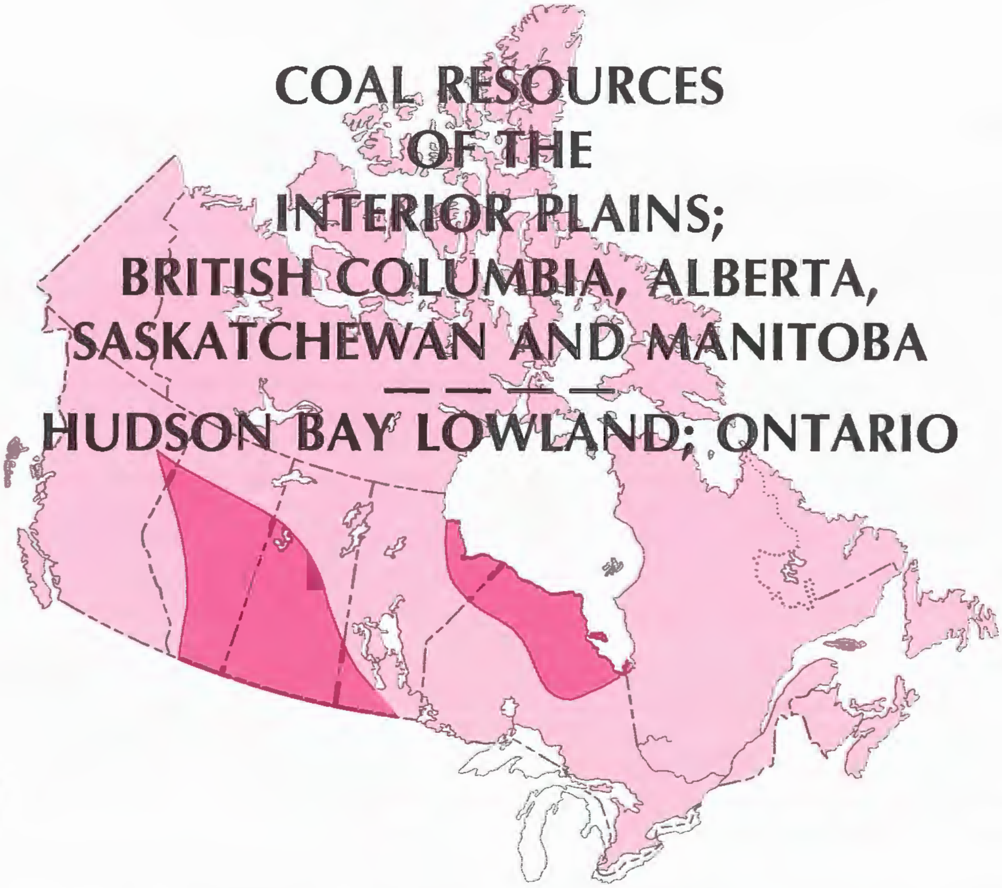
Correlative strata of the Saunders Group in the Foothills and the coal-bearing Edmonton Group in the Interior Plains to the east differ primarily as a result of their respective depositional environments. The Edmonton Group comprises mainly deltaic and brackish water deposits, and the correlative Saunders strata are associated mainly with lacustrine and alluvial depositional environments.

Estimated coal resource quantities that are contained in both the Belly River and Coalspur formations are provided in Table 6.13. The general characteristics of these high volatile bituminous coals are indicated in Table 6.14.

HIGHVALE MINE AND SUNDANCE POWER STATION, ALBERTA

CHAPTER 7

COAL RESOURCES OF THE INTERIOR PLAINS; BRITISH COLUMBIA, ALBERTA, SASKATCHEWAN AND MANITOBA — — — — HUDSON BAY LOWLAND; ONTARIO



FEATURES

COAL RESOURCES OF THE INTERIOR PLAINS; BRITISH COLUMBIA, ALBERTA, SASKATCHEWAN AND MANITOBA. HUDSON BAY LOWLAND; ONTARIO

INTRODUCTION

Coal-bearing formations underlie approximately 385 000 square kilometres of the western Canadian Interior Plains, extending north from the U.S.A. border (49th Parallel) to about the Peace River, and from the eastern limit of the Rocky Mountain Foothills to south-central Manitoba (Fig. 7.1). Most of Canada's lignitic and subbituminous coal resources occur within this basically flat region. The coal commonly occurs close to the surface, and in near-horizontal beds — conditions that are often ideal for large-scale strip mining operations. About 47 per cent of Canada's 1987 total coal production was mined in the region, principally from 11 major strip mines (Fig. 3.7). Most of the production is used to fuel mine-mouth electric power generating stations. These produce more than 90 per cent of the electricity generated in Alberta, and more than 70 per cent of the electricity generated in Saskatchewan. More than one megatonne of lignite is shipped annually from mines in southern Saskatchewan to electric power generating stations in Manitoba and Ontario. With the exception of the Hat Creek deposits of southern Intermontane British Columbia, all of Canada's lignitic and subbituminous coal reserves occur in the region.

Near surface stratigraphic sequences in the Interior Plains were deposited mainly in Late Cretaceous and Tertiary times. Early Cretaceous deposits approach the surface toward the eastern and northeastern margins of the region (Fig. 7.1). Alternating periods of marine transgression and regression during Cretaceous and Tertiary times profoundly affected the nature of sedimentation. Favourable coal-forming conditions often occurred in deltaic environments near the shores of the epicontinental seas, and in alluvial plain environments between the shorelines and uplifted areas to the west (Fig. 3.4).

Although almost the entire region is underlain by coal-bearing formations, coal beds thicken, thin, split, coalesce, and pinch out according to local depositional controls during original peat accumulations. Additionally, postdepositional erosion has limited the extent of coal beds in many areas. These depositional and erosional processes, which have limited the lateral continuity of coal beds, have resulted in the presence of discrete coalfields (Fig. 7.2). Most of the region, except steep slopes resulting mainly from stream incision, was mantled by glacial deposits during Late Pleistocene time. The general lack of bedrock exposure requires that effective coal resource evaluation be based, to a large extent, on subsurface exploration.

Cretaceous and Tertiary stratigraphic sequences of the Interior Plains generally dip gently westward toward the axis of the Alberta Syncline (Fig. 7.3). The near surface coal deposits, which constitute resources of immediate interest, also extend down-dip to depths where resources can only be considered of future interest. Large quantities of deep coal, commonly occur in relatively thick beds (Williams and Murphy, 1981) and could provide a significant contribution to Canada's future energy supply with the advancement of in situ gasification technologies and favourable economic conditions.

The Alberta Syncline, Sweetgrass and subsidiary arches, and Williston Basin are the major structural features of the region (Fig. 7.3). These features affected drainage and sedimentation patterns during Cretaceous and Tertiary times, and subsequent organic maturation. They have left a regional structural impression on Cretaceous and Tertiary stratigraphic sequences. Generally, coal measures of the Interior Plains have not been tectonically deformed except in a regional sense. However, they have been deformed to varying degrees by differential compaction. Additionally, strata occurring near the bedrock surface have been variably folded and faulted by overriding glacial movements. This deformation tends to complicate mining operations. The effects of surface weathering, which can negatively alter both coal qualities and the strengths of associated noncoal rock units, can penetrate strata for up to several tens of metres.

BACKGROUND

Coal occurrences in the region have been known since 1793, but the use of coal was not reported until 1858, when Sir James Hector of the Palliser Expedition described its use in the forges at Edmonton. In 1857, Hector found coal along the Souris River in southeastern Saskatchewan (Dowling, 1914). He was, however, disappointed in the coal potential of what has become the mining district of Estevan and Boundary Dam (Spry, 1963). Bell (1874) observed and sampled numerous lignite deposits between the Red and South Saskatchewan rivers.

The earliest detailed geological investigations of the coal measures in the Interior Plains were done in the last quarter of the 19th century by the Geological Survey of Canada (Dawson, 1875, 1883; McConnell, 1886; Tyrrell, 1887). Each recognized the vast coal potential of the region at that important time of planning and development of transcontinental railways. Dawson (1875) produced the first

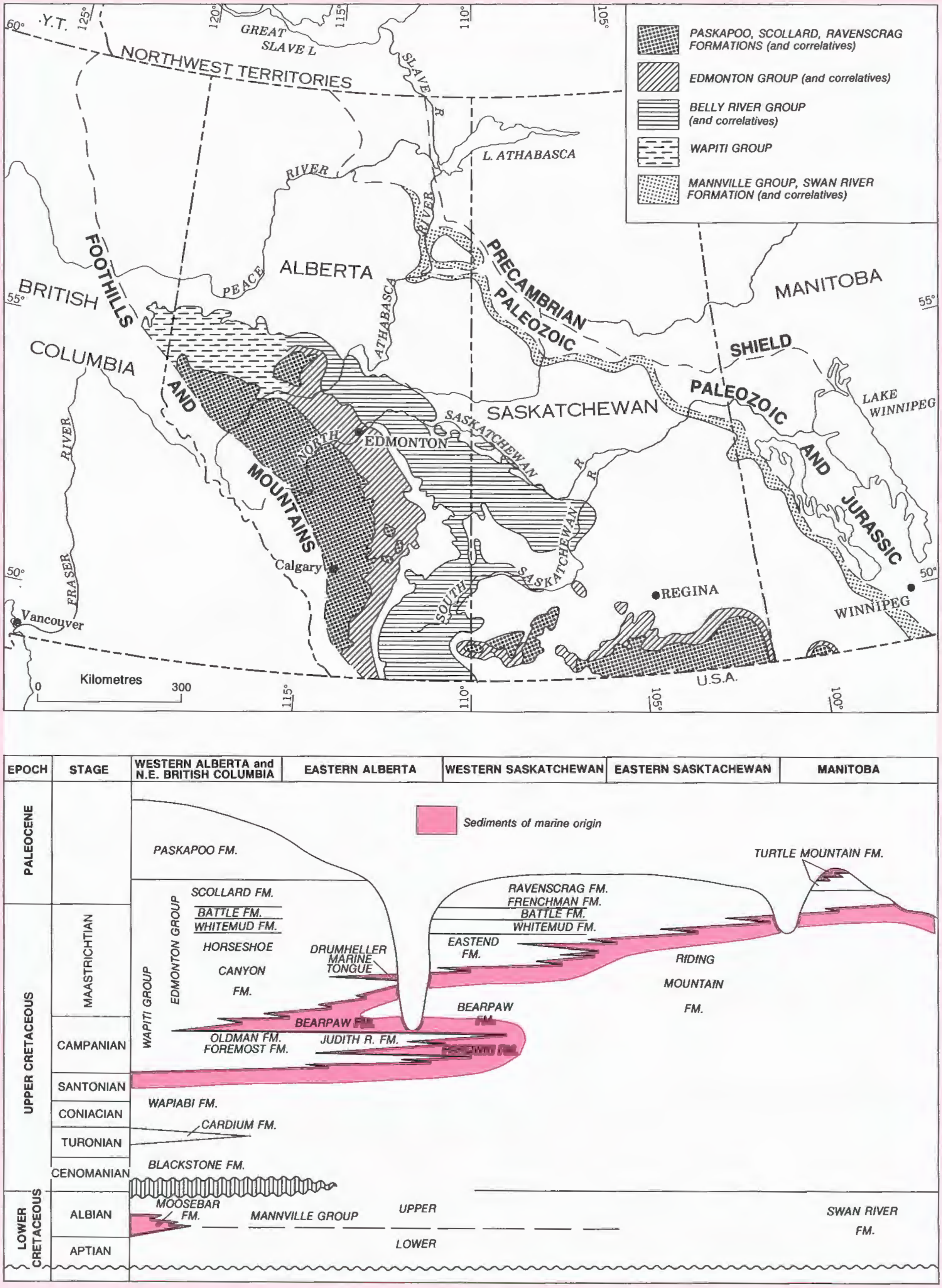


Figure 7.1. Generalized map and stratigraphic section showing major coal-bearing formations in the Interior Plains.

comprehensive report pertaining to the geology and economic potential of the coal deposits near the 49th Parallel. D.B. Dowling published several reports in the early 1900's pertaining to the vast coal potential of the Interior Plains. His reports provided critical information for subsequent coal exploration and mining to support railway development and other industrial growth (Dowling, 1914).

About 25 tons of lignite were barged down the Souris River from Roche Percée to Winnipeg in 1880. This represented one of the first examples of relatively large scale commercial exploitation of coals in the Plains. Subsequent railway developments provided access to markets in other major centres, including Regina, Brandon, etc. By 1910, nearly 50 mines were operating in southern Saskatchewan, with a total production of about 160 000 tonnes of lignite (Dowling, 1914). Across southern Saskatchewan, more than 130 mines in the Estevan Coal District, about 200 mines in the Willow Bunch and Wood Mountain coal districts, and about 60 mines in the Cypress Coal District have been established to date (Irvine et al., 1978). Mining was by both surface and underground means until the 1950's, by which time relatively large scale strip mining techniques had eliminated the competitiveness of more costly underground mining. Most coal produced to the mid-1950's was used for local consumption, with the exception of relatively small quantities shipped by railroad mainly to Winnipeg and Brandon markets.

More than 1200 coal mines in the Plains of Alberta, dating back to the 1880's, have been officially registered in the Provincial Government of Alberta's records (Alberta Energy Resources Conservation Board, 1985). Mining has been by both surface and underground methods, and has produced coals ranging in rank between lignitic and high volatile bituminous.

In 1987, 29 megatonnes of coal were produced from 11 major strip mining operations in the region (Fig. 3.7). About two-thirds of this tonnage was subbituminous coal mined in Alberta. Most of the remainder was lignite mined in Saskatchewan, although a relatively small amount of high volatile bituminous coal was also produced.

MANNVILLE GROUP AND CORRELATIVES

INTRODUCTION

In 1893, beds of lignite up to 1.5 m thick, were reported in Lower Cretaceous strata along and near the Athabasca River near Fort McMurray (McConnell, 1893). These lignites, which have been assigned to the **McMurray** and **Grand Rapids formations**, were further described and analyzed in 1924 (Clark and Blair, 1925), and presently constitute resources of the Firebag Coalfield (Fig. 7.2). They often occur with bitumen-bearing sands, and are commonly impregnated with bitumen.

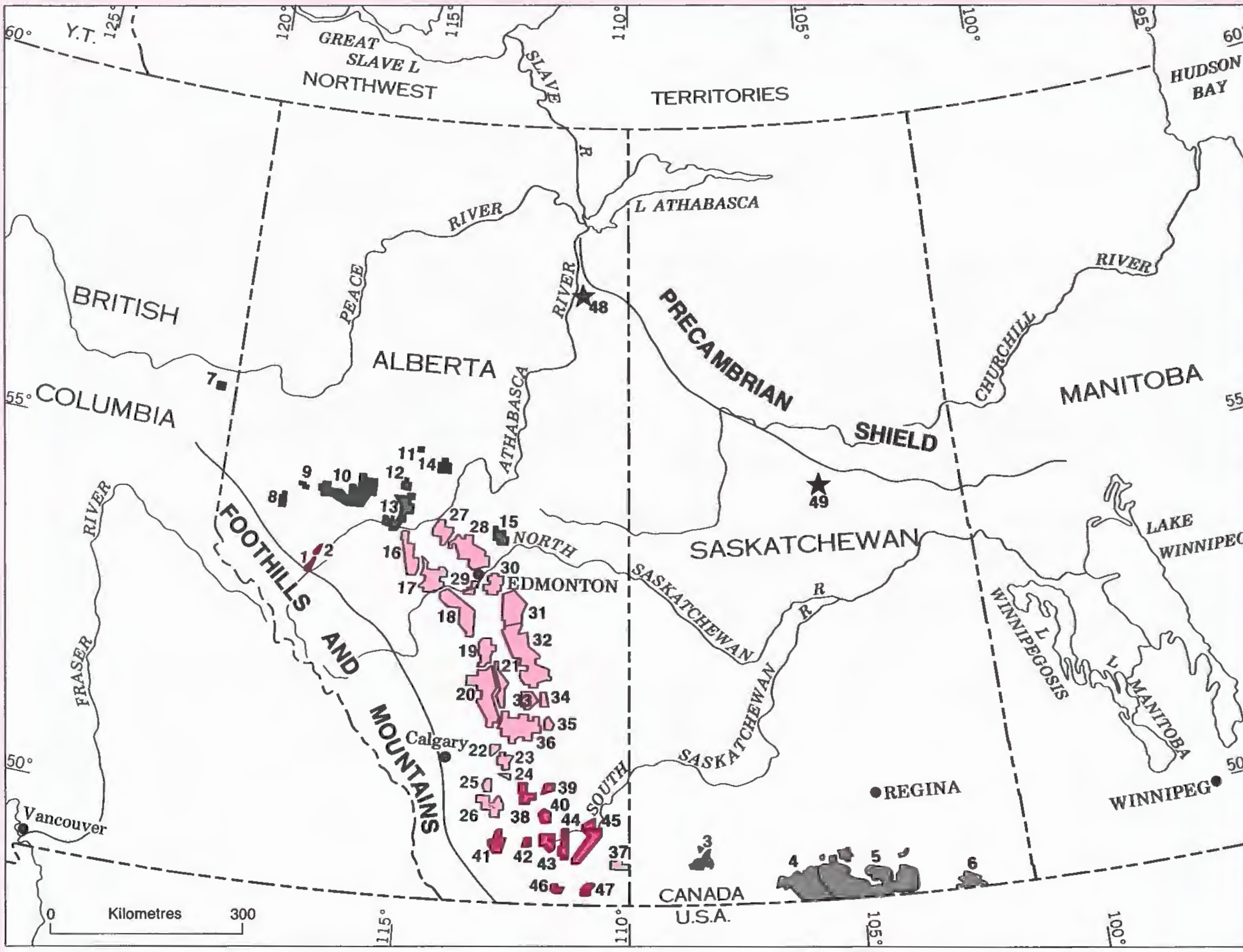
In 1908, lignitic deposits were found in Lower Cretaceous strata south of Lac La Ronge in north central Saskatchewan (McInnes, 1909, 1910). These coal-bearing strata, which are assigned to the **Swan River Group** (correlative with the Mannville Group), have subsequently been found in outcrop and in drillholes at several localities in the Lac La Ronge-Wapawekka Lake area (Guliov, 1972). These deposits constitute the relatively small Wapawekka Coalfield, which has also been referred to as the La Ronge Coal Basin.

With the exception of the Firebag and Wapawekka coalfields, Lower Cretaceous coal deposits within the **Mannville Group** and its correlatives occur at depths beyond conventional coal mining capabilities, and might be considered resources of future interest at best. Information pertaining to the Mannville Group has been derived mainly from petroleum wells, most of which have been drilled since the discovery of oil near Leduc, in 1947.

GEOLOGY

Early Cretaceous sedimentation throughout the region was controlled by mountain building processes to the west, which began in Late Jurassic time (Columbian Orogeny). Widespread nonmarine clastic sedimentation followed the expulsion of the Jurassic Fernie Sea, and the subsequent period of erosion in the Interior Plains (Rudkin, 1966). Stratigraphic units that were deposited include the Jurassic-Cretaceous Kootenay Group and Nikanassin Formation, and Early Cretaceous lower Blairmore Group in the central Rocky Mountains and Foothills; Bullhead Group and correlative lower part of the Luscar Group in the north-central Rocky Mountains and Foothills; and lower Mannville in the southern and central Plains. The mainly alluvial plain and deltaic depositional environments were often suitable for peat accumulation, although only thin coal beds occur in the lower Mannville of the Interior Plains (Mellon, 1967).

During mid-Cretaceous time the boreal Clearwater-Moosebar Sea advanced southeasterly over northern and central Alberta (Caldwell, 1984). The upper Mannville was deposited on a base of glauconitic sandstones during the withdrawal of this sea (Fig. 3.4b). It comprises dominantly continental and transitional marine to nonmarine shoreline facies (Mellon, 1967; Glaister, 1959). Several coal beds were deposited in the upper Mannville, with the greatest number developed in the Edmonton area (Glaister, op. cit.). The thickest and most extensive Mannville coal deposits occur between latitudes 52° and 53° North, and between longitude 112° West and the eastern edge of the Rocky Mountain Foothills. Cumulative coal thicknesses exceed 12 m, with individual beds exceeding 4.5 m (Yurko, 1976). The depths of the coal



COALFIELDS

TERTIARY

PASKAPOO FORMATION

1 OBED MOUNTAIN
2 HANNINGTON

RAVENSCRAG FORMATION

3 CYPRESS
4 WOOD MOUNTAIN
5 WILLOW BUNCH
6 ESTEVAN

UPPER CRETACEOUS

WAPITI GROUP

7 WAPITI
8 MUSREAU LAKE
9 SIMONETTE
10 FOX CREEK
11 SAWRIDGE HILL
12 SWAN HILLS
13 SOUTH SWAN HILLS
14 LESSER SLAVE LAKE
15 THORHILD-ABEE

UPPER CRETACEOUS (cont.)

EDMONTON GROUP

SCOLLARD FM.

16 MAYERTHORPE
17 WABAMUN
18 WETASKIWIN
19 ALIX
20 ARDLEY
21 SCOLLARD

HORSESHOE CANYON FM.

22 STRATHMORE
23 HUSSAR
24 BLACKFOOT
25 BUFFALO HILL
26 McGREGOR LAKE
27 BARRHEAD
28 MORINVILLE
29 DEVON
30 EAST EDMONTON
31 TOFIELD-DODDS
32 BATTLE RIVER
33 CHAIN LAKES
34 GARDEN PLAIN
35 SHEERNESS
36 DRUMHELLER
37 CYPRESS HILLS

UPPER CRETACEOUS (cont.)

BELLY RIVER GROUP

38 BROOKS
39 EAST BROOKS
40 ROLLING HILLS
41 LETHBRIDGE
42 TABER
43 GRASSY LAKE
44 BOW ISLAND
45 MEDICINE HAT
46 LUCKY STRIKE
47 COMREY

LOWER CRETACEOUS

★ *MANNVILLE GROUP*

48 FIREBAG
49 WAPAWEKKA

Figure 7.2. Coalfields of the Interior Plains.

measures, however, extend to about 2500 m at the Foothills margin (Yurko, op. cit.). Although the Mannville Group extends into southwestern Manitoba, the delineation of coal measures east of Alberta has not been published. Substantial quantities of deep coal in the Mannville Group of southern Saskatchewan, however, have been estimated on the basis of petroleum well information (Williams and Murphy, 1981).

Following deposition of the Mannville Group, the southern Interior Plains were entirely inundated by a major marine transgression which united the boreal and gulfian seas (Rudkin, 1966). The mainly marine Colorado Group was deposited until the late stages of Cretaceous time (early Campanian), when conditions associated mainly with the withdrawal of seawater (Fig. 3.4c), again became suitable in many areas for relatively long periods of peat accumulation.

RESOURCE QUANTITIES

The Alberta Energy Resources Conservation Board (1987) classifies resources of the Firebag Coalfield as "underground-mineable", with an estimated 65 megatonnes of coal in beds 1.5 to 3.6 m thick, and 40 megatonnes in beds greater than 3.6 m thick, occurring between 47 and 126 m from surface. The only reported surface mineable Lower Cretaceous coal resources in the Interior Plains are within the Wapawekka Coalfield where about 30 megatonnes of coal in beds at least 1.5 m thick are reported to occur within 45 m of surface (Broughton et al., 1974). In this report, the estimated resource quantities of the Firebag and Wapawekka coalfields are classified as immediate interest, and arbitrarily proportioned to indicated and inferred categories (Table 7.1).

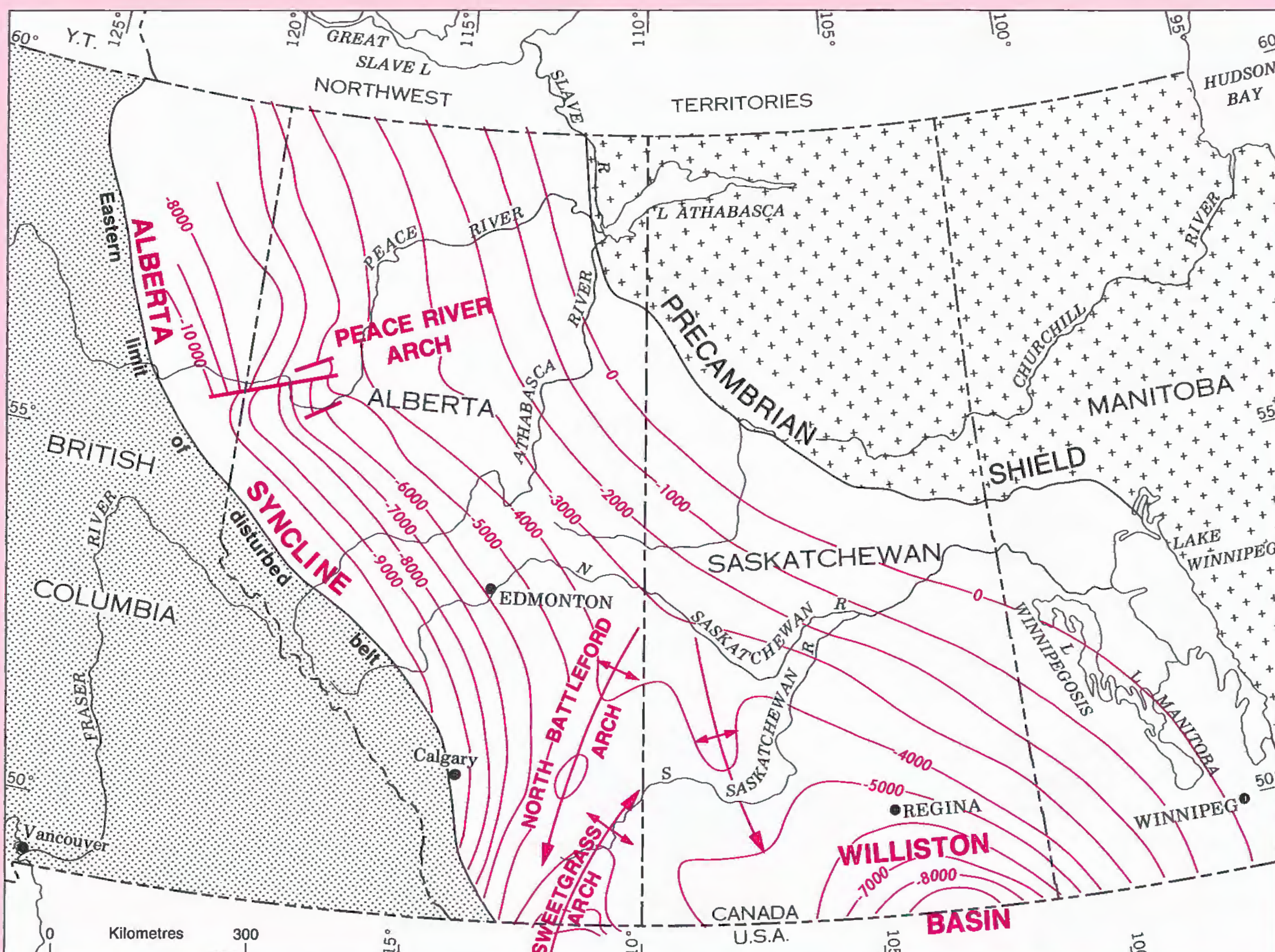


Figure 7.3. Major structural features, expressed by the Precambrian surface underlying the Interior Plains, which have affected drainage, sedimentation, and organic maturation patterns associated with Cretaceous and Tertiary coals (modified from Herbaly, 1974).

COAL QUALITY

Coals of the Firebag and Wapawekka coalfields appear to have similar characteristics when one considers the limited available proximate analysis data. The general characteristics of these coals, summarized in Table 7.2, are based on 12 samples of Firebag coals and 4 samples of Wapawekka coals, all acquired from surface exposures. Although these coals have been consistently referred to as lignites, analyses show them to be subbituminous C rank according to ASTM standards (Fig. 2.4).

TABLE 7.1
COAL RESOURCES OF IMMEDIATE INTEREST
MANNVILLE GROUP AND CORRELATIVES

Coalfield	Predominant Rank*	measured	indicated (megatonnes)	inferred
Firebag	sub	-	25	80
Wapawekka	sub	-	10	20
TOTALS	lig-sub	-	35	100

*totals by general rank class

TABLE 7.2

GENERAL COAL QUALITY CHARACTERISTICS
FIREBAG AND WAPAWEKKA COALFIELDS
(Mannville Group and Correlatives)

Proximate analysis (per cent by weight)	
moisture (equilibrium)	25
moisture (air dried)	11
ash (dry)	25
volatile matter (d.a.f.)*	45
fixed carbon (d.a.f.)	55
Calorific value (d.a.f.) MJ/kg	28.5
Rank classification (ASTM)	subC

*dry, ash-free

These generalized coal characteristics are based on unpublished analyses by the Research Council of Alberta of coals from the Firebag Coalfield, sampled during the period 1924-30; and on information of the Wapawekka Coalfield, summarized by Pearson (1961) for the Saskatchewan Department of Mineral Resources.

BELLY RIVER, EDMONTON AND WAPITI GROUPS AND CORRELATIVES

INTRODUCTION

In the Interior Plains of Alberta almost all coal resources of immediate interest, and all reserves except those at Obed Mountain, occur in the Upper Cretaceous Belly River Group, and Upper Cretaceous-Tertiary Edmonton and Wapiti groups. These coals constitute the vast majority of Canada's subbituminous coal resource and nearly half of the nation's total measured resources of immediate interest on a tonnes coal equivalent basis (referenced to a standard 7000 kcal/kg or 29.3 MJ/kg). Five of the 11 major strip mining operations in the Plains are currently exploiting these resources. In 1986, they produced 17.5 megatonnes of subbituminous coal — more than 30 per cent of the nation's total annual coal production. This was destined mainly for mine-mouth electric power generating stations.

Coal resources of immediate interest occur in the Belly River, Edmonton and Wapiti groups in the Plains of southern, central and northern Alberta, respectively (Fig. 7.2). A single deposit (named "Wapiti") in the Wapiti Group of northeast British Columbia contains all of that Province's coal resources of immediate interest in the Plains. Each of the coal-bearing stratigraphic units is time-equivalent to part of the Saunders Group in the Outer Foothills of west-central Alberta.

GEOLOGY

The Belly River Group, also referred to as the Judith River Formation, was deposited as an eastward-thinning clastic wedge in southern Alberta, in floodplains and several coalescing deltas between the shore of the regressing epicontinental Pakowki Sea and newly elevated (Laramide Orogeny) highlands to the southwest (McLean, 1971). Alluvial, lacustrine, aeolian, lagoonal, swamp, beach, and shallow marine depositional environments have been interpreted for these sediments (McLean, op. cit.). Unlike the undifferentiated Belly River Formation of the Foothills, the Belly River Group in the southern Plains comprises the Foremost and Oldman formations (Fig. 7.1). The **Foremost Formation** is a transitional sequence between the underlying marine deposits of the Pakowki Formation and correlatives, and overlying fresh and brackish water deposits of the Oldman Formation (Ogunyomi, 1976). The continental **Oldman Formation** is characterized by repeated fining-upward cycles that probably indicate a dominance of floodplain deposition.

The most significant coal development in the Foremost Formation is within the **MacKay Coal Zone** near the base of the formation, and in the **Taber Coal Zone** at the top. Up to eight thin and usually laterally impersistent seams occur within the 20 to 27 m thick MacKay Coal Zone. The 18 to 30 m thick Taber Coal Zone contains up to five seams, which are often laterally persistent, and sometimes exceed 1 m in thickness (Holter and Chu, 1978). Coal beds of the Foremost Formation are best developed between Lethbridge and Medicine Hat.

Commercially significant coal beds occur in the upper part of the Oldman Formation, within the **Lethbridge Coal Zone**. This coal zone, which is up to 18 m thick, is relatively persistent throughout southern Alberta. Individual coal beds, however, are laterally continuous only in the Lethbridge area (Holter and Chu, 1978). Although individual coal beds do not generally exceed 1 m in thickness, greater aggregate thickness of beds that occur in close stratigraphic proximity, enhances mining possibilities in some areas. Relatively large tonnages of Belly River subbituminous and high volatile bituminous coals have been mined since the late 1800's, in the area between Lethbridge and Medicine Hat. The last of these mines closed within the past 20 years.

The Sweetgrass Arch and subsidiary, regional folds in southern Alberta, in addition to structures on the western flank of the Alberta Syncline (Fig. 7.3), are structurally expressed in the Belly River Group (Russell and Landes, 1940). Further north, where coal measures occur in the Edmonton Group, effects of the Sweetgrass Arch are absent and the Alberta Syncline becomes the only dominant regional structure.

The favourable coal-forming conditions that prevailed during deposition of the Oldman Formation were terminated when the epicontinental Bearpaw Sea inundated the southern and central Plains (Fig. 3.4d). Sedimentation during this last major Late Cretaceous marine transgression is characterized by a series of upward-coarsening deposits that have been interpreted to represent repeated delta construction cycles following trangressive pulses (Habib, 1981). A transition between the mainly marine sedimentation of the **Bearpaw Formation**, and continental sedimentation of the overlying Horseshoe Canyon Formation marked the withdrawal of seawater following the last trangressive pulse (Shepheard and Hills, 1970). Major coal beds were deposited toward the top of this transitional sequence and within the fluvial-deltaic and alluvial plain deposits throughout the Horseshoe Canyon Formation.

The **Horseshoe Canyon Formation** constitutes the lower part of the Upper Cretaceous-Tertiary Edmonton Group in the central Plains of Alberta (Fig. 7.1). Its correlative in the central Foothills and northwest Plains occurs within the Brazeau Formation of the Saunders Group, and the Wapiti Group. The Blood Reserve, St. Mary River, and Eastend formations are approximately correlative in the southern Plains (Russell and Landes, 1940). The Horseshoe Canyon Formation has been extensively studied along the Red Deer River, particularly between Ardley and the Drumheller area. Thirteen coal beds, with a maximum individual bed thickness of 3.3 m, have been identified within the 227 to 267 m thick formation in this area (Gibson, 1977b). The coal-forming peat accumulated in interdistributary and interchannel areas within fluvial-deltaic and alluvial plain environments. Overbank flood events controlled, to a large degree, the extent and thickness of individual coal beds (Hughes, 1984). Flooding resulted in the drowning of peat swamps, and burial of peat beds beneath variable amounts of clastic sediments. The most prolific accumulations of peat were in areas least affected by flooding, such as topographically higher terrains within the swamps, or swamp-marsh areas most remote from distributary channels (Hughes, op. cit.; Smith, 1987). The subbituminous coals have been extensively mined by surface and underground methods where they are relatively easily accessible along the banks of the Red Deer River and adjacent coulees. The formation has also been extensively explored and mined to the east and northeast, where the coal-bearing strata approach the surface. Current large scale surface mining operations along this subcrop margin (Vesta, Paintearth and Montgomery) are annually producing about 3.5 megatonnes of subbituminous coal to fuel mine-mouth electric power generating plants (Fig. 3.7).

Marine pelecypod-bearing beds, referred to as the **Drumheller Marine Tongue**, occur near the top of the Horseshoe Canyon Formation, and divide the formation into upper and lower units. All but two of the 13 coal beds of the Horseshoe Canyon Formation, which have been identified along the Red Deer River valley, occur in the lower part of the formation. The **Carbon** and **Thompson coal zones** occur above the Drumheller Marine Tongue, and although coal bed thicknesses reach about 1.5 m along and near the Red Deer River valley, it is conceivable that they may attain greater thicknesses in the adjacent subsurface (Gibson, 1977b). Coal has previously been mined from both of these zones.

Coal beds of mineable thickness occur in the **Eastend Formation** in the Cypress Hills Coalfield of southeastern Alberta (Russell, 1948; Campbell, 1965). This formation is correlative with the Horseshoe Canyon Formation in the Edmonton Group that occurs further north in the province. Relatively small quantities of surface mineable coal that occur within 36 m of surface, and lesser amounts of potentially underground mineable coal that occur in seams from 0.6 to 1.5 m thick at greater depths, have been assigned to the Eastend Formation. Some resources might also occur in the Ravenscrag Formation that overlies part of the area (Campbell, 1965; Alberta Energy Resources Conservation Board, 1987).

In the southern Plains, stratigraphic units that are correlative with the Horseshoe Canyon Formation (i.e. **Blood Reserve,**

St. Mary River and **Eastend formations**) contain only thin coal beds of no commercial significance, like those of the correlative Brazeau strata in the Outer Foothills.

The coal-bearing Horseshoe Canyon Formation is overlain by the non coal-bearing **Whitemud** and **Battle formations**. Although the origin of these formations is uncertain, they appear to contain high portions of altered volcanic ash, including distinct white-weathering montmorillonite-rich sediments and the **Kneehills Tuff**. Explosive volcanic activities in a western source area, and a more arid climate within the depositional region may have been the main factors that combined to mitigate against coal-formation (Gibson, 1977b).

The **Scollard Formation** is the youngest formation in the Edmonton Group. It contains the commercially important Ardley coal beds that are apparently associated with a progradational sequence of clastic sediments deposited in shallow-water basins or lakes, such as may have existed during deposition of the upper Horseshoe Canyon Formation (Gibson, 1977b). The **Ardley Coal Zone**, which occurs within a stratigraphic interval up to 60 m thick, can be traced from about 100 km south of Red Deer, to about 100 km north of Whitecourt. It has been subdivided into three units, referred to as Lower Ardley 'A', Lower Ardley 'B', and Upper Ardley (Holter et al., 1975). The Lower Ardley 'B' zone contains the most laterally persistent and thickest coal beds, attaining thicknesses in excess of 7 m. The Lower Ardley 'A' zone attains thicknesses of up to 4.5 m and often coalesces with the Lower Ardley 'B' zone (Horachek, 1985). The Upper Ardley, which directly underlies the massive sandstone beds of the Paskapoo Formation, is discontinuous, often non coal-bearing, and can be difficult to identify. Near-surface subbituminous Ardley coals have been extensively mined between the Red Deer River, east of the city of Red Deer, and the Athabasca River, near Whitecourt. Eight minesites are currently permitted by the Alberta Government, and two large strip mines (Whitewood and Highvale) are operating (Fig. 3.6). These two mines produced nearly 13 megatonnes of subbituminous coal in 1986 to fuel mine-mouth electric power generating plants. This represented more than 20 per cent of the nation's total 1986 coal production.

In the northwestern part of the Interior Plains, northwest of the Athabasca River, strata that are correlative with the Belly River Group, Bearpaw Formation and Edmonton Group are assigned to the **Wapiti Group** (Fig. 7.1; Kramers and Mellon, 1972). Several relatively thin coal beds, less than 1.6 m thick, occur in the lower and middle parts of the Wapiti, and several thicker coal intervals up to 6 m thick occur near the top (Horachek, 1985). Although Wapiti coals have been mined in the past, there are currently no permitted minesites for exploiting these coals.

RESOURCE QUANTITIES

Coal resources of immediate interest in the Belly River, Edmonton and Wapiti groups and correlative strata in the Interior Plains, summarized in Table 7.3, have been derived mainly from recent estimates by the Alberta Energy Resources Conservation Board (1987). ERCB estimates have been modified and reported in a manner that reflects the Geological Survey of Canada's coal resource classifications (Fig. 2.3). Resources that ERCB classifies as 'underground-thin' are classified as coal resources of future interest herein. In this report, nomenclature of coalfields in Alberta conforms with that used by the ERCB (Fig. 7.2). Estimated coal resource quantities of the Wapiti Deposit in northeastern British Columbia are based on information provided by the British Columbia Geological Survey (W. Kilby, pers. comm., 1987).

TABLE 7.3

COAL RESOURCES OF IMMEDIATE INTEREST BELLY RIVER, EDMONTON AND WAPITI GROUPS AND CORRELATIVES INTERIOR PLAINS

Coalfield Deposit	Predominant Rank*	measured	indicated (megatonnes)	inferred
Belly River Group				
Bow Island	sub	30	15	40
Brooks	sub	85	35	115
Comrey	sub	-	5	5
East Brooks	sub	50	20	70
Grassy Lake	sub	30	15	45
Lethbridge	hvb	115	50	170
Lucky Strike	sub	5	5	5
Medicine Hat	sub	175	75	245
Rolling Hills	sub	45	20	70
Taber	sub	10	5	10
Edmonton Group				
Alix	sub	880	380	1265
Ardley	sub	2500	1000	3550
Barrhead	sub	100	40	140
Battle River	sub	1000	350	1170
Blackfoot	sub	70	35	95
Buffalo Hill	sub-hvb	660	285	945
Chain Lakes	sub	20	10	30
Cypress Hills**	lig	10	5	20
Devon	sub	5	5	5
Drumheller	sub	500	220	725
East Edmonton	sub	440	190	620
Garden Plain	sub	20	10	30
Hussar	sub	260	130	335
Mayerthorpe	sub	505	220	720
McGregor Lake	sub-hvb	5	5	5
Morinville	sub	540	230	780
Scollard	sub	90	40	130
Sheerness	sub	140	10	125
Strathmore	sub	400	170	565
Tofield-Dodds	sub	900	390	1300
Wabamun	sub	920	395	1300
Wetaskiwin	sub	1530	655	2190
Wapiti Group				
Fox Creek	sub	555	240	800
Lesser Slave Lake	lig	30	15	40
Musreau Lake	sub-hvb	25	10	35
Sawridge Hill	lig	10	5	10
Simonette	sub	35	15	60
South Swan Hills	sub	385	165	550
Swan Hills	sub	5	5	10
Thorhild-Abee	lig	10	5	10
Wapiti (B.C.)	hvb	5	40	100
TOTALS	sub-hvb	1240	585	1860
	lig-sub	11860	4935	16575

*total by general rank class
**Eastend Formation

Estimated deep coal resources within the region, based mainly on information from Williams and Murphy (1981), are summarized in Chapter 10 pertaining to coal resources of future interest.

COAL QUALITY

All Upper Cretaceous-Tertiary coal resources, summarized in Table 7.3, range in rank between lignite A and high volatile C bituminous. Stansfield et al. (1925) showed a distinct pattern of decreasing rank of near surface coals from west to east across Alberta, based on analyses of coals that were extensively sampled from mines across the province. Steiner et al. (1972) further demonstrated this pattern, to a higher degree of refinement, based on data that were subsequently acquired. They also showed regional distributions of other coal attributes, such as ash and sulphur contents. Isorank contours were shown to parallel approximately the eastern margin of the deformed belt (Fig. 7.4). Nurkowski (1985) postulated a geological model of maximum depths of burial of the coal measures to explain the coal maturation pattern. General coal quality characteristics of resources in the Belly River, Edmonton and Wapiti groups, based on information from several sources, are summarized in Table 7.4. It is noteworthy that coal resources of the Wapiti Group occur near surface from the western to eastern limits of the northern Interior Plains, across the general rank trends. Hence, coal ranks from high volatile C bituminous to lignitic are represented therein.

The composition of ash and associated properties vary within a relatively wide range around the roughly median values shown in Table 7.4. These values, therefore, should be used with caution.

All coals might be considered particularly suitable to fuel mine-mouth electric power generating plants. Their hydrogenation characteristics might also make some of these coals that are rich in reactive components particularly well suited for conversion to liquid and gaseous petroleum-derivative substitutes (Parkash, et al., 1984; Chakrabartty and du Plessis, 1985; Steller et al., 1987).

PASKAPOO AND RAVENSCRAG FORMATIONS

INTRODUCTION

The youngest coal-bearing stratigraphic units in the Interior Plains are the Tertiary Paskapoo and Ravenscrag formations, deposited during the Paleocene Epoch. The Paskapoo Formation overlies the Edmonton Group in the central and northern Plains and Foothills of Alberta. Correlative beds in the southern Plains and Foothills of Alberta are assigned to the Porcupine Hills Formation which is not coal-bearing. The southern Interior Plains, from Cypress Hills in southeastern Alberta to Turtle Mountain in southwestern Manitoba, is underlain by the coal-bearing Ravenscrag Formation, or the correlative Turtle Mountain Formation (Fig. 7.1).

Both the Paskapoo and Ravenscrag formations contain significant coal resources of immediate interest, most of which are amenable to large scale strip mining. In 1987, more than 10 megatonnes of thermal coal were produced from six mines operating in these formations. This represented more than 15 per cent of Canada's total 1987 coal production.

GEOLOGY

The only known commercially important deposits in the **Paskapoo Formation** occur within the Obed Mountain and Hannington coalfields, northeast of Hinton (Fig. 7.2). In this area, the coal-bearing units occur in isolated erosional remnants of the uppermost part of the formation, which cap local ridges. Six coal zones occur within a 150 m thick sequence of sandstones, siltstones, shales and carbonaceous shales, which may have been deposited mainly in alluvial plain environments like those postulated for the underlying Coalspur Formation in the Outer Foothills Belt (Jerzykiewicz and McLean, 1980). The Obed-Marsh mine was designed to exploit the two lower coal beds in areas where they average up to 4.2 m thick, and occur under a maximum of 130 m of cover (Union Oil, 1979). This mining operation, which is the only one presently exploiting Paskapoo coals, began in 1983 and produced nearly 0.8 megatonnes of saleable high volatile C bituminous thermal coal in 1986.

In southwestern Alberta, strata that are correlative with the Paskapoo Formation are assigned to the **Porcupine Hills Formation**. The Porcupine Hills Formation is not coal-bearing possibly as a result of more arid syndepositional climatic conditions than those further north in the Paskapoo Formation. This south-north paleoclimatic variation has been recognized in the Willow Creek and Coalspur formations that underlie the Porcupine Hills and Paskapoo formations respectively (Jerzykiewicz and Sweet, 1988).

The **Ravenscrag Formation** contains a maximum of 19 coal zones within lignite-bearing sand, silt and clay units up to 300 m thick. Coal zones occur at approximately the same stratigraphic positions throughout the extent of the formation. Postdepositional erosion and nondeposition have resulted in the presence of discrete deposits and/or coalfields (Fig. 7.2; Irvine et al., 1978). Erosion has resulted in only the lowermost coal zones being preserved in the Cypress Hills, whereas the uppermost coal zones approach surface near Estevan. The lateral extent, thickness and geometry of coal beds, including splitting and coalescing of seams, were controlled in part by the underlying deltaic deposits of the

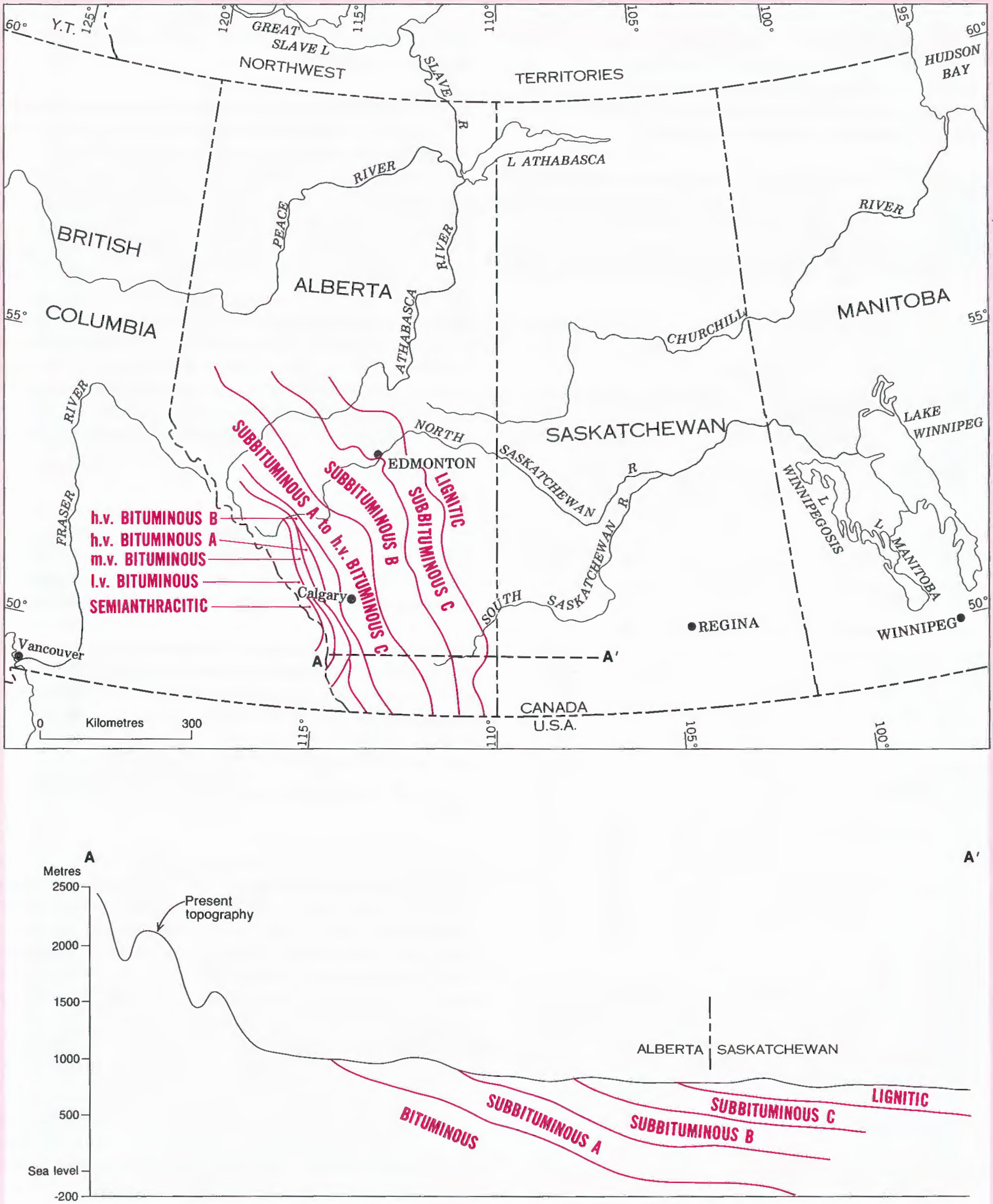


Figure 7.4. Regional rank distribution of near-surface coals in the Interior Plains (from Steiner et al., 1972; Nurkowski, 1985).

Frenchman Formation, and in part by differential subsidence caused by regional dissolution of thick Middle Devonian salt beds (Broughton, 1985). Tertiary downwarping of the Williston Basin (Fig. 7.3), caused by reactivation of Precambrian basement blocks, appears to have significantly influenced the nature of deposition and occurrence of coal in the Ravenscrag Formation (Broughton, op. cit.).

Although the Ravenscrag coal measures extend from southeastern Alberta to southwestern Manitoba, all coal resources occur in four districts across southern Saskatchewan, referred to as Estevan, Willow Bunch, Wood Mountain and Cypress (Fig. 7.2). The land surface of the region overlying these resources is generally flat and mantled with glacial till. Dissection by streams in addition to structures of the coal measures, commonly result in coal zones occurring near or at surface.

TABLE 7.4

**GENERAL COAL QUALITY CHARACTERISTICS
BELLY RIVER, EDMONTON AND WAPITI GROUPS
INTERIOR PLAINS**

	Belly River	Edmonton Group Horseshoe Canyon	 Scollard	Wapiti
Proximate analysis (per cent by weight)				
moisture (equilibrium)	12	20	20	10-35
ash (dry)	15	15	15	5-25
volatile matter (d.a.f.)*	45	44	42	40-50
fixed carbon (d.a.f.)	55	56	58	50-60
Calorific value (d.a.f.) MJ/kg	29	29	28	26-32
Ultimate analysis (dry, ash-free) (per cent by weight)				
carbon	75	75	74	68-74
hydrogen	5	5	4.5	4.5-5.0
nitrogen	2.0	1.5	1.0	1.3-1.6
sulphur	0.5	0.5	0.5	0.1-1.0
oxygen	17.5	18.0	20.0	20-25
Analysis of ash (per cent by weight)				
SiO_2	45.0	50.0	50.0	-
Al_2O_3	25.0	20.0	20.0	-
Fe_2O_3	7.0	7.5	4.0	-
CaO	9.0	9.0	10.0	-
MgO	2.0	2.0	2.0	-
Na_2O	2.0	4.0	2.0	-
K_2O	0.9	0.7	0.3	-
P_2O_5	0.5	1.0	0.1	-
TiO_2	0.7	0.4	0.7	-
SO_3	5.0	5.0	4.0	-
undetected	2.9	0.4	6.9	-
Petrographic indices (per cent by weight)				
mean max. reflectance (R_0max)	0.38-0.56	0.36-0.47	0.38-0.47	-
total reactives	87	74-98	74-87	-
total inerts	13	2-26	13-26	-
Properties				
grindability index (Hardgrove)	35-50	35-40	40-50	-
ash softening temp. (reduce-°C)	1150-1250	1100-1250	1150-1350	-
ash softening temp. (oxid.-°C)	-	1150-1250	1200-1400	-
Rank classification (ASTM)	subA	subC	subC/B	ligA/hvbC

*dry, ash-free

These generalized coal characteristics result from the synthesis and consideration of information from several sources, including Stansfield et al. (1925), Stansfield and Lang (1944), Nicolls (1952), Swartzman (1953), Swartzman and Tibbetts (1955), Campbell (1964), Nurkowski (1985), and Bonnell and Janke (1986). Values do not necessarily result from representative sampling of deposits and, therefore, are intended only as an indication of general coal characteristics that might be expected of near surface Upper Cretaceous-Tertiary coal resources in the Interior Plains.

Of the 19 coal zones identified in the **Estevan Coal District**, the upper four, which occur within an average stratigraphic interval of about 80 m, average 1.5 to 4.2 m thick. A fifth coal zone, which averages 2.2 m thick, occurs within an average interval of about 14 m below the overlying zone (Irvine et al., 1978). The remaining 14 coal zones occur beyond depths considered to be of immediate interest and, hence, have not been well explored. Six coal zones, which average from 1.4 m to 4.4 m in thickness, occur within a stratigraphic interval of about 100 m in the **Willow Bunch Coal District**. Six coal zones also occur in the **Wood Mountain Coal District**. These average 1.0 m to 6.1 m in thickness within an interval of about 70 m. In the **Cypress Coal District**, two coal zones have been identified, averaging 2.5 and 6.3 m thick within a stratigraphic interval of about 15 m (Irvine et al., 1978).

The thickness of individual coal beds averages between 1.5 and 3 m in the Estevan and Willow Bunch coal districts, and 2 m or less in the Wood Mountain and Cypress coal districts. Seams 5 to 7 m thick can occur locally, with particular reference to the upper seams in the Estevan Coal District.

In Alberta, the Ravenscrag Formation occurs only in the Cypress Hills area in the southeastern corner of the province. It contains relatively thin coal beds that were deposited near the western margin of the Williston Basin. All coal resources in this area are assigned to the underlying Eastend Formation, which is correlative with the Horseshoe Canyon Formation of the Edmonton Group (Russell, 1948; Campbell, 1965).

Thin seams of lignite, rarely exceeding 1.5 m thick and generally averaging less than 1 m thick, outcrop on the flanks of Turtle Mountain in southwestern Manitoba. Until the mid-1940's, about 1000 tonnes were mined annually for local use. The coal beds occur in an erosional remnant of the **Turtle Mountain Formation**, which is correlative with the Ravenscrag Formation to the west. The coal measures may formerly have been continuous with those of the Estevan Coal District. Lignites having characteristics that are similar to those near Estevan occur in discontinuous lenses and generally subcrop under several metres of glacial till. Commercial exploitation of these lignites for use beyond limited local consumption has been considered unlikely. A study by the Manitoba Government concluded that further exploration for these coals was unjustified (Bannatyne, 1978).

In 1986, about 8.5 megatonnes of Ravenscrag lignite were produced from five major strip mining operations located near the 49th Parallel in Saskatchewan (Fig. 3.7). One of these mines (Poplar River) is in the Willow Bunch Coalfield, and the others (Utility, Boundary Dam, Costello and Bienfait) are in the Estevan Coalfield (Fig. 7.2).

RESOURCE QUANTITIES

Estimated quantities of coal resources of immediate interest that are contained in the Tertiary Paskapoo and Ravenscrag formations of Alberta and Saskatchewan are summarized in Table 7.5. Resource estimates of the Paskapoo Formation in the Obed Mountain and Hannington coalfields of north-central Alberta are based mainly on information published by the Alberta Energy Resources Conservation Board (1987), modified to suit the Geological Survey of Canada's resource classifications. Resource estimates of the Ravenscrag Formation in southern Saskatchewan are based mainly on results of an extensive joint study that was completed in 1978 by the Geological Survey of Canada, Saskatchewan Department of Mineral Resources and Saskatchewan Research Council (Irvine et al., 1978). No resources of immediate interest have been estimated for the Turtle Mountain Coalfield of Manitoba.

COAL QUALITY

The general characteristics of Paleocene Paskapoo and Ravenscrag coals in the Interior Plains are indicated in Table 7.6. Paskapoo coals in the Obed Mountain and Hannington coalfields of Alberta are subbituminous A to high volatile C bituminous in rank, slightly lower than the Paleocene coals of the Coalspur Formation in the Outer Foothills Belt. These coals can be prepared, mainly by reducing ash content, to meet specifications of conventional thermal coal markets both in Canada and abroad. Ravenscrag coals are generally lignite A in rank and are particularly suitable to fuel electric power generating plants. Although most lignite production is consumed in mine-mouth plants, some is being shipped to power stations in Manitoba and Ontario. A subtle but consistent increase in rank of these lignites, attributed to present day geothermal patterns, has been detected from west to east, from the Cypress Hills to Estevan (Cameron, 1988). At isolated sites lignites in the Ravenscrag Formation contain uranium contents up to 825 ppm (Cameron and Birmingham, 1971).

HUDSON BAY LOWLAND (ONAKAWANA)

(mainly extracted from Graham and Morgan, 1985)

Relatively thick and extensive deposits of lignite occur at Onakawana in the Moose River Basin (Price, 1978) of the Hudson Bay Lowland (Fig. 7.5). These lignites constitute Ontario's entire coal resource. Their occurrence has been known since the late 1600's, when small amounts were used by early

TABLE 7.5

COAL RESOURCES OF IMMEDIATE INTEREST PASKAPOO AND RAVENSCRAG FORMATIONS, INTERIOR PLAINS

Coalfield Deposit	Predominant Rank*	measured	indicated (megatonnes)	inferred
Paskapoo Formation				
Obed Mountain	hvb	70	35	90
Hannington	hvb	50	25	85
Ravenscrag Formation				
Cypress	lig	165	405	465
Wood Mountain	lig	275	735	1115
Willow Bunch	lig	740	1045	1420
Estevan	lig	265	495	440
TOTALS	sub-hvb	120	60	175
	lig-sub	1445	2680	3440

*totals by general rank class

TABLE 7.6

GENERAL COAL QUALITY CHARACTERISTICS PASKAPOO AND RAVENSCRAG FORMATIONS, INTERIOR PLAINS

	Paskapoo	Ravenscrag
Proximate analysis (per cent by weight)		
moisture (equilibrium)	14	32
ash (dry)	20	13
volatile matter (d.a.f.*)	49	47
fixed carbon (d.a.f.)	51	53
Calorific value (d.a.f. MJ/kg)	30	27.5
Ultimate analysis (dry, ash-free) (per cent by weight)		
carbon	75	71
hydrogen	5	5
nitrogen	1.5	1
sulphur	0.5	0.5
oxygen (by difference)	18.0	22.5
Analysis of ash (per cent by weight)		
SiO_2	60.0	35.0
Al_2O_3	17.0	15.0
Fe_2O_3	3.0	5.0
CaO	6.5	15.0
MgO	1.5	3.5
Na_2O	0.3	9.0
K_2O	0.4	0.5
P_2O_5	0.2	0.4
TiO_2	0.7	1.0
SO_3	2.5	10.0
undetected	7.9	5.6
Petrographic indices (per cent by weight)		
mean max. reflectance ($R_o$max)	0.52	0.19-0.42 (Huminite A)
total reactives	91-93	75-95
total inerts	7-9	5-25
Properties		
grindability index (Hardgrove)	40-45	55-65
ash softening temp. (reduce-°C)	1250-1300+	1100-1200
ash softening temp (oxid.-°C)	1300-1450	1150-1350
Rank classification (ASTM)	subA/hvbC	ligA

*dry, ash-free

These generalized coal characteristics result from the synthesis and consideration of information from several sources, including Stansfield et al. (1925), Stansfield and Lang (1944), Nicolls (1952), Swartzman (1953), Swartzman and Tibbetts (1955), and Bonnell and Janke (1986). Values do not necessarily result from representative sampling of deposits and therefore, are intended only as an indication of general coal characteristics that might be expected of near surface Tertiary coal resources in the Interior Plains.

settlers at Moose Factory. In 1929, the Government of Ontario sponsored subsurface exploration and an extensive evaluation of the coalfield (Dyer, 1930). Serious interest in these lignites, at that time, was triggered by a decision to proceed with an extension of the Timiskaming and Northern Ontario Railway (now Ontario Northland Railway) to James Bay by a route that crossed the Moose River Basin. The deposit has been explored periodically and assessed but no mining activities have either resulted, or are presently anticipated.

TABLE 7.7

COAL RESOURCES OF IMMEDIATE INTEREST HUDSON BAY LOWLAND (Ontario)

Coalfield / Deposit	Predominant Rank*	measured	indicated (megatonnes)	inferred
Onakawana	lig	170	10	-

TABLE 7.8

GENERAL COAL QUALITY CHARACTERISTICS ONAKAWANA COALFIELD, HUDSON BAY LOWLAND

Proximate analysis (per cent by weight)	
moisture (as received)	48.0
ash (dry)	19.0
volatile matter (d.a.f.)*	48.0
fixed carbon (d.a.f.)	52.0
Calorific value (d.a.f.) MJ/kg	26.7
Sulphur (per cent by weight)	0.5

*dry, ash free

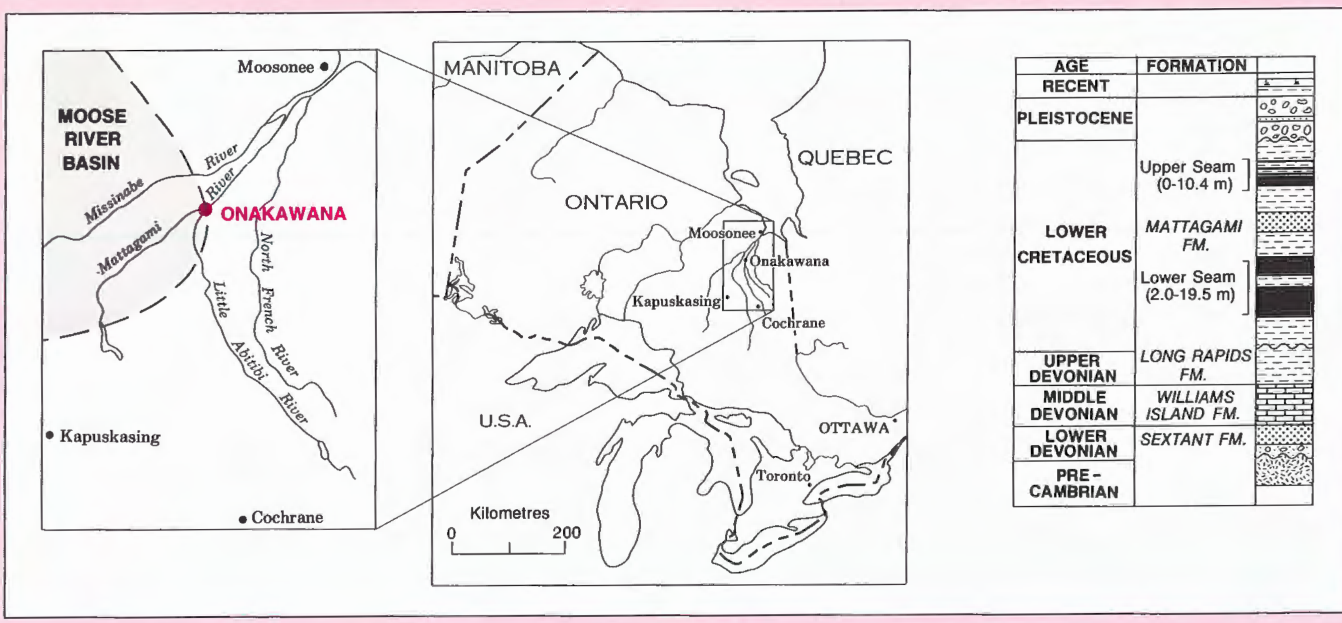


Figure 7.5. Location and generalized stratigraphy of the Onakawana lignite deposit (after Graham and Morgan, 1985).

The Onakawana lignite beds occur within two zones in the Lower Cretaceous Mattagami Formation. Graham and Morgan (1985) summarized the geological context of the resources, estimated their magnitude, and commented on the quality of lignites, based on extensive studies conducted in 1980 by Manalta Coal Ltd. They described the 2.0 to 19.5 m thick lower coal zone and 0 to 10.4 m thick (average 4 m) upper coal zone occurring within a stratigraphic interval of about 40 m comprising "interbedded kaolinite rich clays, carbonaceous clays, lignite and quartzose sand layers". Their comments continued as follows:

> "Strata are generally very poorly cemented, the lignite being the most competent and resistant to erosion. The present bedrock surface is overlain by an irregular layer of till from 10 to 50 m thick. The un-eroded lignite-bearing strata have undergone mild to extreme disturbance at the bedrock-till interface. Such phenomena as scour, folding, faulting, truncation, fracturing, and infilling of clay and gravel material into the lignite are not uncommon. Overlying the till is a thin 1 m to 5 m layer of marine clay, and a 1 m to 1.5 m layer of muskeg."

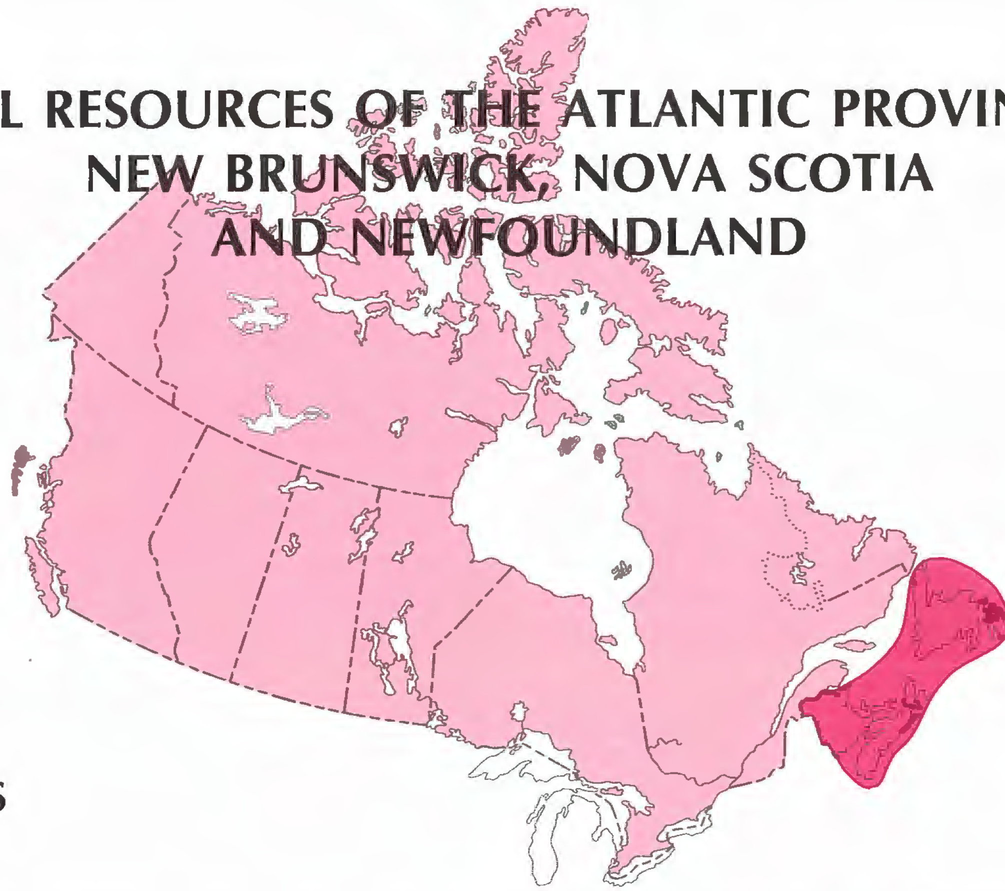
Estimated resource quantities, including seams greater than 1.2 m thick to a maximum depth of 43 m, are shown in Table 7.7. The lower lignite zone contributes about 80 per cent of the total tonnage.

General characteristics of these lignites, based on information reported by Graham and Morgan (op. cit.), are shown in Table 7.8.

MABOU COALFIELD - CAPE BRETON ISLAND, N.S. (courtesy W.D. Kalkreuth)

CHAPTER 8

COAL RESOURCES OF THE ATLANTIC PROVINCES; NEW BRUNSWICK, NOVA SCOTIA AND NEWFOUNDLAND



FEATURES

COAL RESOURCES OF THE ATLANTIC PROVINCES; NEW BRUNSWICK, NOVA SCOTIA AND NEWFOUNDLAND

INTRODUCTION

Significant coal deposits occur in the Atlantic Provinces of New Brunswick, Nova Scotia and Newfoundland in eastern Canada. These deposits are contained in strata deposited of Carboniferous age that now underlie nearly 170 000 square kilometres, having a land area of about 65 000 square kilometres (Fig. 8.1). In 1986, about 3.2 megatonnes of high volatile A and B bituminous coals were produced from the region. More than 85 per cent was destined for use as thermal coal and the balance for metallurgical coke-making. With the exception of about 0.5 megatonnes of surface-mined coal from the Minto Coalfield in New Brunswick, most of the coal was mined from the Sydney Coalfield, predominantly by underground methods. Relatively small quantities were also produced from the Pictou and St. Rose-Chimney Corner coalfields in Nova Scotia. The coal deposits of Newfoundland are entirely undeveloped (Fig. 8.2).

The mostly nonmarine Carboniferous strata of the region were deposited in a transcurrent fault setting of the Appalachian Geosyncline referred to as the Maritimes Basin (Fig. 8.1; Bradley, 1982). Syndepositional block faulting and basinal subsidence commonly resulted in favourable coal-forming environments (Poole, 1967). Sedimentation occurred in discrete fault-bounded intermontane subbasins, separated by uplands, and in a series of connected troughs. Variations in the time and nature of tectonic activity throughout the Maritimes Basin resulted in each subbasin having a unique geological history (Kelley, 1967; Bradley, 1982), although strike-slip faulting is prevalent.

The subbasins are generally distinct in lithostratigraphy; mappable units or formations in one subbasin are not necessarily common to other subbasins. Occasionally, in the past, a lithostratigraphic unit has been applied to more than one subbasin, such as the middle Carboniferous Mabou Group (Belt, 1965). More recent studies do not regard this as correct (Benson, 1974). Lithostratigraphic relationships between different basins are generally obscure.

It is convenient, when addressing Carboniferous stratigraphy of the region in general terms, to group rock units according to time-stratigraphic intervals. Accordingly, the Carboniferous stratigraphic framework has been divided into seven chronostratigraphic groups including, in order of decreasing age, Horton, Windsor, Canso, Riversdale, Cumberland, and Pictou/Stellarton and Morien (Fig. 8.2; Bell, 1927). With the exception of the mainly marine deposits of the Windsor Group, deposits are predominantly continental and include fan-conglomerate, fluvial, lacustrine and swamp-marsh facies (Hacquebard, 1972).

Upper Carboniferous coal deposition began with the Riversdale Group, containing the coal deposits of the Port Hood and St. Rose-Chimney Corner coalfields of Nova Scotia, and St. George's Coalfield of Newfoundland. This was followed by deposition of the Cumberland Group, which contains the coal deposits of Joggins-Chignecto and Springhill coalfields of Nova Scotia. Prolific periods of coal formation occurred during subsequent deposition of the Pictou/Stellarton and Morien (term restricted to the Sydney Basin) groups. Deposits of the Minto, Beersville and Lakestream coalfields of New Brunswick, and Debert-Kemptown, Pictou, Mabou-Inverness and Sydney coalfields of Nova Scotia originated during this time.

Transcurrent forces, postulated to have been associated with the collision of continental plates in the Carboniferous and subsequent Permian periods during the final stages of the Appalachian orogeny, resulted in the faulting and folding of coal measures in the Maritimes Basin. Strata were less severely compressed and distorted in the Atlantic Provinces of Canada, where this orogenic activity is referred to as the Maritimes Disturbance, than further south in Pennsylvania, West Virginia and adjacent areas of the Appalachian Region (Roland, 1982). Even gentle folding and small displacement faulting, however, can complicate mining operations.

Most major Carboniferous coal-forming swamp-marsh conditions of the region apparently occurred in one of two general types of depositional environments: floodplain, or lacustrine (Hacquebard et al., 1967; Hacquebard and Donaldson, 1969; Hacquebard, 1972). Coal deposits that originated on floodplains generally have greater lateral continuity, but do not attain the same thickness as coal deposits that originated near the more stable intermontane lake basins. Coal deposits in mainly fluvial and fluviolacustrine strata, which may also have originated in intermontane settings, are typically autochthonous and banded, and contain rock partings originating from floodwater transported clastic sediments. In contrast, coal deposits associated with lacustrine deposition are typically hypauthochthonous, more uniform in composition, contain fewer rock partings, and often grade laterally into shale (Hacquebard, 1972).

Coal ranks in the region appear to have been modified after the measures were tectonically deformed. Consequently, the rank of coal in a specific bed increases with present depth. Also, a distinct pattern of organic maturation at the present

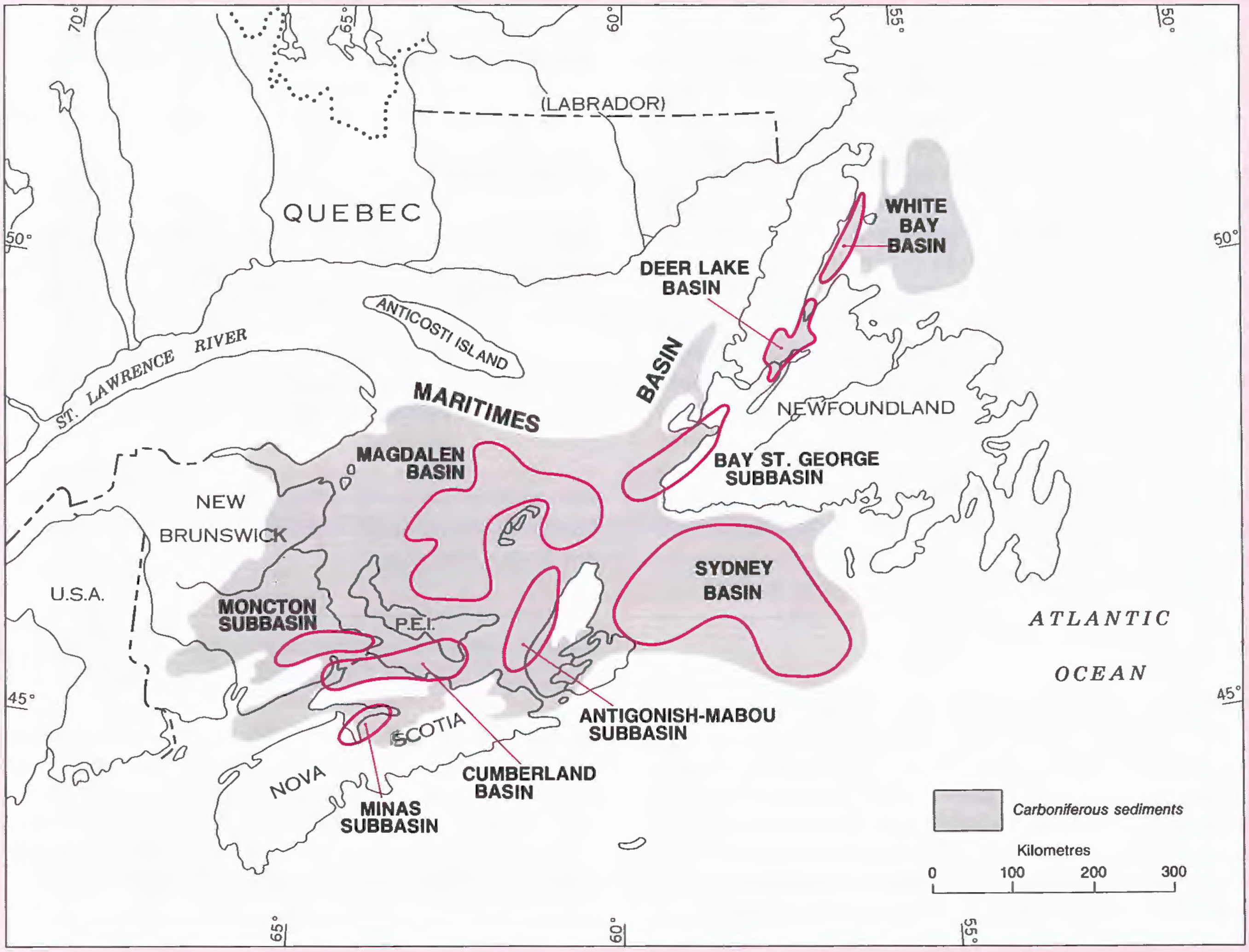


Figure 8.1. Subbasins of the Carboniferous Maritimes Basin in eastern Canada (modified from Bradley, 1982; Knight, 1983).

bedrock surface appears related to the tectonic development of the Appalachian Region. Maturation tends to increase progressively toward the southern and eastern margins of the Maritimes Basin (Hacquebard and Donaldson, 1970).

Carboniferous strata in Newfoundland occur in an elongated belt, about 25 km wide, trending northeast from Cape Anguille on Cabot Strait south of St. George's Bay, to White Bay (Fig. 8.1). Prospective coal deposits are present in the St. George's Coalfield and Howley Coal Area (Fig. 8.2). However, they are generally lenticular and exploration to date has failed to prove adequate continuity for commercial development (Knight, 1983). Commercial coal development in Newfoundland would have to compete with the well established mines of Nova Scotia.

Prince Edward Island is underlain by Carboniferous strata. Coal beds that attain thicknesses up to 3 m have been interpreted from geophysical logs of petroleum wells (Hacquebard, 1986). These coal beds, however, which are contained in the Pictou/Stellarton Group, are relatively deep (greater than 1200 m) and no coal resources are assigned to Prince Edward Island.

BACKGROUND

The earliest recorded export of coal in North America was in 1643 when the Governor of New England reported receipt of a small shipment from New Brunswick (Brown, 1985). A coal shipment from the Minto Coalfield in New Brunswick to New England was also reported in 1739 (King and Johnson, 1935). The same single, thin (30-75 cm thick), near-surface and flat-lying seam has been in somewhat continuous production to the present. In his dispatches to France in 1673, the Governor of Nova Scotia reported the existence of large seams of coal on Cape Breton Island. Systematic mining of these coals was first attempted in 1720, for supplying fuel to support the construction of Fortress Louisbourg. By 1724, coal was being exported from Cape Breton to Boston (Nova Scotia Department of Mines, 1978). The existence of coal in Newfoundland was acknowledged by the Treaty of Utrecht in 1713, whereby coal development was prohibited on the western side of the island where the French exercised fishing rights (Howley, 1913). During this period, a thriving coal mining industry was being developed elsewhere in the region. Coal mining, particularly in Nova Scotia, prospered until the 1950's when traditional coal users, mainly in Ontario and Quebec, began intensive conversion to oil and gas substitutes. Increasing prices for hydrocarbon fuels that began in the 1970's, along with global depletion of relatively inexpensive conventional hydrocarbon resources, have resulted in the reassessment of the role of coal in the energy economy of the Atlantic Provinces, as elsewhere in Canada and around the world. Annual coal production from the region increased by nearly 40 per cent during the 11 year period from 1976 to 1986 (from about 2.3 megatonnes to nearly 3.2 megatonnes). Annual coal consumption in the region doubled during the same period (from about 1.4 megatonnes to 2.8 megatonnes).

The distinct character of each coal-bearing Carboniferous subbasin requires that each subbasin be assessed independently. This has resulted in a proliferation of coal publications during the past century that can appear disproportionate to the overall size of the Maritimes Basin and quantities of contained coal resources. A large portion of the region's coal resource potential is located offshore. Recent drilling and seismic surveys are providing significant new information to consider fully this potential (Hacquebard, 1986).

Numerous underground and surface mining operations of various scales have exploited coals in each of the coalfields of New Brunswick and Nova Scotia during the past century and earlier. In 1986, seven mines operated in the region, including

Minto	(Minto Coalfield, New Brunswick)
Prince	(Sydney Coalfield, Nova Scotia)
Lingan	(Sydney Coalfield, Nova Scotia)
Phalen	(Sydney Coalfield, Nova Scotia)
Brogan	(Sydney Coalfield, Nova Scotia)
Pioneer	(Pictou Coalfield, Nova Scotia)
Evans	(St. Rose-Chimney Corner Coalfield, Nova Scotia)

These mines, of which Minto, Prince and Lingan are the major coal producers (Fig. 3.7), provide about 5.6 per cent of the nation's overall coal production tonnage for the year. Although minor coal for local consumption has been mined in the past from the St. George's Coalfield and Howley vicinity in Newfoundland, future successful coal mining ventures have been considered unlikely (Hayes, 1949).

COALFIELDS

The commercially important coals within each coalfield of the region are assigned to one of the following four chronostratigraphic groups, in order of decreasing age:

Riversdale
Cumberland
Pictou/Stellarton
Morien

The Morien Group is applied uniquely to the Sydney Coalfield and is mainly correlative with the Pictou/Stellarton Group (Fig. 8.2).

Descriptions of the coalfields of Nova Scotia in the following summary have been extracted, with only minor modifications, from "Coal in Nova Scotia" (Calder et al., 1985).

No attempt has been made to discuss all coal occurrences in the region. A comprehensive catalogue of occurrences, along with an associated extensive bibliography for New Brunswick was prepared by Ball and Gemmell (1975). Similarly, Hayes (1949) prepared a comprehensive paper entitled 'Coal Possibilities of Newfoundland'.

RIVERSDALE GROUP

Port Hood Coalfield (Nova Scotia)
(extracted from 'Coal in Nova Scotia', Calder et al., 1985).

The Port Hood Coalfield lies on the west coast of Cape Breton Island (Fig. 8.2), on the gently dipping southeast limb of a syncline which plunges to the southwest. The 600 m thick coal-bearing section dips beneath the Gulf of St. Lawrence. Though only one mineable seam has been identified, the coalfield is open-ended to the south and the possibility exists that coal seams may persist offshore beneath the southern tip of Henry Island. Gersib and McCabe (1981) described the environment of deposition as a continental floodplain with fluvial and fluviolacustrine deposition.

The coals of Port Hood have a rank of high volatile B to C bituminous. Mining in the field was abandoned in 1969 primarily because of economic considerations.

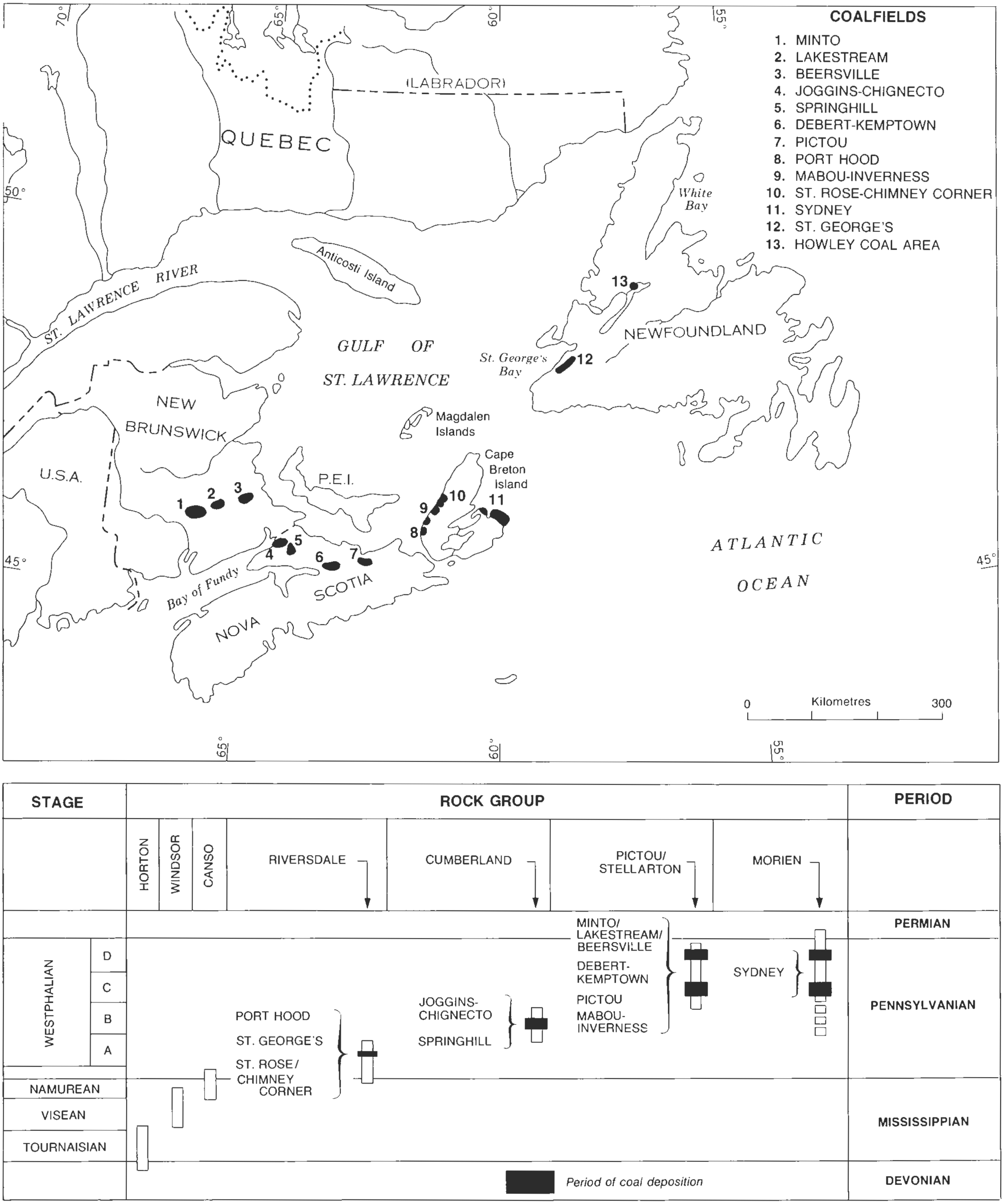


Figure 8.2. Location and chronostratigraphy of coalfields in the Atlantic Provinces (chronostratigraphy after Roland, 1982).

St. Rose-Chimney Corner Coalfield (Nova Scotia)
(extracted from 'Coal in Nova Scotia', Calder et al., 1985).

The St. Rose-Chimney Corner Coalfield also occurs on the west coast of Cape Breton Island (Fig. 8.2). Separated from the Chimney Corner field to the north by a 3.5 km wide zone of block faulting, the St. Rose field is of limited area because of a fault downdip of the mine workings, which truncates the coal measures and brings them into contact with evaporites of the Windsor Group.

The coal-bearing section is 150 m thick at Chimney Corner, increasing to 250 m at St. Rose. At Chimney Corner, the coal seams dip beneath the Gulf of St. Lawrence. Hacquebard (1951) correlated the seams of the Chimney Corner and St. Rose fields on the basis of microscopic coal petrography. Bivalve (shell) fossils overlying the coals probably indicate a lacustrine depositional environment.

The rank of coals in both areas is high volatile C bituminous. A small underground mine (Evans Mine) has been in continuous operation at St. Rose since the late 1940's.

St. George's Coalfield (Newfoundland).

The St. George's Coalfield, which is located south of St. George's Bay in southwestern Newfoundland (Fig. 8.2) occurs in a doubly plunging syncline, and has maximum dimensions of about 25 km by 10 km. Two coal-bearing sequences that are separated by about 550 m of barren sandstones and shales contain at least seven coal beds. The three seams in the upper sequence, between about 0.9 m and 1.5 m thick, appear to be the most prospective (Knight, 1983). The coal measures are highly faulted and folded. The structural complexity often results in steeply dipping, sheared, and truncated coal beds, which seriously detracts from mining possibilities. Only small amounts of coal, for local consumption, have been mined in the past by tunnelling into beds exposed along river banks.

The rank of coals ranges up to high volatile B bituminous.

CUMBERLAND GROUP

Joggins-Chignecto Coalfield (Nova Scotia)
(extracted from 'Coal in Nova Scotia', Calder et al., 1985).

The Joggins-Chignecto Coalfield extends more than 30 km east from the shores of Bay of Fundy (Fig. 8.2). The coal-bearing strata dip to the south, on the north limb of the Athol Syncline. At Joggins, the coal section is approximately 1500 m thick, thinning dramatically eastward.

The coal-bearing strata were apparently deposited as part of a complex of gradational facies changes within the Cumberland subbasin, from alluvial fans in the south to lacustrine in the north. Fluvial deposition, with coals formed in a shoreline position, is indicated.

The coal beds at Joggins are characteristically less than 1 m thick; however, extensive mining operations have been conducted in the coalfield in the past. The last mining operations closed in 1979, and most readily accessible coal resources have been exhausted. The coals have a rank of high volatile B bituminous.

Springhill Coalfield (Nova Scotia)
(extracted from 'Coal in Nova Scotia', Calder et al., 1985).

The Springhill Coalfield is located on the south limb of the Cumberland subbasin (Fig. 8.2). The coalfield has been moderately to severely deformed by a diapir of Windsor Group evaporites. The structural configuration of the coalfield is that of a southwesterly plunging anticline, the axis of which is severely faulted. The coal measures attain a maximum thickness of 1080 m on the north limb of the anticline. This sequence appears to thin to 150 m toward the pre-Carboniferous Cobequid Highlands, which were the source of the sediments that filled the basin.

Within the coalfield, seams exhibit progressive onlap over braidplain and distal alluvial fan sediments. The center of coal deposition within successively younger seams migrated to the south. Elongated coal swamps formed adjacent to alluvial fans and appear to have been controlled by major trunk meandering rivers (Calder, 1984). Minor ephemeral streams occasionally invaded the coal-forming moor where it bordered the alluvial fans. Early basin filling may have been characterized by transverse flow terminating in a shoreline of possible lacustrine origin.

The coals of the Springhill Coalfield exhibit an increase in rank with depth from high volatile A to medium volatile bituminous. The bulk of the remaining resources occur on the north limb of the anticline, downdip from the old workings. Resources of lesser quantity exist within the axial region of the anticline in a structurally complex geological setting.

PICTOU/STELLARTON AND MORIEN GROUPS

Minto, Beersville and Lakestream Coalfields (New Brunswick)

The Minto Coalfield, which is located in southern New Brunswick at the northern end of Grand Lake (Fig. 8.2), underlies an area of about 30 km by 15 km (Muller, 1951). A single near surface and relatively flat-lying seam (Minto Seam), about 30 to 90 cm (average about 45 cm) thick, has been mined for more than 300 years by both surface and underground methods. The elongated shape of the coal measure and associated fluvial deposits indicate that coal probably originated in a poorly drained river valley (Hacquebard and Barss, 1970). Pre- and post-glacial erosion have interrupted the lateral continuity of the seam. The coal is classified as high volatile A bituminous and contains run-of-mine ash ranging between 15 and 25 per cent, and sulphur (mainly pyritic) between 5 and 9 per cent. The coal is highly fractured and tends to size-degrade easily when handled (Hacquebard and Barss, op. cit.).

Underground mining ceased in 1970 and all coal is currently produced by strip mining. Between 0.45 and 0.55 megatonnes are used annually to fuel electric power generating stations at Grand Lake and Dalhousie (Ball and Gemmell, 1985).

In the vicinity of Beersville, about 50 km northeast of the Minto Coalfield (Fig. 8.2), a coal bed about 35 to 45 cm thick occurs within 36 m of surface, within an area of possibly 50 sq. km. (Ball and Gemmell, 1975, 1985). A commercially important coal deposit referred to as Lakestream, which may be correlative with that at Beersville, is located between the Minto and Beersville coalfields (Fig. 8.2). Beersville and Lakestream coals are Upper Carboniferous Westphalian D age, whereas the Minto seam is Westphalian C (Ball and Gemmel, 1985).

Debert-Kemptown Coalfield (Nova Scotia)
(extracted from 'Coal in Nova Scotia', Calder et al., 1985).

The Debert-Kemptown Coalfield is located north of the western extent of Minas Basin, Bay of Fundy (Fig. 8.2). It is situated within a narrow, structurally complex, fault-bounded syncline. Within this syncline, the Pictou/Stellarton Group occupies an area of approximately 100 sq km. Neither extent of the coalfield, nor associated depositional environments are well known. The coals have a rank of high volatile B bituminous. The only coal operations in the district were the short-lived mines that operated between 1903 and 1936.

Pictou Coalfield (Nova Scotia)
(extracted from 'Coal in Nova Scotia', Calder et al., 1985).

The Pictou Coalfield is located near Northumberland Strait in north-central Nova Scotia (Fig. 8.2). The coalfield underlies an area of about 165 sq. km., extending 18 km in an east-west direction and 9 km north-south. It occurs within a graben that was filled with a succession of sediments derived from the highland area to the southwest, beginning with the New Glasgow Conglomerate. Deposition continued until drainage was impeded, shallow lakes developed and the fluvio-lacustrine and associated coal-forming deposits referred to as the Stellarton Group were laid down.

There are 15 major coal seams in the coalfield, ranging from 1 to 14 m in thickness; 12 have been mined extensively during the past 160 years, yielding about 55 megatonnes of mainly high volatile A bituminous coal. The coalfield contains the only known low volatile bituminous coal in eastern Canada. Much of the better quality coal has been mined and, with the exception of downdip extensions (600 to 1200 m deep) of some previously worked seams, the remaining resources lie in peripheral areas where quality deteriorates. Approximately one million tonnes may be amenable to surface mining.

Mabou-Inverness Coalfield (Nova Scotia)
(extracted from 'Coal in Nova Scotia', Calder et al., 1985).

Though the Mabou and Inverness coalfields are approximately 10 km apart, along the northwest shore of Cape Breton Island (Fig. 8.2), they are thought to be part of the same stratigraphic sequence and to merge at depth beneath the Gulf of St. Lawrence (Hacquebard, 1975, 1986). At Mabou, less than one square kilometre of the coalfield is on land; the remainder dips under the sea to the west. The exposed area is severely faulted, but there is a stratigraphic section about 365 m thick along the shoreline in which six seams have been identified. Deposition apparently took place on the subaerial portion of a delta (Norman, 1935).

Faulting obscures the relationship between the Mabou and Inverness coalfields. Nevertheless, fossil spores, offshore drilling and seismic surveys indicate that the coal-bearing section at Inverness is younger than that at Mabou. Ten seams outcrop at Inverness in a section dipping moderately seaward and five have been mined. However, faulting offshore has limited their submarine extent. Five offshore oil and gas exploration wells have penetrated two continuous coal zones, within a 762 m thick section in the Pictou Group, that appear to correlate with the Mabou-Inverness section (Hacquebard, 1975, 1986).

The coals are high volatile C bituminous. They were mined at Mabou from 1899 to 1909, when the mine became flooded with seawater. Less than 0.1 megatonnes were extracted. At Inverness, coal was first produced in 1865 but has not been mined since the 1966. Nearly 7.5 megatonnes were extracted.

Sydney Coalfield (Nova Scotia)
(extracted from 'Coal in Nova Scotia', Calder et al., 1985).

The Sydney Coalfield contains most of the coal resources and reserves of the Atlantic Provinces. The approximately 2000 m thick Morien Group underlies a roughly triangular area with an apex at the east end of Cape Breton Island and a base off the south coast of Newfoundland (Figs. 8.1, 8.2). More than 98 per cent of the coalfield is located offshore, although 11 of the 13 major coal seams outcrop on land.

Their geological settings are relatively well known through surface exposure and underground workings. The only direct information available on their offshore geology comes from the deep coal mines and the 20 wells drilled for petroleum and coal, and these data are largely limited to the area within 10 km of the Cape Breton coast. Geophysical techniques, primarily seismic surveying, have been used to define the geological structure of the greater part of the submarine basin.

The coal measure was apparently deposited mainly in a fluvial environment. Great volumes of coarse sandy sediments from uplifted areas to the south accumulated in a braided river environment, leaving 900 m more of sediments in the eastern part of the basin where deposition was initiated and subsidence was greatest. The braidplain migrated steadily westward. As the gradients decreased over extensive and possibly coastal floodplains, drainage was probably characterized by meandering streams with fewer major channels. These river channels were apparently separated by broad marshy flats where coal-forming peat and floodwater transported clastic sediments accumulated.

Early clastic deposition and a later initiation of major peat deposition occurred in the southeastern part of the basin. Significant peat accumulation began with the formation of the Tracy Seam, the lowest mineable seam in the section. The progressive westward onlap of younger seams reflects the overall development of the Morien Group. The later seams (Harbour, Hub, and Point Aconi) are well developed over most of the basin. Throughout Morien time the centre of deposition remained in the eastern Donkin area where seams attain their greatest thickness. They invariably deteriorate as rock partings increase near the western basin margin.

The major structural features of the coalfield are the bounding faults to the west and southeast, and large-scale folds which define a broad structure known as the Sydney Synclinorium. The coal seams dip approximately 5 degrees toward the deeper offshore basin centre, except where affected by northeast-trending open flexures. Even on the flanks of these folds, dips rarely exceed 15 degrees. Seams tend to be thicker in the synclines than over the anticlines.

The rank of coals varies considerably, increasing to the east and with depth. They are generally classified as high volatile A bituminous (Hacquebard, 1983) but in places reach medium volatile bituminous.

With the exception of a relatively small quantity of surface mined coal from the Brogan pit, all mining in 1986 was by underground means, managed by the Cape Breton Development Corporation (DEVCO).

RESOURCE QUANTITIES

Quantities of coal resources of immediate interest in the Atlantic Provinces, which are provided in Table 8.1, are based mainly on estimates published by Hacquebard (1979). The republication of these estimates by MacLean (1985) are indication of their acceptability. The estimates have been modified, where necessary, in the light of other pertinent published information (e.g. Ball and Gemmel, 1985), and unpublished information in the records of the Geological Survey of Canada.

The differences in the two sets of estimates published by MacLean (1985), are assumed to reflect the difference between only coal resources of immediate interest according to Hacquebard (1979), and all coal resources, including coal resources of future interest, according to the Nova Scotia Department of Mines and Energy (1980).

TABLE 8.1

COAL RESOURCES OF IMMEDIATE INTEREST ATLANTIC PROVINCES

Coalfield / Deposit	Predominant Rank*	measured	indicated (megatonnes)	inferred
New Brunswick				
Minto	hvb	10	10	20
Lakestream	hvb	10	-	-
Beersville	hvb	25	-	-
Nova Scotia				
Joggins-Chignecto	hvb	-	-	10
Springhill	hvb	5	-	25
Debert-Kemptown	hvb	5	-	-
Pictou	hvb	20	25	15
Port Hood	hvb	10	5	10
Mabou	hvb	5	-	125
St. Rose-Chimney Corner	hvb	5	5	-
Sydney	hvb	250	320	565
TOTALS	h-mvb	345	365	770

*totals by general rank class

COAL QUALITY

Significant diversity of the characteristics of coals in the Atlantic Provinces occurs within individual seams, between different seams within the same coalfield and subbasin, and between coals of different subbasins. Although the wide variation in properties defies general characterization for all but the broadest considerations, a range of values that indicates general coal quality is provided in Table 8.2. Most commercially significant coal resources fit into the broad ranges indicated, but the values should be used cautiously. These values allow one to compare, in general, eastern Canadian Carboniferous coals of mainly high volatile bituminous rank, with coals of similar rank elsewhere in the country. For more information pertaining to the quality of coal in specific seams and coalfields, the reader is referred to Stansfield and Nicolls (1918), Strong et al. (1941), Swartzman et al. (1944), Hayes (1949), Swartzman (1953), Nicolls (1952) Hacquebard and Lahiri (1954), Swartzman and Tibbetts (1955), and Bonnell and Janke (1986). Often, the range of values within a single coalfield embraces those characteristics of all coalfields. The composition of ash is so variable, both within coalfields and between coalfields and subbasins, that no attempt has been made to indicate in Table 8.2 the general ash composition for the region.

Most commercially significant coals of the region are high volatile bituminous, although ranks ascending to low volatile bituminous are also present. The coals are typically high in sulphur content relative to western Canadian Cretaceous coals. They are generally good fuels for conventional coal-fired electric power generating stations, and often have characteristics suitable for metallurgical coke-making. The offshore portion of the Sydney Coalfield appears to contain large quantities of metallurgical grade coal (Hacquebard, 1983). The Maritimes coals are richer in reactive components, and have higher fluidity than western Canadian coals. They are similar, in many respects, to coals of the Appalachian Region in the United States.

TABLE 8.2

GENERAL COAL QUALITY CHARACTERISTICS ATLANTIC PROVINCES

Proximate analysis	
(per cent by weight)	
moisture (as received)	1-10
ash (dry)	5-25
volatile matter (d.a.f.)*	35-41
fixed carbon (d.a.f.)	59-65
Calorific value (d.a.f.) MJ/kg	32-36
Ultimate analysis (dry, ash-free)	
(per cent by weight)	
carbon	75-85
hydrogen	5-6
nitrogen	1-2
sulphur (total)	1-10
oxygen (by difference)	
Petrographic indices	
(per cent by weight)	
mean max. reflectance ($R_o$max)	0.7-1.2
total reactives	75-90
total inerts	10-25
Properties	
grindability index (Hardgrove)	55-65
ash softening temp. (reduce-°C)	1000-1350
ash softening temp (oxid.-°C)	1250-1450
Rank classification (ASTM)	hvbC to hvbA

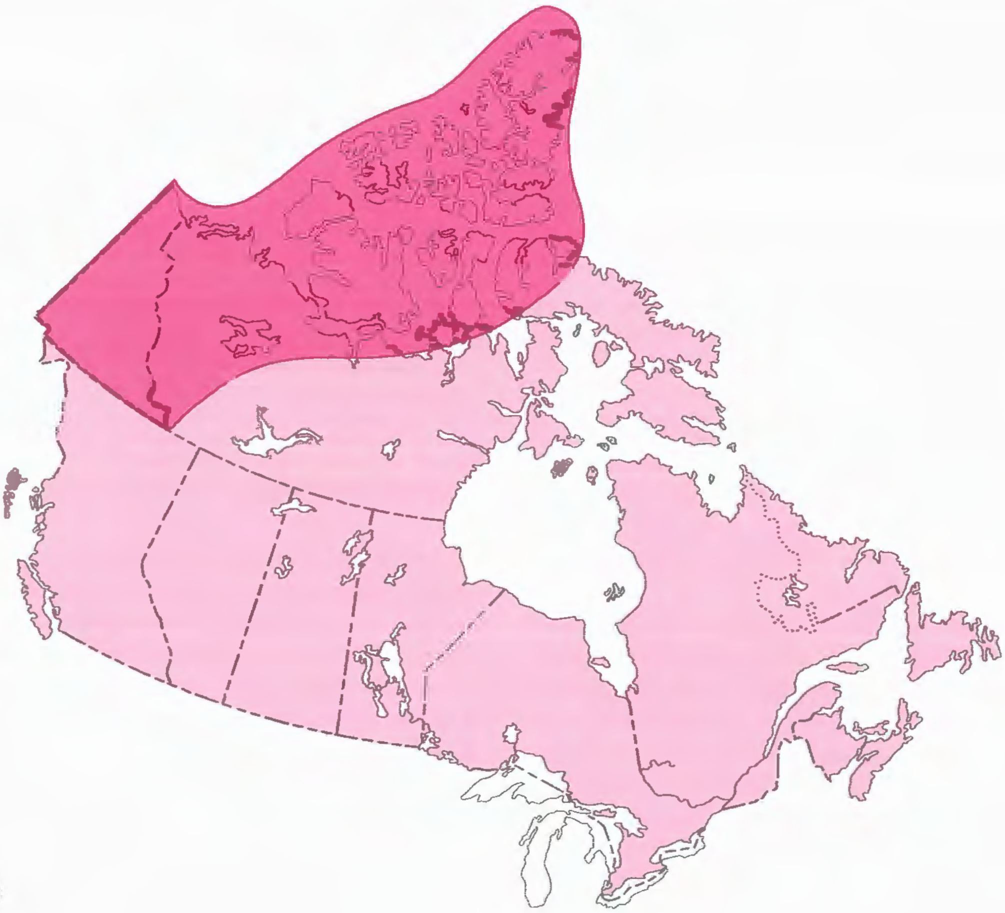
*dry, ash-free

These generalized coal characteristics result from the synthesis and consideration of information from several sources, including Stansfield and Nicolls (1918), Strong et al. (1941), Swartzman et al. (1944), Hayes (1949), Nicolls (1952), Swartzman (1953), Hacquebard (1954), Swartzman and Tibbetts (1955), and Bonnell and Janke (1986). Values are intended only to indicate a general range that might be expected of Carboniferous coals in the Atlantic Provinces.

TERTIARY HILLS - BRACKETT BASIN, N.W.T. (courtesy A.R. Sweet)

CHAPTER 9

COAL RESOURCES OF NORTHERN CANADA



FEATURES

COAL RESOURCES OF NORTHERN CANADA

INTRODUCTION

The occurrences of coal in northern Canada (north of the 60^{th} Parallel) are widespread, and diverse in terms of geological setting, age, rank and composition. Although coal resource quantities are potentially very large, most deposits have generally not been well explored because of their remoteness and other factors that have mitigated against possible exploitation. The coal resources that occur in the Yukon Territory and District of Mackenzie will be considered separately from those in the Arctic Archipelago. All coal resources of immediate interest occur in the Yukon Territory and District of Mackenzie.

Coal beds in northern Canada occur in strata deposited in each period of geological time from Devonian to Tertiary (Fig. 3.2). All rank classes from lignitic to anthracitic are known to exist in the region. The tectonic development of the coal-bearing sedimentary basins and subsequent deformation of coal measures was often complex. Existing knowledge of the occurrences of coal is based mainly on surface exposures. Estimates of coal resource potential are usually made on the basis of broad geological inference regarding coal thickness and areal extent. Lack of subsurface data often makes resource estimates highly speculative.

Information pertaining to coal occurrences in northern Canada is contained in both published reports, and numerous unpublished papers mainly in the files of the Geological Survey of Canada. References to coal occurrences have often been made in reports pertaining to regional geological reconnaissance. The Geological Survey of Canada is continuing to verify and characterize these reported occurrences. The transformation of much of the region's coal endowment to various resource categories, however, will require additional subsurface exploration to determine areal extent, thickness variability and structural geometry of coal beds.

Coal mining in northern Canada has been on a very limited scale, with the most substantial operations having been developed in the Carmacks area of southern Yukon (Fig. 9.1). There are many factors that inhibit coal exploration and development in the region, related mainly to remoteness and climate; however, continuing development of the region for other reasons may make indigenous coals a viable fuel for electric power generation, space heating, ore drying, etc., in future. The need for a more definitive inventory of coal resources in the Yukon Territory and District of Mackenzie has increased during the past 20 years when matters, such as the proposed development of a Mackenzie Valley pipeline, establishment of national parks, and expansion of electric generating capabilities, have been more thoroughly considered. Industrial expansion in the north will depend on available energy supplies. Indigenous coals provide an important option to be considered. Coal production at Healy, Alaska, for use in utilities in the Fairbanks district, along with serious planning of other Alaskan mine developments for coal export to Pacific rim countries such as Korea and Japan, and successful coal mining operations near Carmacks, Yukon, are some examples of northern coal development possibilities (Orheim, 1983).

Summaries of information pertaining to known coal occurrences in northern Canada have been compiled by several authors, including Cairnes (1912), MacKay (1946a, 1946b), Campbell (1967b), Latour (1968), Caine (1973), Milner and Craig (1973), Ricketts and Embry (1984) and Ricketts (1988).

These summaries, along with reports of coal occurrences resulting from regional geological surveys (see Appendix), provide the primary basis for establishing future coal exploration strategies.

BACKGROUND

Occurrences of coal in the northern Canadian mainland and archipelago were noted by several of the earliest expeditions to the north, including those of Mackenzie (1785-1790), Parry (1819-1825), and Richardson (1848-1850). In 1785, Sir Alexander Mackenzie discovered coal in the banks of the Mackenzie River, in the vicinity of Fort Norman, west of Great Bear Lake (Fig. 9.1). The coal beds, which were on fire at the time, were still burning in 1848 when described in some detail by Sir John Richardson (1852), and some are still burning today. One to four coal beds, with the thickest being about 3 m, interstratified with layers of gravel, were then exposed above the water level. Susceptibility to spontaneous combustion was a noted characteristic of these coals. In 1888, during his exploration in the Yukon and Mackenzie basins, R.G. McConnell (1891) noted several seams of lignite at the same location, ranging in thickness from about 0.5 - 1.5 m. He also noted the occurrence of coal at several other localities, including those along the Liard, Coal and Old Crow rivers. Many of the earliest geological observations in northern Canada, like those by Sir John Richardson, were recorded during expeditions of the mid-1800's in search of the Sir John Franklin expedition. Isbister (1855) recapitulated observations by geologists and travellers in "the northernmost parts of America", and produced a coloured geological sketch map that illustrated coal distribution in the region. In his 1859 account of the geology of the Arctic Archipelago, Haughton (1859) recorded the occurrence of coal on several of the Arctic islands.

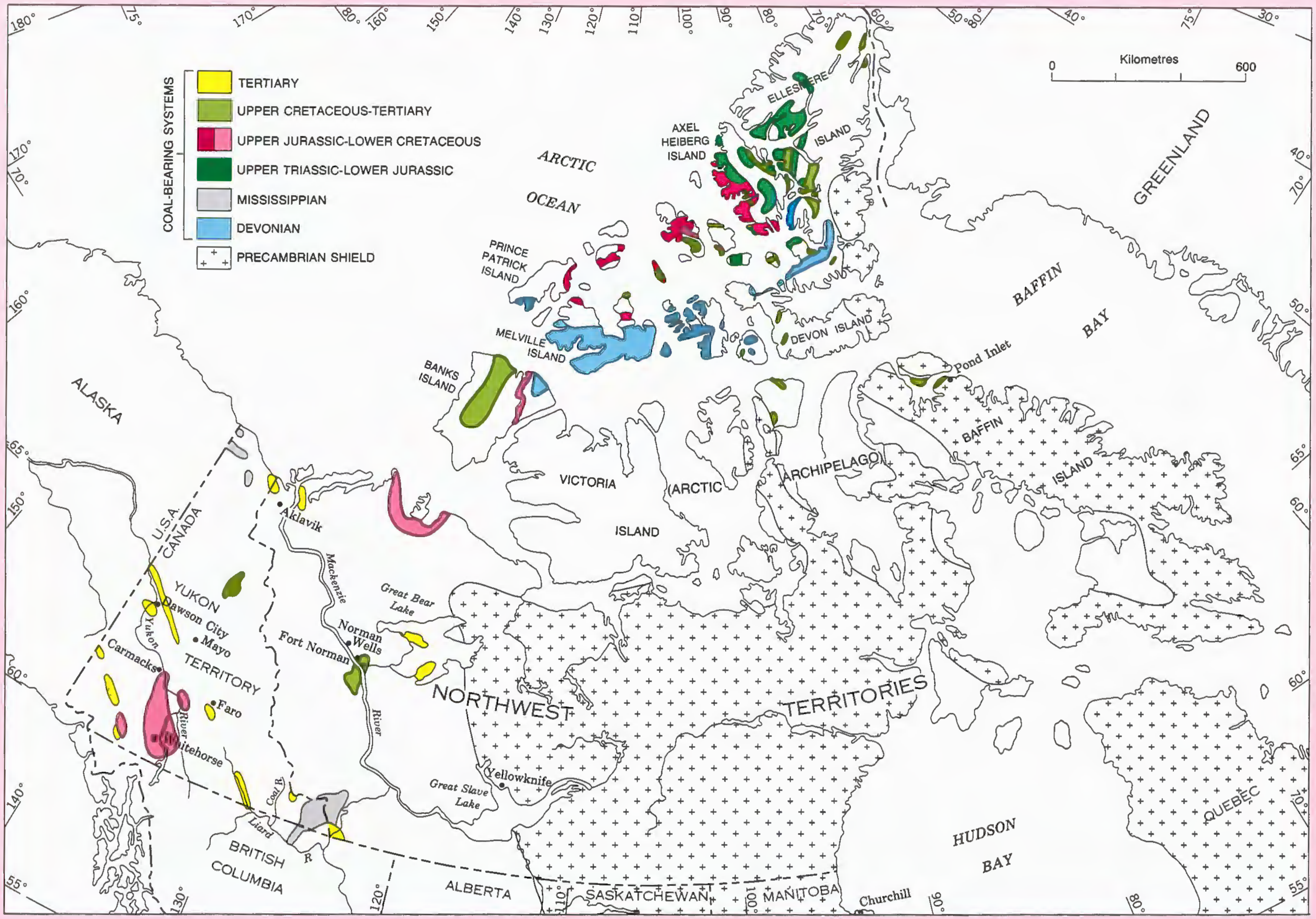


Figure 9.1. Prospective coal areas in northern Canada.

Although small amounts of coal throughout northern Canada were probably used historically for domestic purposes, the first attempted use on a relatively large scale followed the discovery of the Klondike goldfields, near Dawson, Yukon (Fig. 9.1). Large quantities of fuel were then needed for heating, for use in steam plants to thaw frozen ground, and for operating river boats. Readily accessible wood became scarce and mines with associated infrastructure (including railways) were developed, about the year 1900, to exploit the lignite deposits (Rock Creek, Coal Creek and Cliff Creek mines). Wood, however, continued to be the only important fuel (Green, 1972). Coal has been used at government offices, R.C.M.P. stations, Hudson Bay Company posts and other facilities in communities such as Aklavik on the Mackenzie Delta (Moose River Mine — ceased operation in 1960), and Pond Inlet, on Baffin Island.

Geological surveys of northern Canada increased significantly following the Second World War. They were encouraged by improved access to the region, mainly as a result of the completion of the Alaska Highway and availability of longer range aircraft. The subsequent search for oil and gas and metallic minerals, which began in the 1950's, has increased progressively to the present. The hydrocarbon possibilities of the region had already been indicated by the discovery, in the 1920's, of oil and gas at Norman Wells.

The principal coal mining in the region has been in the Carmacks area, Yukon (Five Fingers, Tantalus and Tantalus Butte mines). Mining, which began about 1904 to supply coal mainly to Dawson, has continued to the present with the exception of a few nonproducing years. Base metal mining operations near Mayo and Faro have used the coal for many years for plant heating and concentrate drying. Coal is currently being supplied to the lead-zinc mine near Faro. Annual coal production during the years of operation has ranged from about 4000 to 30 000 tonnes.

Coal exploration in the Yukon Territory and District of Mackenzie, particularly in the Brackett Basin near Fort Norman, and in the Bonnet Plume Basin of central Yukon, accelerated during the mid-1970's. This increased activity was mainly in response to anticipated developments associated with the possible construction of a pipeline to transport hydrocarbons south from the Mackenzie Delta.

YUKON TERRITORY AND DISTRICT OF MACKENZIE

INTRODUCTION

Coal deposits of Yukon Territory and western District of Mackenzie occur within the northern extensions of Cordilleran and Interior Plains physiographic regions of western Canada, and in the Arctic Coastal Plain (Bostock, 1976). The context of these northern coal deposits, in both physiographical and geological terms, is characteristically distinct from that further south. The numerous physiographic subdivisions in the north generally reflect the relatively complex geological evolution of the region (Fig. 9.2).

Prospective coal occurrences of the Yukon Territory and District of Mackenzie are shown in Figure 9.3, and are listed in Table 9.1. No attempt has been made to refer to all reported coal occurrences in the region, although most have been catalogued by others such as MacKay (1946a), Campbell (1967) and Ricketts (1984, 1988). In this report, coal occurrences are considered prospective by virtue of a combination of factors such as reported coal thickness, indicated lateral continuity, access to deposits, or proximity to established communities or to possible future developments (e.g. Mackenzie Valley pipeline).

GEOLOGY

The stratigraphic, sedimentological and structural context of coal beds and, hence their thickness variability and extent, are usually known only in the broadest sense afforded by large-scale surface mapping. In most cases, regional reports and maps by the Geological Survey of Canada provide the primary information for considering coal potential in general terms. Surface and subsurface exploration that has been conducted during the past decade by private sector companies, has better defined the most prospective coal deposits. These activities, supported by confidential company reports, have been conducted in the following areas (Fig. 9.3):

- Fort Liard and Sawmill Mountain (detailed mapping by Utah Mines Ltd.).
- Rock River (mapping and drilling by Sulpetro Limited).
- Watson Lake (trenching and drilling by Canex Placer Ltd.).
- Whitehorse (trenching and drilling by Whitehorse Coal Corp.).
- Carmacks (trenching and drilling by Cyprus Anvil Ltd. and by R.J. Kirker).
- Brackett Basin (mapping and drilling by Manalta Coal Ltd., and detailed mapping by Luscar Ltd.).
- Bonnet Plume (drilling by Pan Ocean Oil Limited and Mountaineer Mines Limited).

Most prospective coal measures in the region contain a significantly higher proportion of conglomerate and conglomeratic sandstone than is characteristic of coal measures in southern Canada where coal beds are commonly associated mainly with sandstone, siltstone and shale. The presence of these coarse clastic sediments, dykes and sills in coal measures west of the Tintina Trench, and thick volcanic ash beds like those of the Brackett Basin, indicate a relatively high level of tectonic activity. This appears incongruous with the long periods of swamp-marsh development that are required for thick accumulations of coal-forming vegetal debris. Thick and often laterally extensive coal beds, however, have been confirmed in areas throughout the region.

The tectonic evolution of the region had a significant influence on the development of coal-bearing sedimentary basins, postdepositional deformation of coal measures, and thermal maturation of contained organic matter. The complex evolution and main elements that comprise the tectonic framework of the region have been described and interpreted

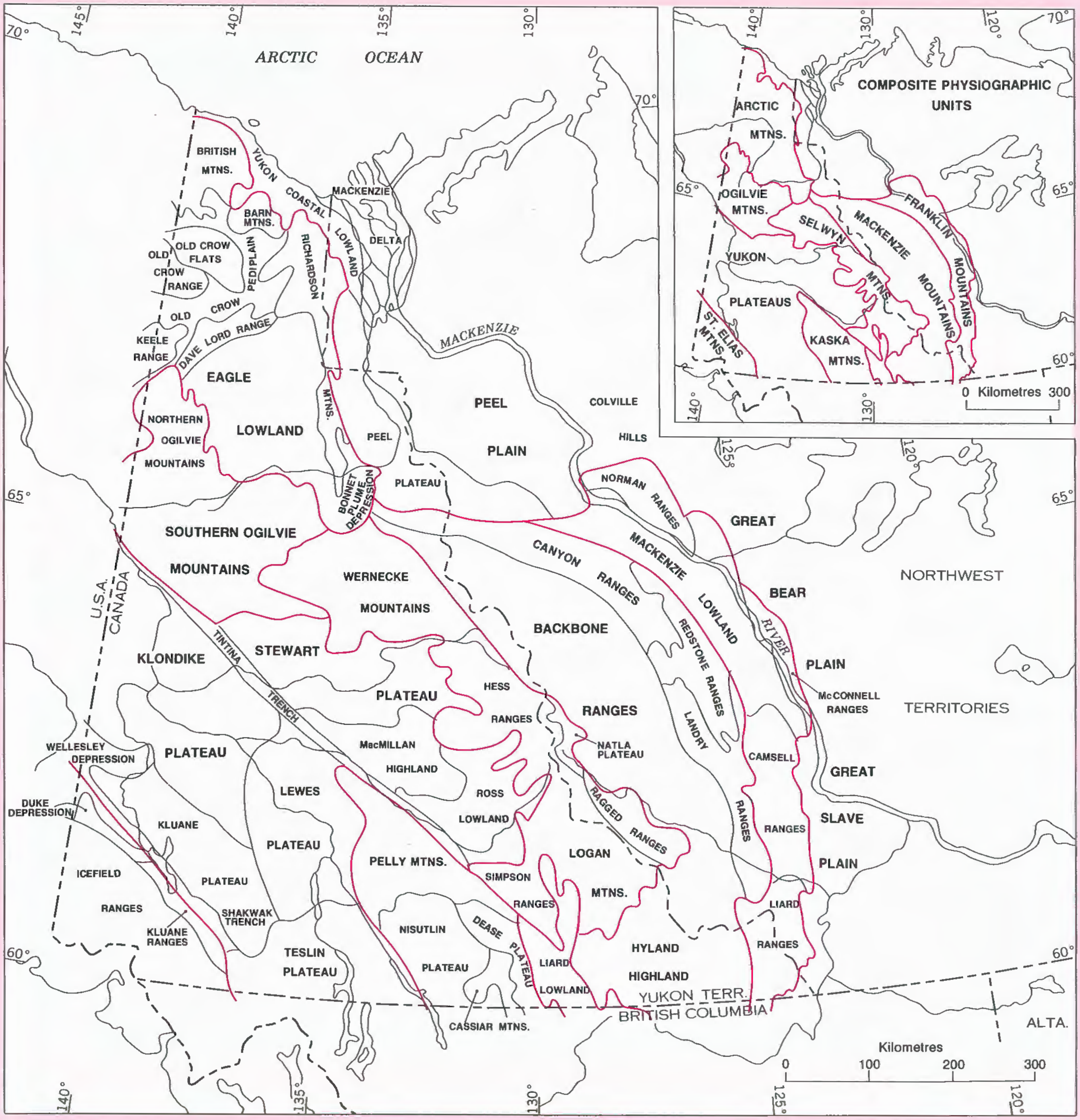
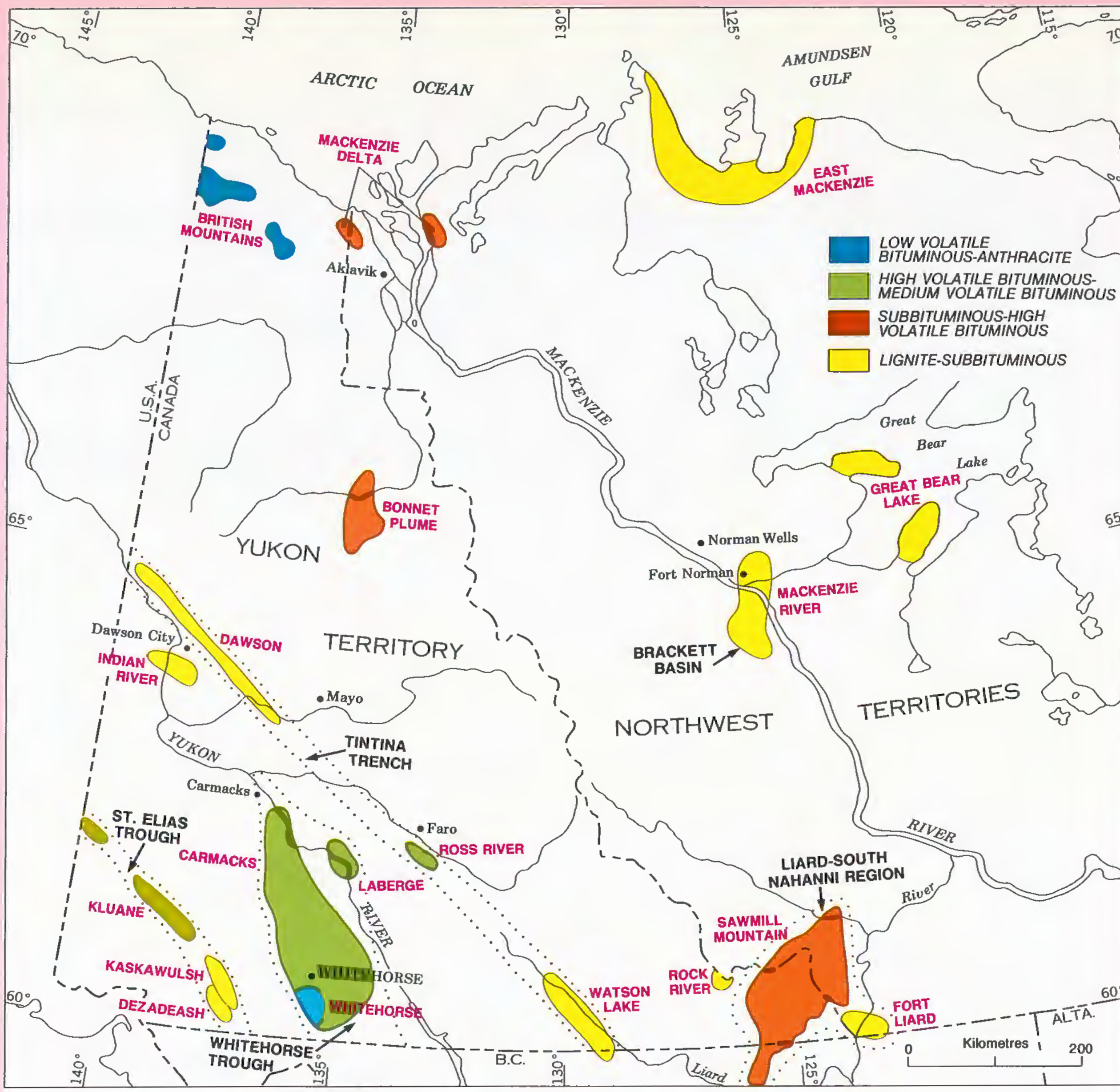


Figure 9.2. Main physiographic divisions in Yukon Territory and western District of Mackenzie (from Geological Survey of Canada, Map 1701A, 1986).



	ST. ELIAS TROUGH	WHITEHORSE TROUGH	TINTINA TRENCH	INDIAN RIVER	ROCK RIVER	LIARD-SOUTH NAHANNI REGION	BRACKETT BASIN	GREAT BEAR LAKE	BONNET PLUME	BRITISH MOUNTAINS	MACKENZIE DELTA	EAST MACKENZIE
TERTIARY	AMPHI-THEATRE FM. (unnamed)		(unnamed)	(unnamed)	(unnamed)	WAPITI GP.	SUMMIT CR. FM.	(unnamed)	BONNET PLUME FM.		REINDEER FM.	
CRETACEOUS	DEZADEASH GP.	TANTALUS FM.					LITTLE BEAR FM.					LANGTON BAY FM.
JURASSIC		LABERGE GP.										
TRIASSIC												
PERMIAN-PENNSYLVANIAN												
MISSISSIPPIAN						MATTSON FM.				KAYAK FM.		

Coal-bearing formations

Figure 9.3. Coal districts and prospective coal areas in Yukon Territory and western District of Mackenzie.

by Gabrielse (1967). The diversity of styles of regional geological structures in the northern part of the region, resulting from the complex tectonic evolution, has been described and interpreted by Norris (1973). The occurrence of coal in the region in general, or within large parts of the region, defies characterization. Assessments of resource potential for each prospective coal deposit must consider the possibly unique tectonic environment within which the coal deposit originated, evolved and was preserved. Thickening and thinning of coal beds often results from structural deformation of coal measures. Local geothermal conditions that control coalification can be significantly modified by tectonic activity. As elsewhere in Canada, tectonic activity might have both enhanced and complicated coal mining possibilities in the Yukon Territory and District of Mackenzie. The amount of geological information required to define a coal deposit to a specified level of precision, will be greater under these geological conditions, than required in tectonically more stable coal regions.

Additional geological information of areas in the Yukon Territory and District of Mackenzie having prospective coal deposits is contained in reports that are referenced in the Appendix. A more complete list of references has been compiled by Ricketts (1984, 1988). Ziegler (1969) also compiled a useful bibliography and synopsis, in the form of maps and sections, pertaining to the general development of sedimentary basins in western and Arctic Canada.

COAL RESOURCES

Table 9.1 lists estimated coal resource quantities according to district, age and associated coal rank. The in situ coals commonly contain less than 30 per cent and occasionally less than 15 per cent ash. Coals produced for shipment outside of the region would likely require preparation to reduce ash in the run-of-mine to levels below 10 per cent. Sulphur contents are characteristically less than 0.5 per cent, with the exception of Mississippian coals in the Nahanni region, which have sulphur contents that approach 2 per cent. Most coals appear to be suitable fuels for conventional coal-fired electric power generating plants, and some are suitable for metallurgical coke-making.

Continuing exploration and possible development of the region's coal resources will depend on local energy requirements and energy supply options during the course of the region's future industrial development. It is unlikely that coals would be produced, within the foreseeable future, for shipment outside of the region, because of relatively high production and transportation costs. The industrial development of the region, however, which has grown significantly during the past 40 years, has potential that may be analogous to growth in southern regions of western Canada since the turn of the century. The possible need for coals of the region within the foreseeable future has been indicated by the private sector investments in the exploration of several deposits in recent years. Accordingly, the inferred coal resource quantities shown in Table 9.1, which are all associated with areas that have been explored by the private sector during the past decade, are classified as resources of immediate interest, although no imminent new mine developments are suggested. Mining is continuing in the Carmacks area, and exploration is continuing in the Whitehorse area.

ARCTIC ARCHIPELAGO

INTRODUCTION

Vast quantities of coal of possible future economic importance occur in three distinct geological provinces of the Canadian Arctic Archipelago - the Franklinian Geosyncline, Arctic Platform, and Sverdrup Basin (Fig. 9.4). Occurrences are widespread and coal types are diverse. The most prospective coal areas appear to be on southwest Melville and northeast Banks islands, where accumulations of Devonian bituminous coal may be extensive, and on central Axel Heiberg and west-central Ellesmere islands, where several billion tonnes of subbituminous and lignitic coals might occur in the Sverdrup Basin. Formations of greatest coal potential include the Heiberg, Isachsen, Hassel and Eureka Sound Group, with the latter unit possessing the largest accumulations. With the exception of local operations, which have supplied coals for short periods to small communities, such as Pond Inlet until 1959, no large scale coal mining operation has been undertaken.

Although coal occurrences in the Arctic Archipelago were reported more than 150 years ago, systematic geological reconnaissance and mapping of the region has been conducted mainly during the past 30 years. As elsewhere in northern Canada, most knowledge pertaining to the geology of the region that is relevant to initial assessment of coal potential has been acquired during the course of more general geological reconnaissance conducted mainly by the Geological Survey of Canada. Recently, however, information useful for assessing coal potential has also been obtained from oil and gas exploration wells.

In 1946, MacKay summarized available information regarding the occurrences of coal on the Arctic Islands. He noted the possible significance of these resources with respect to the desirability, at that time, of finding "some local available source of fuel supply for meteorological stations that are to be established as guides for air, land and sea exploration and navigation" (MacKay, 1946b). He subsequently estimated, on the basis of limited information regarding thickness and lateral extent of coal beds, a resource potential in excess of 2000 megatonnes for seams at least one metre thick

TABLE 9.1

PROSPECTIVE COAL DISTRICTS AND ESTIMATED COAL RESOURCE POTENTIAL YUKON TERRITORY AND DISTRICT OF MACKENZIE

Coal District	Stratigraphic Unit	Age	General Rank Class	Inferred Resources (megatonnes)
St. Elias Trough				
Dezadeash	(unnamed)	Tertiary	lig-sub	-
Kaskawulsh	Dezadeash Group	U. Jur.-L. Cret.	lig-sub	-
Kluane	Amphitheatre Formation	Tertiary	lig-sub	-
Whitehorse Trough				
Whitehorse	Tantalus Formation	U. Jur.-L. Cret.	lvb-an	90[1]
Laberge	Laberge and Tantalus	U. Jur.-L. Cret.	h-mvb	140[1]
Carmacks	Laberge and Tantalus	U. Jur.-L. Cret.	h-mvb	10
Tintina Trench				
Watson Lake	(unnamed)	Tertiary	lig-sub	-
Ross River	(unnamed)	Tertiary	h-mvb	2[3]
Dawson	(unnamed)	Tertiary	lig-sub	-
Indian River	(unnamed)	Tertiary	lig-sub	-
Rock River	(unnamed)	Tertiary	lig-sub	50[2]
Liard — South Nahanni Region				
Fort Liard	Wapiti Group	U. Cret.-Tertiary	lig-sub	240[4]
Sawmill Mountain	Mattson Formation	Mississippian	sub-hvb	150[4]
Brackett Basin				
Tertiary Hills	Summit Cr./Little Bear	U. Cret.-Tertiary	lig-sub	1000[5]
Mackenzie River	Summit Creek Formation	U. Cret.-Tertiary	lig-sub	1000[5]
Great Bear Lake	(unnamed)	U. Cret.-Tertiary	lig-sub	-
Bonnet Plume	Bonnet Plume Formation	U. Cret.-Tertiary	sub-hvb	200[6]
British Mountains	Kayak Formation	Mississippian	lvb-an	-
Mackenzie Delta	Reindeer Formation	Tertiary	sub-hvb	-
East Mackenzie	Langton Bay Formation	L. Cretaceous	sub-hvb	-
Total Inferred Coal Resources of Immediate Interest			lvb-an	90
			m-lvb	-
			hvb-mvb	152
			sub-hvb	350
			lig-sub	2290

[1]MacKay (1946a)
[2]Canada; Department of Indian and Northern Affairs (1982)
[3]Hughes and Long (1980)
[4]Lord (1983)
[5]Ricketts et al. (in prep.)
[6]Tempelman-Kluit (1981)

occurring within 330 m from surface (MacKay, 1947). Analyses of coal samples, collected over a large area of the Canadian Arctic Archipelago, were systematically reported by Fortier et al. (1963). The variable composition and ranks, ranging from lignitic to anthracitic, indicate the diversity of coal types that occur in the region. An updated list and summary descriptions of known coal occurrences in the Arctic Archipelago were compiled by Caine (1973). A 1984 summary of the geology and resource potential of coal deposits in the region, by Ricketts and Embry, constitutes the main source of information herein (Ricketts and Embry, 1984).

Most recently, Bustin and Miall (in press) summarized the geology and coal resource potential of the Arctic Islands. Estimated coal resource quantities in this report have been extracted from their manuscript.

GEOLOGY

(extracted from Ricketts and Embry, 1984).

Coal occurs in all six geological provinces in the Arctic Islands and is found in Devonian, Mississippian, Permian,

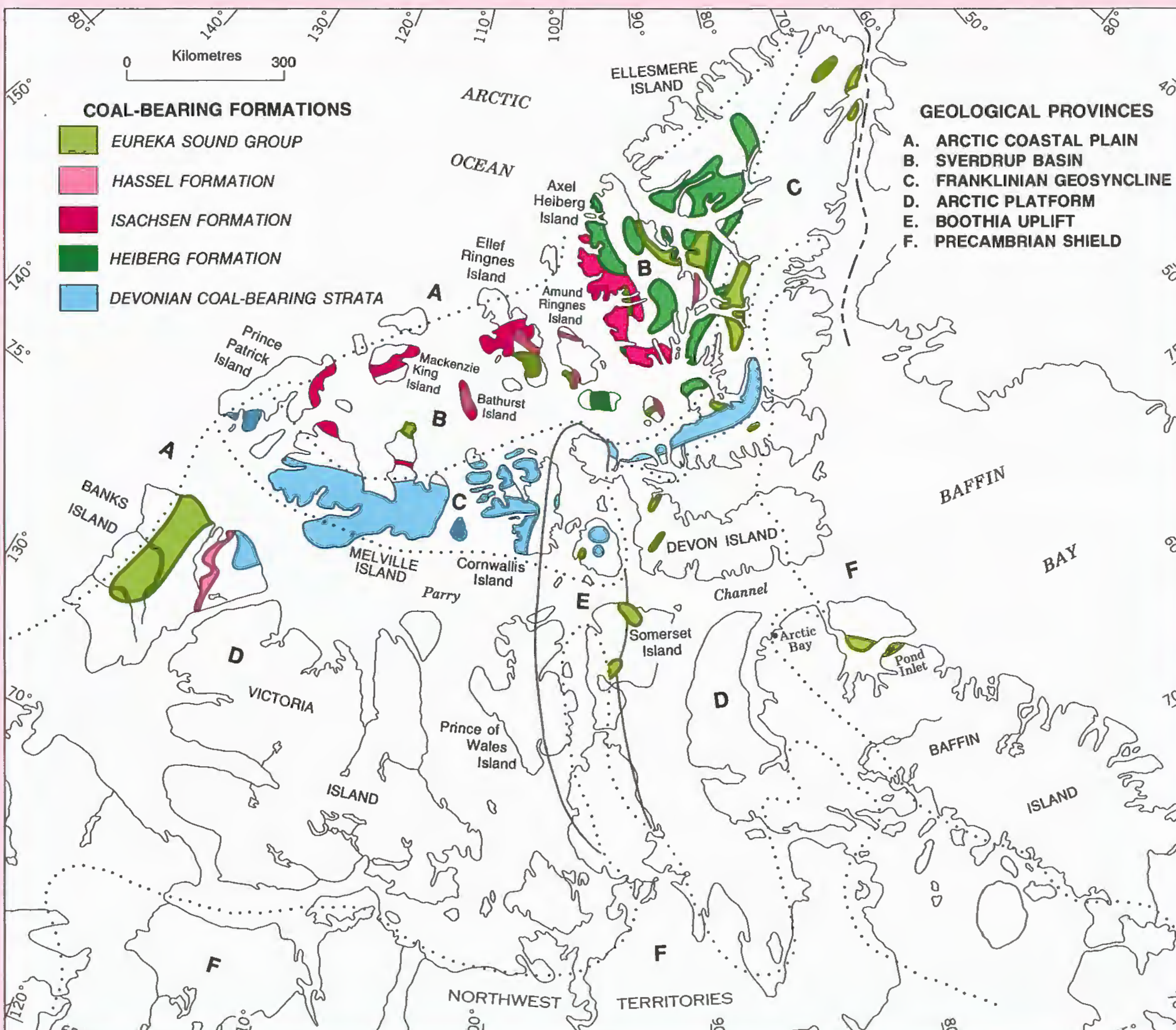


Figure 9.4. Geological Provinces and near-surface distribution of major coal-bearing units in the Canadian Arctic Archipelago (after Ricketts and Embry, 1984).

Triassic, Cretaceous and Tertiary strata (Fig. 9.4). Seam thickness and extent depend largely on depositional environments that existed in each province, the subsidence rate during deposition, and the present structural setting of the strata.

On the Canadian Shield, Cretaceous and Tertiary coal-bearing strata occur in small, fault-bounded basins on southern and northern Baffin Island. Bordering the shield to the north and west is the Arctic Platform, which consists of a thin succession of flat-lying to gently tilted Lower Paleozoic carbonate and clastic strata with local occurrences of younger rocks. Coal-bearing strata in the Arctic Platform occur mainly on Banks Island and are of Late Devonian, Cretaceous and Tertiary age. Small grabens containing Tertiary coal-bearing strata also occur on Devon Island. Similar small outliers of latest Cretaceous and Tertiary coal-bearing strata occur on Cornwallis and Somerset islands, within the Boothia Uplift.

The Franklinian Geosyncline lies north and west of the Arctic Platform and consists mainly of a thick succession of Lower Paleozoic carbonate and clastic strata which, unlike the Arctic Platform, are strongly folded and faulted. Overlying Cretaceous and Tertiary rocks are preserved in a few areas. Coal measures in the Franklinian Geosyncline are found mainly in Middle and Upper Devonian sequences, comprising an extensive clastic wedge that is preserved over much of this structural province. In addition, Cretaceous coal-bearing strata occur on southwestern Melville and Cornwallis islands, and Tertiary coal is found on central Ellesmere and Cornwallis islands.

The Sverdrup Basin trends northeast and contains up to 13 000 m of predominantly clastic strata with subordinate amounts of carbonate, evaporite, volcanic and intrusive igneous rocks. They range in age from Mississippian to Tertiary, and coal occurs in all ages of sedimentary rocks except the Pennsylvanian. This province contains the greatest coal potential in the Arctic.

The Arctic Coastal Plain is underlain by unconsolidated clastic sediments of Neogene age that contain a few lignite seams. These deposits represent the edge of the continental terrace wedge that borders the Arctic Ocean.

Coal-bearing strata were deposited in distinctive tectono-stratigraphic settings during various periods of geological time (Fig. 9.4). Devonian coal-bearing strata are part of an extensive clastic wedge that was the final phase of deposition of the Ellesmerian foredeep in the Franklinian Geosyncline. Mississippian and Permian coals were deposited in coastal-plain to strand-plain settings along the margin of the Sverdrup Basin. During the Triassic to mid-Cretaceous interval, large deltaic complexes prograded into the Sverdrup Basin at various times, and coals are associated with delta-plain strata. The youngest coals, those of latest Cretaceous-Tertiary age, are part of a clastic wedge that was deposited during various phases of the Eurekan orogeny, which deformed the eastern portion of the Arctic Islands.

Additional geological information of coal-bearing areas in the Arctic Archipelago is contained in reports that are referenced in the Appendix.

COAL RESOURCES
(mainly from Ricketts and Embry, 1984)

Of the six geological provinces in the Arctic Archipelago, all except the Arctic Coastal Plain contain both lignite and higher rank coals. Generally, too little is known about the local geology of coal deposits to assess resource potential in quantitative terms. However, a number of general comments can be made with regard to coal geology in the various provinces.

Most coal occurrences on the Arctic Platform (except Banks Island), Boothia Uplift and Canadian Shield occur in outliers or downfaulted blocks within lower Paleozoic rocks or crystalline basement, and thus have only limited areal extent. Therefore, prediction of regional trends of coal-seam distribution is virtually impossible at present, and estimates of the potential for this region should be based on the merits of individual occurrences.

Coal deposits at Pond Inlet, north Baffin Island, may have some resource potential, given the relatively low overburden to coal ratio, proximity to an established settlement, coastal transport routes, and the presence of economic lead-zinc-silver deposits located near Arctic Bay (northwest Baffin Island) and mined by Nanisivik Mines Ltd. (Jackson et al., 1975; Gibbins, 1983).

In the Franklinian Geosyncline and Sverdrup Basin, stratigraphic units are more readily correlated because of greater continuity of exposure. Therefore, some idea of regional trends of coal-bearing facies can be inferred, as has been done for the Devonian clastic wedge and major deltaic sequences in the Sverdrup Basin. The Eureka Sound Group holds the greatest potential for coal resources in the Arctic Archipelago (Table 9.2; Bustin and Miall, in press).

In summarizing the coal resource potential of the Arctic Islands, Bustin and Miall (in press) noted:

> "With the exception of the Isachsen Formation on Banks and Axel Heiberg islands, and the Hassel Formation on northern Baffin Island, all major resources occur in the Eureka Sound Group. About 80 per cent are lignite or subbituminous coal and the remaining 20 per cent is high volatile bituminous coal; i.e. all are thermal coal and no significant deposits of metallurgical (medium or low volatile bituminous) coal are known."

"The quality of coal has only been determined for a few areas. Obtained analyses indicate that, with a few exceptions, the sulphur content is low (less than 1.0%, averaging 0.5%). The ash content is highly variable but it is noteworthy that seams of clean coal (less than 10% ash) occur in many deposits. Measured calorific values are similarly variable, ranging from 23 000 to 32 500 kJ/kg. All major deposits consist exclusively of humic coal, comprising mainly the macerals vitrinite (70-90%) with minor inertinite, semi-inertinite and liptinite."

Estimated coal resources in the Arctic Archipelago (Table 9.2), are classified by Bustin and Miall (in press) as inferred. The outcrop information, preliminary mapping, and broad geological knowledge of coal-bearing regions, upon which the estimates are based, however, suggest that a large portion of the resources is likely speculative, particularly in the absence of subsurface data. The estimates by Bustin and Miall (op. cit.) have been arbitrarily subdivided in this report to categories of indicated, inferred and speculative coal resources of future interest. They have not speculated on the potentially vast coal resources that might exist on central and southeastern Banks Island.

TABLE 9.2

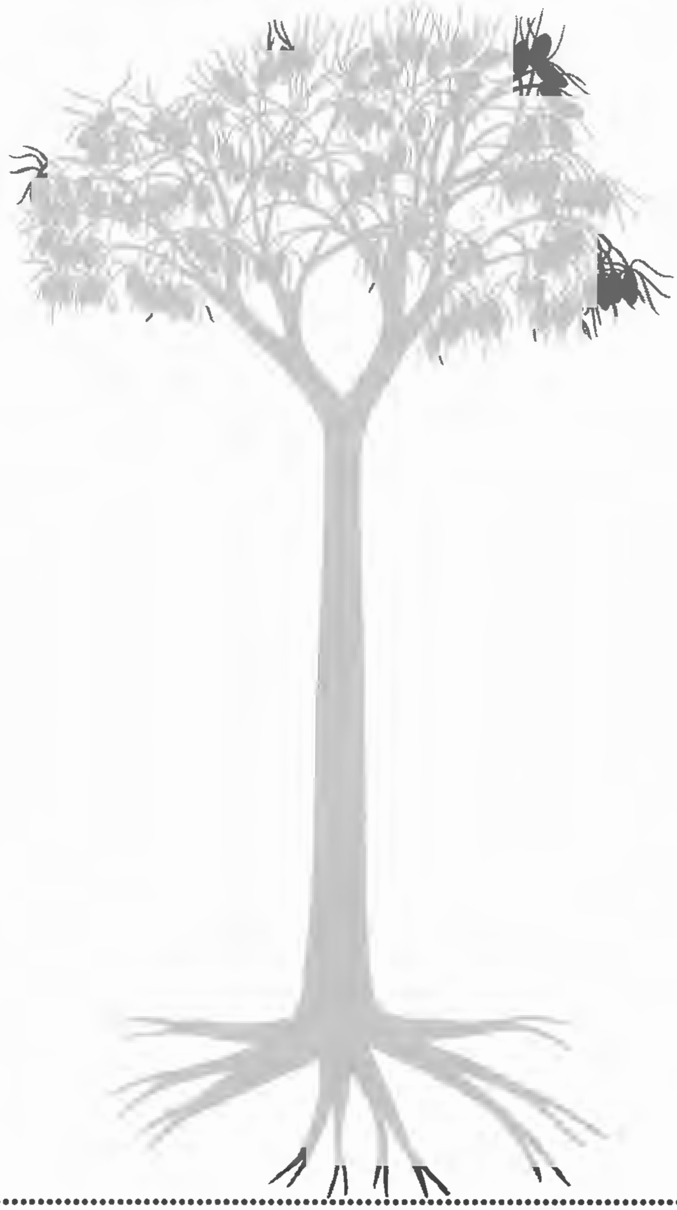
COAL RESOURCES OF FUTURE INTEREST ARCTIC ARCHIPELAGO (from Bustin and Miall, in press)

Location	Formation	Rank lig	sub (megatonnes)	hvb
Banks Island	Eureka Sound	-	5000+	-
	Isachsen	-	2	-
Axel Heiberg				
Strand Fiord area	Eureka Sound	-	-	230
Glacier Fiord area	Eureka Sound	-	-	2
East Axel Heiberg	Eureka Sound	5000	4000	300
	Isachsen	-	-	5
Ellesmere Island				
West Fosheim Pen.	Eureka Sound	10000	7000	4000
East Fosheim Pen.	Eureka Sound	2500	500	200
Southern Ellesmere	Eureka Sound	8000	3500	-
Lake Hazen	Eureka Sound	-	-	600
Judge Daly	Eureka Sound	-	-	10
Bache Pen.	Eureka Sound	-	14	-
Baffin Island				
Bylot Island	Eureka Sound	-	5	-
Eclipse Trough	Hassel	-	-	200
TOTAL		25500	20021	5547
		(rounded and arbitrarily categorized)		
	Measured	-	-	-
	Indicated	5000	2000	500
	Inferred	5500	2000	550
	Speculative	15000	16000	4500

CAÑON FIORD - ELLESMERE ISLAND, N.W.T. (courtesy B.D. Ricketts)

CHAPTER 10

COAL RESOURCES OF FUTURE INTEREST



FEATURES

COAL RESOURCES OF FUTURE INTEREST

INTRODUCTION

A coal resource estimate should reflect the wealth that coal endows to the land within which it occurs. It forms the basis for long term public and commercial planning in areas such as future coal supply possibilities, and land use options. Coal beds occur in a variety of forms and amounts in most sedimentary basins in Canada. Coal bed thickness, depth from surface, geographical location and coal quality are primary indicators of a deposit's potential utility. Exploitation of some coal deposits is currently unfeasible for economic and/or technological reasons associated with the nature of their occurrence. Some of these deposits may become viable sources of coal, or coal-derived products, in the foreseeable future as technologies advance and economic conditions change. Other deposits, such as those that are extremely deep or thin, have no imaginable future utility and are not included in estimates of the nation's coal resources.

Most of this report focuses on Canada's coal resources of immediate interest (refer to Chapter 2). Additional large quantities of coal that might be exploited in the foreseeable future given more favourable economical, technological, and/or statutory conditions are classified as coal resources of future interest.

Resources of future interest generally consider coal beds that are less than 60 cm thick (with the exception of resources in New Brunswick, where thinner beds are currently mined), occurring at depths that are greater than 600 m from surface, (with the exception of resources in Nova Scotia, where mining to much greater depths is currently planned). For relatively thin coal beds to be considered resources of future interest where underground mining is the likely coal extraction method, they must contribute to a minimum aggregate thickness of 1.5 m with other beds in close proximity. This is often referred to as a coal zone or mining zone.

LIMITATIONS TO COAL EXPLOITATION POSSIBILITIES

Several factors influence the exploitation possibilities of coal deposits. The nature of these factors may be economical, technological, social, environmental and/or political. Coal might be regarded as a strategic commodity of national importance for long term energy security and, therefore, future exploitation might not be considered in a free-market commercial sense. Presently, however, Canadian coal resource development is closely tied to national and international energy demands and economic conditions in a competitive marketplace. These economic conditions can provide the primary motivation for research and development, in both the public and private sectors, required to advance coal exploitation technologies. Energy supply and demand conditions that profoundly influence economical and technological factors pertaining to future coal exploitation, can also significantly influence social, environmental and political trends toward future coal development.

ECONOMIC CONSTRAINTS

Many economic elements influence the utility of a coal deposit. Factors such as the price of coal, and costs of production and transportation of coal products are transitory. Estimates of available coal made according to these factors can be subject to rapid change. Although coal reserve estimates should reflect in situ coal availability according to current economic conditions, coal resource estimates should have a broader perspective in recognizing coal quantities having the potential to create new wealth over the long term. Adverse size, thickness and depth of a deposit, however, can mitigate against future exploitation potential on economic grounds. This is the case when vast quantities of coal are available under more favourable conditions.

Other factors such as the geomechanical properties of roof and floor strata, attitude of coal beds, groundwater, geometry of coal beds, proximity to old mine workings and topographic considerations can also mitigate against possible exploitation on economic grounds (Weir and McNulty, 1981).

The composition and properties of the coal itself might render a deposit economically unuseable. These factors were not considered when estimating Canada's coal resource quantities.

Even where technological capabilities exist to exploit coals that occur in adverse conditions, implementation of these technologies can often be economically unfeasible. Thus, it is currently inconceivable that coals existing beyond the limits of thickness and depth applied to coal resources of future interest will be commercially exploited in Canada in the foreseeable future. It is noteworthy, however, that technologies exist, and continue to be developed, to exploit coals beyond these limits. These technologies are particularly useful to countries desiring to exploit their indigenous coals that occur in conditions that are less favourable than those in Canada.

TECHNOLOGICAL CONSTRAINTS

Technological advances in coal exploitation (extraction, processing, transportation, utilization, etc.) during the past several decades have rendered accessible vast quantities of-coal that might previously have been unexploitable. Mechanized mining, and conveying, along with widespread introduction of automated control systems, allow safe extraction of coals that were previously inaccessible. Additionally, the development of coal gasification, coal liquefaction and coal combustion technologies, among others, have expanded the possible utility of certain kinds of coals. Some previously unuseable deposits can now potentially create new wealth and, thus, contribute to the nation's coal resource inventory.

Exploitation of some coal deposits, with particular reference to thin deposits occurring beyond the practical limits of surface mining, remains technologically unfeasible or impractical. Current underground mechanized mining techniques can not mine an interval less than about 90 cm thick. Thinner coal beds can, therefore, only be extracted by including roof and floor materials. Depending on geological conditions, application of these techniques at depths of greater than about 600 m becomes economically doubtful, and often technologically impractical.

Although depth and thickness limit a coal resource estimate, the greatest technological constraint to possible exploitation is a function of the geological complexity of the rocks within which the deposit resides. Coal beds that are severely deformed and/or are highly irregular in terms of continuity or thickness can present insurmountable technological problems for their successful extraction by underground mining methods. Similarly, extremely unfavourable roof and floor conditions can present insurmountable obstacles to successful mining. These physical conditions of a coal occurrence, which can mitigate against future coal exploitation possibilities on technological grounds, have not been considered when estimating Canada's coal resource quantities.

SOCIAL, ENVIRONMENTAL AND POLITICAL CONSTRAINTS

Although coal exploitation can significantly contribute to the nation's wealth and resulting standard of living, it can also cause major social and environmental disturbances. The potential cost and benefit to society resulting from the exploitation of a coal deposit is a matter of public concern. These concerns are usually addressed by government coal leasing policies and various regulations that govern possible coal exploration, production, utilization, etc. Some Canadian coal deposits are excluded from possible future exploitation as a result of these constraints.

Coal deposits that occur within urban areas (e.g. Edmonton) and within National Parks (e.g. Banff National Park) are excluded from the national inventory of coal resources. Although coal deposits that occur within Provincial Parks (e.g. Naikoon Provincial Park, British Columbia, and Kananaskis Country, Alberta) are included in the inventory, they often contribute to coal resources of future interest. Factors associated with land reclamation in Canada's high Arctic could mitigate against future large scale surface coal mining, even if other economic and technological factors were favourable.

Proceeding with coal developments in future will likely depend, to a large degree, on associated social and environmental impacts relative to alternative energy options. Canadian coal deposits are widespread, and coal composition and properties are diverse. These factors provide a basis for choice in selecting a coal that best suits a particular need, and in optimizing social benefit. The problems associated with coal exploitation may be more manageable than those associated with other energy sources. Coal research and development activities by the private and public sectors continue to address the challenge of more efficiently exploiting this fuel and, thus, provide additional potential for coal to contribute greater wealth to the nation.

COAL RESOURCES OF FUTURE INTEREST

Canada's coal resources of future interest (Table 10.1) have been estimated on the basis of information from several sources. Information from provincial governments has been very useful. In some cases, particularly where there has been little or no recent coal exploration, information compiled by MacKay (1947) in support of his submission to the 1946 Royal Commission on Coal was useful. Additional, more recent information is contained in the files of the Geological Survey of Canada at Calgary's Institute of Sedimentary and Petroleum Geology.

Estimates of coal resources of future interest that occur in British Columbia are based mainly on information provided by the British Columbia Geological Survey Branch (W. Kilby, pers. comm., 1987), and information published by Dolmage Campbell & Associates Ltd. (1975).

Estimates that pertain to coals occurring in Alberta are based mainly on information published by the Alberta Energy Resources Conservation Board (1987), and include quantities that it refers to as "underground thin". Estimated deep coal resources of the Plains region of Alberta are based on published estimates by Williams and Murphy (1981), and include those quantities within beds at least 2 m thick, occurring between 300 and 500 m from surface, interpreted within their "Reliability Index Categories 1 and 2". Similar estimates based on their "Reliability Index Categories 3 to 5" are considered speculative resources. Estimates in this report exclude their quantities categorized as "inferred 'B'", which are considered to be too hypothetical at this time.

TABLE 10.1

CANADA'S COAL RESOURCES OF FUTURE INTEREST

Coal Region	General* Rank Class	measured	indicated	inferred	speculative
			(megatonnes)		
Coastal British Columbia					
- Vancouver Island	h-mvb	-	-	300	-
- Queen Charlotte Islands	lig-sub	-	-	-	500
Intermontane British Columbia					
- Groundhog District	lvb-an	-	-	-	4000
- Buckley River District	h-mvb	-	-	-	100
Rocky Mountains and Foothills					
- Front Ranges					
- East Kootenay	h-mvb	-	2700	-	-
- Crowsnest	m-lvb	-	200	-	-
- Cascade	lvb-an	-	210	-	-
- Panther/Clearwater	lvb-an	15	15	700	-
- Inner Foothills					
- Southern District	m-lvb	-	245	-	-
- Northern District	m-lvb	-	100	-	-
- Outer Foothills	sub-hvb	-	200	-	-
Interior Plains					
- Mannville Group	lig-sub	-	-	30	-
- Belly River Group	sub-hvb	-	205	-	-
	lig-sub	-	1090	-	-
- Edmonton Group	sub-hvb	-	550	-	-
	lig-sub	-	12295	-	-
- Wapiti Group	sub-hvb	-	65	-	-
	lig-sub	-	730	-	-
- Paskapoo Formation	sub-hvb	-	25	-	-
- Ravenscrag Formation	lig-sub	165	3910	23510	-
- *Deep coal*	sub-hvb	1200	4000	50000	85000
Hudson Bay Lowland (Ontario)	lig-sub		(no available estimates)		
Atlantic Provinces (Nova Scotia)	h-mvb	-	1500	215	-
Northern Canada					
- Yukon Territory and District of Mackenzie			(no available estimates)		
- Arctic Archipelago	sub-hvb	-	500	550	4500
	lig-sub	-	7000	7500	31000
TOTALS	lvb-an	15	225	700	4000
	m-lvb	-	545	-	-
	h-mvb	-	4200	515	100
	sub-hvb	1200	5545	50550	89500
	lig-sub	165	25025	31040	31500

*for explanation of general rank classes, please see p. 11-12 of text

Estimates that pertain to coals occurring in Saskatchewan are based on information contained in a published report by Irvine et al. (1978).

Estimates of coals occurring in Nova Scotia are based mainly on information published by Hacquebard (1979), and by the Nova Scotia Department of Mines and Energy (1980). The difference between estimated in situ coal quantities in areas of immediate interest that were published by the Nova Scotia Government, and estimated coal resource quantities for corresponding areas that were published by Hacquebard, are considered here as coal resources of future interest.

Estimates that pertain to coals occurring in the Arctic Archipelago are based entirely on information by Bustin and Miall (in press).

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adit: A nearly horizontal entry into the subsurface from the surface.

agglomerating: Property of caking coals (refer to 'caking capacity') to coalesce and bind after passing through a transient plastic stage when heated to sufficiently high temperatures in an atmosphere that will not support combustion.

allochthonous: Formed or produced elsewhere than in its present place. Term applied to coal that originated from accumulations of plant debris moved from their place of growth and deposited elsewhere.

alluvial fan: A fan-shaped deposit formed by a stream either where it issues from a narrow mountain valley onto a plain or broad valley, or where a tributary stream joins a main stream.

alluvial plain: A plain formed from the deposition of detrital materials that were eroded and transported by streams or rivers; usually adjacent to a river that periodically overflows.

anthracitic: A class of coal of the highest degree of coalification, or highest metamorphic rank (ref. Figure 2.4).

ash: Inorganic residue derived from mineral matter after burning coal.

autochthonous: Formed in the place where found. Term applied to coal that originated from accumulations of plant debris at the place where the plants grew.

basin: An area within which sediments have accumulated.

bituminous: A class of coal that is intermediate in degree of coalification, or rank, between subbituminous and anthracitic (ref. Figure 2.4).

boreal: Relating to, or located in northern regions.

caliche: A crust of calcium carbonate that forms on the stony soil of arid regions.

caking capacity: The tendency of coal particles to coalesce or agglomerate when heated to about 400 degrees Centigrade.

calorific value (heat value): The amount of heat produced by a specified quantity of coal under specified conditions.

carbonization: The conversion of coal into carbon by driving off, through distillation, the volatile components.

char: A combustible residue remaining after the destructive distillation of coal.

chronostratigraphic (time-stratigraphic): Representing the rocks formed during a certain time span.

clastic sediments: Deposits of rock fragments or grains transported by mechanical agents.

clinker: Stony matter fused together.

coal basin: A coalfield within a basinal structure.

coal district: An area in which coalfields of similar character occur.

coalfield: An area in which coal deposits of possible economic value occur in relatively close proximity. May be synonymous with a single coal deposit of possible economic value.

coalification: The process of transformation of plant remains into coal by diagenesis and metamorphism.

coal measure: A succession of coal-bearing sedimentary rock strata.

coal occurrence: The presence of coal of undetermined extent.

coal preparation: The process applied to coal to improve its suitability for a particular use.

coal rank: The classification of a coal according to the degree of coalification in the natural series from lignite to anthracite.

coal reserve: The quantity of coal within given boundaries for which exploitation is anticipated to be commercially feasible under prevailing socioeconomic conditions, or those prescribe by a commercially acceptable long term exploitation plan (feasibility study).

coal resource: Naturally occurring deposits of coal in such forms and amounts that exploitation is currently or potentially feasible.

coal seam (coal bed): A lithostratigraphic unit comprising one or more plies of coal, marked by a well defined divisional plane from its noncoal neighbours above (roof) and below (floor); may contain thin "partings".

coal zone: A group of associated coal beds that occurs at about the same stratigraphic position but within which separate beds might split, coalesce, thicken or pinch out.

coke: A porous cellular mix of fused mineral matter and fixed carbon derived from bituminous coal from which the volatile constituents have been driven off by heat (i.e. carbonized).

contraction fault: A fault in sedimentary rocks along which there has been bed-parallel shortening, giving rise to tectonic thickening.

cyclothem: An informal lithostratigraphic unit that is commonly associated with an alternating marine transgression and regression.

delta: The low, nearly flat, alluvial tract of land near the mouth of a river.

depocenter: An area or site of maximum deposition; the thickest part of any specified stratigraphic unit in a depositional basin.

diagenesis: Chemical and physical changes occurring in sediments during and after their deposition but before consolidation.

diapir: An anticlinal fold in which a mobile core has broken through brittle overlying rocks.

diatomaceous: Consisting of planktonic unicellular or colonial algae or their silicified (skeletal) remains.

domain (structural): The area in which a given set of physical controls combine to produce a distinctive structural style.

epicontinental sea: A sea lying upon a continent or continental shelf.

estuarine: Relating to a water passage where the tide meets a river current.

extension fault: A fault in sedimentary rocks along which there has been bed-parallel elongation, giving rise to tectonic thinning.

facies: Any observable, areally restricted part of a lithostratigraphic body, differing in lithology or fossil content from other beds deposited at the same time and in lithological continuity, usually as a result of conditions of origin.

fixed carbon: The solid combustible matter remaining after removal of moisture, mineral matter, and volatile matter in coal, coke and bituminous materials.

fluvial: Pertaining to or produced by the action of a stream or river.

fusinite: The micropetrological constituent of fusain which consists of carbonized woody tissue.

geomechanical properties: The characteristics of rock materials that relate to the nature of deformation or changes caused by the application of stress and/or strain energy.

geosyncline: A downwarping of the crust of the Earth in which sedimentary and volcanic rocks accumulate to thicknesses of thousands of metres.

geothermal gradient: The change in temperature of the earth with depth.

graben: An elongated block of the Earth's crust, which is bounded by extension faults on its long sides, and which has dropped relative to the blocks on either side.

hydrocarbons: Any organic compound, gaseous, liquid, or solid, consisting solely of carbon and hydrogen, such as petroleum and natural gas.

hypautochthonous: Formed near the place where found. Term applied to coal that originated from the accumulation of plant remains that no longer occur in their exact place of growth, but still within the same general area.

imbrication (tectonic): Tabular masses that overlap one another through a series of nearly parallel and overlapping contraction faults.

incompetent: Easily deformed by a tectonic force.

inertinite: A coal maceral group characterized by a relatively high carbon content and a reflectance higher than that of vitrinite, which is relatively inert during the carbonization process.

isorank: A line of equal degree of coalification or organic maturation (rank).

lacustrine: Pertaining to or produced by lakes.

lignitic: A class of coal of the lowest rank, intermediate in degree of coalification between peat and subbituminous coal (ref. Figure 2.4).

limnic: Pertaining to inland deposition in freshwater, as opposed to paralic.

liptinite: A coal maceral group characterized by relatively high hydrogen content, which is derived from spores, cuticular matter, waxes and resins.

lithostratigraphic unit: A body of rock that is unified by a substantial degree of homogeneity of physical characteristics and composition.

macerals: Distinct organic entities in coal which are derived from the originating plant tissue.

macroscopic (megascopic): Too large to be entirely observed directly.

marker: An easily recognized stratigraphic feature having characteristics distinctive enough to serve as a reference surface or to be traceable over long distances.

mesoscopic: Large enough to be observed without the aid of a microscope yet small enough to be entirely observed directly.

mineral matter: The inorganic component of coal.

orogen (orogenic belt): A linear or curvilinear region that has been subjected to folding and other deformation associated with mountain building by crustal movements.

overburden: Uneconomic, waste rock and unconsolidated materials that overlie a coal deposit (or other mineral deposit).

paralic: Pertaining to deposition along the margin of a sea, as opposed to limnic.

parting: A noncoal layer of rock in a coal seam or strata that separate coal beds within a coal zone.

peat: An unconsolidated deposit of semicarbonized plant remains in a water saturated environment. Ancestral material of coal.

permitted minesite: An area for which permission to mine has been granted by government regulatory authorities.

petrography: The branch of geology that deals with the description and systematic classification of rocks, especially by means of microscopic examination.

petrology: The branch of geology concerned with the origin, occurrence, structure, and history of rocks.

progradation: The building outward toward the sea of a coastline by continuous accumulation of sediments along the shoreline.

proximate analysis: An assay of the moisture, ash, volatile matter, and fixed carbon composition of coal, as determined by prescribed methods. A "complete" proximate analysis includes determinations of the sulphur content and calorific value.

regression: Retreat of the sea from land areas, and the consequent geological evidence of such withdrawal.

rheological: Pertaining to deformation and flow of matter.

rhythmite: An independent lithostratigraphic unit formed by a frequent and regular recurrence of the same sequence of depositional conditions.

run-of-mine (mine run): The output of a mine prior to any processing.

split: Thick parting of sedimentary rock that separates coal beds or coal zones.

stratigraphic sequence: A geographically discrete informal chronological succession of sedimentary rocks.

strip mining: Surficial mining in which coal (or other minerals) is exposed by removal of overburden in a series of strips whereby the overburden from one strip is used to fill the preceeding strips from which the coal has been extracted.

subbasin: A discrete area of sediment accumulation having some unifying characteristics within a broader region or basin of sediment accumulation.

subbituminous: A class of coal intermediate in rank between lignitic and bituminous coals.

subcrop: Subsurface truncation of a rock unit at a surface buried by dominantly unsorted and unconsolidated sediments.

successor basin: A tectonically produced area of sediment accumulation within an older basin.

syndepositional: Occurring at the time of deposition; as opposed to postdepositional.

tear fault: A steep to vertical fault associated with and perpendicular to the strike of an overthrust fault.

tectonism: Crustal movements that result in architectural changes in the crust including the formation of ocean basins, continents, plateaus and mountain ranges.

thermal maturation: The progressive alteration of organic matter by temperature.

transgression: Extension of the sea over land areas, and the consequent geological evidence of the incursion.

ultimate analysis: The composition of coal in terms of carbon, hydrogen, nitrogen, sulphur and oxygen (by difference), on a dry and ash-free (d.a.f.) basis.

vitrinite: A coal maceral group that is rich in oxygen and composed of humic material associated with peat formation.

volatile matter: Matter that is driven off as gas or vapour when coal is heated to about 950 degrees centigrade.

wrench fault: A nearly vertical strike-slip fault.

COAL RESOURCE/RESERVE TERMINOLOGY

Refer to:

Hughes, J.D., Klatzel-Mudry, L. and Nikols, D.J.
in press: A standardized coal resource/reserve reporting system for Canada; Geological Survey of Canada, Paper.

Relative Exploitation Potential

coal resources of immediate interest: Resources suitable for continuing exploration and possible development by virtue of a favourable combination of thickness, depth, quality and location.

coal resources of future interest: Resources having factors pertaining to thickness, depth, quality and location that mitigate against the possibility of immediate exploitation, but may be exploitable in the foreseeable future with some changes in economics and/or technology.

sterilized coals: Coals having factors pertaining to thickness, depth, quality and location that are favourable to qualify them as resources, but other economical, technological, social, environmental and/or political factors are considered to render the coals unusable (e.g. coals underlying urban areas).

Relative Assurance of Existence

measured, indicated, inferred and speculative: Categories used to define assurance of existence, in order of increasing uncertainty, based on the spacing of control data with respect to the complexity of the geological environment (ref. Hughes et al., in press).

speculative resources: Estimated coal resources based on extrapolation of a few data points over large distances; confined to areas where intensive coal exploration has not yet taken place.

Coal Reserves

coal in mineable seams: In place reserve base with no recovery factors applied.

recoverable coal: That portion of coal in mineable seams that can be recovered with the mining techniques considered in the feasibility study.

saleable coals: Coal that meets acceptable product specifications.

INDEX

APPENDIX

SUPPLEMENTAL READING: GEOLOGY OF COAL-BEARING AREAS IN NORTHERN CANADA

Yukon Territory and District of Mackenzie

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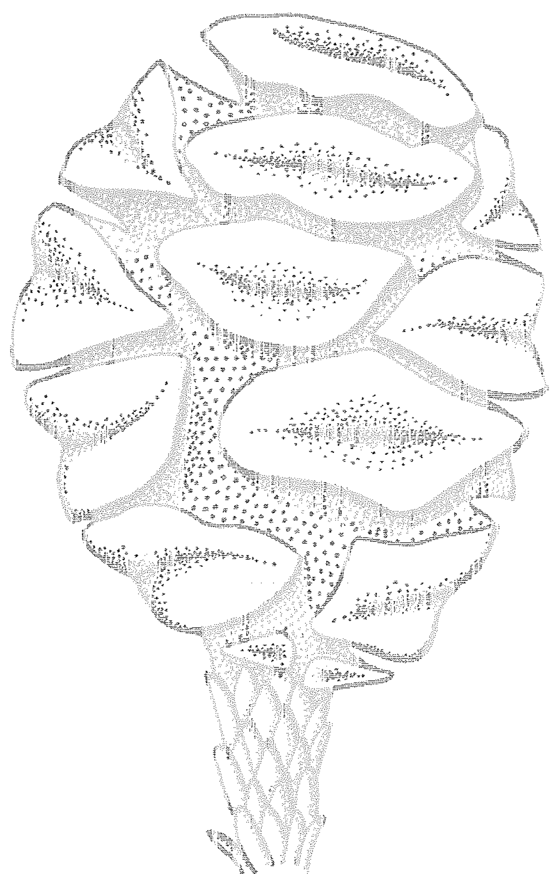

ABBREVIATIONS AND CONVERSION FACTORS

ma	-	meta-anthracite
an	-	anthracite
sa	-	semianthracite
lvb	-	low volatile bituminous
mvb	-	medium volatile bituminous
hvb	-	high volatile bituminous
hvbA	-	high volatile A bituminous
hvbB	-	high volatile B bituminous
hvbC	-	high volatile C bituminous
sub	-	subbituminous
subA	-	subbituminous A
subB	-	subbituminous B
subC	-	subbituminous C
lig	-	lignite
ligA	-	lignite A
ligB	-	lignite B
lvb-N	-	non-coking low volatile bituminous and anthractic coals.
m-lvb	-	medium and low volatile bituminous metallurgical coals.
h-mvb	-	high and medium volatile bituminous coals that may be applied to conventional metallurgical and/or thermal uses.
sub-hvb	-	subbituminous and high volatile bituminous coals commonly used in both national and international thermal coal markets.
lig-sub	-	lignitic and subbituminous thermal coals commonly used in mine-mouth power generating stations.

MJ/kg	-	megajoule / kilogram = 429.923 Btu per pound
t	-	tonne or metric ton = 2,204.6 pounds
tce	-	tonne coal equivalent = 29,308 megajoules
m	-	metre = 3.281 feet
km	-	kilometre = 0.621 miles

Prefix	Multiplication Factor
exa	10^{18}
peta	10^{15}
tera	10^{12}
giga	10^{9}
mega	10^{6}
kilo	10^{3}
hecto	10^{2}
deka	10^{1}
deci	10^{-1}
centi	10^{-2}
milli	10^{-3}
micro	10^{-6}
nano	10^{-9}
pico	10^{-12}
femto	10^{-15}
atto	10^{-18}

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