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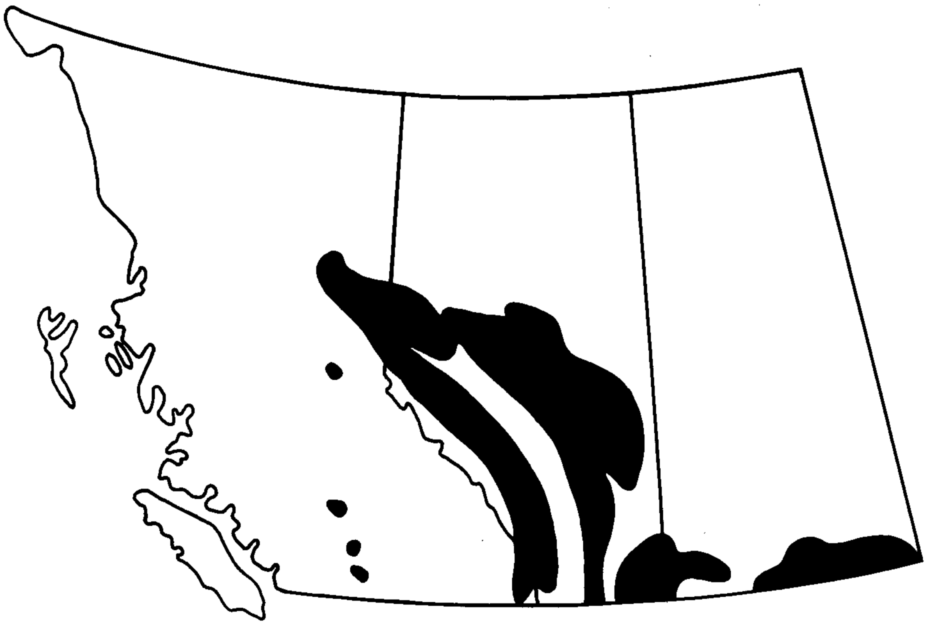

PROCEEDINGS

FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL

EDMONTON, ALBERTA

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FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL

Sponsors Edmonton Geological Society
Canadian Association of Petroleum Geologists
Research Council of Alberta

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FOREWORD

The widespread coal deposits of Western Canada have become the subject of renewed exploration and development activity in the last few years after nearly two decades of relatively little attention. In part, this renewed interest is due to current concern over the rapidly increasing demand for energy resources in North America; also, industrial development in Japan and the United States has provided new markets for the high grade metallurgical (coking) coals of the Foothills region. Thus, it seemed appropriate early in 1971 to organize a conference on the geology, exploration, and related aspects of Western Canadian coal deposits through the auspices of the Edmonton Geological Society, with a view to updating our technical knowledge of an increasingly valuable mineral resource.

The First Geological Conference on Western Canadian Coal was held in Edmonton, Alberta on November 18 and 19, 1971. Sponsored by the Edmonton Geological Society, the Canadian Association of Petroleum Geologists, and the Research Council of Alberta, the Conference was attended by nearly 400 delegates and students from various parts of Canada and the United States. The technical program consisted of nineteen papers presented during four consecutive sessions. Of these papers, fourteen are published in this volume, and two of the remaining five papers are to be published elsewhere. In addition, a paper by M. E. Holter dealing with the lignite deposits of southern Saskatchewan has been included, although it was not presented at the Conference. Undoubtedly, there is still much scope for geologic investigations of Western Canadian coal deposits, but it is hoped that the material presented here will fill some of the gaps in our present knowledge.

In conclusion, I would like to thank those individuals, companies, and agencies who generously provided the time, effort, material, and financial assistance required to organize and carry out the Conference. Contributors to the technical program deserve special mention, for many authors prepared papers on short notice, in spite of the other duties and responsibilities which required their attention. Special thanks also are owing to the Edmonton Geological Society, which, in addition to sharing the sponsorship of the Conference, generously contributed towards the cost of preparing these Proceedings for publication.

M. a. Carrigy

M. A. Carrigy
Chairman, Organizing Committee

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COAL DEPOSITS OF WESTERN AND NORTHERN CANADA

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ABSTRACT

Western Canada is estimated to contain some 118 billion tons of coal of all ranks from lignitic to anthracitic. The coals, ranging in age from Jurassic to Tertiary, are widely distributed across this region and occur under widely diverse conditions. These coal deposits are reviewed to include such features as their distribution by age, rank and quality, some depositional and structural characteristics, and estimates of reserves by various categories. The review is confined to what are considered to be high potential resource areas. Also included is a summary of information pertaining to the more significant coal occurrences in northern Canada.

INTRODUCTION

The coal deposits of Western Canada are highly varied and widely distributed. This paper will not attempt to describe or comment on all of them but rather will serve as a review of the more significant deposits as regards their geographical distribution, their rank and quality, and some stratigraphic and structural features. Also included are the most recent estimates of the resources of these deposits.

In Northern Canada exploration for coal has scarcely started, the deposits are relatively unknown, and reserves cannot yet be estimated. These deposits are reviewed in very broad terms.

RESOURCE ESTIMATES

The estimates of coal resources are presented in three categories defined as follows:

Measured Resources

Measured resources are resources for which tonnage is computed from dimensions revealed in outcrops, trenches, mine workings and drillholes. The points of observation and measurement are so closely spaced, and the thickness and extent of the coal are so well defined, that the computed tonnage is judged to be accurate within 20 per cent of the true tonnage. Although the spacing of the points of observation necessary to demonstrate continuity of coal differs from region to region according to the character of the coal beds, the points of observation are, in general, about half a mile apart.

Indicated Resources

Indicated resources are resources for which tonnage is computed partly from specific measurements and partly from projection of visible data for a reasonable distance on the basis of geologic evidence. In general, the points of observation are about 1 mile apart, but they may be as much as 1 1/2 miles apart for beds of known continuity.

Inferred Resources

Inferred resources are resources for which quantitative estimates are based largely on broad knowledge of the geologic character of the bed or region and for which few measurements of bed thickness are available. The estimates are based primarily on an assumed continuity in areas remote from outcrops of beds which, in areas near outcrops, were used to calculate tonnage classed as measured or indicated. In general, inferred coal lies more than 2 miles from the outcrop or from points for which mining or drilling information is available.

The estimates of resources presented here were obtained as a result of a study recently undertaken by the Department of Energy, Mines and Resources. This study marked the first attempt to determine the measured coal resources of Western Canada.

DISTRIBUTION BY RANK

The general areal distribution by rank of the coal deposits of Western Canada is shown in figure 1. It is quite evident that westward from the low rank lignitic deposits of Saskatchewan there is a steady progression upward in rank through the subbituminous coals of the Alberta Plains and the high volatile bituminous coals of the Outer Foothills Belt to the low and medium volatile bituminous coals of the Inner Foothills Belt of western Alberta and southeastern and northeastern British Columbia. Though not shown, coals of anthracitic rank do occur in the Inner Foothills Belt, notably in the vicinity of Canmore, Alberta, some 60 miles west of Calgary. This progression upward in rank from east to west is attributable mainly to the fact that from east to west the coal measures are increasingly

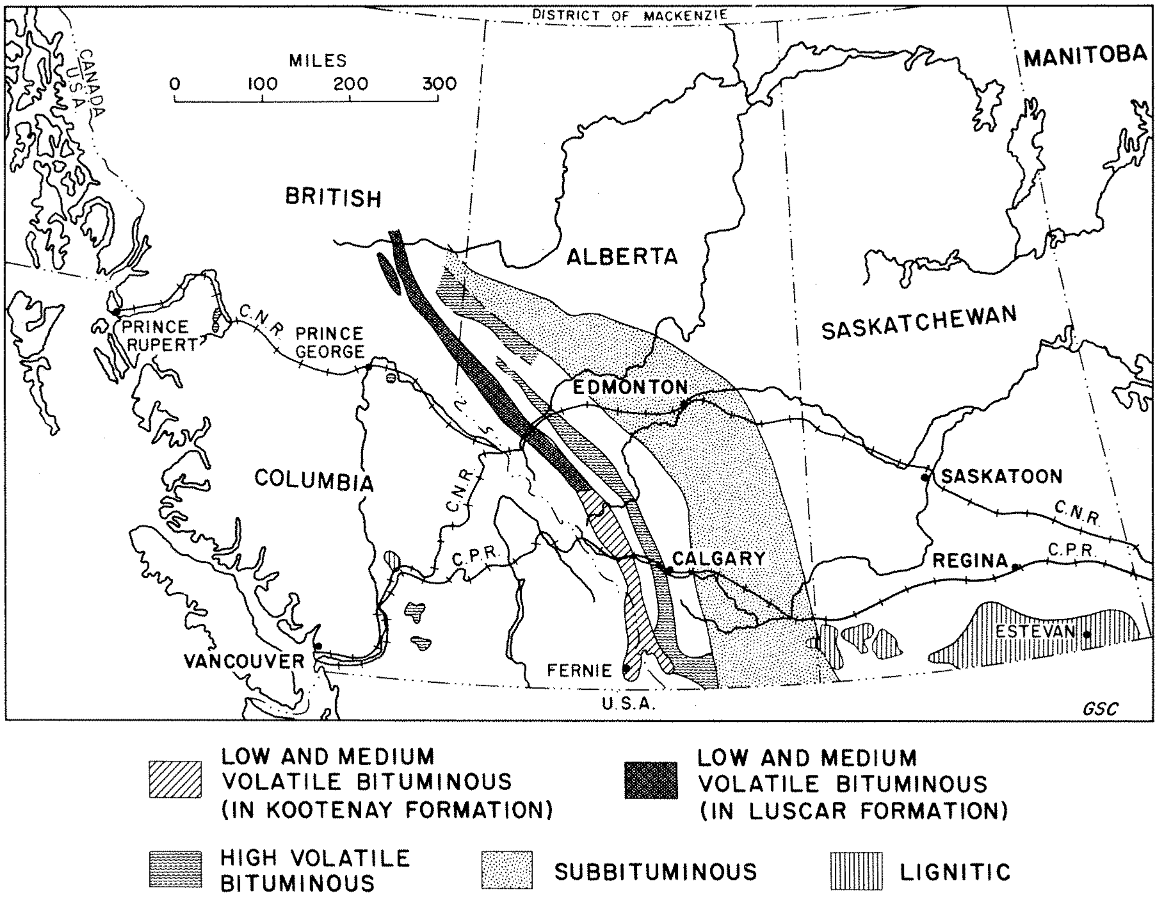

FIGURE 1. General areal distribution by rank of high potential coal deposits of Western Canada.

geologically older and this greater degree of maturity is manifested by an increase in the rank of the contained coal. The relatively high rank of the coals in the mountain belt is attributable mainly to the heavy load placed on the seams in the geosyncline that occupied the present position of the mountains with structural deformation playing only a minor role in the upranking of the coals.

In British Columbia, except for the deposits in the southeastern and northeastern parts, the coal deposits are confined mainly to small, widely separated areas, and the coals exhibit a wide range in rank.

RESOURCES AND DESCRIPTION OF WESTERN CANADA COAL DEPOSITS

Table 1 provides a summary of the estimated coal resources of Western Canada. From this it can be seen that Western Canada contains an estimated 118.7 billion tons of coal. Measured resources are 9.8 billion or 8.3 per cent of the total; indicated resources are 50.3 billion or 42.4 per cent; and inferred resources are 58.6 billion or 49.3 per cent of the total.

Provincial coal resources, in decreasing order, are British Columbia with 50.1 per cent, Alberta 39.8 per cent, and Saskatchewan 10.1 per cent. This order differs considerably from previous estimates which placed Alberta in the leading position followed by British Columbia and then Saskatchewan. The change in order between Alberta and British Columbia has been brought about, not because Alberta's resources are considered any less than before, but rather because it is estimated that British Columbia now possesses significantly greater resources than before. This increase in British Columbia's resources is due to the great increase in exploration in southeastern British Columbia in the past few years. Exploration in Alberta has been

Table 1. Coal Resources of Western Canada by Province (thousands of short tons)

Province	Measured	Indicated	Inferred	Total
British Columbia	7,328,600	11,175,400	40,953,000	59,457,000
Alberta	2,203,900	32,096,100	12,940,200	47,240,200
Saskatchewan	291,500	7,024,000	4,698,400	12,013,900
Western Canada Total	9,824,000	50,295,500	58,591,600	118,711,100

progressing at a slower rate because of the very large area to be explored and the more inaccessible character of much of the terrain.

Additional comments concerning the resources and the coal deposits are presented as each province is considered separately.

Saskatchewan

Saskatchewan's coal deposits, all lignitic in rank, occur in a belt along the southern edge of the province and are contained in the Ravenscrag Formation of Early Tertiary age. This belt is the northern fringe of a large basin that extends through western North Dakota and eastern Montana. In Saskatchewan the coal measures are almost everywhere well covered with a mantle of glacial deposits, a factor that has hampered exploration.

The coal measures attained their best development in the Estevan area where eight seams are recognized of which only the upper four have thicknesses of five feet or more. All four have been mined in the Estevan area, and production has been mainly by strip mining. Only in the Estevan area has there been sufficient exploration to permit estimates to be made of measured resources.

Westward from the Estevan area the seams become fewer and thinner. In the central part of the belt five seams are present, whereas at the western end of the belt only three seams are known. The areal extent of the various seams has not been determined. In the few instances where seams have been traced along the sides of valleys, the seams appear to extend for distances of as much as 50 miles but show considerable lensing.

The resources are shown in table 2. The measured resources represent only that coal contained in seams five feet or more in thickness at depths not greater than 150 feet from surface. The same limit of seam thickness applies to the indicated and inferred categories, but the depth of overburden is extended to a maximum of 500 feet.

Alberta

Coal-bearing formations underlie much of the southern half of Alberta and contain coal of all ranks under a great variety of geological conditions. The coal deposits are readily grouped into three large areas that extend throughout the province parallel to the mountains. These are termed the Plains Area, Outer Foothills Belt and Inner Foothills Belt, and it is convenient to comment on each belt separately.

Plains Area

Throughout this large area the coals are almost entirely subbituminous in rank and occur in the Edmonton Formation and the Belly River Group of Late Cretaceous age. There are two exceptions to this, one in the extreme southeast corner where lignitic coal is contained in a small area underlain by the Ravenscrag Formation, and the other in the extreme southwest corner where the Belly River coals are high volatile bituminous. The seams are generally flat or gently dipping and covered with a mantle of glacial deposits so that they are rarely exposed in outcrop. Near-surface seams are suitably disposed for strip mining, and almost the entire production from this area is by this means. Mining in this area does encounter problems in that the areal extent of a seam may be limited due to depositional lensing or it may be partly or entirely removed by glaciation. In some instances glaciation has squeezed and fractured the coal, causing pronounced undulations in the roof and floor of the seam, or has actually caused displacement of the seam with considerable accompanying distortion.

Table 2. Coal Resources of Saskatchewan (thousands of short tons)

District	Measured	Indicated	Inferred
Estevan	291,500	1,044,400	487,200
Radville Block		2,352,000	1,008,000
Willowbunch Block		2,408,000	2,184,000
Wood Mountain Block		616,000	672,000
Pinto Butte Block			44,800
Eastend Block		570,000	268,800
Cypress Lake Block		33,600	33,600
Saskatchewan Total	291,500	7,024,000	4,698,000

The resources of the Plains Area are shown in table 3. They total nearly 10 billion tons of which approximately 1.2 billion tons are in the measured category. The measured resources include only that coal contained in seams five feet or more in thickness at depths from surface of not more than 150 feet.

Outer Foothills Belt

Coal in this belt is all high volatile bituminous in rank and is Late Cretaceous and Tertiary in age. The Upper Cretaceous formations extend in narrow bands along the full length of this belt and contain coal seams which, for the most part, are rather thin although, in a few instances, thicknesses of between 5 feet and 15 feet have been recorded. The Tertiary coal deposits are the most important in this belt and these are best developed in the area between North Saskatchewan River and Athabasca River and include seams of good mineable thicknesses.

Table 3. Coal Resources of Alberta (thousands of short tons)

District	Measured	Indicated	Inferred
Plains Area	1,221,800	6,197,300	2,530,000
Outer Foothills Belt		6,278,600	3,043,700
Inner Foothills Belt			
North (Luscar Fm)	542,000	7,426,500	3,535,400
South (Kootenay Fm)	440,100	12,193,700	3,831,100
Alberta Total	2,203,900	32,096,100	12,940,200

Because of their proximity to the mountains the coal deposits in this belt have been subjected, to a considerable degree, to the same forces that formed the mountains. Consequently, the seams may be at any attitude, or folded, or truncated by faults or otherwise structurally deformed. These conditions together with a terrain that provides limited outcrop make exploration difficult. It is known that in some places seams have been structurally thickened, and one such occurrence – wherein a seam of normal thickness of some 20 feet is thickened to 120 feet – was successfully strip-mined in the vicinity of Sterco-Coal Valley.

The resources of this belt (Table 3) total some 9.3 billion tons, none of which is in the measured category.

Inner Foothills Belt

Reference to the map readily shows that two areas in British Columbia are geologically part of a larger belt which, in Alberta, is termed the Inner Foothills Belt. In this paper the discussion of the geological conditions of the Inner Foothills Belt will apply to and include these two areas of British Columbia, though the estimates of resources are kept separate.

For the most part this belt extends along the eastern front of the Rocky Mountains from near the International Boundary through to Peace River. This belt is characterized by numerous major folds and faults which together with the dissection of the land by glacial and stream erosion permits ready delineation of the areal extent of the coal-bearing formations. As is to be expected in an area of such structural disturbance the seams are normally steeply inclined and, in some instances, severely contorted, thickened or thinned, cut off by faults, and the coal so severely crushed as to make it extremely friable. In other instances, however, these structures have so oriented the seam with respect to the surface or so thickened the seam that excellent recovery can be made by strip mining.

The coal, with few exceptions, is low and medium volatile bituminous in rank and invariably has a low sulphur content. Coals of excellent coking quality have been found at various localities throughout the belt, but certainly not all the coal is of this quality and there is no way of predicting those areas or seams most favourable for its occurrence. Within a given stratigraphic section containing several seams, the coking quality may vary from seam to seam and, indeed, within a seam.

From the southern extremity of this belt for a distance of about 200 miles northward, the coal seams are contained in the Kootenay Formation which is mainly Late Jurassic with the highest beds considered to be Early Cretaceous in age. The Kootenay appears to have attained its maximum development in the Fernie-Michel area of British Columbia. Eastward from this area there is a rapid reduction in the thickness of the formation and in the number of contained coal seams, and there is a similar but less pronounced reduction northward from this area. The British Columbia part of the belt is separated from the Alberta part by an area of older non-coal-bearing rocks which were thrust into place by a major west-dipping fault. The separation becomes less to the north, and the two belts merge together where the British Columbia belt crosses into Alberta.

At about the same latitude that coal seams disappear in the Kootenay Formation, other seams start to appear in the overlying Luscar Formation of Early Cretaceous age. The seams increase in number and thickness to the north and would seem to be best developed in the Mountain Park area and again in the Smoky River area. The belt extends northward into British Columbia at least as far north as Peace River. In northeastern British Columbia the coal is contained in the Gething Formation and the Commotion Formation. The two are separated by the non-coal-bearing, marine Moosebar Formation, but all three formations are equivalents of the Luscar Formation to the south.

The ultimate distance that this belt can be extended northward is not known. There are a few reports of coal being found well to the north on Halfway, Sikanni Chief and Minaker Rivers. Only very limited exploration for coal has been carried out in this large area, which is rather difficult of access.

The coal resources of the Alberta Inner Foothills Belt are shown in table 3. A subdivision has been made to show the resources of each of the two coal-bearing formations in the belt. In total the belt is estimated to contain nearly 28 billion tons of which about one billion tons are in the measured category. All the resources are contained in seams five feet or more in thickness and at a depth not exceeding 2,500 feet.

British Columbia

As shown on the map, apart from southeastern and northeastern British Columbia, those coal deposits of British Columbia that are considered to be of high potential are confined to a few small, widely scattered areas. Omitted from consideration in this paper are many areas where coal has been reported or, as in the case of the Vancouver Island deposits, where coal has actually been mined. The former have been omitted because there is so little information concerning them or because, in some instances, there is even doubt as to the presence of mineable coal deposits. The Vancouver Island deposits have been omitted because the better areas appear to be mined out, and information concerning the remaining areas does not warrant considering them as a high potential resource.

Southeastern Area

The main characteristics of this area were discussed along with those of the Inner Foothills Belt of Alberta. The resources of the area are presented in table 4. Some 57 billion tons are estimated to occur in the area, and nearly 7 billion tons are in the measured category. That such relatively large resources can be assigned to this area is a reflection of the information available due to the recent high level of exploration and development in the area.

Table 4. Coal Resources of British Columbia (thousands of short tons)

District	Measured	Indicated	Inferred
Southeastern Area	6,930,500	10,402,300	40,033,200
South-central Area	373,600	395,900	353,200
Central Area	12,000	4,600	119,700
Northeastern Area	12,500	372,600	446,900
British Columbia Total	7,328,600	11,175,400	40,953,000

South-central Area

Three small coal basins are included here for consideration: the Tulameen, Merritt-Nicola and Hat Creek deposits. All three of the deposits are Tertiary in age, but the rank of the coal is different in each: the Tulameen coal is subbituminous to high volatile bituminous; the Merritt-Nicola coal is mostly high volatile bituminous; and the Hat Creek coal is lignitic. Outcrops of coal are scarce, and the seams are normally covered with a great thickness of younger sediments and alluvium and, at Hat Creek, by younger volcanic rocks as well. The deposits are folded and cut by faults so that the total picture is one of difficult exploration. The Hat Creek deposits are unique in that they contain the thickest assemblage of seams so far known anywhere in Canada. At least five seams are known to be present and their aggregate thickness is in the order of 2,000 feet. It is recognized that these seams are not pure lignite but instead contain many interbeds of clay. Nevertheless, they do constitute a deposit with a very high potential and, moreover, they do pose the possibility that some of the other scattered occurrences that have been reported elsewhere in British Columbia may be similar to the Hat Creek deposits.

The resources of the South-central Area are shown in table 4. The measured resources are estimated to be approximately one-third of the total resources of one billion tons.

Central Area

At least 21 coal occurrences have been reported from this area, but only two are considered to contain resources within the definitions set forth. Lower Cretaceous coal deposits occur in the vicinity of Telkwa, and the coal is classified by rank as medium to high volatile bituminous. Mining experience over the past 25 years has shown the deposits to be intensely folded and faulted in some places and at some localities intruded by volcanic rocks. The other deposit located on Bowron River is thought to be Tertiary in age, but the coal is ranked as high volatile bituminous. A limited amount of exploration has been carried out in this area which, in part, indicates that the seams are rather irregular in thickness.

The resources of this area, as shown in table 4, are not large and reflect the small areal extent of the deposits and the lack of information concerning them.

Northeastern Area

The coal deposits of this area were discussed along with those of the Inner Foothills Belt of Alberta. Because of the

Table 5. Coal Resources of Western Canada by Rank and Province (thousands of short tons)

Province	Measured	Indicated	Inferred	Total
		Low & Medium Volatile Bituminous		
Alberta				
Inner Foothills Luscar Formation	542,000	7,426,500	3,535,400	11,503,900
Inner Foothills Kootenay Formation	440,100	12,193,700	3,831,100	16,464,900
Alberta Total	982,100	19,620,200	7,366,500	27,968,800
British Columbia	6,943,000	10,775,000	40,480,100	58,198,100
RANK TOTAL	7,925,100	30,395,200	47,846,600	86,166,900
		High Volatile Bituminous		
Alberta				
Outer Foothills		6,278,600	3,043,700	9,322,300
British Columbia	45,600	100,400	172,900	318,900
RANK TOTAL	45,600	6,379,000	3,216,600	9,641,200
		Subbituminous		
Alberta	1,221,800	6,197,300	2,530,000	9,949,100
		Lignitic		
British Columbia	340,000	300,000	300,000	940,000
Saskatchewan	291,500	7,024,000	4,698,400	12,013,900
RANK TOTAL	631,500	7,324,000	4,998,400	12,953,900
GRAND TOTAL	9,824,000	50,295,500	58,591,600	118,711,100

relative remoteness of the area, exploration has lagged behind that in the more accessible parts of the belt to the south. Results of recent exploration do indicate that the reserves of this area are very considerable, but it is too early for detailed estimates to be made. Resource estimates shown in table 4 are therefore still rather conservative.

As a quick means of review the resource estimates of coal in Western Canada by rank and by province are presented in table 5.

COAL OCCURRENCES IN NORTHERN CANADA

Early explorers in the North reported occurrences of coal in Yukon Territory and Northwest Territories including the Arctic Islands. Incentives for undertaking coal exploration were lacking, and only in a very few places were the seams ever worked and then for very brief periods. Systematic geological mapping carried out by the Geological Survey of Canada has confirmed some of these reported occurrences, has shown others to be grossly inaccurate, and has discovered other significant occurrences. Exploration for coal in Yukon Territory has been carried out in the past two seasons with at least three different areas being investigated.

Figure 2 shows the locations and ranks of coal occurrences where one or more seams are known to be at least five feet thick.

Yukon Territory

The coal deposits of the Yukon are of Mesozoic and Tertiary ages. In the southwestern part the Mesozoic coals occur in two formations, the Laberge and the immediately overlying Tantalus Formations. The Laberge is regarded as Lower Jurassic with possibly some Upper Jurassic, and the age of the Tantalus Formation is considered to be Upper Jurassic and Lower Cretaceous. The Mesozoic coals are mostly bituminous in rank, and the most important occurrences are at localities 5, 6, and 7 (Fig. 2).

The Tertiary coals, which are all lignitic, occur in Yukon and White River drainage areas in the western part of the Yukon (Locs. 1 and 2), Upper Liard River in southeastern

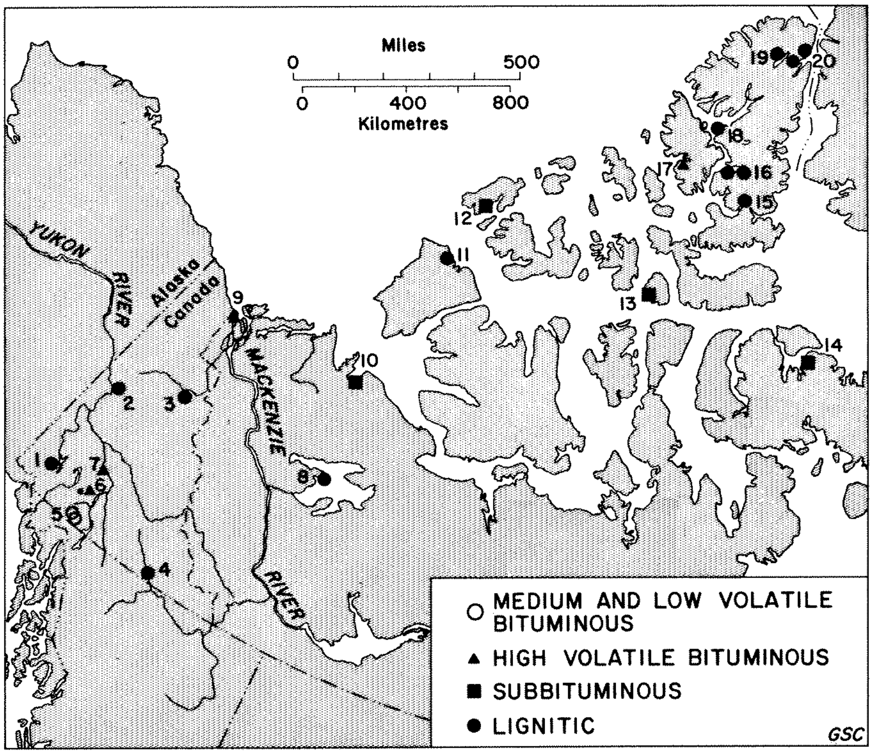

FIGURE 2. Coal occurrences in Yukon Territory and Northwest Territories.

Yukon (Loc. 4), and in the Bonnet Plume area (Loc. 3) in the northern part of the Yukon.

Northwest Territories, Mainland

Only three occurrences in this large area are worthy of note. Four seams of lignitic coal occur in Tertiary sediments on the west side of Great Bear Lake (Loc. 8, Fig. 2). Upper Cretaceous strata on the northwestern edge of Mackenzie River delta contain at least one seam of high volatile bituminous coal (Loc. 9). This seam was mined for several years and the coal used as a fuel at Aklavik. Seams of subbituminous coal of Cretaceous age occur at locality 10, with one seam reported to be 25 feet thick but containing some bands of shale.

Northwest Territories, Arctic Islands

There are now a sufficient number of reliable reports of coal seams of mineable thickness to indicate that the Arctic Islands coal deposits are extensive. The rank of the coals contained in these deposits is still uncertain as most analyses to date have been made on samples of severely weathered coal taken from outcrops. However, it seems safe to say that generally the coals are poorly consolidated and low in rank, seldom exceeding the subbituminous rank.

Subbituminous coal of Pennsylvanian age occurs on Cornwallis Island (Loc. 13, Fig. 2). Lower Cretaceous or Jurassic subbituminous coal is present on Baffin Island (Loc. 14). On Prince Patrick Island (Loc. 12) there is subbituminous coal that is Early Cretaceous in age. On the north coast of Banks Island (Loc. 11) there is Upper Cretaceous coal of lignitic rank. Ellesmere Island (Locs. 15 to 20) appears to be underlain by much coal. These deposits are Late Cretaceous or Tertiary, and all the coal is lignitic. Medium volatile bituminous coal of Late Cretaceous or Tertiary age is reported on Axel Heiberg Island (Loc. 17), but the reliability of the analyses is questionable due to the nature of the sample provided.

EXPLORATION TECHNIQUES, UPPER ELK COAL FIELD, BRITISH COLUMBIA

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ABSTRACT

The Upper Elk coal field is a narrow folded belt of Kootenay strata 2 to 6 1/2 miles wide paralleling the Continental Divide in southeastern British Columbia for a distance of 60 miles. The strata, repeated in places by overlapping folds and thrust faults to form a maximum apparent thickness of 4,000 feet, consist of sandstone, siltstone, and mudstone interbedded with coal seams ranging from 4 to 50 feet thick.

The geology of this region poses a complex framework for coal exploration. Reconnaissance studies involving field mapping and photo interpretation provide the initial basis for delineating target areas which warrant further investigation by trenching, construction of test pits and adits, and drilling and logging of testholes. Tests performed on bulk samples from test pits and adits provide the best indicators of coal quality, although these results can be augmented to some extent by similar tests of drilling samples.

INTRODUCTION

Interest concerning coal measures of the Upper Elk Valley was originally generated by an expanding industry early in this century. By 1910 most available land was staked and actively explored by companies such as Imperial Coal and Coke Company and the Canadian Pacific Railroad. Although geological studies ceased after 1910, the records of original workers assisted renewed exploration after 1950. Several companies, including Cominco, Utah Construction, Emkay, Scurry, and Crows Nest Industries, began work in this area after 1950. A brief description of the location and geology of the Upper Elk coal field constitutes the basis for a discussion of Rocky Mountain coal exploration techniques.

Acknowledgments

I would like to thank Mr. J. J. Crabb, Crows Nest Industries Limited, and his staff for assistance and information in preparing this report. I also thank Mr. A. A. Johnson and Denison Mines Limited for helping in the preparation and presentation of this paper.

DESCRIPTION AND LOCATION

The intermontane coal belt in southeastern British Columbia includes three subsections based on structural features which set each area apart from the others (Fig. 1). The Flathead coal field in the south comprises several isolated fault blocks and erosional remnants of Kootenay Formation. The Crows Nest coal basin in the centre is a tear-shaped synclinorium with a general north-south axis. The Upper Elk coal field in the north is a narrow fold belt of Kootenay strata paralleling the Continental Divide. The divisions have been segregated by high intervening ridges of Paleozoic rocks — for example, Erickson Ridge between the Upper Elk coal field and the Crows Nest coal basin.

The Upper Elk coal field commences on the west side of Alexander Creek, 7 miles north of Highway No. 3. The folded strata extend approximately 60 miles north to the headwaters of the Elk River, widening a short distance north of the Fording Coal Ltd. mine to a maximum width of about 6 1/2 miles. The belt consists of erosional remnants south of Horseshoe Ridge but is continuous north to the Elk Lakes and the Alberta border. In many regions erosion has removed most of the overlying Blairmore Group strata and in a few areas the upper portions of Kootenay Formation, leaving shallow cover over the thick coal seams included in the lowermost section.

STRUCTURAL GEOLOGY

The Upper Elk coal field is located within the Lewis thrust sheet. The structural style is concordant with the general tectonic framework of the Rocky Mountains in southeastern British Columbia. Fold axes have a general north-south trend with parallel west-dipping faults (Fig. 1). These structures express a west-east compression resulting in a general shortening of the crust and thickening of the sedimentary beds deposited there. Three dominant structural features are apparent within the coal field. In order of importance these features may be described as (1) the Fording River Syncline, (2) a series of drag folds and thrusts on the eastern border, and (3) a related syncline and anticline in the Green Hills (Fig. 1).

The Fording River Syncline, a local name, can be delineated on the ground from Line Creek Ridge north to Miller Creek. Beyond Miller Creek the fold axis must follow the

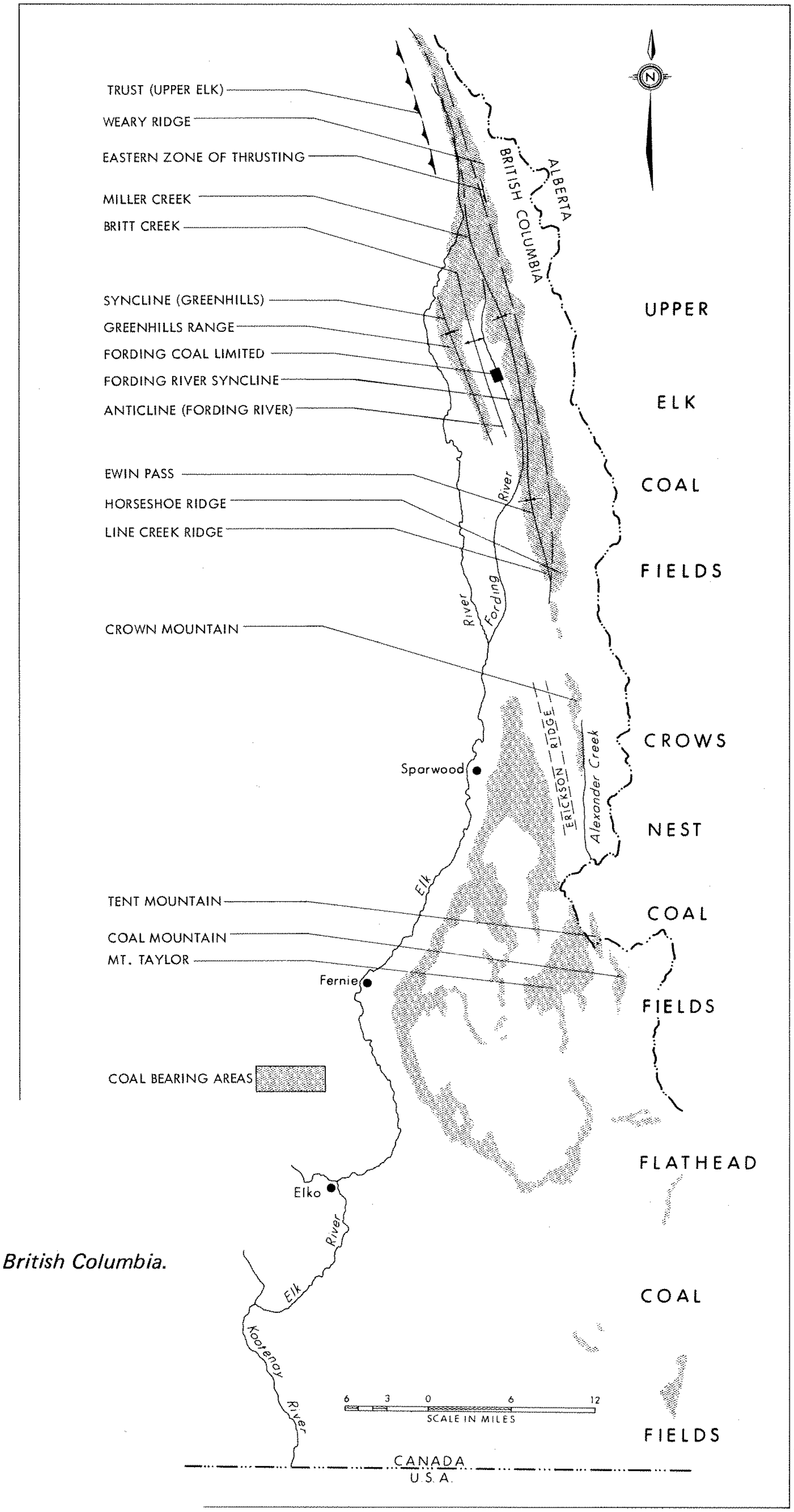


FIGURE 1. Coal basins of southeastern British Columbia.

Elk River Valley, but deep alluvium has buried the axial trace. This steep-limbed, asymmetric fold plunges northward at 8% to 10% in the region of Line Creek. The attitude of the axial plane varies from east through vertical to west while maintaining a general northward strike. In the upper reaches of the Elk River, the Fording River Syncline tightens, becoming isoclinal and recumbent to the east along a major overthrust paralleling the west side of the Elk River (Plate 1A).

The eastern border of the coal belt and the east limb of the Fording Syncline are complicated by a series of tight folds and thrust faults. The thrusts generally have steep westward dips, but angles relative to the bedding are quite shallow, indicating that the faulting preceded the folding in this area. Each of these structures is discontinuous, but en echelon they form a tectonic zone paralleling the Fording River Syncline. These overlapping folds and thrusts have produced an apparent 4,000-foot thickness of Kootenay strata in the Line Creek area (Plate 1B, 1C; Plate 2A).

In the area just north of the Fording Coal Ltd. mine operation, where the Upper Elk coal belt widens from its average of about 2 miles to approximately 6 1/2 miles, the increase in width is caused by a complementary syncline and anticline west of the main Fording River Syncline. The crest of the anticline lies beneath the Fording River where erosion has exposed the underlying Fernie shales. The trough of the syncline caps the Green Hills Range, leaving a strip of Kootenay extending south from Britt Creek. Subsidiary structures exposed on the south and east side of the Green Hills point to a possible northward continuation of the Erickson Fault.

STRATIGRAPHY

The Kootenay Formation of the Upper Elk coal field remains largely as an incomplete stratigraphic succession as a result of high uplift and rapid erosion. On Line Creek Ridge an 1,800-foot section of sediments has been measured, all of which contains interbedded coal seams. Care must be taken in measuring sections due to faulting. Low angle or bedding plane thrusts can pass undetected through a section resulting in exaggerated thicknesses and missing intervals.

The lowermost sandstone bed has been given member status within the Kootenay Formation. The Moose Mountain Member (Norris, 1959) is a remarkably persistent cliff-forming unit lying conformably on the transition beds of the Jurassic Fernie Formation. This resistant sandstone, measuring between 80 and 100 feet in thickness, is the one identifiable cliff marker bed throughout the intermountain coal belt of southeastern British Columbia. Standing out as the base of the coal measures, it can be traced from the International Boundary north to the Elk Lakes (Plate 2B).

The lithology of the Kootenay Formation is comprised of thin- to thick-bedded sandstone, siltstones, mudstones and shales with interbedded coal seams. The fine- to coarse-grained clastics vary in color from light grey to black. Differential erosion has produced a general rib-like expression on the mountain sides, although rapid lateral facies changes reduce the effect of most cliff marker beds. Except for the basal sandstone, few lithological units show the continuity required of correlatable horizons.

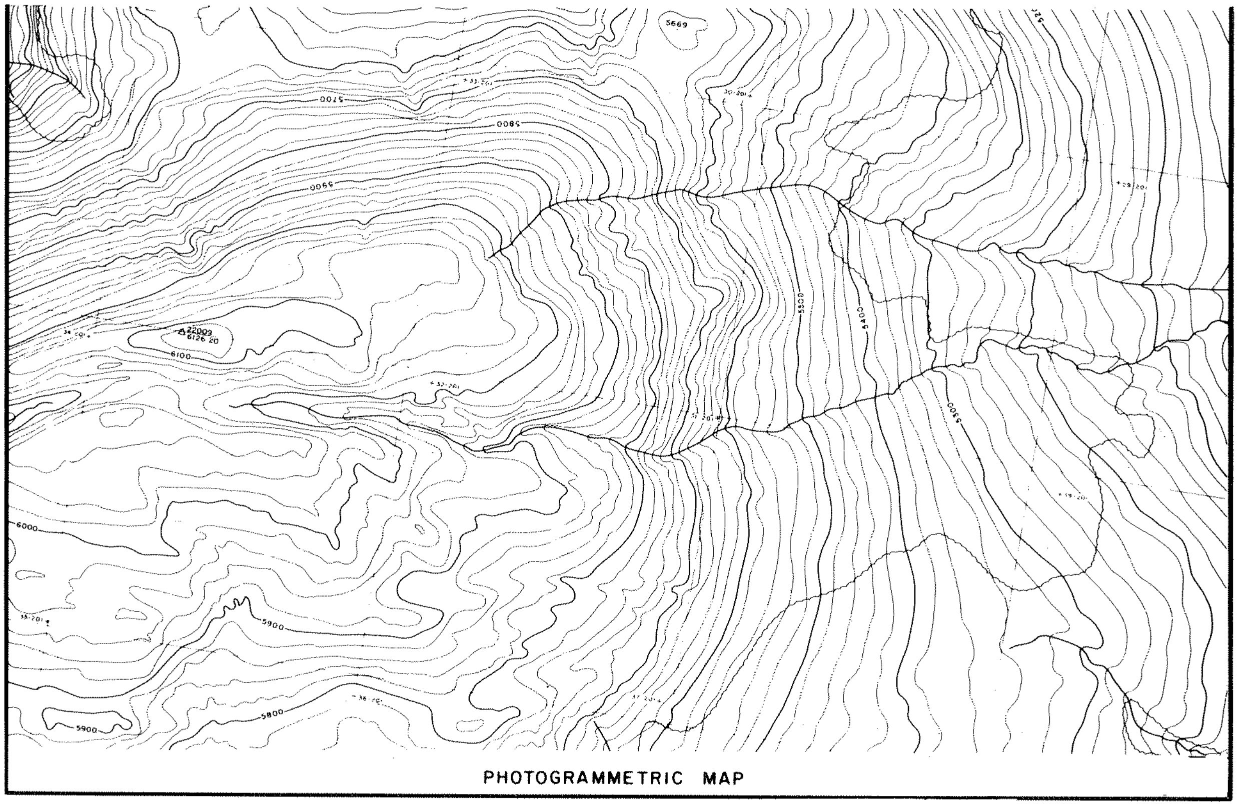
The coal seams of the Kootenay Formation are remarkable for their thickness and continuity. Thicknesses vary up to 50 feet of coal with the thicker seams providing excellent marker horizons on the surface and in drill holes. More than thirteen (13) seams greater than 4 feet in thickness have been identified in the section with the lowermost coal lying on the upper surface of the Moose Mountain Member. The seams commonly have gradational boundaries with the transition from coal to shale taking place over a few feet of section. In rare cases coarse clastics rest in sharp contact with coal.

EXPLORATION

The geology of the Rocky Mountains imposes a complex framework for coal mine exploration. Rugged mountains and severe climate pose difficult access, short exploration seasons, steep mining areas, and complex restoration problems. Gentle folding rapidly changes along strike to isoclinal and recumbent folding. Innumerable overthrusts and normal faults repeat or remove sections of strata, and this, compounded by a lack of marker horizons, makes coal seam correlations over large areas extremely difficult.

Because interest in Western Canadian coal deposits started to decline about 40 years ago, tracts of land were left virtually untouched. Any signs of previous work soon disappeared because of erosion. Consequently, many areas existed which required a program commencing with basic reconnaissance and progressing through to three-dimensional exploration involving drilling and tunnelling. Tools and techniques are discussed below as they might be employed in a modern exploration program.

PHOTO ENLARGEMENT



PHOTOGRAMMETRIC MAP

FIGURE 2. Topographic map derived from air photo interpretation.

Reconnaissance Investigations

Preliminary reconnaissance studies of an unexplored coal area ought to entail low cost investigation to ascertain the existence of coal seams and areas of relative structural simplicity and shallow cover. Both for underground and surface mining potential the degree of faulting and folding, the attitude of the beds, and the depth of rock covering the coal seams must be fully assessed. In the Rocky Mountains, overburden is variable in depth from deep alluvium in valleys to barren rock on mountain tops. Survey teams provided with air photographs, hand tools and helicopter access can quickly delineate coal seam outcrops and derive the degree of structural complexity. Data can be plotted on Government air photos and later transferred to enlargements of existing or newly completed maps. A program of this scope will result in a preliminary geological map of the coal field and delineate target areas which warrant further expenditure. Initial outlay in terms of money and time can be minimal, thus allowing a project to advance to the next stage of development within the same field season.

Detailed Mapping

Detailed geological mapping of target areas requires additional aerial photography and topographic map preparation. Enlargements of the photographs to the same scale as the map provide a base for recording field data. Photo-identified points transferred to topographic sheets constitute a reasonably accurate series of references by which geological and other data may be traced onto base maps. Photo points should be arranged in a closely spaced pattern approximating a grid. Map sheets are oriented as overlays on the enlarged photographs using three or four adjacent points. By transcribing information in the immediate vicinity of these identified points before moving the overlays, problems of photographic distortion are reduced. A comparison of the distance between points as measured on the map and on the photo furnishes a quick check on photo scale. Photo distortion is impossible to remedy, especially towards the edges of a print or between points of extreme relief; however, careful enlargement can reduce overall distortion and tilt. New methods of orthophotography in which stereo photo pairs are employed now appear capable of correcting distortion even in areas of extreme relief (Fig. 2).

Photogeology

Photogeology of coal-bearing strata such as the Kootenay Formation provides useful data during reconnaissance and later stages, even though up-to-date photography is usually not available for initial reconnaissance. Color positive pictures, flown at low elevations specifically for geological detail, provide a permanent record for immediate and future reference. A marker horizon such as the Moose Mountain Member of the Kootenay Formation can be readily traced over great distances. Possible coal seam locations are identified by distinctive vegetation, recessive zones, carbonaceous-appearing soil, and actual coal outcrop.

Bulldozers

The use of bulldozers facilitates the requisition of data on coal measures. These machines are employed to uncover sections and to trace coal seams. Fresh rock exposures in "cat" trenches furnish fine details of the lithology and structure, permitting detection of isoclinal folding and thrust faulting. Comparison of numerous sections measured from a known datum such as the Moose Mountain Member eventually elucidates the original stratigraphy and the location and degree of structural complexity.

Thick and relatively continuous coal seams of the Kootenay Formation furnish a second source of correlatable horizons. Bulldozers employed to trace these seams can effectively join widely spaced coal outcrops exposing the nature of the roof and floor strata for careful study (Plate 2C). Although not important in open pit mining, the size and frequency of minor roof structures and the degree of graded and interbedded roof lithology can often limit underground mineability of a seam (Plate 3A, B).

Three-Dimensional Detail

To complete the three-dimensional picture of a coal mine prospect, access to the strata beyond the outcrop must be developed. Three methods can be used, none of which is completely new, although significant improvements in equipment and techniques have enhanced the validity of the data produced. Test pits, adits, and drill holes all can be utilized to generate coal samples, although costs and data vary between methods.

Test Pits

Test pits, as the name implies, are model scale open pits. One or more bulldozers are employed to remove the superincumbent strata, exposing the coal relatively close to the original surface. The amount of material which must be moved quite often limits access to only the oxidized zone, reducing the effectiveness of this method. (It is imperative that large quantities of unoxidized coal be made available for coking tests.) However, following initial investment in the pit, any number of repeat samples are available at low cost.

Adits

Tunnels driven in coal seams are described as ***adits*** or ***adit entries*** (Plate 3C). They should be developed in the lowermost section of the seam at a location which permits strike or horizonal entry. Partial pitch or declining entries are also possible, but the cost is considerably greater and there exists an ever-present water problem. During construction, miners excavate coal by drilling an augerhole pattern to outline the entry and then free coal with permissible powder. Conveyor systems are often heavy machine installations, but within 100 feet of the portal a common wheelbarrow or cement buggy is very effective.

Coal coking quality indications are tested daily by checking ***free swelling index*** and ***ash level***. A graphic presentation of increasing entry distance versus F.S.I. will usually show an improvement in F.S.I. until the zone of oxidation has been penetrated. To be valid, F.S.I. must be compared at approximately the same ash level. Adits are completed by driving crosscuts or raises, thus exposing the entire seam for sampling. Well-constructed adits will permit almost permanent access for resampling.

The number and the spacing of adits or test pits is predetermined by the characteristics of seams, access to outcrops, and by the exploration budget. In Rocky Mountain coal areas, spacing intervals of 3,000 feet are feasible to ascertain stratigraphic relationships. However, significant differences in quality between adits at 3,000-foot intervals may necessitate shorter distances between locations. Large samples carefully obtained to represent the entire seam thickness are sufficient to determine the characteristics of the coal at each site, but more than one site must be prepared to describe the seam qualities over a large area. A large area in this region could be described as encompassing 1 to 2 square miles.

Samples ranging in the order of one to three tons are required to conduct tests calculated to determine washing and carbonization characteristics of a coal seam. Coking qualities of the coal are determined by the Metals Reduction and Energy Centre, Department of Energy, Mines and Resources in Ottawa. These tests are conducted in 12-inch or 18-inch scale ovens on unoxidized coal cleaned to the ash and moisture level of the probable product from each seam. The probable market product is determined by studying the washing characteristics of each size fraction screened from the "run of mine" coal. One key to success lies in defining the size consist of the mined product, which will be a function of the mining method. So far no clearcut method of determining the percentage of coal in each size interval has been discovered; therefore, at the exploration stage samples are often crushed to produce size percentages normal to nearby mines.

Drilling

Drilling is the third method of exploring beneath the surface and beyond the outcrop. There are various methods or types of drilling available, including rotary, reverse circulation, and diamond drilling. The relative merits of each constitute the basis for heated and continuing discussion. The most important factors limiting the success of an initial drilling program are the percentage and quality of sample recovered, the number of structural questions answered, and the total amount of drilling completed within budgeted costs.

Rotary Drilling

Rotary drills are not commonly employed during the initial stages of exploration. Although cost per foot for this type of drilling is less than other methods, the problems inherent in coal sampling, both from a quantity and a quality viewpoint, limit usefulness. The sample carried to the surface in the annulus between drill pipe and the wall tends to mix with chips of wall rock or tends to be lost in formational fractures. Further problems such as wind, ground and water loss arise in trying to control the sample when it reaches surface. There is a definite application for this type of drilling later in the program when closely spaced drilling is employed to define subsurface structures. Rotary drilling can produce a core but at greater cost and usually with limited success in rock and complete failure in coal (Fig. 3).

Reverse circulation drilling is a relatively new technique, employing dual-wall pipe (Fig. 4). The drilling medium, usually air, is forced down the annulus between the inner and the outer pipes and over the drill bit before returning to surface up the centre. The distance between the bit sub and the cutting edges of the bit is approximately 4 inches, which is the limit of exposure of the sample to contamina-

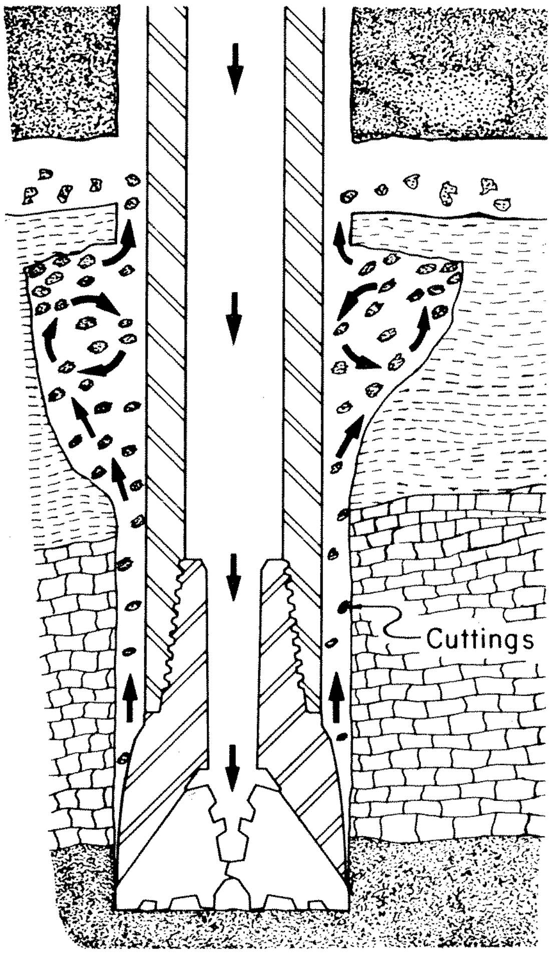


FIGURE 3. Conventional rotary drilling system: rock cuttings carried to surface between drill pipe and borehole wall.

tion. The outer diameter of the drill pipe is usually 4 5/8 inches and the drill bit is 4 7/8 inches, allowing 1/8-inch clearance between the outside of the pipe and the wall of the hole. The bit commonly employed is a tricone which produces rock or coal chips 1/4 inch in maximum size. Coal cuttings show a high percentage of minus 28 mesh, which constitutes 50 per cent or more of the sample. By changing to a diamond coring bit the drill is capable of recovering a continuous core in 5-inch lengths from the harder rock horizons but not from the soft rock or coal horizons (Fig. 5). Cores are 2 1/8 inches in diameter and return along with all of the rock cuttings up the centre of the pipe.

Rotary dual-wall drilling costs are a function of formation hardness. A high percentage of coarse sandstone and conglomerate units in a formation will slow drilling but will not reduce effectiveness of the method. Greatest success using reverse circulation lies in drilling soft formations and thick soft coal seams. Winter drilling is no more expensive than summer drilling since the unit is a self-contained airdrill with no mud or water-freezing problems. Broken formations which cause lost circulation for other drilling methods usually pose few problems since the method resembles drilling a cased hole, which isolates problem areas.

Rock and coal chip samples are recovered by means of a cyclone at the surface. A small percentage of the rock is saved for each 5-foot interval, whereas an attempt is made to collect the entire thickness of coal. Rock chips are

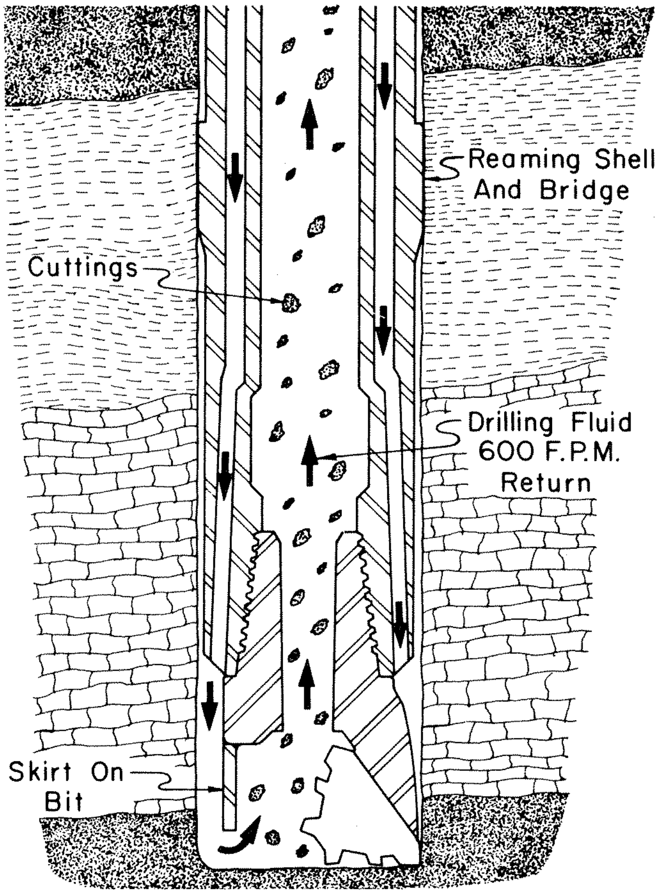


FIGURE 4. Reverse circulation drilling system: rock cuttings carried to surface through drill pipe.

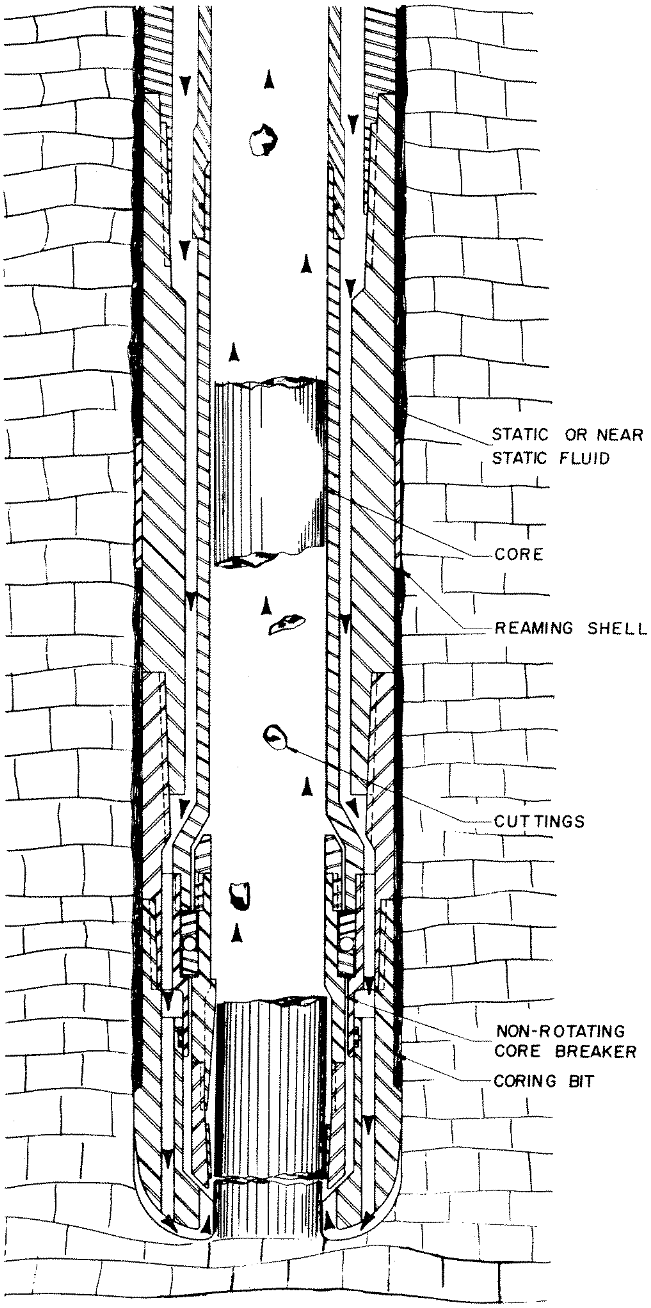


FIGURE 5. Continuous coring system.

collected at the base of a splitter designed to take 1/256th of the total rock sample returned to the surface. This sample therefore represents the entire 5-foot interval. In the absence of formation water, the coal is collected in sample bags as it leaves the cyclone in predetermined footage increments. When the drill hole is producing water, coal samples are run onto a filter table, where coal is retained on filter paper. Previously the practice with wet samples has been to collect water and sample in barrels, and after a settling period of time the water was decanted. This method permitted the loss of greater volumes of light fraction coal than heavy high ash coal, since in the time allowed the heavier fraction would settle first. There are still losses associated with the filter table, although these are of a random nature based entirely on size and not specific gravity. The result of one sample of table underflow shows a loss of approximately 0.07 pounds per gallon, although this rate would rapidly decrease as a filter cake built up on the cloth.

Diamond Drilling

Diamond drilling companies specializing in core drilling produce cylindrical samples of both rock and coal. Core recovery is a function of formation hardness and strength with continuous core sections being obtained in competent units such as sandstone, whereas broken or crushed cores are commonly produced in coal seams. Core yield, often a lineal measure of sample generated, ignores irregular core surfaces and missing soft coal partings. The missing coal fraction, although small by weight, will represent a sizeable volume of coal important in later testing.

The forte of core drilling lies in structural and stratigraphical interpretation of coal field geology. Visual identification of marker beds, bedding dips, possible faults and overturned strata permits clarification of complicated Rocky Mountain geology. Estimations for true seam thickness resulting from bedding angle measurement may produce more realistic reserve figures, although closely spaced drilling required in the mountains provides better average dip corrections.

Drill Samples

Coal samples obtained by drilling methods rarely, if ever, represent 100 per cent of coal in place. Although sample losses may be small, the missing fraction will be the light and friable coal important to all testing, especially carbonization. As little as 5 per cent loss effectively reduces the authenticity of test results, since the loss represents part of the fines fraction in wash testing and part of the actives in coke testing. Sample testing is discussed in terms of sample type.

Washability Tests

Washability studies conducted on drill samples can be used only to augment tests on bulk samples. Poor sample recoveries and unrepresentative size consists are two factors which reduce the effectiveness of this technique. Reverse circulation coal with a size range of 1/4 inch x 0 will give an unrealistic picture since ash is released with increased crushing. Coal cores might be crushed to a predesignated size consist, but the larger fractions over 1 inch will be missing. The size range in the order of 1 inch x 0 would give helpful indications of coal far from the outcrop.

Carbonization

The light friable coal lost in drilling represents a coal fraction important to coke production; however, it is possible to assume that, although results obtained will be different than actual seam quality, these results will be conservative rather than optimistic. Placing coal in a furnace and studying the coke produced is the ultimate analysis of a metallurgical coal. Samples ranging upwards in size from a minimum of 50 pounds are required for tests conducted by the Metals Reduction and Energy Centre, Ottawa, in a 30-pound coke oven. A reasonable correlation has been established between results obtained from 30-pound tests and full scale tests, although a greater percentage of breeze is generated in the small oven. Coal representing the unoxidized seam must be cleaned to a future product ash level before testing. The sample size consist is not important since tests are conducted on minus 1/8-inch coal. Reverse circulation drilling, which generates approximately 3 1/2 times as much sample from a 4 7/8-inch diameter hole as HQ wireline drilling produces in a 2 1/2-inch core, will often supply the required coal, especially from thin 10- to 12-foot seams.

Geophysical Logging

Regardless of drilling method employed, all exploration boreholes should be logged with downhole geophysical tools. Logs produced by an uninterrupted process furnish an objective picture of the strata present. Costs involved are a fraction of the original drilling investment and provide an unbiased interpretation of lithological succession and thickness. Continuous stratigraphic units are often correlatable between drill holes since these units appear on successive logs as diagnostic marker beds. Coal seams with distinctive shale partings, groups of thin coal seams, radioactive ash layers, and prominent sandstone or shale horizons are usual key beds identified on logs even when visible markers are absent in drill cores and surface exposures.

Table 1. A Comparison of Coal Sample Weights[1]

Sample Type	HQ Core	Reverse Circulation
Sample Diameter	2 1/2 ins	4 7/8 ins
Coal weight at 1.45 sg for 1 ft of drill hole	3.1 lbs	11.7 lbs

[1] Assuming 100 per cent recovery and based on 8 per cent ash coal at a specific gravity of 1.35

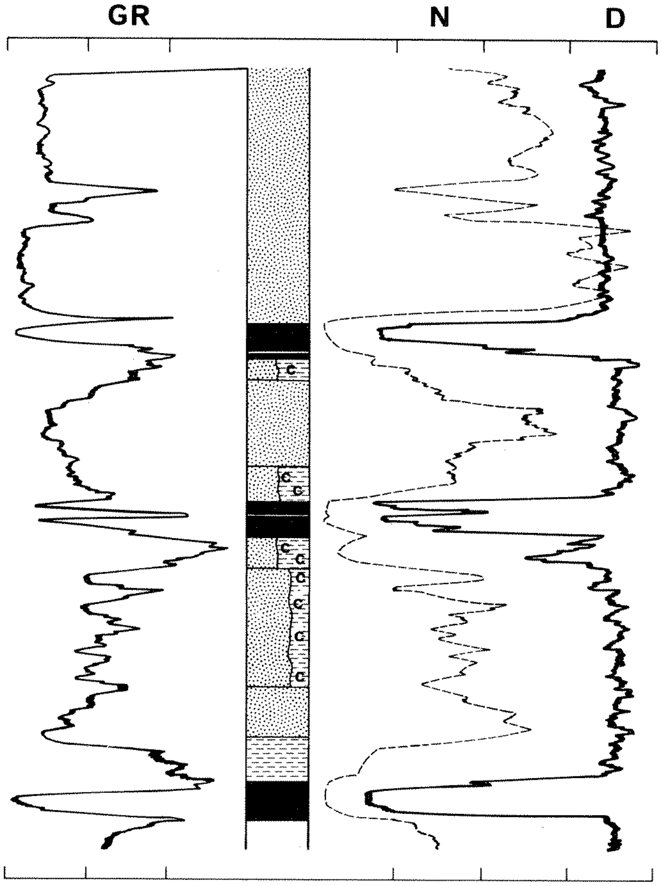


FIGURE 6. Relationship of gamma ray (GR), neutron (N), and density (D) logs. A lithologic log is printed in the center column.

Logs best suited to coal geology include gamma ray, neutron, and density logs. The usual arrangement of these logs in the oil industry, with gamma ray and neutron logs on one sheet and the density log on a second sheet, is improved by producing all three logs on one form: gamma ray on the left and density on the right, with neutron

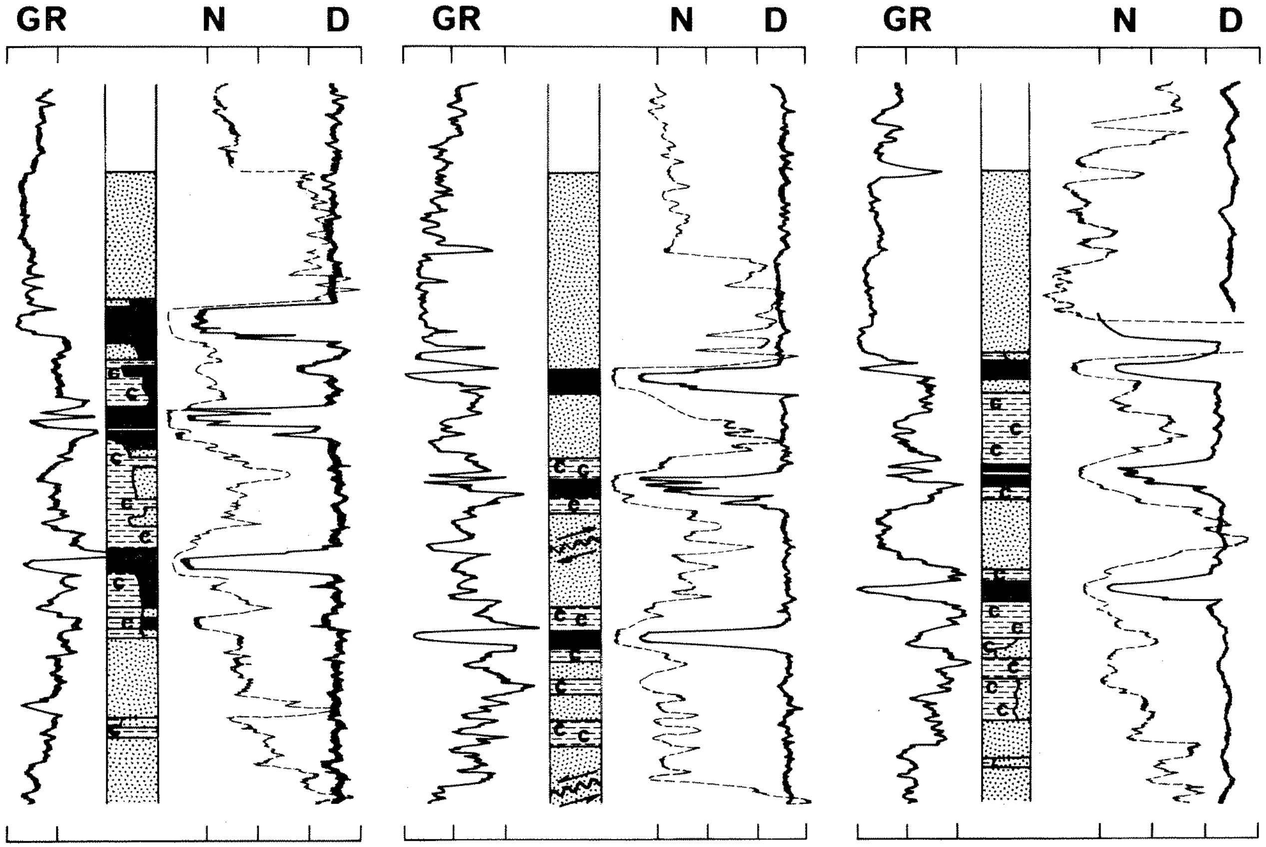


FIGURE 7. Correlation by geophysical logging. Key bed, shown in black, is a thin radioactive horizon. Although the logs are from drill holes 4,000 feet apart, definite similarities are obvious.

superimposed as a dotted line also on the right. Other logs are available but they require fluid, such as water or mud, which, if present, may not continue right to surface (Fig. 6).

Correlation charts are formed by aligning adjacent drill logs on one common distinct or key bed. These charts compiled by arranging logs in order from one side of a drilling area to the other will show definite facies changes and repeat or missing strata sections. Lithology strips furnished by studying either cores or chip samples act as a check on log interpretation but do not introduce subjective evaluations (Fig. 7).

Density Detail Logs

Density detail logs are recorded on an expanded scale of 1 inch = 2 feet over the coal seams, including 20 feet of roof rock and 10 feet of floor. Detail logging tools incorporate a close spacing between source and recorder. Enlarging the scale permits identification of bed boundaries, relative coal ash content, and major rock partings. A graph of sample raw ash placed in juxtaposition shows the relationship between density and ash content. Estimates of ash carefully computed from the log differ slightly from the actual samples (Fig. 8).

CONCLUSIONS

A brief description of the Upper Elk coal field has been employed as a basis for discussion of exploration techniques. The tools and ideas presented for this area are applicable throughout the Rocky Mountain coal belt through similarity of geological setting.

Exploration programs are designed to study coal quality and quantity as well as economic viability. This is accomplished by means of geological mapping, lithological

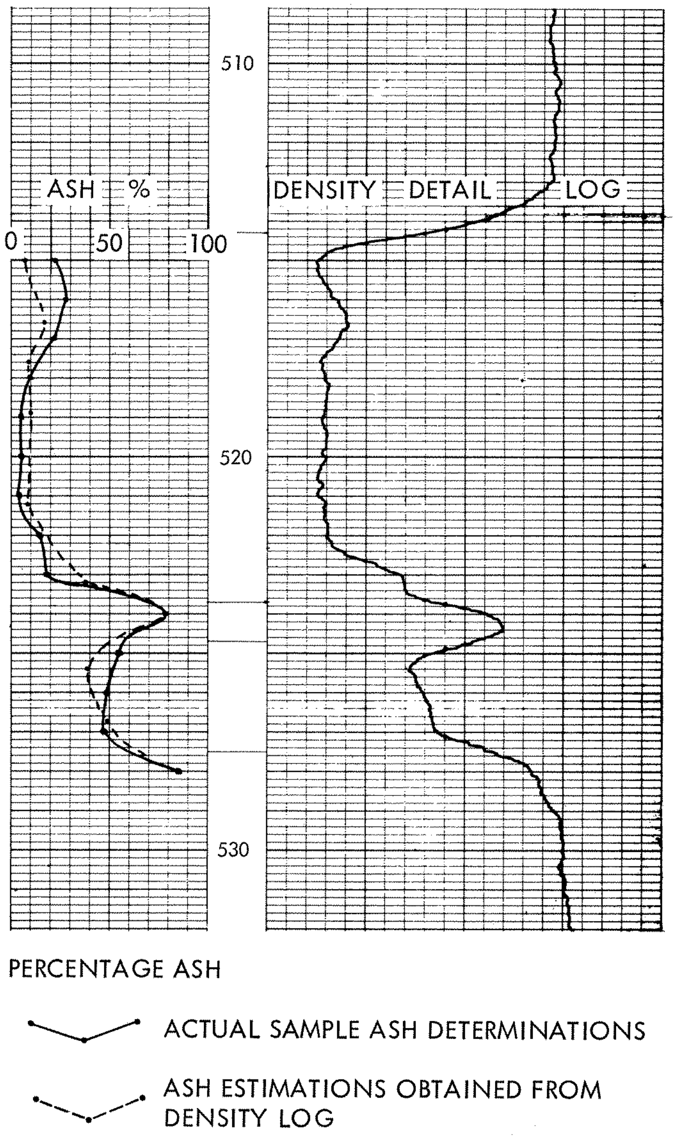


FIGURE 8. Relationship of ash percentage to density detail log.

correlation, and sample testing. The accurate plotting of geological information is essential to provide a reliable data base, and in this regard, air photo enlargements have proven very useful.

Stratigraphic correlation of complicated sections which lack obvious key horizons is accomplished by bulldozer seam tracing and geophysical logging. Tests performed on bulk samples from adits and test pits which prove best for preparation plant design and carbonization detail should be augmented with drill sample analysis. The reverse circulation drill furnishing large uncontaminated coal samples will possibly replace more conventional drilling for coal testing, although structural questions are not easily answered with chip sample studies alone.

The final step in all exploration programs must be the careful restoration of the land. This is a difficult task on the side of a mountain, but some attempt must be made to reconstruct drainage patterns, to remove dead vegetation, and to seed the newly exposed earth.

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PLATE 1

A. Fording River Syncline just north of Line Creek Ridge. Note the assymmetrical nature of the structure.

B. A tight anticline and syncline paralleling the Fording River Syncline which lies to the west. Folded structures such as this can be traced to faults along strike in many cases.

C. A thrust fault on the east side of the Upper Elk coal field has displaced and repeated the Moose Mountain Member.

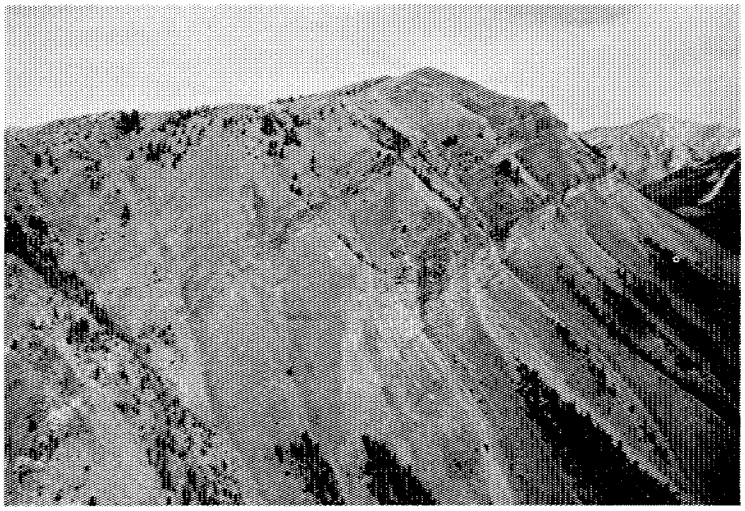
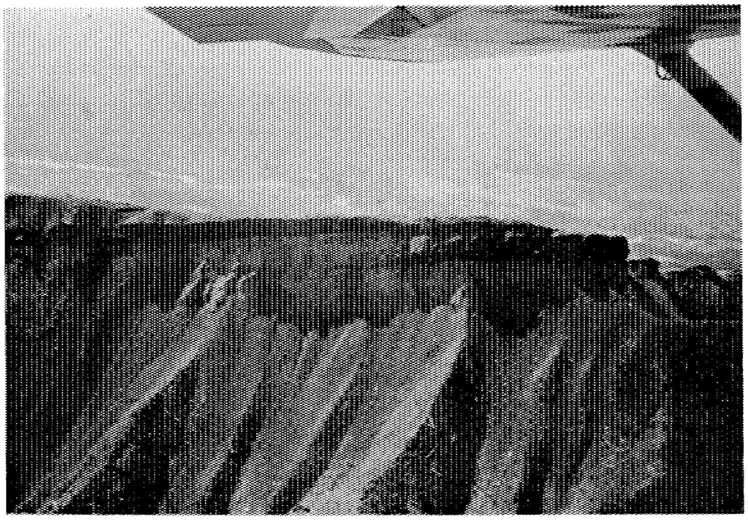
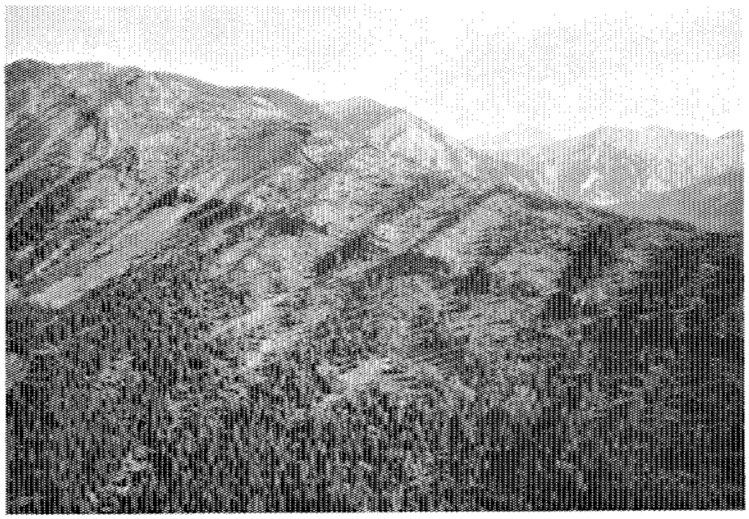


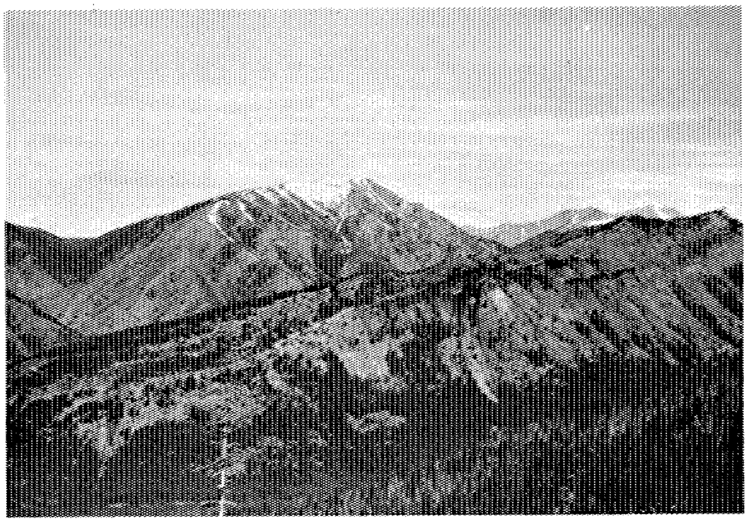
PLATE 2



A. A thrust fault repeats the Moose Mountain Member along the east side of Weary Ridge.



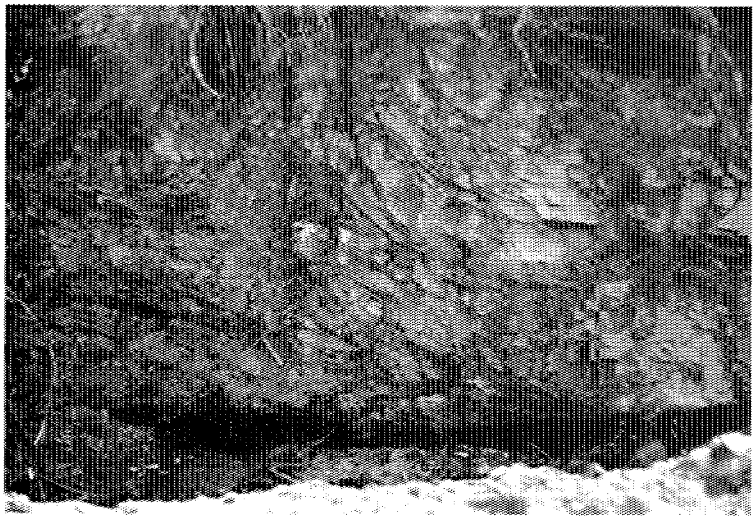
B. The prominent rock outcrop is the Moose Mountain Member. Note the sharp change in dip on the left side of the photograph.



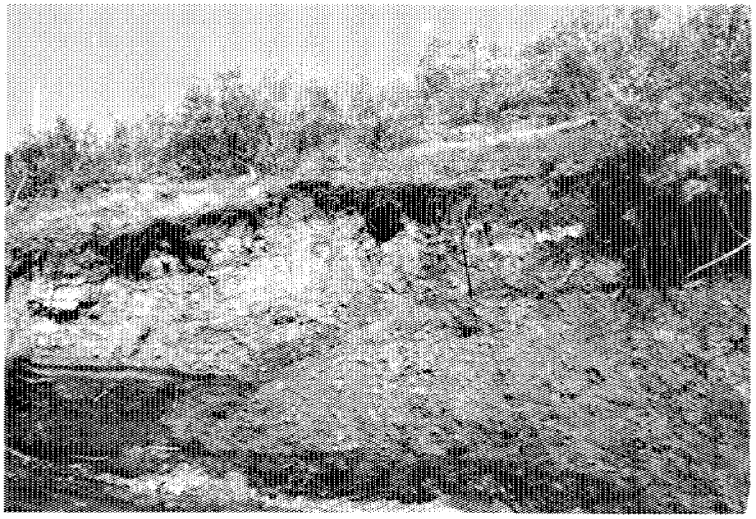
C. Bulldozers have been used to trace a coal seam along the face of this ridge, delimiting a thrust fault which has repeated the lowermost section of Kootenay Formation.

PLATE 3

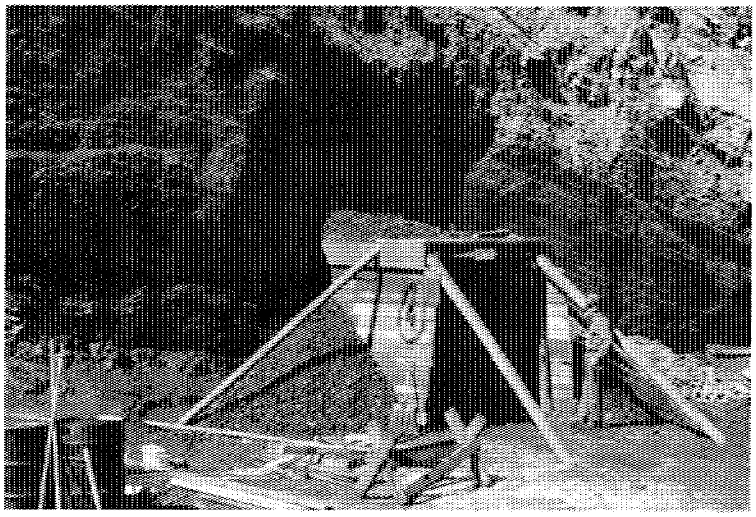
A. A minor tight anticline-syncline structure shows up in a bulldozer exposure of a coal seam roof. The structure poses a difficult roof support problem for underground mining.



B. A thrust fault in the roof of this coal seam has reduced the strata on the right to unconsolidated rubble.



C. Adit entrance with strong permanent construction which should allow access to the unoxidized coal for many years.



LIGNITE EXPLORATION IN THE RAVENSCRAG FORMATION OF SOUTHERN SASKATCHEWAN

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ABSTRACT

An exploration logic is developed for lignite in the nonmarine Ravenscrag Formation in southern Saskatchewan. The operational techniques employed by the Saskatchewan Research Council in lignite exploration are illustrated, with emphasis on drilling and geophysical logging techniques.

INTRODUCTION

Recent concern about national energy reserves has led to renewed interest in the lignite deposits of southern Saskatchewan. Very little information on coal seams is available outside the Estevan coal fields that is subject to objective evaluation because relatively few testholes in the Ravenscrag Formation have had any geophysical logs run in them. Most of the information available from coal exploration programs consists only of drillers' sample descriptions or geologists' descriptions of drill cutting samples, neither of which can be evaluated in any objective manner. However, current coal reserve estimates for the Ravenscrag Formation are placed at 12,013,900,000 tons, the bulk of these reserves being in the ***inferred*** and ***indicated*** categories (Latour and Chrismas, 1970). Greater accuracy of the reserve estimates, therefore, is very important if economic planning is to be based upon them.

In order to maximize information returns from lignite exploration programs, they should be designed with the geologic setting of the Ravenscrag in mind and the information gathered should minimize ambiguity, particularly concerning depth to top of seams, thickness of seam, and internal character of seam for each seam encountered. In addition, it is desirable to obtain information that aids seam correlation within the Ravenscrag Formation.

This paper outlines the geologic setting of the Ravenscrag Formation and presents exploration techniques that it is hoped maximize information returns and minimize information ambiguity.

GEOLOGIC SETTING

Most workers have placed the base of the Ravenscrag Formation at the base of the lowest economic coal seam encountered in outcrop. This technique is difficult to use throughout southern Saskatchewan because there are so few good outcrops of the basal portion of the Ravenscrag and because there is not always a seam present at a position equivalent to the position of the Ferris seam which is the basal seam in the type area of the Ravenscrag Formation. For this paper a more consistently recognizable marker has been taken that occurs about 200 feet below the position of the Ferris seam. This marker is the top of the Bearpaw Formation which is a distinctive marine clay that is readily recognizable on geophysical logs.

Figure 1A shows the structure on the top of the Bearpaw Formation; figure 1B is a structural cross section with known positions of seams shown at several points either from outcrop or from testholes on file with the Saskatchewan Department of Mineral Resources. Figure 1C shows the thickness of sediment down to the top of the Bearpaw Formation.

Several things are apparent following careful study of figure 1.

(1) Lignite occurs throughout the entire thickness of the Ravenscrag Formation but there appear to be concentrations in an upper zone at Estevan and a zone near the base farther west.

(2) One or another seam interval is within 200 feet of the ground surface throughout almost the entire area.

(3) In most of the area a stratigraphic interval of over 100 feet is present at the bedrock surface.

(4) There are several areas where structural complications must be considered in exploration programs.

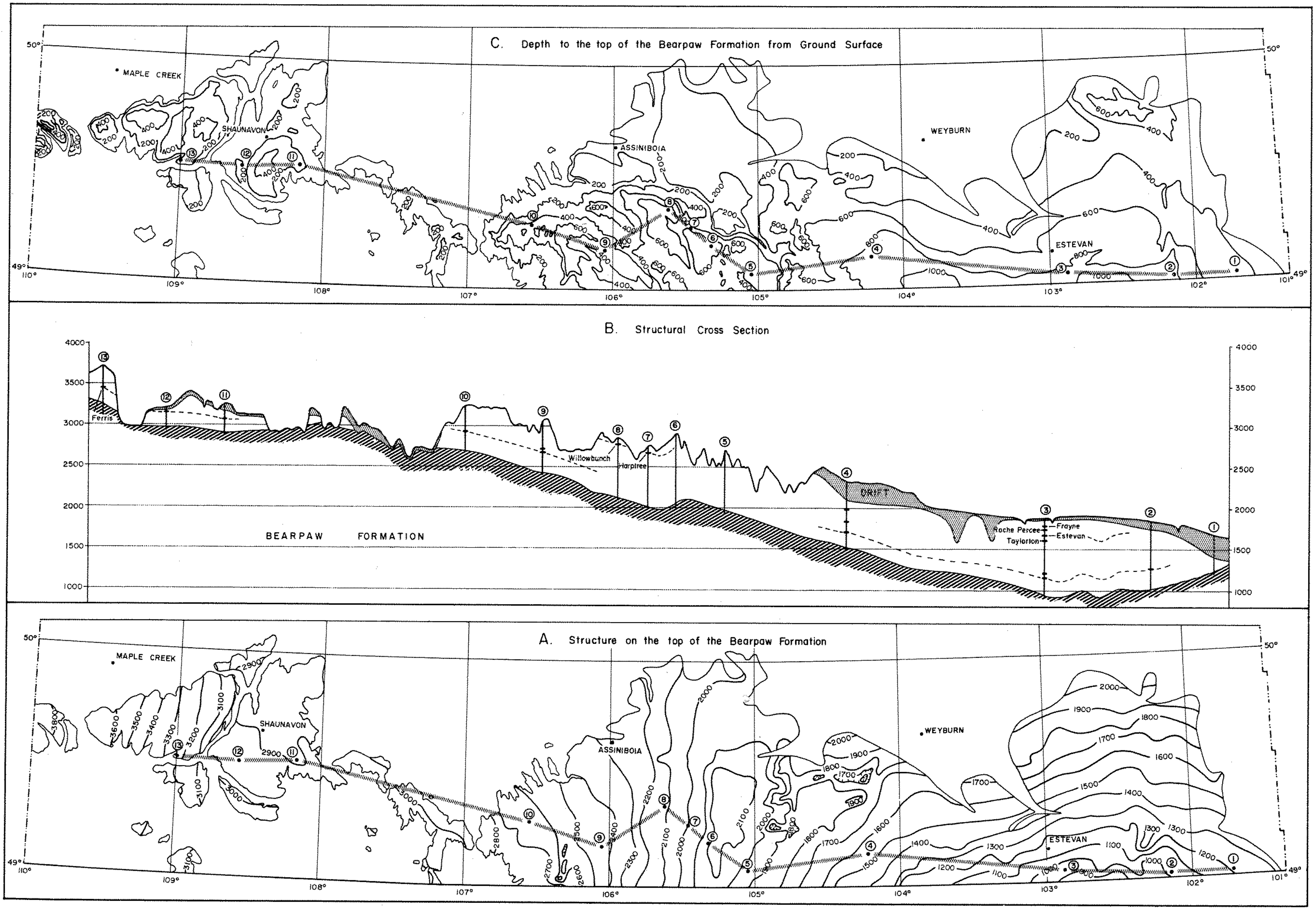


FIGURE 1. Structure on, and depth to, the top of the Bearpaw Formation.

In addition, it appears that the Willowbunch seam, Harptree seam, and Taylorton seam are all at about the same position above the top of the Bearpaw Formation. Although they are connected by a dashed line on figure 1B, it is not known if they are, in fact, correlative with one another.

EXPLORATION LOGIC

The preceding discussion has several implications for exploration programs in the Ravenscrag Formation. The structural complexities that are present require that enough of a regional geologic framework be established that marker beds can be identified within local areas so that individual testholes can be drilled to designated markers. Otherwise, if no coal is encountered at a depth where it would be expected, it is not known whether it is structurally displaced, or was not deposited, or was eroded subsequent to deposition. Establishing a regional framework requires that a certain number of testholes be drilled to depths much greater than is normally considered in lignite exploration; indeed, in this case it requires some holes drilled through the entire thickness of the Ravenscrag Formation.

Once markers have been identified, testholes can be terminated when a marker is encountered. In general, depths can be anticipated with considerable accuracy on the basis of the structural map and the regional drilling. When the setting of a local area containing an economic seam has been established, close-spaced drilling to delineate the seam need not penetrate deeper markers unless there are two or more seams present which are not readily distinguishable.

Following delineation of a particular seam by close-spaced drilling, it may be desirable to take continuous core of the seam at several locations for analytical work, such as proximate analyses. If seam quality appears to be highly variable, proximate analyses can be run on drill cutting samples from the close-spaced drilling.

FIELD TECHNIQUES

The objective of data gathering programs is to obtain a large quantity of high quality information in a short period of time for a small expenditure. Obviously there are "trade-offs" that must be made among these objectives. In the case of lignite exploration, optimization involves decreasing ambiguity in the following categories of information for as small an increase in cost as possible:

(1) depth to lignite seam from ground surface

(2) thickness of lignite seam

(3) presence and thickness of partings

(4) quality of lignite.

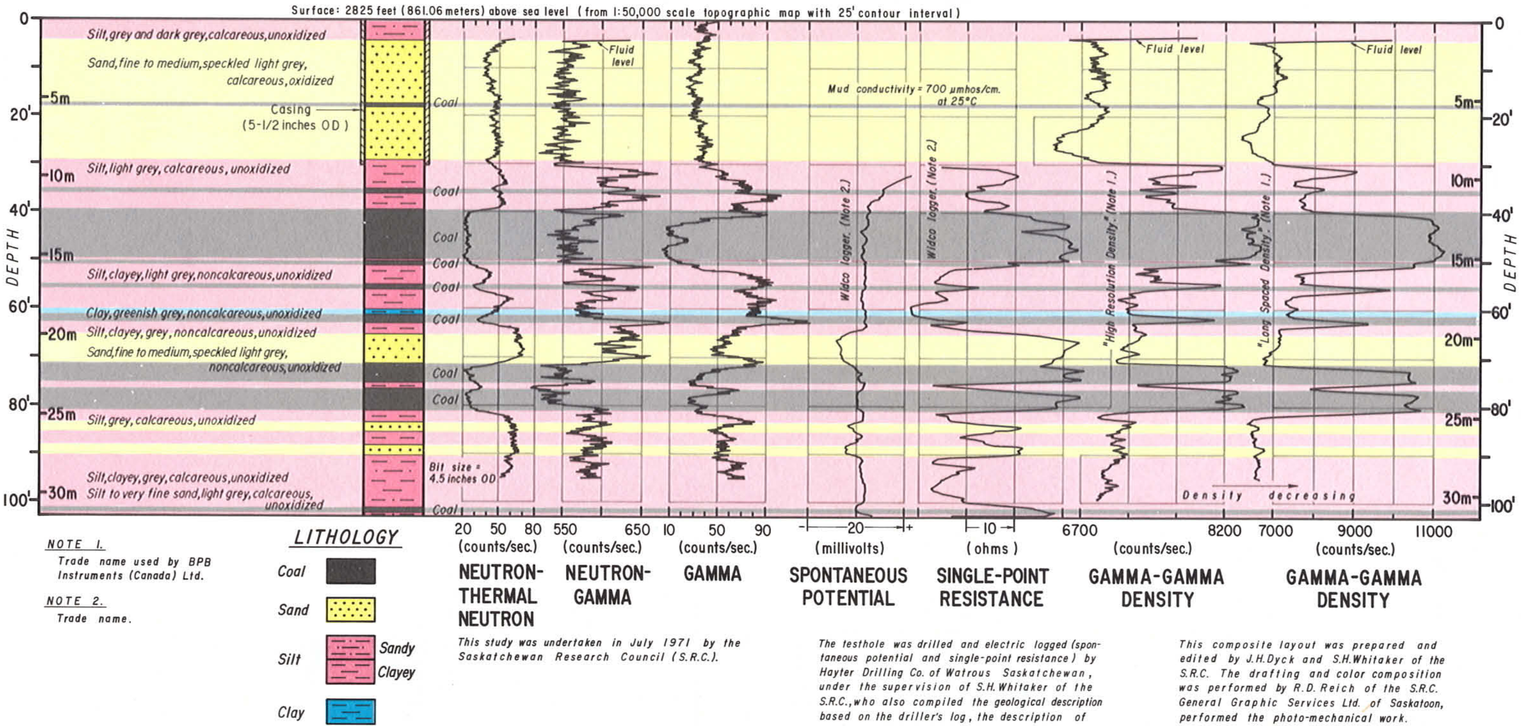
There are many sources of ambiguity in drilling programs which will be discussed in a very general way. Fortunately, it is possible to objectively limit ambiguity by using certain tools and techniques in the exploration program, and the tools and techniques used in the drilling programs of the Saskatchewan Research Council will be outlined below.

Ambiguities occur and may not be resolvable when information must be accepted on faith without an independent means of checking the validity of the information. In a drilling program the driller prepares a log of materials penetrated and depths of contacts between materials. Immediately, one can ask whether the material is accurately identified and whether the depths are correct. Continuous coring is the only technique capable of providing unambiguous information on the material and depth. However, it is only unambiguous if recovery is very close to 100 per cent, and even then one must have faith in the geologist's description, which, no matter how detailed, does not give a very useful characterization of the materials for the purpose of stratigraphic correlation. In addition, continuous coring is an order of magnitude more expensive than normal hydraulic rotary drilling and is, therefore, not suitable for exploration programs. Ambiguity can be somewhat decreased if the geologist also describes the drill cuttings but this still requires faith on the part of any third person. The depth ambiguity can be decreased by installing a footage recorder, such as the "Geolograph," as an accounting tool, but this requires faith that the driller has used it carefully. The only remaining means of decreasing ambiguity is to run geophysical logs, which give a continuous measurement of parameters that are related to the materials encountered in the borehole. Careful selection of the logs that are run should provide an objective description of the materials in the borehole as well as the depth at which they occur. Comparison of the logs with the subjective information of the driller and the geologist should provide quite an accurate record of materials penetrated, and, because the logs are continuous traces, they have a visual character that is very useful for stratigraphic correlation.

The following field procedures are used by the Saskatchewan Research Council to minimize information

QUANTOCK B TESTHOLE, SW. 4-26-2-1-W.3, SASKATCHEWAN, CANADA

A SET OF SEVEN GEOPHYSICAL LOGS



NOTE 1.
Trade name used by BPB Instruments (Canada) Ltd.

NOTE 2.
Trade name.

This study was undertaken in July 1971 by the Saskatchewan Research Council (S.R.C.).

The testhole was drilled and electric logged (spontaneous potential and single-point resistance) by Hayter Drilling Co. of Watrous Saskatchewan, under the supervision of S.H. Whitaker of the S.R.C., who also compiled the geological description based on the driller's log, the description of cutting samples and the electric log. The radiation logs were obtained under the supervision of J.H. Dyck and were recorded by BPB Instruments (Canada) Ltd. of Calgary, Alberta.

This composite layout was prepared and edited by J.H. Dyck and S.H. Whitaker of the S.R.C. The drafting and color composition was performed by R.D. Reich of the S.R.C. General Graphic Services Ltd. of Saskatoon, performed the photo-mechanical work.

FIGURE 2. Geophysical logs in a lignite testhole near Rockglen, Saskatchewan

ambiguity. All test drilling is carried out by the hydraulic rotary method using procedures similar to those in the petroleum industry (Moore, 1966). The driller collects samples from the drilling fluid and places representative samples from each 10-foot interval in trays for the geologist. He makes a continuous written record of material penetrated based on the drilling and examination of the cuttings with footage control provided by a "Geolograph" drilling rate recorder. The geologist selects samples from the trays, dries them in an oven, and describes them immediately. Upon completion of drilling the driller measures the drilling fluid density, and the geologist measures the electrical conductivity of the drilling fluid and the drilling water before geophysical logs are run. The conductivities are used in the electric log interpretation. In Saskatchewan use of high conductance drilling water has an adverse effect on the spontaneous-potential and point-resistance logs; thus, drillers are required to use makeup water with a conductivity less than 1,500 mhos/cm at 25° C. Four geophysical logs are run in lignite exploration holes: spontaneous-potential, point-resistance, gamma, and gamma-gamma-density.

Figure 2 shows how several geophysical logs correlate with lithology in a testhole drilled in the Ravenscrag Formation. A detailed evaluation of geophysical logging techniques for lignite exploration in the Ravenscrag Formation is currently being conducted under the supervision of J. H. Dyck of the Saskatchewan Research Council funded by the Mines Branch, Department of Energy, Mines and Resources and the Saskatchewan Department of Mineral Resources.

Inspection of figure 2 leads to several general conclusions.

(1) The gamma-gamma-density log delineates lignite seams better than any of the other logs run and is particularly good at defining bed boundaries and partings within seams. It is supposed to provide a measure of formation density, which is related to ash content in coals. Therefore, it should also provide information regarding variations in quality within a seam. Evaluation of this aspect of the gamma-gamma-density log is also underway for lignite in the Ravenscrag Formation.

(2) The gamma log is also useful in delineating lignite, but reversals may occur due to the presence of uranium in some of the lignites in the Ravenscrag Formation.

(3) The two types of neutron logs identify lignite, but neither do so as well as the gamma-gamma density.

(4) The spontaneous-potential and point-resistance logs taken together can be used to identify lignite but not as accurately as the radiation logs. However, they are better for identifying interbedded sand, silts, and clays.

Because lithologic information is desired for the purpose of stratigraphic correlation as well as identifying lignite, the four log-suite of spontaneous potential, point resistance, gamma, and gamma-gamma density is used by the Saskatchewan Research Council.

Total contractor cost for drilling and logging as described above can be kept below $2.00 per foot, so that a very high information return can be obtained at relatively low cost. A minimum average daily drilling rate of 500 feet also keeps supervisory and other overhead costs down.

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PETROGRAPHY OF KOOTENAY COALS IN THE UPPER ELK RIVER AND CROWSNEST AREAS, BRITISH COLUMBIA AND ALBERTA

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ABSTRACT

Thirty-nine whole-seam samples representing Kootenay coals were studied petrographically to determine patterns of component distribution. Coals were obtained from Kootenay sections at Fording River, Line Creek, Natal Ridge and Sparwood Ridge in British Columbia and from Grassy Mountain in Alberta. In addition, data were obtained on some of the seams in the Weary Ridge section in British Columbia.

Petrographic composition is expressed in terms of maceral content. The most important macerals occurring in these coals are vitrinite, semifusinite and fusinite. The data show wide variation in the content of these macerals in the seams examined with vitrinite content ranging from 35 to 94 per cent and combined semifusinite-fusinite varying from 2 to 41 per cent on the mineral-free basis. It is considered significant that these variations are not random but rather show a concentration of low vitrinite and high semifusinite-fusinite seams in the lower part of the section, while the upper part contains seams with increasing vitrinite content as one moves up the section. This is true without exception for the British Columbia sections. The three seams at Grassy Mountain all show relatively low vitrinite content and correspondingly high contents of semifusinite and fusinite.

Sedimentological and stratigraphic studies by other authors have suggested a deltaic framework for the deposition of the Kootenay Formation with the stratigraphically lower seams being formed on the lower delta plain and the higher seams in an upper delta environment. This would appear to explain the compositional pattern in the petrography of the Kootenay coals, for in the upper delta environment conditions would probably be better for the preservation of woody material and therefore its coalified equivalent, vitrinite.

INTRODUCTION

This paper presents petrographic information on coal seams exposed in four sections of the Upper Jurassic-Lower Cretaceous Kootenay Formation in the Upper Elk River-Crowsnest coal fields of British Columbia and one section from Grassy Mountain in Alberta. A total of thirty-nine channel samples were analyzed microscopically, each representing one seam. Not every seam in each section was examined, but in most sections a sufficient number of the mineable seams were studied to give a fair representation of the coals in the formation. The geology of the Kootenay Formation in the study areas has been described by MacKay (1934), Newmarch (1953), Crabb (1957), Norris (1959), Price (1962), Rapson (1964) and Jansa (1971).

To prepare the samples for microscopic analysis, a representative portion from each was crushed to minus 20 mesh. From this material grain mounts or pellets were made using a thermoplastic bonding medium. The specimens were then polished and examined microscopically with reflected light under oil immersion at a magnification of 600 times. A point count technique was used to obtain the raw data, which were then converted into volume percentages.

Acknowledgments

The procurement of samples and access to pertinent stratigraphic information would not have been possible without the cooperation and assistance of mining companies active in the study area. The author acknowledges such assistance from the following companies: Crows Nest Industries Ltd., Fording Coal Ltd., Kaiser Resources Ltd., Morrison-Knudsen Company Inc., and Scurry-Rainbow Oil Ltd.

The author also thanks personnel of the Metals Reduction and Energy Centre, Mines Branch in Ottawa, who provided some additional samples. To colleagues in the Coal Research Section, Geological Survey of Canada, the author expresses appreciation for various kinds of assistance. These include Messrs. J. R. Donaldson and T. F. Birmingham who assisted with the microscopy, Mr. C. Gange-Harris who assisted with drafting and photography, and last but not least Dr. P. A. Hacquebard, Head of Coal Research Section, who made numerous helpful suggestions during the study and who critically read the manuscript.

LOCATION

Figure 1 shows the geographic distribution of the Kootenay sections from which samples were studied. All of them are at sites which are either producing coal or are presently being explored. The sections occur in three structurally separated areas of Kootenay rocks. The Fording River and Line Creek sections occur in the Upper Elk River coal field and are separated from the Fernie Basin (Natal Ridge and

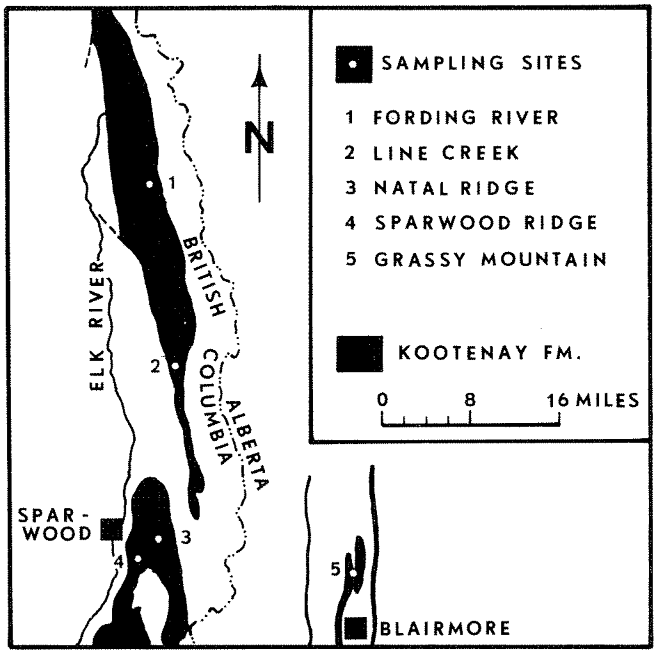

FIGURE 1. Location of Kootenay Formation sections.

Sparwood Ridge sections) by a north-trending fault zone which includes the Alexander and Erickson faults. The Grassy Mountain area is separated from the British Columbia sections by the Lewis thrust fault.

TERMINOLOGY

Coal may be looked upon as an organic rock composed of a mixture of basic constituents called macerals. Macerals are analagous to the minerals of inorganic rocks and can be used to describe quantitatively the petrographic composition of coals as was done in the present study. Discussion of the petrographic data for the Kootenay coals will show that seams can vary widely in the proportions of macerals which they contain.

Table 1 shows the macerals identified in the present study. There are three main groups; namely, vitrinite, exinite and inertinite. These are the groups suggested by the International Committee for Coal Petrology (1963). Each of these major group macerals can be divided into a number of constituents based on optical and morphological properties. Vitrinite is derived mainly from wood and bark, while exinite is composed of the coalified remains of spores, pollen, cuticles and resin. Inertinite is derived also mainly from wood and bark but differs from vitrinite in that it is relatively enriched in carbon due to conditions at the time of deposition. The varieties within the major constituents identified in the present study are indicated in table 1. Not all of these are as recommended by the International Committee; for example, the differentiation of vitrinite into "banded" and "matrix" is a method used in the present study to subdivide on a textural basis this important constituent of coal.

Inertinite is made up of a variety of constituents of which semifusinite and fusinite are the most important representatives in the Kootenay coals. Inertodetrinite is also fairly prominent in occurrence in many of the Kootenay seams. In part at least, it is composed of angular fragments and splinters of semifusinite and fusinite. Its occurrence in coal was described by Stach and Alpern in 1966. Most of the fragments identified in the present study ranged in size from 10 to 80 microns in their longest dimension.

Excluding exinite, the reflectance spectrum in most coals varies from a low of grey or white (depending on rank) in vitrinite to a high of bright yellow in fusinite. In the present study a breakdown of the inertinite macerals was made based on reflectance. Two varieties were identified for each of the inertinite macerals except micrinite and fusinite. One

Table 1. Maceral Types

VITRINITE	Banded Matrix
EXINITE	Resinite Sporinite Cutinite
INERTINITE	Semifusinite[1] Macrinite[1] Inertodetrinite[1] Fusinite Micrinite

[1] subdivided into high and low reflecting varieties

such variety, described as high reflecting, has reflectance trending toward that of fusinite. The second variety (low reflecting) has a more subdued reflectance and ranges down to that of the accompanying vitrinite. This breakdown is indicated in table 1.

Photomicrographs of the microscopic constituents, identified in the present study are shown in plates 1, 2 and 3.

PETROGRAPHIC COMPOSITIONS OF SEAMS WITHIN INDIVIDUAL SECTIONS

Sparwood Ridge and Natal Ridge Sections

Figure 2 shows the petrographic compositions of the seams examined from Sparwood Ridge and Natal Ridge. The data also are given in tables 2 and 3. From each of these two sections ten seams were examined, and the coverage was fairly uniform from top to bottom in the coal-bearing sequence. The petrographic composition for each seam studied is plotted in the form of a bar diagram, and these are arranged in proper stratigraphic order. The petrography in these sections, as in the others to follow, is expressed in volume per cent on a mineral-free basis. Individual bars represent vitrinite, total exinite, semifusinite and fusinite. The fifth bar represents the total of the inertinite macerals other than fusinite and semifusinite. The thickness of the Kootenay indicated is not its total thickness but represents only that part where the seams are thickest and in which exploration has been concentrated. In all cases the sections have been carried down to the basal sandstone.

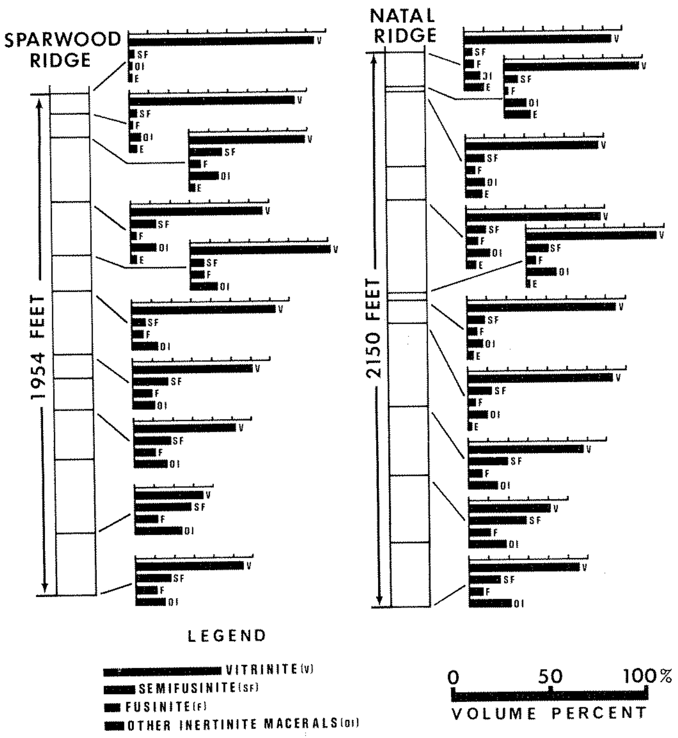

FIGURE 2. Petrographic compositions of coal seams, Natal Ridge and Sparwood Ridge, British Columbia.

In both the Sparwood Ridge and Natal Ridge sections a pronounced trend in petrographic composition is evident. The upper seams have the highest vitrinite contents and are lowest in the inertinite macerals. As one goes down section, vitrinite decreases and inertinite content increases. For example, in the Sparwood Ridge section the uppermost seam studied (D seam) has a vitrinite content of 94 per cent. In contrast, the second seam up from the base of the section (No. 9 seam) has a vitrinite content of only 35 per cent. The seams which are stratigraphically between seams 9 and D have maceral contents which vary between these two extremes. Corresponding to the decrease in vitrinite is an increase in the inertinite macerals in a downward direction. The Natal Ridge section shows a similar pattern.

Exinite was identified in the upper seams of both sections but disappears downward in the section. This is a rank effect. As the rank of coal increases, exinite becomes indistinguishable from vitrinite. This point comes at about 18 to 20 per cent volatile matter, but the ability to identify exinite with confidence is probably affected at around 25 per cent volatile matter. Hacquebard and Donaldson (in press) have shown that the Kootenay coals increase in rank in a regular manner from top to bottom in the section.

The Natal Ridge-Sparwood Ridge sections are close together (l to 2 miles apart across the Michel Creek valley), and the correlation of at least some of the seams has been fairly well established by normal stratigraphic methods. Therefore, this area presents a good opportunity to check on the value of petrographic composition for seam correlation when that composition is expressed on the whole seam basis. As an example, the basal seam in each section might be considered, namely the No. 10 seam. It has been well established that in this case the same seam is represented in each section, and, as figure 2 and table 2 show, the petrographic compositions for each sample are nearly identical. There is some variation in the inertinite content

Table 2. Petrographic Composition of Seams in Natal Ridge Section

	Vitrinite			Low Reflecting Inertinite				High Reflecting Inertinite							
Seam	Banded	Matrix	TOTAL	Semifusinite	Macrinite	Inertodetrinite	TOTAL	Semifusinite	Macrinite	Inertodetrinite	TOTAL	Fusinite	Micrinite	Exinite [1]	Stratigraphic Position [2]
D	30.0	44.0	74.0	1.6	1.2	1.0	3.8	2.4	2.0	1.4	5.8	4.6	2.2	9.6	2150
Upper C	28.6	39.8	68.4	1.0	1.0	1.6	3.6	5.6	1.8	4.4	11.8	1.4	2.2	12.6	2020
Lower C	32.4	34.4	66.8	1.4	0.8	2.8	5.0	8.2	1.8	3.2	13.2	5.4	1.2	8.4	2000
A	31.8	36.2	68.0	3.6	1.8	1.0	6.4	6.2	2.0	5.0	13.2	5.8	2.0	4.6	1586
3	41.4	25.0	66.4	4.2	3.2	4.2	11.6	7.0	1.4	4.4	12.8	4.6	3.0	1.6	1236
5	44.4	30.8	75.2	3.8	0.8	1.2	5.8	5.2	1.4	2.8	9.4	5.0	1.6	3.0	1211
6	43.6	29.4	73.0	3.6	2.4	0.4	6.4	8.0	3.0	2.8	13.8	3.8	1.4	1.6	1121
7	30.5	27.3	57.8	7.3	2.4	3.8	13.5	13.1	1.5	5.3	19.9	6.5	2.0	0.3	806
8	19.6	21.6	41.2	9.4	2.0	3.8	15.2	19.2	2.2	9.0	30.4	11.0	2.2	-	546
10	22.6	33.6	56.2	5.4	2.6	5.6	13.6	11.0	1.2	8.8	21.0	6.6	2.6	-	40

[1] Exinite includes resinite, sporinite, and cutinite

[2] Approximate distance in feet to top of basal Kootenay sandstone

but the vitrinite content in both samples is about 54 per cent. The amount of lateral variation in this seam from Natal Ridge to Sparwood Ridge apparently has not been great. On the other hand, if the two seams at the top of the sections are compared, then considerable lateral change is apparent. These seams, namely the D and Upper C seams, also are considered to be correlative. In the D seam there is a change in vitrinite content from about 94 per cent on Sparwood Ridge to about 74 per cent on Natal Ridge. The Upper C seam also shows a decrease in vitrinite in the same direction: from about 84 per cent on Sparwood Ridge to about 68 per cent on Natal Ridge. The Natal Ridge samples show increases in the inertinite constituents and also in exinite. In these two seams there is considerable change in the overall maceral composition, and this method of seam correlation is therefore not reliable. The nature of the petrographic change involved can only be determined if the vertical petrographic profile *within* each seam is studied. This profile is usually unique in some characteristic or other for every seam and is probably the most reliable petrographic approach for identifying and tracing a given seam.

Line Creek and Fording River Sections

In figure 3 the sections for Line Creek and Fording River are shown together with bar diagrams representing the petrographic compositions of the seams studied. These data are given also in tables 4 and 5. For Line Creek good sample coverage was obtained with ten seams examined from a stratigraphic interval of 1,026 feet. The pattern of variation from top to bottom in the section is the same as that shown by the Natal Ridge and Sparwood Ridge sections. The upper seams are high in vitrinite and low in the inertinite macerals; the reverse is true for the lower seams. Vitrinite content varies from a high of 83 per cent in the second seam from the top to a low of 44 per cent in the No. 9 seam (third up from the bottom). Some exinite was identified in the upper seams but not in the lower seams.

In the Fording River section samples were available from only six seams. Unfortunately it was not possible to obtain samples from the lowest seams in the section nor from the higher seams. Nevertheless the trend seen in the three sections discussed above still is apparent in the Fording

Table 3. Petrographic Composition of Seams in Sparwood Ridge Section

Seam	Vitrinite			Low Reflecting Inertinite				High Reflecting Inertinite							
	Banded	Matrix	TOTAL	Semifusinite	Macrinite	Inertodetrinite	TOTAL	Semifusinite	Macrinite	Inertodetrinite	TOTAL	Fusinite	Micrinite	Exinite [1]	Stratigraphic Position [2]
D	54.0	40.4	94.4	1.6	-	-	1.6	1.0	0.2	0.4	1.6	0.4	-	2.0	2000
Upper C	49.6	34.8	84.4	1.8	0.6	0.2	2.6	1.8	0.6	2.6	5.0	1.8	2.2	4.0	1930
Lower C	25.2	33.8	59.0	5.6	2.0	3.2	10.8	11.4	1.8	6.6	19.8	5.6	1.8	3.0	1865
B	36.0	31.4	67.4	4.0	1.6	1.4	7.0	9.2	2.4	5.4	17.0	3.4	2.0	3.2	1595
A	38.8	32.5	71.3	3.2	3.8	0.9	7.9	4.0	2.3	4.2	10.5	7.2	3.0	0.1	1390
1	40.8	32.2	73.0	4.0	2.8	2.6	9.4	3.0	1.0	4.4	8.4	6.4	1.8	1.0	1255
3	24.9	36.1	61.0	5.5	2.1	1.4	9.0	12.7	3.3	2.8	18.8	9.6	1.6	-	1005
7	25.5	26.8	52.3	8.5	3.4	3.1	15.0	10.8	4.2	4.4	19.4	10.9	2.1	0.3	800
9	12.9	22.2	35.1	10.8	4.9	3.3	19.0	18.3	6.3	6.0	30.6	12.3	2.9	0.1	280
10	21.5	33.8	55.3	6.3	4.0	1.1	11.4	11.7	3.9	3.9	19.5	11.4	2.4	-	95

[1] Exinite includes resinite, sporinite and cutinite

[2] Approximate distance in feet to top of basal Kootenay sandstone

River section; that is, the stratigraphically highest seams studied show the highest vitrinite content, while the lower seams show reduced vitrinite and higher inertinite. The range in vitrinite content is from 74 per cent in the highest seam studied (No. 12) to 50 per cent in the No. 5 seam (second bar diagram up from the base of the studied section).

Grassy Mountain Section

The Grassy Mountain section is interesting because the bar diagrams of all three seams studied are similar to those in the lower part of the Kootenay elsewhere (Fig. 3 and Table 6). The Kootenay section at Grassy Mountain is much thinner than the Kootenay sections to the west, and there would appear to be only three mineable seams (Norris, 1959). The vitrinite content in all three of the Grassy Mountain seams is low, the highest being 56 per cent in the uppermost seam studied. This would suggest that the Grassy Mountain seams are correlative with the basal seams in the sections located farther west, such as at Natal Ridge. This supports observations made by Hacquebard and Donaldson (in press) on the basis of their rank studies. However, it should be remembered that the original sites of deposition of the Grassy Mountain and Natal sections were possibly 70 to 80 miles apart (Norris, 1971), and that tectonic movements associated with the formation of the Rocky Mountains have brought them to their present positions of about 20 miles apart. Because coal seams do vary laterally, it would be desirable to have information on the petrography of the coals at intermediate points between Grassy Mountain and Natal Ridge. Unpublished information in the files of the Coal Research Section, Geological Survey of Canada, on coals from Coleman and Vicary Creek suggests that at least some of these coals are fairly low in vitrinite. However, Coleman originally was probably only 6 to 8 miles west of Grassy Mountain which still leaves a considerable gap. Also it should be pointed out that the British Columbia sections form a north-south line roughly parallel to the axis of deposition. Of the sections studied, Grassy Mountain is unique in relation to the B.C. sections in that it is across the axis of deposition, and lateral petrographic change in this direction is largely unexplored.

Table 4. Petrographic Composition of Seams in Fording River Section

Seam	Vitrinite			Low Reflecting Inertinite				High Reflecting Inertinite							
	Banded	Matrix	TOTAL	Semifusinite	Macrinite	Inertodetrinite	TOTAL	Semifusinite	Macrinite	Inertodetrinite	TOTAL	Fusinite	Micrinite	Exinite[1]	Stratigraphic Position[2]
12	39.1	35.2	74.3	2.9	2.6	0.6	6.1	3.1	2.4	2.9	8.4	8.4	1.3	1.5	1173
11	28.4	43.4	71.8	3.3	2.0	1.0	6.3	6.2	2.1	2.3	10.6	8.3	1.8	1.2	1052
9	26.3	32.4	58.7	3.2	2.4	2.7	8.3	8.8	3.0	5.8	17.6	12.4	2.0	1.0	844
7	38.6	17.0	55.6	3.3	0.9	1.5	5.7	5.8	4.3	9.2	19.3	16.8	2.6	-	731
5	29.2	21.2	50.4	2.2	2.2	-	4.4	7.6	6.5	10.9	25.0	16.4	3.2	0.6	489
4	27.0	35.3	62.3	0.8	1.6	2.0	4.4	4.3	5.5	9.1	18.9	12.4	2.0	-	208

[1] Exinite includes resinite, sporinite and cutinite

[2] Approximate distance in feet to top of basal Kootenay sandstone

Table 5. Petrographic Composition of Seams in Line Creek Section

Seam	Vitrinite			Low Reflecting Inertinite				High Reflecting Inertinite							
	Banded	Matrix	TOTAL	Semifusinite	Macrinite	Inertodetrinite	TOTAL	Semifusinite	Macrinite	Inertodetrinite	TOTAL	Fusinite	Micrinite	Exinite[3]	Stratigraphic Position[4]
Unnamed[1]	33.6	42.8	76.4	3.6	1.6	0.6	5.8	4.6	1.4	2.4	8.4	0.6	1.6	7.2	1026
Unnamed[2]	43.2	39.3	82.5	2.2	1.4	1.2	4.8	1.5	1.2	2.8	5.5	1.6	2.0	3.6	956
2	43.9	37.5	81.4	1.4	1.0	2.4	4.8	5.9	0.4	3.2	9.5	1.6	0.2	2.2	846
4	33.2	35.6	68.8	4.4	2.8	1.8	9.0	6.6	1.8	4.4	12.8	6.6	1.0	1.8	766
6	24.6	27.8	52.4	5.7	2.8	5.5	14.0	12.8	2.2	7.2	22.2	8.5	1.9	1.0	581
7	25.1	35.4	60.5	7.9	1.8	2.7	12.4	9.2	1.9	5.5	16.6	7.2	1.9	1.4	516
8	19.3	23.9	43.2	4.9	4.9	3.5	13.3	15.1	7.5	7.9	30.5	9.6	2.4	1.0	282
9	21.2	23.0	44.2	3.6	4.8	3.2	11.6	20.6	3.0	4.0	27.6	12.2	4.0	0.4	111
10B	23.4	35.6	59.0	5.8	2.0	3.6	11.4	11.6	1.6	6.6	19.8	7.0	2.8	-	36
10A	12.6	34.8	47.4	11.2	2.2	5.4	18.8	13.8	1.6	8.6	24.0	7.2	2.6	-	7

[1] Seam 150-170 feet above No. 2 seam

[2] Seam ± 75 feet above No. 2 seam

[3] Exinite includes resinite, sporinite and cutinite

[4] Approximate distance in feet to top of basal Kootenay sandstone

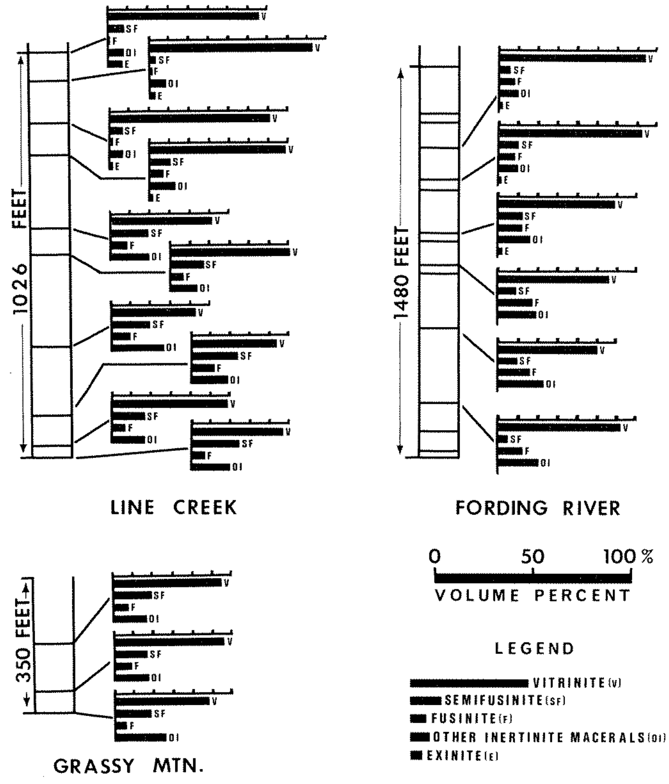

FIGURE 3. Petrographic compositions of coal seams at Line Creek, Fording River and Grassy Mountain, British Columbia and Alberta.

COMPARISON OF PETROGRAPHIC DATA

The most important macerals in the Kootenay coals are vitrinite and total semifusinite-fusinite. The salient features of compositional variation can be shown by examining the distribution patterns in these constituents. In figures 4 and 5 variation plots for these constituents are shown for all five of the sections examined. The length of the bar projecting to the right of each schematic section is proportional to the amount of the constituent present. These plots show clearly the common trend of a decrease in vitrinite accompanied by corresponding increases in the combined semifusinite-fusinite content as one goes down each section.

It may be noted that the lowest vitrinite and hence the highest inertinite contents are not found in the lowest seam of the section but rather in the second or third seam above the base. This is apparent in the Natal Ridge, Sparwood Ridge and Line Creek sections, which are the most complete. An abundance of inertinite represents depositional conditions where plant material in the early peat stage was subjected to accelerated physical and chemical degradation. If this mode of origin is applied to the Kootenay coals, then the most extreme conditions of degradation occurred shortly after deposition of the coal-bearing sequence had begun. Such an environmental marker in the Natal, Sparwood and Line Creek sections may be useful in correlating the two or three seams at the base of the section.

In order to summarize the data for all the samples, the compositions were plotted on a ternary diagram in which the axes are labelled vitrinite, inertinite of low reflectance, and inertinite of high reflectance. Fusinite and micrinite were included in high reflectance inertinite. This plot is shown as figure 6. Exinite, where present, has been added to vitrinite. In addition to the samples already described, petrographic data for eleven seams in a section on Weary Ridge have been included in the ternary plot. This section is located about 12 miles north of Fording River (Fig. 1). These eleven samples are fairly representative of the entire coal-bearing section on Weary Ridge. The trend of higher vitrinite in the stratigraphically higher seams and higher inertinite in the lower seams, which appeared in the sections previously described in this paper, also is apparent in the Weary Ridge Section.

Examination of figure 6 indicates that there are two main populations in terms of the compositional picture, and the break seems to be at about 65 per cent vitrinite (plus

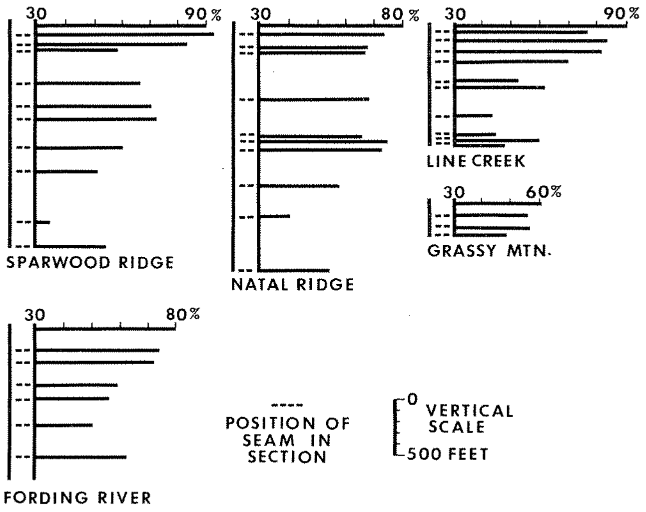

FIGURE 4. Distribution of vitrinite in Kootenay Formation coal seams.

Table 6. Petrographic Composition of Seams in Grassy Mountain Section

	Vitrinite			Low Reflecting Inertinite				High Reflecting Inertinite							
Seam	Banded	Matrix	TOTAL	Semifusinite	Macrinite	Inertodetrinite	TOTAL	Semifusinite	Macrinite	Inertodetrinite	TOTAL	Fusinite	Micrinite	Exinite[1]	Stratigraphic Position[2]
Seam at base of Mutz member	27.0	27.8	54.8	5.8	2.2	3.8	11.8	14.0	1.6	6.8	22.4	7.6	2.4	1.0	192
Seam at top of Adanac member	25.6	30.8	56.4	3.0	3.2	4.0	10.2	13.8	2.4	6.0	22.2	8.6	2.0	0.6	67
Seam at base of Adanac member	15.4	32.6	48.0	3.8	1.6	8.8	14.2	15.4	1.6	10.8	27.8	6.2	3.0	0.8	10

[1] Exinite includes resinite, sporinite and cutinite

[2] Approximate distance in feet to top of basal Kootenay sandstone

exinite). Inspection of the individual sections shows that virtually all the plus 65 per cent vitrinite seams are in the upper part of the sections, while those with less than 65 per cent vitrinite are in the lower part. It would appear also that the plus 65 per cent vitrinite group of samples can be divided into two subpopulations: one with a cluster of points around 75 per cent and another with a grouping of points between 80 and 90 per cent. The latter group represent the uppermost seams in the Line Creek, Natal Ridge, Sparwood Ridge and Weary Ridge sections. The Fording River section apparently has not been carried high enough to catch any of these very high vitrinite seams.

Hacquebard and Donaldson (in press) have shown that rank, as determined by reflectance, increases regularly from top to bottom in the Kootenay coal-bearing section, and is indeed an excellent example of Hilt's Law. On figure 6 the samples have been coded with respect to reflectance. The dots represent coals with reflectances above 1.20; the "Xs" represent reflectances below 1.20. Examination of the diagram suggests that higher rank is related to higher inertinite content because nearly all the dots are restricted to those samples with combined vitrinite-exinite contents below 65 per cent. This is a coincidence and is not based on a genetic relationship. The higher rank coals in the Kootenay are toward the base of the section and are higher

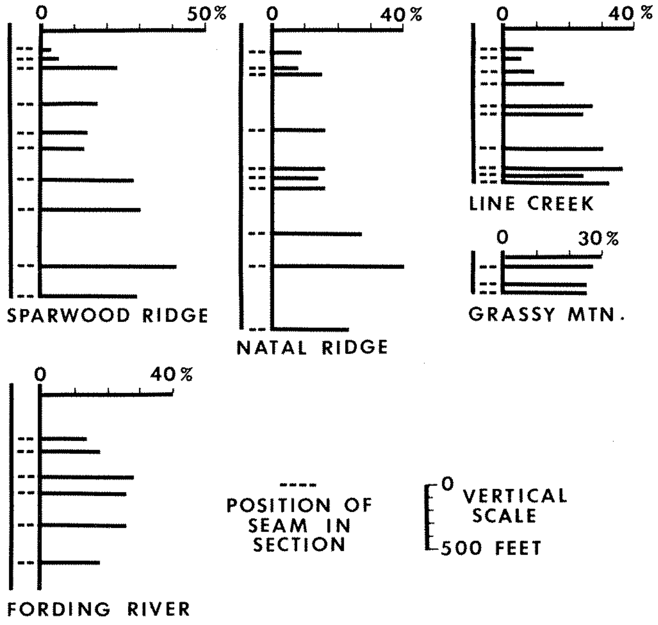

FIGURE 5. Distribution of semifusinite and fusinite in Kootenay Formation coal seams.

rank because of greater depth of burial. That these coals are also high in inertinite is accidental because the inertinite content results from a different cause; namely it is related to environmental conditions at the time of accumulation. If one looks at other thick coal-bearing sections with a relatively wide range in rank across the section, one finds either little difference in the petrography of the older seams as compared with the younger seams, or, indeed, one finds that the older seams of higher rank have higher vitrinite contents than the younger seams of lower rank. This is true for the Carboniferous sections of southern West Virginia and the Ruhr area of Germany.

ENVIRONMENTAL INTERPRETATIONS

Figure 7 is a panel diagram showing the position of the 65 per cent vitrinite content in the different sections from which samples were studied. This position has been plotted on the section halfway between the stratigraphically highest seam with a low vitrinite content and the stratigraphically lowest seam with a plus 65 per cent vitrinite content. The seam below which the 65 per cent threshold occurs is indicated in each section; for example, in the Sparwood Ridge section it is below the No. 1 seam, in the Natal Ridge section it is below the No. 6 seam, and so on. The 65 per cent threshold may be a time line, although for the moment it is best to regard it as a line separating different environmental conditions.

Excluding the Grassy Mountain section, the thickness of the low vitrinite zone (that is the zone with less than 65 per cent vitrinite) as measured from the basal sandstone upward varies from 580 feet at Line Creek to over 900 feet at Sparwood Ridge, Natal Ridge and Fording River. At Weary Ridge it is 700-750 feet. In a recent discussion of the Kootenay Formation, Jansa (1971) suggested that the coal-bearing part could be subdivided into two submembers the lower of which has a thickness of 600 feet in the Michel-Fernie area. It is interesting to compare these figures to see what equivalence exists between Jansa's lower submember and the low vitrinite zone. The latter appears to be thicker; however, Jansa indicated that the boundary between his submembers is subjective so that perhaps there is closer agreement than would appear at first glance. Also, if the threshold were drawn on the panel diagram (Fig. 7) at the top of the stratigraphically highest seam with a low vitrinite content, instead of halfway between it and the next highest seam, then the low vitrinite zone would be reduced in thickness by about 100 to 150 feet. At the moment one can say that the low vitrinite zone apparently

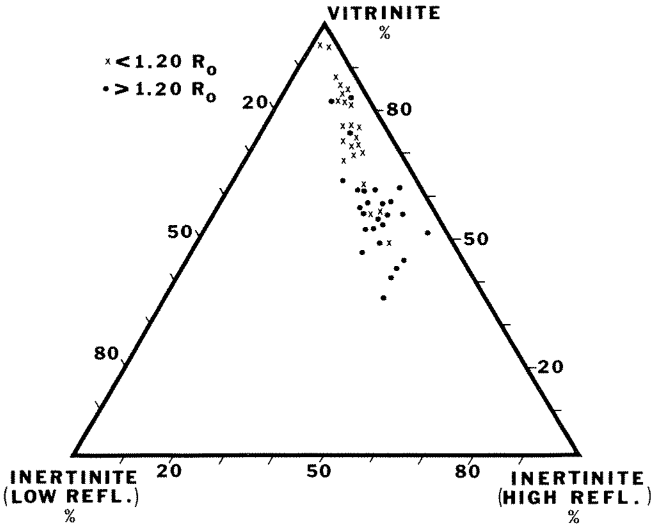

FIGURE 6. Ternary plot of petrographic compositions of all Kootenay Formation seams studied.

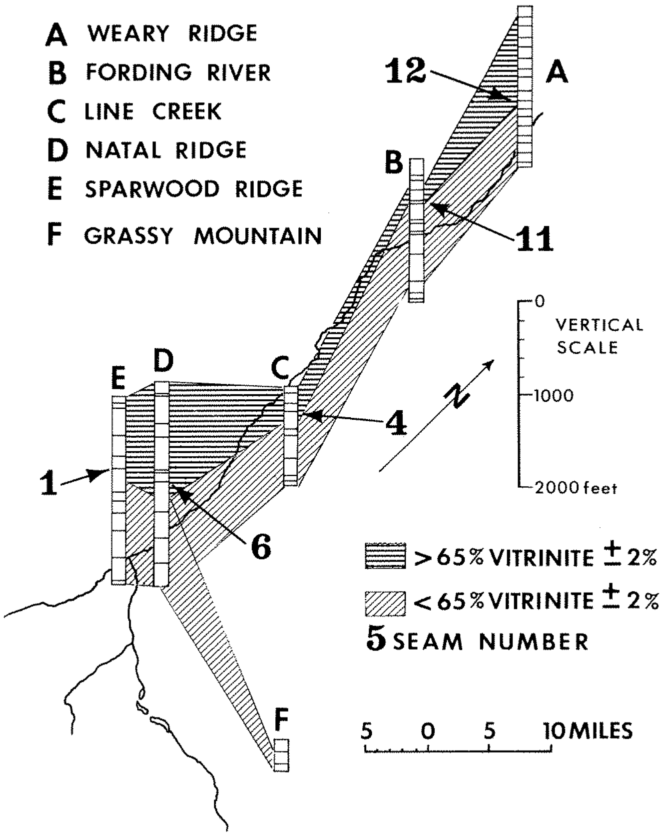

FIGURE 7. Panel diagram showing vertical distribution of seams with high and low vitrinite content.

encompasses all of Jansa's lower submember and possibly extends into the upper submember. Jansa suggested that the lower submember was laid down in a lower delta plain environment, while the upper unit was deposited in an upper delta plain environment, probably more distant from the shoreline. He suggested that in the latter environment more woody material might be preserved. This agrees with the higher vitrinite content in the upper seams of the Kootenay. By following Jansa's model, the high inertinite content of the lower seams must be related, therefore, to different depositional conditions and possibly a different plant community on the lower delta plain. Inertinite is considered to be the product of varying exposure to atmospheric oxygen during the peat stage and suggests that subsidence was not great enough to provide water cover for protection of the peat (MacKowsky, 1968). However this idea is at variance with the results of Jansa's sedimentological studies on the Kootenay Formation, for in his opinion such dessication effects are not consistent with the lower delta plain environment. It may be possible, however, for large amounts of inertinite to form in environments with a substantial water cover. Hacquebard and Donaldson (1969) described coals from the Pictou coal field in Nova Scotia which may have been formed in such an environment. These coals have large proportions of inertinite and, in the opinion of the authors, were formed under hypautochthonous conditions. This term refers to peat formed from vegetal debris subject to some movement within the basin of deposition (International Committee for Coal Petrology, 1963). It contrasts on the one hand with autochthonous, which refers to peats where there has been little or no movement of material. Allochthonous, on the other hand, refers to the deposition of plant material in areas other than those in which it grew. Hypautochthonous environments probably develop best where the swamp is more open, that is, where there is a lack of large trees, or at least a lack of uniform forest cover. Under such conditions there probably would be more free movement of water than in a stagnant forested bog.

The coals which Hacquebard and Donaldson described as hypautochthonous, are high in inertinite, lack well defined banding and are low in sulphur. The Kootenay coals, at least the lower seams, also lack well defined banding, are high in inertinite and the sulphur content is low. On the basis of structural and stratigraphic evidence Hacquebard and Donaldson felt that the coals of the Pictou field were laid down in an intermontane limnic basin. The general geological framework of the Kootenay Formation does not favour such an environment for the basal seams of the study area; yet the petrographic evidence suggests some variant of a hypautochthonous origin for these coals in contrast to the upper coals, which appear to have accumulated under more forested bog conditions.

In the effort to discover relationships between the petrographic characteristics of the coals and more general geological parameters, various combinations of maceral data were plotted against such items as average seam thickness, coal-clastic ratio and so forth. One of the most interesting relationships to appear is that between the sand-shale ratio for the individual sections and the inertodetrinite-total inertinite ratio for the coals of the given section. For the calculation of the sand-shale ratio only that part of the section containing the coals under study was used. The results are shown in figure 8. The Weary Ridge section is not included because sand-shale data were not available. Figure 8 indicates that a high sand content in the section is associated with a higher proportion of inertodetrinite in inertinite.

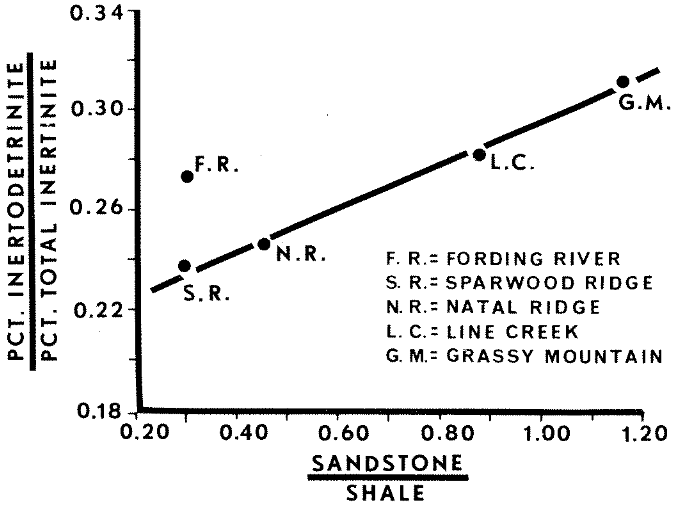

FIGURE 8. Relation of inertodetrinite content to sandstone-shale ratio.

Why inertodetrinite? The origin of this constituent has probably some bearing on the relationship. Inertodetrinite is a clastic entity probably formed to some extent from the splintering and fragmentation of semifusinite and fusinite. These constituents are formed in the peat stage and, in part, may be formed outside the actual basin of peat accumulation and then transported into the basin. One would expect that if they undergo much movement before final deposition, there is a greater chance of fragmentation and hence increased amounts of inertodetrinite. Therefore, in any given section, one might expect to get more inertodetrinite associated with relatively large amounts of sand and less in sections where shale is a more prominent clastic constituent, assuming that the shale-rich section represents more placid conditions of deposition. At least, this seems like a plausible explanation for the relationship shown by the relatively few points plotted on figure 8.

SUMMARY AND CONCLUSIONS

On the basis of their petrographic composition, the coals of the Kootenay Formation in southeastern British Columbia may be divided into two groups, those which are high in inertinite and those which are high in vitrinite. The former are concentrated in the lower part of the coal-bearing sequence, whereas the latter occur toward the top. This trend persists for a distance of about 46 miles from Natal Ridge to Weary Ridge, parallel to the axis of deposition of the Kootenay Formation. The only coals from Alberta examined for this study were from Grassy Mountain. These coals exhibit petrographic compositions similar to the lower Kootenay coals from British Columbia, that is, the inertinite content is high and vitrinite is low.

The petrographic changes in the coals from bottom to top in a given section undoubtedly are effects of the evolution through time of the deltaic system which produced the Kootenay Formation. According to Jansa (1971) the earliest coal-forming swamps were on the lower delta plain, while the upper ones were on the upper delta plain. The former may have been characterized by areas of open water and by plant communities in which large trees were not dominant elements. With time, the shoreline retreated farther east, and the swamp type also changed into a forested bog with stagnant water where the preservation of relatively unaltered peat was more probable, resulting eventually in the high vitrinite seams found today at the top of the coal-bearing section.

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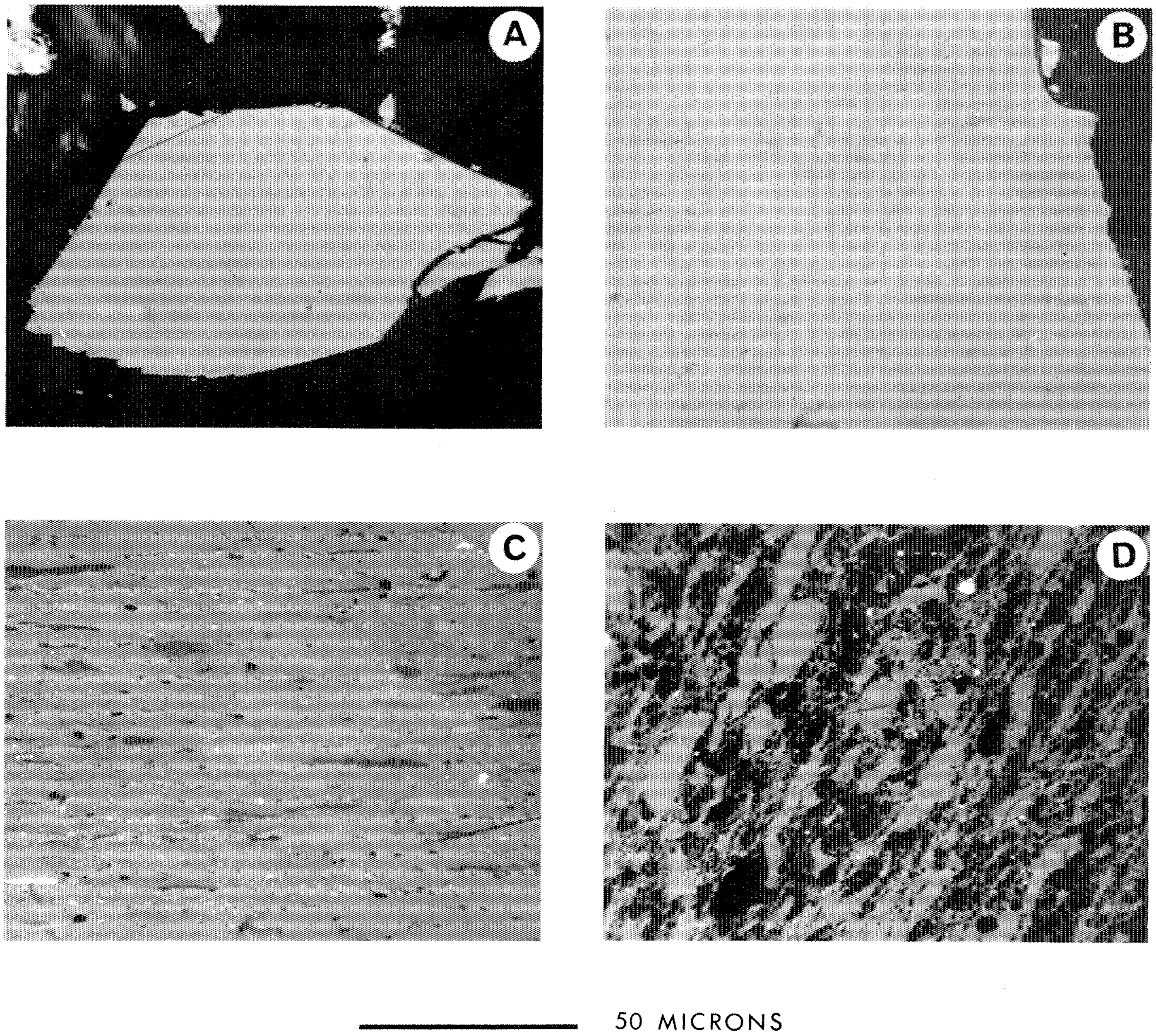

PLATE 1 - VITRINITE

A, B: examples of "banded" vitrinite. These are relatively large fragments composed entirely of vitrinite. Photograph A in particular is a good example of pseudovitrinite as described by Benedict et al. *(1968).*

C: "matrix" vitrinite (grey groundmass) associated with micrinite (small white granules) and exinite (dark grey elongate stringers).

D: vitrinite (grey material) intimately associated with mineral matter (black and dark grey areas).

All photographs taken with reflected light and oil immersion.

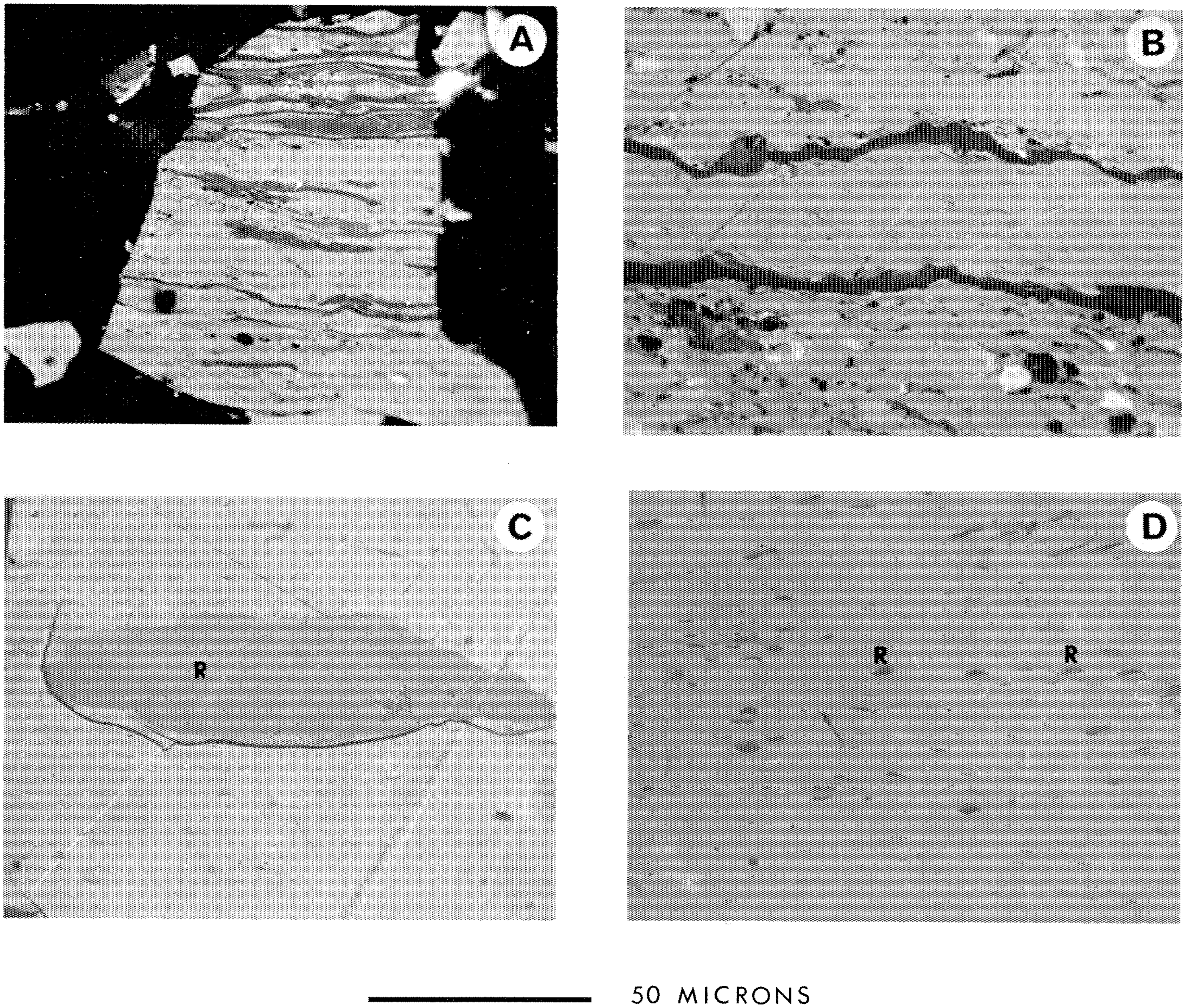

PLATE 2 - EXINITE

A: good example of exinite associated with vitrinite. The dark grey stringers are spore, pollen and possibly cuticle remains. This microscopic aspect of exinite is to be seen only in the uppermost Kootenay seams. With increasing rank the reflectance of exinite approaches and finally reaches that of vitrinite.

B: two dark strands dominating the central part of the photograph are examples of cutinite or coalified cuticle. Cutinite strands are often characterized by a serrate or saw-tooth edge. The reflectance of cutinite is essentially that of the associated sporinite.

C, D: examples of coalified resin or resinite. Photograph C shows a single large bleb (R) enclosed in a matrix of lighter coloured vitrinite. Photograph D, taken at the same magnification, shows much smaller masses of resinite (R) possibly filling remnant cell cavities.

All photographs taken with reflected light and oil immersion.

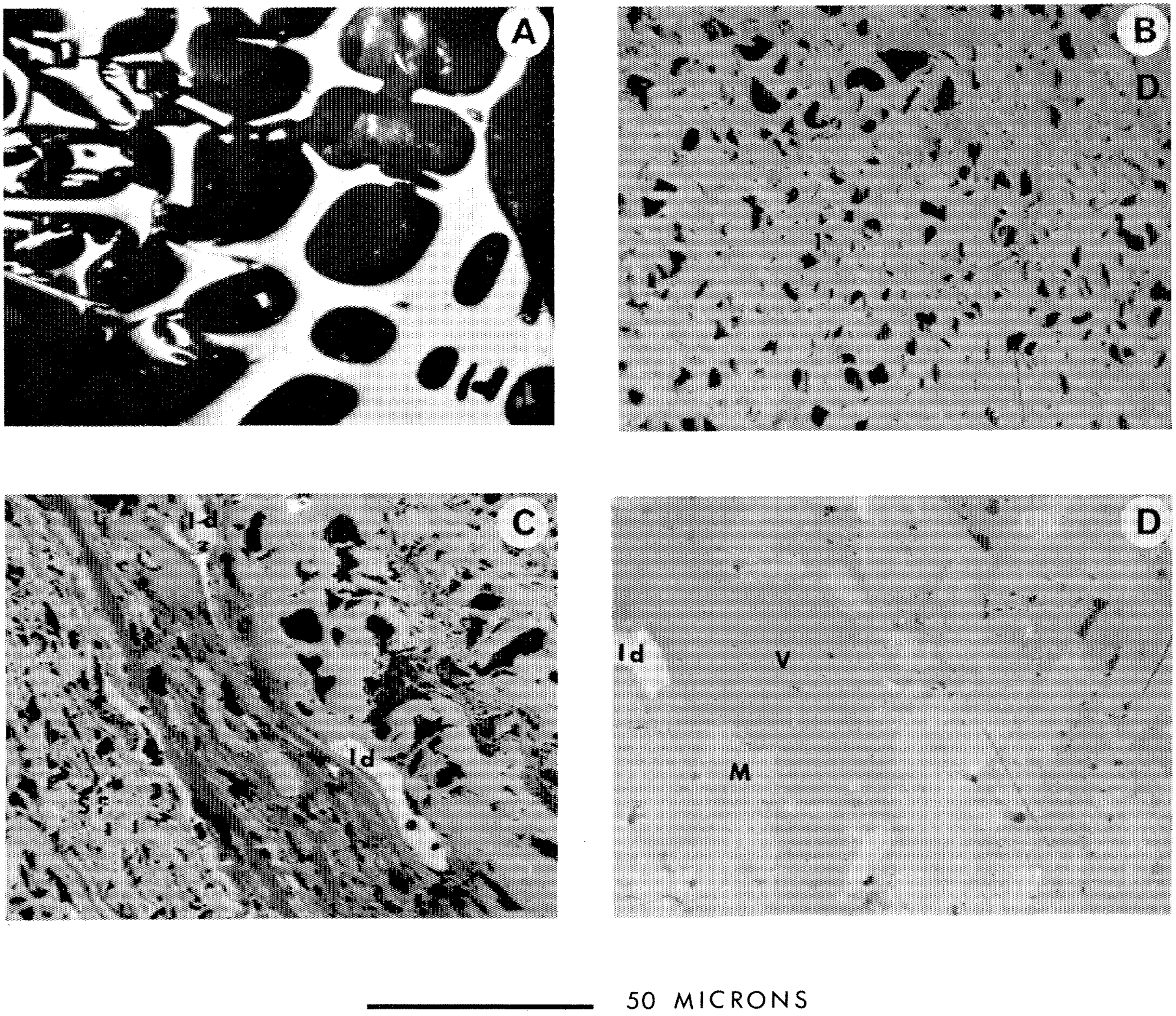

PLATE 3 - INERTINITE

A: *fusinite. Note the high reflectance, well-developed cavities or cell structure, and high relief.*

B: *semifusinite. In comparison with fusinite in photograph A semifusinite shows lower reflectance, less well-developed cell structure and more subdued relief, characteristics which are diagnostic of semifusinite.*

C: *mixture of inertinite macerals: on the left — semifusinite (SF); in the centre — fragments of inertodetrinite (Id).*

D: *macrinite (M) and inertodetrinite (Id) associated with vitrinite (V). Note the lighter colour (reflectance) of the inertinite macerals as compared to that of the vitrinite.*

All photographs taken with reflected light and oil immersion.

PETROGRAPHY IN COAL PROCESSING

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ABSTRACT

There are many ways in which petrographic logging and analysis of coal seams can assist the process engineer in plant design. These are based on the knowledge that the four main coal types or macerals — vitrain, clarain, durain, and fusain — possess different mechanical and surface chemical properties which can be exploited during processing to bring about the separation of the more reactive coking macerals.

For example, particle size is an important factor in processing metallurgical coals; finely crushed material reacts more readily than coarser particles during carbonization and forms stronger thermal bonds. Observations of coal types present in seam sections allow predictions to be made for the resultant size distribution of "as mined" coal, the size distribution of the raw feed to the plant, and the design factor necessary to account for degradation during handling and processing. Similarly, the "reactive index" — a measure based on petrographic terms — can be used to predict the coking propensity of metallurgic coals, which in turn can be controlled by a particular choice of separating gravity. However, use of coal types to predict the surface chemical properties of Western Canadian coals for separation by froth flotation has been only partly successful owing to oxidation and metamorphic effects.

INTRODUCTION

An infinite number of combinations of the various petrographic constituents results in the apparently different characteristics of individual coal seams. Rank is determined by various parameters which are directly affected by petrographic composition.

The coal processing engineer is concerned with petrography to the extent that it influences the coal-cleaning operation. Prior to discussing these, it is necessary to outline the petrographic terms of reference used, since these may vary from time to time. We refer to the coal types first proposed by Dr. Marie Stopes in 1919 and 1935 namely ***vitrain, clarain, durain,*** and ***fusain***. By definition these macroscopic forms account for the bright, soft, dull, and hard properties pertinent in separation processes. With respect to the petrographic units or macerals, we confine our remarks to the items listed in table 1.

To an audience of coal geologists it is clearly not necessary to detail the properties of the four coal types or of the macerals constituting them. It therefore suffices to outline their application and significances in coal preparation. The occurrence of the four coal types provides a ready means of assessing general mechanical properties simply by observation, while microscopic examination affords a means of detailing the petrographic bricks or units directly affecting the coking properties of metallurgical coals.

Segregation of petrographic constituents during gentle comminution may be exploited in the processing concept, and more significant is the separation of the more reactive coking macerals at low gravities in dense medium processes.

The surface chemical properties of coals improve with increase in rank to the extent that froth flotation processes become highly selective of the coking properties of metallurgical coals.

Petrography of Western Canadian Coals

To what extent may Carboniferous-based petrography be applied to Western Canadian coals? Is there any real meaning to coke stability predictions derived from petrographic analysis? The answers to these questions are still open, but there are several observations which might be considered.

(1) Coal type is determined by the nature of the plant material from which the coal is formed and is an inherent characteristic of the coal. Cretaceous plant material is more "woody" than its Carboniferous counterpart, and the resulting coal types are not so readily recognized.

(2) It appears that the lignitious tissues of wood, bark, and leaves when transparent are vitrinites and when opaque are fusinites. Raistrick and Marshall (1939) described a maceral intermediate between vitrinite and fusinite named vitrifusinite. Dulhunty (1946) similarly observed intermediate properties which make up a series between the two macerals. There is a case for assuming that the processes responsible for the formation of vitrinite and fusinite are closely allied. What is the significance of vitrifusinite in Western Canadian coals?

(3) The petrographic constituents of coal can be characterized by their optical properties. Reflectance varies significantly from vitrain to fusain, and, as rank

Table 1. Summary of Nomenclature Used in Coal Petrology (Stopes-Heerlen System)

Lithotypes	Macerals		Microlithotypes		
	Maceral	Maceral Group and Symbol	Microlithotype	Principal Groups of Constituent Macerals in the Microlithotypes	Number of Maceral Groups in each Microlithotype
Vitrain	Collinite Telinite	Vitrinite (Vt)	Vitrite	Vt	Monomaceral
			Vitrinertite	Vt + I	Bimaceral
Fusain	Micrinite Semifusinite Fusinite Sclerotinite	Inertinite (I)	Microite	I	Monomaceral
			Fusite	I (except micrinite)	Monomaceral
	Cutinite Resinite Sporinite Alginite	Exinite (E)	Sporite	E	Monomaceral
Durain			Durite	I + E	Bimaceral
Clarain			Clarite	Vt + E	Bimaceral
			Duroclarite	Vt + E + I	Trimaceral
			Clarodurite	I + E + Vt	Trimaceral

increases, constituents of high reflectance become more abundant. Possible problems in use of reflectance techniques relate to the optical properties of clay coatings and the tectonic changes which can increase the reflectivity of less reactive macerals.

Petrography in Carbonization

Finely crushed material reacts more readily than coarser particles during carbonization and forms stronger thermal bonds. Vitrain, clarain, and fusain predominate in the finer fractions, but durain remains relatively coarse and may inhibit coke production by promoting weak areas in the coke structure. Ideally the coarser durain particles should be recrushed before feeding to the coke ovens, and the vitrain and clarain particles should approximate 2 to 3 mm in size. The noncoking constituent, fusain, is extremely soft and concentrates in the fines fraction. Where the dedusted material from process plants is predominantly fusain, it would improve coke strength to remove the dust from the coking blend.

Figures 1, 2, and 3 show how the properties relevant to good coking potential vary with specific gravity and how they are related to petrographic composition.

PARTICLE SIZE DISTRIBUTION

Separation of the Barnsley coals by accurate sink-float methods enabled samples of the four coal types to be obtained over a period of time. Comminution and sizing tests on these samples and others yield information with respect to the differential hardnesses of coal types. Dull coals are generally harder than bright coals, and the compressive strength increases considerably as the vitrain content decreases, especially below 12 per cent.

Structurally, fusain is the softest coal type, vitrain is stronger but brittle, clarain is mechanically strong, and durain is the strongest. Segregation during mining and processing results in clarain and durain predominating in the coarse size fractions and vitrain and fusain in the finer fractions.

Estimating Size Distributions

Size distributions can be empirically estimated from petrographic logs of given seam sections. Durains on the average produce 60 per cent greater than 1/2 inch and 15 per cent less than 28 mesh (approx. 0.023 ins). Very soft vitrain produces 30 per cent less than 28 mesh during strip mine

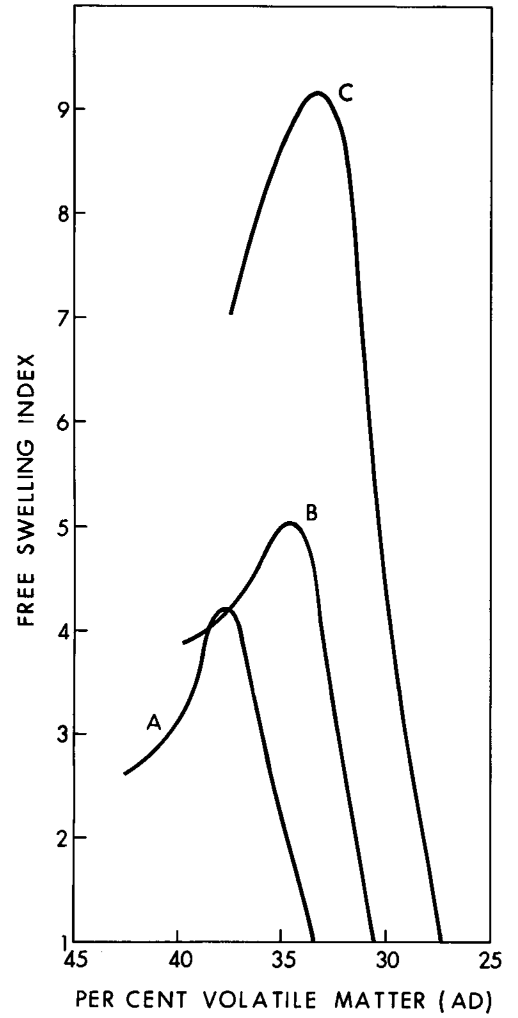

FIGURE 1. Relationship between volatile matter and free swelling index for three Barnsley Seam coals (after Thomas, 1968).

operations. Such size distribution effects, by petrographic types, can be compounded on a volumetric basis to give an estimated "as mined" size consist.

When the size distribution estimate has been plotted on a Rosin Rammler Grid, adjustments can be made for the effect of subsequent handling or top size reduction in the processing plant and excessive degradation by coal-getting machines, such as continuous miners and disc shearers in underground work.

A worldwide appraisal of changes between "as mined" and final processed coal/shale size distributions reconstituted after washing shows that a degradation factor of 1.5 minimum and 2 maximum should be applied to the compounded proportion of minus 28 mesh material. In crushing to minus 2 inches, the crushed material will show a similar size distribution to the original natural minus 2-inch material except where durain is predominant. Durain is naturally greater than 1 1/2 inches "as mined" and crushes down to an average natural durain size distribution.

A factor of 1.5 is applied for plant design purposes when normal handling and washing is practiced on relatively hard coals. For severe handling of soft coals the applied factor would be 2. These are, of course, the extreme values, and the most commonly used value is 1.8. Estimates of size distribution from the inspection of adits are usually worse than the actual wet screening analyses of bulk samples in the laboratory. In practice, however, the size distributions experienced in process plants approximate very closely to the inspection estimates after a degradation factor has been applied.

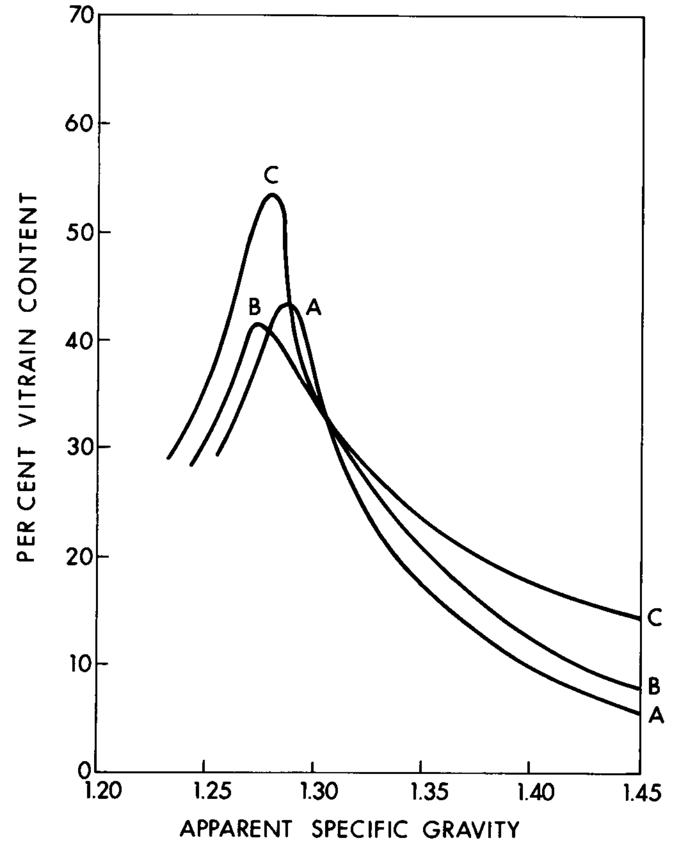

FIGURE 2. Variation of vitrain content with apparent specific gravity (after Thomas, 1968).

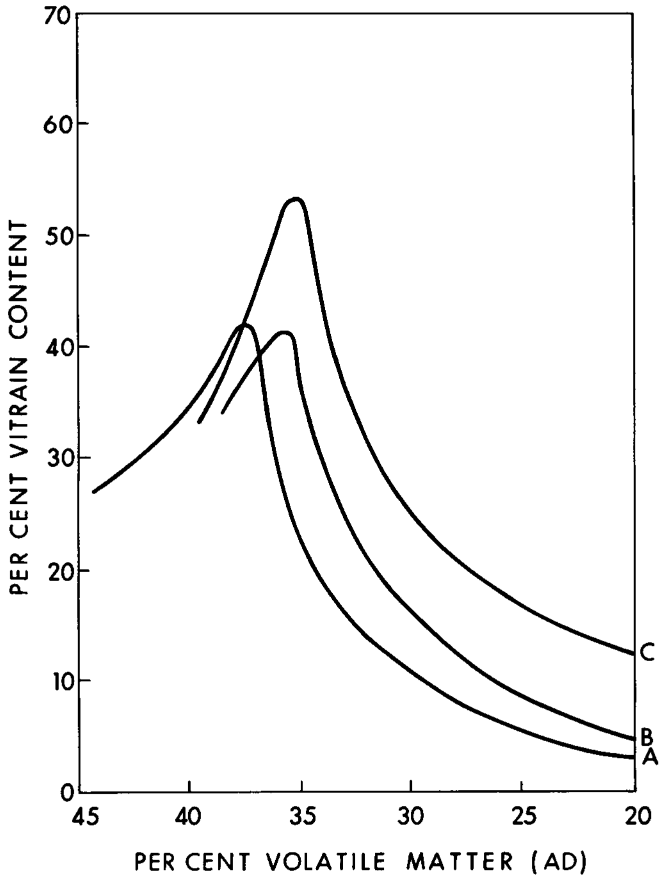

FIGURE 3. Variation of vitrain content with volatile matter (after Thomas, 1968).

It should be realized that this approach to size content prediction is only a guide for plant design purposes and, when applied in the beginning to Western Canadian coals, gave results which appeared excessively high in fines content. At that time, there was no real case for accepting such high fines predictions, since nowhere in the world were such values ever experienced. No criticisms can be levelled in any direction for any underestimates of fines design capacity in Western Canadian plants, since the actual size distributions are unique; it is only hindsight that confirms the usefulness of the adit inspection approach at the present time.

Observations of the coal types present in seam sections allow predictions to be made for:

(1) the resultant size distribution of the "as mined" coal;

(2) the size distribution of the raw feed to the plant, estimating the effect of the loading, dumping, rotary breaker size reduction, and stockpiling;

(3) the design factor necessary to take account of the degradation within the plant by handling, crushing, and recirculation of middlings.

Table 2 represents a typical example of the macroscopic examination of a Western Canadian coal seam section resulting in a predicted size analysis. In this particular example the "as mined" fines prediction amounts to 22.5 per cent less than 28 mesh which corresponds to 11 per cent in figure 4 for the laboratory head sample analysis. The method of recovering coal from test adits does not readily simulate the commercial mining operation. For plant design purposes the proportion of minus 28 mesh fines is adjusted by a degradation factor of 1.8 related to moderate handling of the raw material in the process and blending plant. Therefore, in this particular case, the fines plant would allow for desliming 40 per cent of the raw feed.

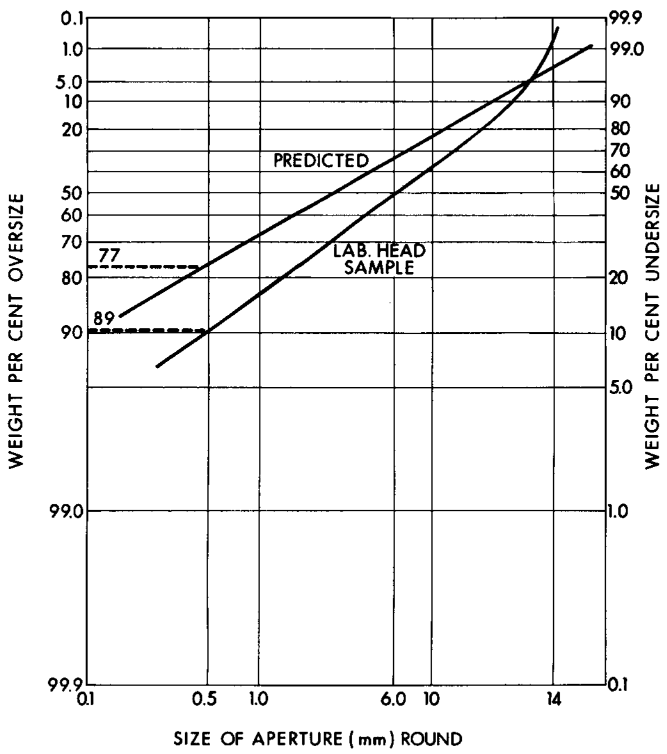

FIGURE 4. Comparison of predicted and observed size analyses, Seam "E", Birtley Engineering (Canada) Ltd.

Table 2. Petrographic Description and Predicted Size Distributions of Seam "E", Birtley Engineering (Canada) Ltd.

Petrographic Description	Proportional Thickness	% Seam	Forecast Sizes %+1/2	Forecast Sizes %-28	Weighted Sizes %+1/2	Weighted Sizes %-28
Soft flaky vitrain	6 ins	4.8	10	27	0.48	1.30
Durain, banded	6 ins	4.8	30	20	1.44	0.96
Clarain (vitrainous)	1 ft	9.5	15	25	1.42	2.36
Clarain (durainous)	1 ft	9.5	25	20	2.36	1.90
Interbanded vitrain, clarain, durain with dispersed fusain	1 ft 6 ins	14.3	15	26	2.15	3.70
Clarain (firm)	2 ft 6 ins	23.7	20	20	4.74	4.74
Clarain (vitrainous)	6 ins	4.8	15	25	0.72	1.20
Durain banded with clarain and fusain	1 ft 6 ins	14.3	28	20	4.00	2.86
Clarain (firm)	6 ins	4.8	20	20	0.96	0.96
Vitrain (soft)	1 ft	9.5	10	27	0.95	2.56
Total		100.0			19.22	22.54

A full graphically derived size distribution would be: -

+ 1 1/2 ins	- 5%
1 1/2 ins x 1/2 in	- 15%
1/2 in x 1/4 in	- 15%
1/4 in x 28 mesh	- 42.5%
- 28 mesh	- 22.5%

SEGREGATION OF MACERALS BY DENSITY

The work of Hacquebard and Lahiri (1954) and Lahiri *et al.* (1968) clearly demonstrates a decrease in vitrinite content with increasing gravity of the elementary fractions. Conversely, the proportion of inertinite decreases. The reactive index, a measure of coking propensity in petrographic terms, decreases rapidly above 1.4 sg for Indian and Western Canadian coals in particular (Fig. 5). A distribution of coal types with respect to specific gravity is shown for three different Barnsley coals in table 3. There is a definite concentration of vitrain and clarain in the lighter fractions and durain/fusain in the heavier fractions. Clearly the coking propensity of metallurgical coals as indicated by reactive index can be controlled in the processing plant by a particular choice of separating gravity. Other gravity processes not employing dense media are affected by size and shape of particles and cannot concentrate the lighter macerals as readily.

Commercial Dense Media Processes

In commercial practice the lower size limit for sink-float separations is 1/4 inch in static baths and 28 mesh in centrifugal dense media systems. It is possible to concentrate the more reactive coal types in the clean product by accurate sink-float separation. The specific gravities of the various macerals are not constant, and the gravity differential between reactive and unreactive constituents might only be 0.02. Reputedly, the first attempts at commercial

Table 3. Variation in Petrographic Composition and Selected Physical Properties with Specific Gravity for Three Barnsley Seam Coals (after Thomas, 1968)

SG Fraction	Coal	Petrographic Composition				Ash Content %	Volatile less Moisture Content %	F.S.I.
		Vitrain %	Clarain %	Durain %	Fusain %			
1.30F	A	36.5	57.5	4	2	1.65	38.4	4
	B	37	53.0	6	4	2.3	36.2	4 1/2-5
	C	45.5	47	3.5	4	1.9	35.6	8 1/2
1.30S-1.36F	A	24	48	14	14	4.5	35.4	2
	B	25	47.5	16	11.5	4.8	33.9	4 1/2-5
	C	26	39.5	18	16.5	4.9	32.0	6 1/2-7
1.36S-1.40F	A	12	43	23	22	8.85	32.7	1-1 1/2
	B	15	42	25	18	8.35	30.7	1-1 1/2
	C	21	30	29	20	9.3	28.8	2-2 1/2
1.40S-1.60F	A	5	28	43	24	17.0	27.6	1
	B	8	37	29	26	17.35	28.3	1
	C	13	40	19	28	19.95	27.6	1-1 1/2

separation of "hards" and "brights" were carried out in the Barvoys D.M. bath using barytes medium. It was considered that this method most nearly approached ideal sink-float conditions. The more reactive macerals can be concentrated in the clean coal product by dense media processes, but this is greatly controlled by the economic considerations of product yield.

Laboratory Sink-Float Separation

In the laboratory, dense media processes are simulated by the use of true liquids and solutions of suitable density range. For the purpose of measurement, laboratory sink-float ***carefully performed*** is the "absolute" measure and gives rise to what is considered to be the theoretically possible separation. Commercial separations are compared with these, and the efficiencies of the various processes are determined. Such a concept is technologically valid so long as the laboratory technique is maintained reliable and the commercial process is always less efficient than the theoretical. A simple study of Stokesian-Newtonian falling velocities for coal/shale particles in organic liquids of relatively high specific gravity shows great differences in accuracy for particles plus and minus 28 mesh. There is no readily available method for measuring the accuracy of laboratory sink-float determinations below about 28 mesh, but physical concepts indicate that large errors are probable.

Figure 6 accounts for the settling velocities and time for laboratory separation of coal/shale particles in an organic liquid of 1.6 sg. There is a significant change in separation time for particles below 28 mesh, and below 100 mesh no accurate separation is possible. Centrifugal force speeds up the separation and offsets to some extent the viscous forces on fine particles, but accuracy of separation is still questionable. Wall effects and low interparticle spacing in centrifuge tubes mitigate against reliable separation of particles by density. All that can be guaranteed in these cases is that the float fraction will be lower in ash content than the sinks. The true specific gravity-ash relationship for a particular coal is still unknown. Accurate sink-float analysis below 28 mesh is questionable and serves no useful purpose in the estimation of product yield and quality. Coal processing engineers have already pointed out that for data used in design of plant, sink-float analysis should terminate at 28 mesh (Blanchflower and Worthington, 1971).

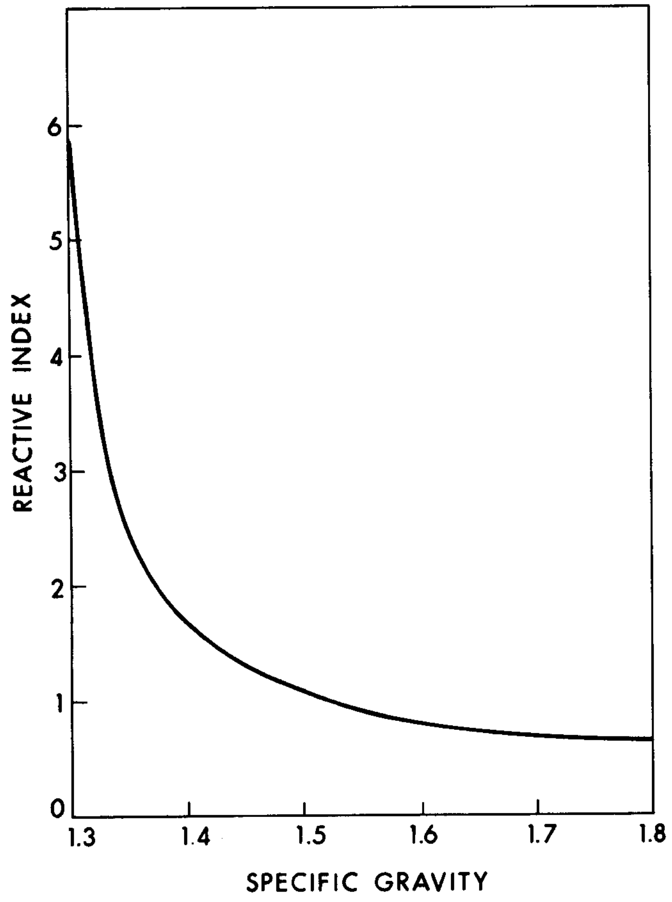

FIGURE 5. Variation of reactive index with specific gravity (after Lahiri et al., *1968).*

Water-Only Methods of Separation

The gravity processes employing dense media are, of course, the most accurate separators, but acceptable performances can be achieved by other methods. It is important to assess the probable distribution of the petrographic units in the commercial products of separation. In water-only systems size and shape affect the migration of particles to each of two or three products of separation. For example, in the water-only cyclone, the situation may arise that due to the inherent errors of separation, a better coking product is obtainable than by an ideally accurate performance. Such a circumstance would be the exception rather than the rule but might be exploited to advantage. Where the fines fractions contain large proportions of fusian in relation to vitrain, there would be a case for (1) accurate cleaning of these fractions, or (2) discarding the fines altogether. In the event of low fusain content in the fines and very little clay material, the degree of cleaning is not important. The losses of coal to discard which might occur would be the coarser durain particles, and the overall effect would be to improve coking propensity through inaccuracy. On the other hand, the petrographic distribution may well necessitate the use of the most accurate separating process. It is concluded, therefore, that petrographic analysis of the raw coal should be considered prior to the final choice of process.

PETROGRAPHY AND SURFACE CHEMICAL PROPERTIES

Experience with Carboniferous bituminous coals has indicated selective differences in coal type surfaces which

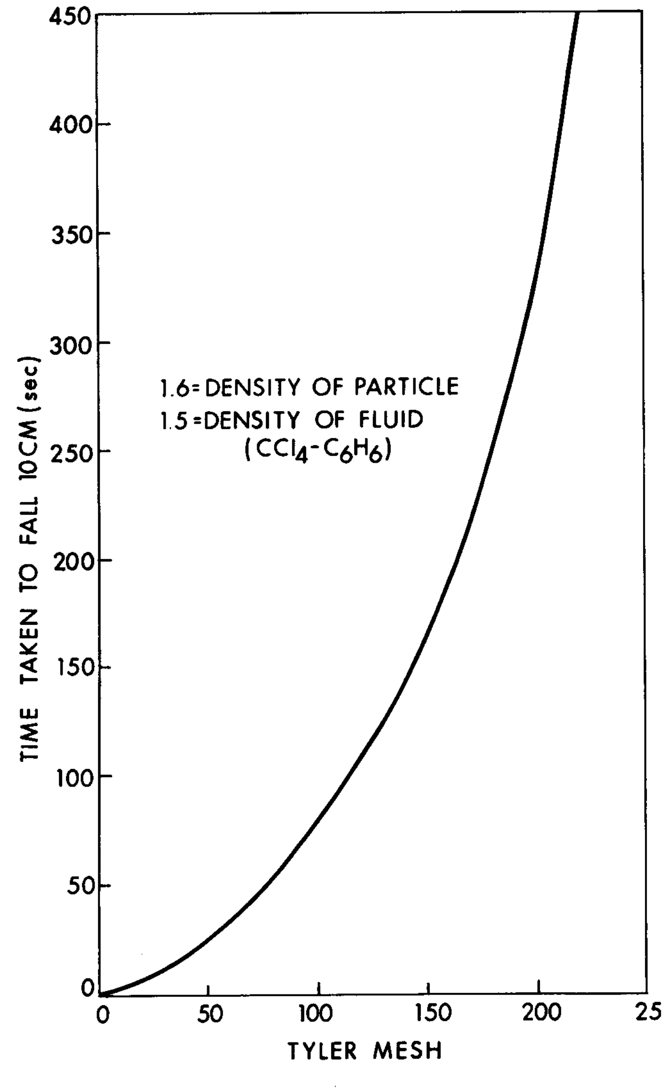

FIGURE 6. Settling velocity of small spheres.

have been exploited in separation by froth flotation. The hydrophobic nature of vitrain and clarain affords a means of selecting the better coking constituents and rejecting the inert materials. These differences in the nature of coal-type surfaces have been well enough defined to make froth flotation of European coals relatively easy. Unfortunately, there have been experiences with Western Canadian coals in which froth flotation has not been successful. The major reasons for this are twofold: (1) surface oxidation which renders the coal particles nonfloatable, and (2) petrographic distributions associated with "tectonic metamorphism." Surface oxidation can be short term in its occurrence, for example, resulting from exposure to the atmosphere in stockpiles. This is usually only significant in high volatile coals. "Geologic" oxidation is long term in the sense that the coal has been oxidized *in situ* by leaching solutions, and the coal material is still oxidized even after the production of new surfaces by comminution. Oxidized coals make froth floation difficult; this is evidenced by the loss of coal in rejects. Metamorphism beyond normal coalification produces apparent changes in rank which affect surface chemical separation in the opposite way – that is, the clean product is high in ash content, and there is no real selectivity.

Since the vitrains and clarains are generally easily floatable, there should be a flotation rate which is related to the proportions of these coal types present in the plant. Figure 7 shows clearly that for a given flotation time, the yield of product is related to reactive index for a group of low volatile bituminous coals. A similar relationship was not possible for a group of medium to high volatile coals, and this is being further investigated.

Froth Flotation Tests

Froth flotation tests are usually carried out to obtain information for plant design purposes, but it seems that a useful application extends beyond this. The analysis of core samples usually involves a sink-float separation at some suitable specific gravity, for example, 1.5, and the minimum particle size for this exercise varies from operator to operator. The relevance of this lower size limit has already been discussed in the section on sink-float separation. Froth flotation tests can be applied to the fines fraction lying outside the practical sink-float size range – that is, 28 mesh x 0. The information obtained from such tests is best illustrated by examples.

Table 4 gives a value for raw coal ash of 18.39 per cent and a corresponding F.S.I. of 3 1/2. The gravity float product at 1.5 sg gives values of 10.71 and 4 1/2 for ash and F.S.I., respectively. The froth-floated fines produced an ash of 12.96 per cent with a swelling index of 2, which is less than the raw coal value of 3 1/2. There are two possible explanations for this anomaly: (1) that the fine coal fractions are oxidized, or (2) that excessive amounts of fusain have concentrated in the fines fractions. The flotation test results do not indicate oxidation since the tailings ash level is not low enough to indicate substantial coal loss. It would appear that the noncoking coal type fusain was predominantly present. Similarly in table 5 the fines in the froth flotation product would probably contain a high proportion of fusain.

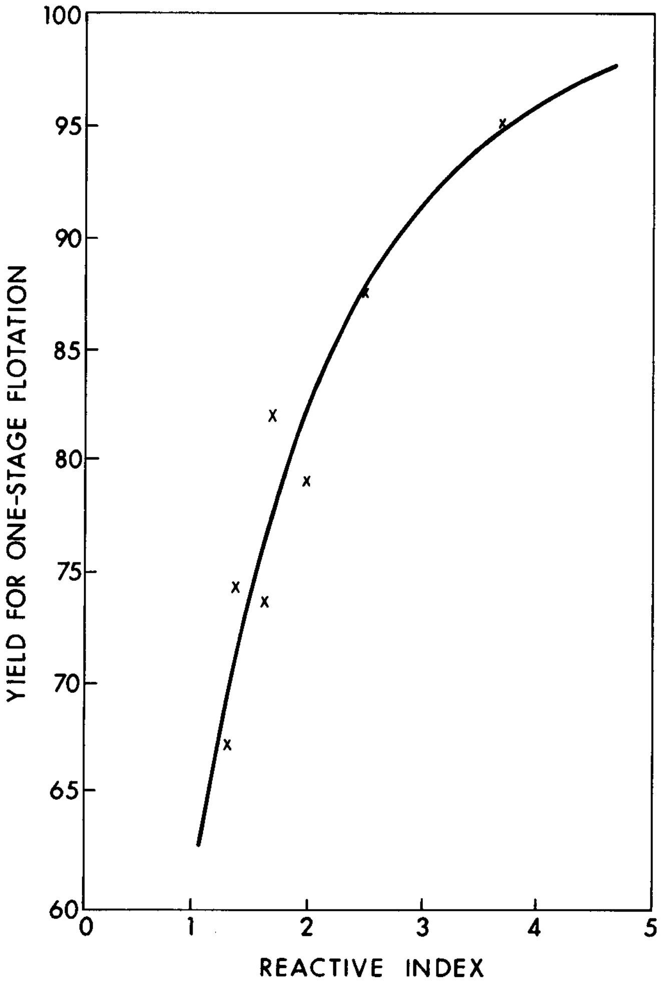

FIGURE 7. Relationship between ease of flotation and reactive index for a group of low volatile bituminous coals.

Table 4. Sample Data Sheet Used in Froth Flotation Test of Coal "A"

COAL SCIENCE AND MINERALS TESTING
CUSTOMER
DATE

RAW COAL	WT. %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I.	C.V.
3/4" x 28M	80.56		18.82					
28 MESH x 0	19.44		16.63					
TOTAL	100.00	0.52	18.39	22.90	58.19	0.38	3 1/2	

PLUS 28 MESH ANALYSIS (SINK-FLOAT 1.50 S.G.)								
S.G. FRACTION	WT. %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I.	C.V.
Floats	79.97	0.32	10.71	24.64	64.33	0.39	4 1/2	
Sinks	20.03		51.20					
TOTAL	100.00		18.82					

MINUS 28 MESH ANALYSIS (FROTH FLOTATION)

ELEMENTARY ANALYSIS			
STAGE	WT. %	ASH %	F.S.I.
1	64.94	12.96	2
2	29.84	18.97	1
3	5.22	48.99	

CUMULATIVE ANALYSIS							
WT. %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I.	C.V.
94.78	0.10	14.85	22.50	62.55	0.50	1 1/2	

TOTAL CLEAN COAL (FLOAT PRODUCT PLUS FLOTATION CONCENTRATE)								
	YIELD %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I.	C.V.
	82.85	0.27	11.63	24.16	63.94	0.41	3 1/2	

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Table 5. Sample Data Sheet Used in Froth Flotation Test of Coal "B"

COAL SCIENCE AND MINERALS TESTING
CUSTOMER
DATE

RAW COAL	WT. %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I.	C.V.
3/4" x 28M	86.93		22.32					
28 MESH x 0	13.07		17.30					
TOTAL	100.00	0.33	21.66	22.01	66.00	0.42	3 1/2	

PLUS 28 MESH ANALYSIS (SINK-FLOAT 1.50 S.G.)

S.G. FRACTION	WT. %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I.	C.V.
Floats	72.62	0.34	7.07	24.38	68.21	0.44	6	
Sinks	27.38		62.75					
TOTAL	100.00		22.32					

MINUS 28 MESH ANALYSIS (FROTH FLOTATION)

ELEMENTARY ANALYSIS

STAGE	WT. %	ASH %	F.S.I.
1	40.24	12.14	2 1/2
2	45.26	14.43	1 1/2
3	14.50	40.55	

CUMULATIVE ANALYSIS

WT. %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I.	C.V.
85.50	0.40	13.35	22.60	63.65	0.51	2 1/2	

TOTAL CLEAN COAL (FLOAT PRODUCT PLUS FLOTATION CONCENTRATE)

	YIELD %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I.	C.V.
	74.30	0.34	8.01	24.11	67.54	0.45	4 1/2	

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Table 6. Sample Data Sheet Used in Froth Flotation Test of Coal "C"

COAL SCIENCE AND MINERALS TESTING
CUSTOMER
DATE

RAW COAL	WT. %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I.	C.V.
3/4" x 28M	89.97		27.18					
28 MESH x 0	10.03		21.53					
TOTAL	100.00	0.75	26.61	21.79	50.85	0.70	5	

PLUS 28 MESH ANALYSIS (SINK-FLOAT 1.50 S.G.)								
S.G. FRACTION	WT. %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I	C.V.
Floats	70.04	0.19	7.62	26.57	65.62	0.70	6 1/2	
Sinks	29.96		72.92					
TOTAL	100.00							

MINUS 28 MESH ANALYSIS (FROTH FLOTATION)

ELEMENTARY ANALYSIS			
STAGE	WT. %	ASH %	F.S.I.
1	41.38	9.89	6 1/2
2	38.73	17.34	4 1/2
3	19.89	53.88	

CUMULATIVE ANALYSIS							
WT. %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I.	C.V.
80.11	0.45	13.49	24.75	61.31	1.06	6	

TOTAL CLEAN COAL (FLOAT PRODUCT PLUS FLOTATION CONCENTRATE)								
	YIELD %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I.	C.V.
	71.05	0.22	8.28	26.36	65.14	0.8	6	

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Table 7. Sample Data Sheet Used in Froth Flotation Test of Coal "D"

COAL SCIENCE AND MINERALS TESTING
CUSTOMER
DATE

RAW COAL	WT. %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I.	C.V.
3/4" x 28M	81.93		23.23					
28 MESH x 0	18.07		28.18					
TOTAL	100.00	0.46	24.12	22.98	52.44	0.92	6 1/2	

PLUS 28 MESH ANALYSIS (SINK-FLOAT 1.50 S.G.)

S.G. FRACTION	WT. %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I.	C.V.
Floats	73.69	0.52	6.84	27.68	64.96	0.90	7 1/2	
Sinks	26.31		69.14					
TOTAL	100.00		23.23					

MINUS 28 MESH ANALYSIS (FROTH FLOTATION)

ELEMENTARY ANALYSIS

STAGE	WT. %	ASH %	F.S.I.
1	48.20	16.63	7 1/2
2	37.05	27.21	5
3	14.75	68.34	

CUMULATIVE ANALYSIS

WT. %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I.	C.V.
85.25	0.30	21.23	22.82	55.65	1.04	5 1/2	

TOTAL CLEAN COAL (FLOAT PRODUCT PLUS FLOTATION CONCENTRATE)

	YIELD %	MOIST.%	ASH %	V.M.	F.C.	SULPHUR	F.S.I.	C.V.
	75.77	0.47	9.76	26.69	63.08	0.93	7	

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The froth flotation product in table 6 has an F.S.I. of 6 1/2 for a relatively high ash content of 9.89 per cent, and this indicates relatively high vitrain/clarain proportions in the raw feed fines. A good swelling index is obtained for the minus 28 mesh fraction in table 7 which again indicates the predominance of vitrain and clarain and a marked decrease in fusain.

SUMMARY

There are many ways in which the petrographic logging and analysis of coal seams can assist the process engineer in plant design. In this paper we have attempted to outline some of these without becoming involved in too much detail. The usefulness of adit inspections and logging of seams on a macroscopic scale is by now well established, and a knowledge of maceral distribution in particular coals is helpful in the choice of process technique, especially for metallurgical coals.

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MONETARY EVALUATION OF COAL PROPERTIES

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ABSTRACT

Realistic evaluations of proven and unproven coal properties are important for sales, borrowing, mergers, issue of securities, and tax purposes. The mineral industry has tended to assign properties a value representing cost of acquisition and work carried out. More meaningful values can be obtained by applying methods based on the future net cash flows discounted at rates consistent with current commercial practices.

Proven or developed properties are valued at the present worth of net cash flow over the predicted productive life of the property. This implies accurate knowledge of reserves, mining and processing costs, contracts, and long-term markets.

Unproven properties are evaluated by first estimating the present worth of the net cash flow to be obtained from the size and type of mine or mines, which may reasonably be expected to be developed on the property. The resulting values are weighted using suitable risk factors which are strongly influenced by experience, the amount of geological data available, and the interpretation of long-term market potential and economic factors.

Evaluations are applicable as of a specific date only and may change rapidly because of the acquisition of new technical knowledge or a change in the market outlook.

INTRODUCTION

This paper presents a method for evaluation of unproven potential coal properties which may be readily used by persons unfamiliar with advanced statistical techniques and perhaps without ready access to computer facilities. The method suggested allows for the breakdown of the evaluation problem into a number of components, so that each of the variables may be considered separately. Independent consideration of each of these components should result in increased overall accuracy in the evaluation.

CONCEPT OF FAIR MARKET VALUE

There are many reasons for evaluating properties, including the following:

(1) determination of the fair market value for the sale or purchase of a property,

(2) borrowing of money to develop or operate properties,

(3) mergers of two or more companies to ensure a fair settlement for the shareholders of each of the merging companies,

(4) the issue of securities (many authorities require a realistic independent evaluation of the worth of company properties),

(5) estate taxation (this requires a realistic evaluation of the worth of the estate holdings),

(6) justification of expenditures to explore or develop a property.

The simplest approach to describe what is meant by the value of a property is through a discussion of some of the misconceptions of what constitutes a value.

It is often suggested that the fair market value of a property is the price that it will bring on the open market. Where a flourishing and competitive market in similar properties exists, this is probably close to the truth, since competition will result in realistic evaluations by prudent operators. Where no such active market exists, the price offered or asked may bear little resemblance to a reasonable value. It may be something like offering a camel for sale at the Calgary Bull Sale. The price obtained for our camel might be well below the true value of camels if the only offer is from the only camel expert in the crowd. The seller might find it profitable to hold his camel until more camel experts can be approached or the beast can be offered on a competitive camel market.

It is frequently contended that the value of a property, especially of an unproven property, is determined, at least in part, by the expenditures already made upon the property. While this figure no doubt has a value for bookkeeping purposes, it has little relationship to the "fair market value" of the property.

The change in value of a property in relationship to any program carried out on that property is related only to the results obtained from the work, and in no way to the expenditures incurred through the work. On a long-term and rational basis, however, one should expect the value of a property to increase in relation to the exploration expense. Otherwise, continued exploration could not be justified, and the property would be dropped. In many exploration programs, there comes, unfortunately, a time when increased exploration costs result in a drastic lowering of the value of the property.

The value of a property is often incorrectly directly related to the exploration expenses planned for the property or required by the nature of the property. In other words, it is often argued that the value of a property is at least as high as the future exploration expense required to investigate the property. This is not so. The value should instead be related to the revenue that may be expected less the total cost of acquiring and exploring the property. If the anticipated revenue is low and the exploratory cost high, the value of the property could be zero. There is no direct relationship between past or future exploration costs and property value. To use a very simple example, consider two small properties shown in figure 1 that have equal potential for the occurrence of equal reserves that could be sold under equal sales contracts. If the cost of exploring and producing property B is much greater than that of exploring and producing property A for logistical reasons, then the potential net return from property A is higher than that from property B. Thus, the value of A as a property is higher than that of B in spite of, or in this case because of, the much greater exploration and development budget required for B.

Eggleston (1965) quotes D. B. Montgomery as follows: "The term 'fair market value' has generally been defined by the courts as the price at which a seller willing, but not compelled to sell, and a buyer willing, but not compelled to buy, both having reasonable knowledge of the material circumstances, will trade."

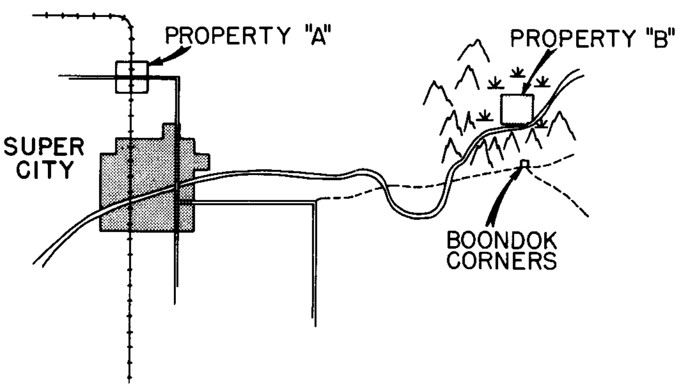

FIGURE 1. Example of the effect of logistics on the cost of exploration, development, and production of two similar properties.

If the above definition is kept in mind, the problem of determining a fair market value in the absence of an active and competitive market should be approached through the determination of the net return that may be realistically expected from the property.

Eggleston (1965) has stated that in considering purchase of a producing property, three specialists should be continuously consulted:

(1) the valuation engineer

(2) the financial director or advisor

(3) the income tax consultant.

This particular paper deals only with the work normally performed by the evaluation engineer and, for simplicity, has been restricted to a discussion of before-tax values. The engineering phase of the work requires consideration of coal reserves, costs of exploration, development, production, and market considerations. It should be emphasized, however, that the evaluation engineer must be able to call on the services of a number of experts in different fields, including geology, mining practice, coal treatment, and marketing.

Reference has been made to the "fair market value" of properties. Depending on the purpose of the evaluation, other values, such as "value to the company" may be more appropriate. In some cases, it is possible to switch from one value to another merely by changing the discount rate used.

In this paper the value to the company, as a going concern, is considered to be the present worth value obtained by discounting expected future net revenue at a rate of interest approximating the cost of money to the company. In the examples used later, an 8 per cent discount rate has been applied to represent the value to the company, and a 15 per cent discount rate to represent a fair market value.

DEFINITION OF COAL RESERVES

At this point, certain definitions must be established. The terms, "Measured" (Proven), "Indicated" (Probable), and "Inferred" (Possible) have been frequently used as modifiers for the terms, "Resources" or "Reserves." As usually defined in literature dealing with coal, these terms describe only the degree of certainty regarding the amount of coal present. A reference to the distance between control points is frequently included in the definitions. There is generally no reference to the possibility of commercial recovery of the coal.

For evaluation purposes adequate definitions must be based on the economic recoverability of coal as well as on the degree of assurance of the presence of coal.

In this paper ***proven coal reserves*** are defined as those reserves of coal considered to be economically recoverable under present conditions and for which the tonnage is computed from measurements at control points spaced closely enough to provide a high degree of assurance that the amounts of coal so computed will actually be found in place. Control points may be drill holes, outcrops, adits or existing mine workings.

It should be noted that the definition does not include any reference to the actual spacing of control points since this will vary with the stratigraphic and tectonic characteristics of the coal deposit under consideration. Likewise, the thickness of seam and the amount of overburden are not specified, since these parameters will depend on mining engineering and economic factors, and will vary from one area to another.

Because coal is usually mined and sold under sales contracts and since there is no guaranteed market for coal not under contract, in the strictest sense proven reserves should be assigned only to coal bodies covered by existing sales contracts. In practice, it may be possible to assign proven reserves to uncontracted deposits when there is reasonable assurance that an economic market will be found for these reserves. Accordingly, a distinction must be made between proven reserves that we anticipate will be produced and sold under existing contracts and those reserves that would have to be produced independently of, or at the end of the existing contracts.

Probable coal reserves are defined as those reserves of coal, economically recoverable under present or foreseeable future conditions, which may reasonably be assumed to exist on the basis of available geological evidence. Once again we have not specified the geological, engineering or economic conditions that determine which reserves fall into the unproven category, since these depend on conditions peculiar to the deposit under consideration.

Unproven holdings or lands are defined as those lands to which proven or probable reserves of coal are not assigned. They may or may not ultimately be proven to be underlain by economically recoverable coal.

To avoid any confusion between the economics-based definitions given above and definitions applying only to the amount of coal established in an area, it is suggested that the definitions of the latter should not include the terms "reserves" or "resources."

Proven coal-in-place may be used to describe coal for which tonnage is computed from measurements at control points spaced closely enough to provide a high degree of assurance that the amounts of coal so computed will actually be found in place, and ***probable coal-in-place*** as coal that may reasonably be assumed to exist on the basis of available geological evidence.

Although, by definition, coal reserves and holdings are divided into three distinct categories, there is in practice continuous variation in the degree of assurance with which coal lands can be considered to contain economically recoverable coal. This variation extends from the very high degree of doubt existing for lands that have been subjected to very limited exploration to the very high degree of certainty for lands that have been thoroughly explored and developed and for which there are firm sales contracts.

Figure 2 illustrates the possible changes in the prospects of a property as exploration and development proceed. An exploration prospect will start somewhere in the unproven portion of the diagram. As exploration is carried out and more information is obtained, the position will change either to the left or to the right. If movement is to the left, the property would normally be dropped or at least exploration would be restricted. If movement is to the right, one would expect increased expenditures for exploration in the hope of continued movement to the right.

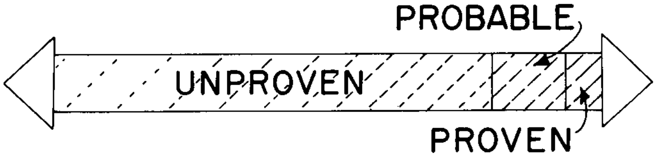

FIGURE 2. Illustration of the possible changes in the prospects of a property as exploration and development proceed.

The point to be emphasized is that a change in direction of movement can occur at any time. Movement to the right is normally slow and orderly. Reversals to the left can occur suddenly and movements can be large. Sudden movements to the left can be caused by a number of factors including, for example:

(1) unfavorable results from a drillhole indicating coal beds thinner than anticipated,

(2) discovery of unsuspected faulting,

(3) unfavorable results on bulk samples taken for testing,

(4) determination of expensive mining conditions,

(5) changes in world markets,

(6) discovery of a competitive deposit by another operator closer to transportation.

Sudden changes to the left are most common in the unproven and probable portions of the scale but are not impossible in the proven portion where disasters such as mine flooding or the financial collapse of the coal purchaser can remove properties from the "proven reserves" category. There is, therefore, always an element of risk, and this must be allowed for in an evaluation.

While the anticipated progression from unproven property to proven reserves has been illustrated as a double-headed arrow, it might be more realistic to look at it as a "snakes and ladders" game with few and short ladders and numerous and long snakes as shown in figure 3.

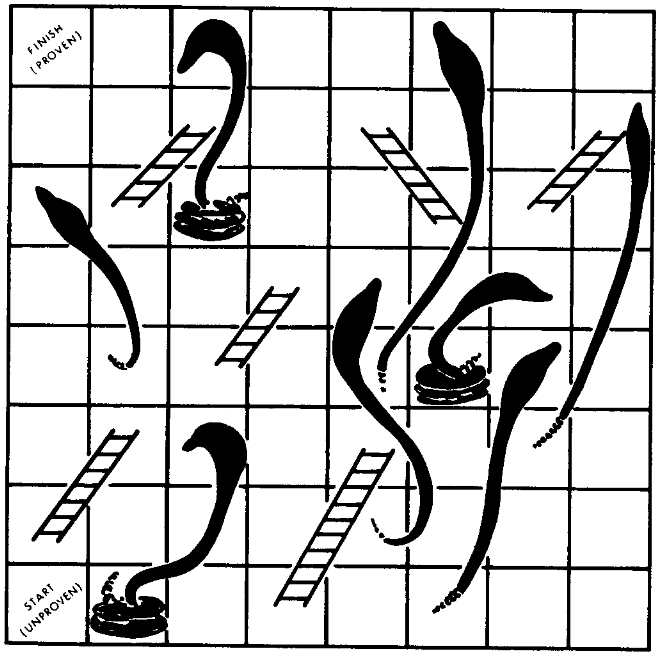

FIGURE 3. Illustration of the progression from unproven property to proven reserves showing similarity to a game of snakes and ladders.

EVALUATION PROCEDURES

The objective of an evaluation is to establish a realistic value at any given stage in the progression. An evaluation is applicable only for the point in time at which it is made. As stated earlier, new data or changing conditions can drastically alter a property's prospects for commercial production and hence its value.

One of the most difficult parts of an evaluation is determining the position of the property on the scale referred to earlier. As far as possible in the actual evaluation process, work proceeds from the known to the unknown. Firstly, therefore, consider the evaluation of a proven producing property with firm sales contracts.

The method based on the present worth of anticipated net revenue is used, since this approach is the best available and is commonly accepted by financial institutions. The method is best illustrated by examples. All examples are hypothetical.

Table 1 is a forecast of coal production, revenue, and present worth before taxes for an operating mine with 100 million tons of contract specification coal. Throughout the following discussion, all references to tonnages refer to short tons. For this operating mine, production is estimated at 5 million tons a year under a twenty-year contract. All initial capital investment outlays have been made and therefore are not considered in the calculations.

Gross revenue has been obtained using an initial price of $11.75 Canadian a ton, f.o.b. mine, which has been escalated at 25 cents a ton every second year. Production expenses have been estimated at $9.00 a ton. The assumption has been made that capital investment to maintain production at contract levels would be required in the tenth and fourteenth years. Net revenues are obtained by subtracting production expenses and capital investment from gross revenue. Cumulative revenue is based on net revenue.

Table 1. Forecast of Coal Production, Revenue, and Present Worth (Before Taxes) of an Operating Mine with 100 Million Tons Proven Reserves

Year	Net Production (million tons/yr)	Gross Revenue ($ million)	Production Expense ($ million)	Capital Investment ($ million)	Net Revenue ($ million)	Cumulative Revenue ($ million)
1	5	59	45	-	14	14
2	5	59	45	-	14	28
3	5	60	45	-	15	43
4	5	60	45	-	15	58
5	5	61	45	-	16	74
6	5	61	45	-	16	90
7	5	62	45	-	17	107
8	5	62	45	-	17	124
9	5	64	45	10	9	133
10	5	64	45	-	19	152
11	5	65	45	-	20	172
12	5	65	45	-	20	192
13	5	66	45	-	21	213
14	5	66	45	5	16	229
15	5	68	45	-	23	252
Subtotal	75	942	675	15	252	-
Remaining 5	25	345	225	-	120	-
TOTAL	100	1287	900	15	372	-

Cumulative net revenue = $372 million

Present worth at 8 per cent = $175 million

Present worth at 15 per cent = $109 million

Present worth at 20 per cent = $ 84 million

Present worth of the net revenue to the predicted end of production in the twentieth year has been calculated at discount rates of 8, 15, and 20 per cent per annum as shown. The discount process reflects the time-value of money. The selection of a discount rate to reflect a value to the company depends on the prevailing financial conditions and other factors. Assuming that an 8 per cent discount rate is applicable to obtain the value to the company, the present worth value of the anticipated production over the next 20 years, discounted at 8 per cent per annum, is 175 million dollars. This is the value of the property to the company on the basis of the definition presented earlier.

It has been pointed out that, even in the case of proven properties, some risk exists, and a company purchasing this property would certainly wish to pay a price lower than that based on an 8 per cent discount rate. A price that a willing buyer might be prepared to pay for the property, may be obtained by using a higher discount rate, say 15 per cent, giving a fair market value of some 109 million dollars. The difference between 8 and 15 per cent discount rates allows for the risk involved and for a return on investment greater than that provided by the 8 per cent discount rate.

A second method of obtaining the fair market value is to discount the value to the company by an appropriate amount. In the example above the 15 per cent present worth value is approximately 40 per cent less than the 8 per cent value, but this relationship varies with each property.

The techniques used for evaluation of proven reserves can be applied to reach a reasonable value for unproven properties. The basic concept is that of determining the type of coal deposit most likely to be found on the property and using the present worth method to obtain a value for the production from such a mine developed on the holding. This value is then reduced to allow for the risks of not finding such a deposit.

For the hypothetical case that is used for an example, the following assumptions are made.

(1) The company concerned, having decided to indulge in coal exploration and development, undertakes in the first year a general regional exploration study of a potential area with a view to determining the best properties for acquisition. It is suggested that the expenses for the first year will be $75,000, which include one man spending an entire year on the project and a party in the field for three months, including the use of a helicopter for one month.

(2) After completion of the study, the company is able to select a property of 20,000 acres extent, which, in their opinion, justifies further exploration expenses.

(3) The exploration expenses for the next four years are estimated as shown in table 2.

(4) It is the opinion of the operator that there is a reasonable chance that these expenditures will permit the establishment of proven reserves on the property totalling 100 million tons of economically recoverable coal.

(5) Development work is expected to commence at the beginning of the fifth year, with production beginning in the sixth year at a rate of 2 million tons a year. This is estimated to increase to a rate of 5 million tons a year in the eighth year, and to continue for a total productive life of twenty years.

Table 2. Estimated Schedule of Exploration Costs, Exploratory Property

Year	Phase	Expense (dollars)
-1	Regional Study	75,000
	Acquire Property	
1	Exploration	155,000
2	Exploration	320,000
3	Exploration	370,000
4	Exploration	410,000
		1,255,000

A forecast of coal production, revenue, and present worth, as of the time of the acquisition of the property, may now be prepared. In this forecast, exploration and development expenses must be included.

As shown in table 3, based on the assumptions made, the present worth of the predicted net revenue for this property, discounted at 8 per cent, would be $62 million. Using a 15 per cent discount rate, the present worth would be $5 million. The problem now is to obtain a realistic value of the property, since, at the present stage, there is certainly no guarantee that the suggested mine will be developed.

Let us assume that the operator's best estimate is that there is one chance in six, or a probability of 0.17, that the mine will be developed as predicted and five chances out of six, or a probability of 0.83, that geological, engineering, or economic factors will preclude mine development, and that the property will be dropped after four years of detailed study. At this stage, a total of $1.2 million will have been spent on exploration. The present worth value of the $1.2 million discounted at a rate of 8 per cent per annum over the four-year period is approximately $1.0 million.

Note that at this stage the first year's exploratory costs of $75,000 have already been spent and need not be considered in an evaluation as of the present date. This money is gone whether the property is acquired or not.

If risk is considered, then it might be reasonable to assume in this case that there is one chance in six of obtaining net income with a present value of $62 million and five chances in six of spending $1.0 million in present value with no return, based on a discount of 8 per cent per annum.

The following example illustrates the application of probabilities to a situation where the odds are fixed. A habitual gambler would be willing to bet $1.00 on a one in six chance of a return of $6.00. Multiplying the possible return by the probability gives the sum that he is justified in risking for this return.

Event	Probability	Net Return (dollars)	Expected Value (dollars)
Win	0.166	5.00	0.83
Lose	0.834	-1.00	-0.83
			0.00

Table 3. Forecast of Coal Production, Revenue, and Present Worth (Before Taxes) of an Exploratory Property with 100 Million Tons Potential Reserves

Year	Net Production (million tons/yr)	Gross Revenue ($ million)	Production Expense ($ million)	Capital Investment ($ million)	Net Revenue ($ million)	Cumulative Revenue ($ million)
1	-	-	-	0.15	-	-0.15
2	-	-	-	0.32	-	-0.47
3	-	-	-	0.37	-	-0.84
4	-	-	-	0.41	-	-1.25
5	-	-	-	50	-50	-51
6	2	24	22	50	-48	-99
7	4	50	40	-	10	-89
8	5	62	45	-	17	-71
9	5	64	45	-	19	-53
10	5	64	45	-	19	-34
11	5	65	45	-	20	-14
12	5	65	45	-	20	6
13	5	66	45	-	21	27
14	5	66	45	-	21	48
15	5	68	45	10	13	61
Subtotal	46	594	422	111	61	-
Remaining 11	54	765	487	5	274	-
TOTAL	100	1360	908	116	335	-

Cumulative net revenue = $335 million

Present worth at 8 per cent = $62 million

Present worth at 15 per cent = $ 5 million

Present worth at 20 per cent = $-8 million

This is a breakeven situation which means that if he plays the game often enough, the gambler will not lose but neither will he win. The game is a waste of time. Of course, if he bets slightly less than $1.00 for the same return, he can come out ahead. Note that his net return on a win is only $5.00, since his own dollar is one of those he gets back. In a similar manner, some of the dollars the mineral developer gets back are his own investment dollars. Their return is delayed and their present worth is less at the time of return than at the time of investment.

A similar table can be set up for the coal producer, using present worth values shown previously in table 3.

Event	Probability	Present Worth ($ million)	
		Net Return at 8%	Expected Value
Win (Develop 100 million tons as planned)	0.166	62.0	10.1
Loss (Conduct exploration program with no success)	0.834	-1.0	-0.8
			9.3

The various possible outcomes have been weighted using the probabilities of their occurrence, and the resulting $9.3 million is a weighted average or expected return, using the 8 per cent discount rate.

The probabilities that are assigned are personal probabilities which reflect the experience and judgement of the evaluator rather than statistical information. Note that there is no suggestion that the actual return from development of the property will be $9.3 million, for only one event will actually occur. Only two possible events are considered likely to occur in this example. The operator will either gain $62 million or lose $1 million.

The same situation using 15 per cent present worth values can also be illustrated. In this case possible events are a gain of $5 million or a loss of $1 million, and the expected value would be zero.

Consideration must now be given to the earlier question of how to determine the position of the unproven property on the double-headed arrow, or, in terms of the foregoing example, how to establish that the probability of obtaining commercial production on the property is one in six.

Perhaps there is someone, somewhere, who is familiar enough with all aspects of the problem and has enough experience to assess all of the variables together and confidently state that the probability is one in six or some other number. This seems unlikely.

Like most complex problems, this one can best be solved by breaking it into as many parts as possible and considering each part separately. This particular problem lends itself to a simple division into the four following subproblems:

(1) geology

(2) coal quality

(3) mining

(4) marketing.

Assume that at this early stage of development the geologist is confident that there is one chance in two, or a probability of 0.5, that there are 100 million tons of coal-in-place at a depth that will permit economic mining.

Further assume that, since the available data are limited to non-representative outcrop samples, no specific knowledge of coal quality exists, but it is known from other data that 80 per cent of the coal in the area is of good coking quality and that it is reasonable to assume that 0.8 may be realistically used as a probability for the occurrence of coking coal.

The mining experts contend that there is a 0.5 probability that mining conditions, logistics, and other factors will permit mining at competitive prices.

The marketing expert asserts that there is a 0.8 probability of obtaining a sales contract for the coal.

These separate independent probabilities must now be combined by multiplication to obtain an overall probability of the existence of 100 million tons of coking coal which can be marketed profitably under a sales contract. We thus obtain a 0.16 (0.5 x 0.5 x 0.8 x 0.8) probability of this occurrence.

Of course, it is even more desirable to break each part of the problem down into even smaller subdivisions. From this point on, however, consideration will be given to a subdivision of only the geological phase, although other factors can and should be considered in the actual evaluation.

Under the sort of cross-examining to which evaluation engineers love to subject geologists, it is discovered that the geological work to date has shown an exposure on the flank of a syncline. The geologist has obtained surface dips of a magnitude that will permit economic mining. He believes that there is a 0.5 probability that the seam will continue to dip at this or at a lower angle.

Measurements at the outcrop indicate a coal thickness of something less than a minable thickness but the geologist knows that outcrop measurements are not reliable and he believes that the true thickness, especially towards the axis of the syncline, has a 0.5 probability of being minable.

In his examination to date he has not detected the presence of any faults of a sufficient magnitude to move the coal seam out of reach, and he believes that there is a 0.75 probability that he would have found such faults if they had been present.

When this part of the problem has been broken down into its component parts, it is evident that the geological probability for the occurrence of 1 million minable tons is not 0.5 as suggested above but instead is:

$$0.5 \times 0.5 \times 0.75 = 0.1875 \text{ (approximately 0.19).}$$

The original probability of 0.5, therefore, was not realistically determined because the separate components of the problem were not given individual attention.

Similarly, each of the other estimates could be divided into components with the probable result that the greater the number of subdivisions, the lower the probabilities for a favorable outcome, although this would not always be the case.

Care must be taken that each variable treated in the problem is independent of any of the other variables. It might be argued that, in the example given above, there could be some interdependence between dip and thickness, but it has been assumed for simplicity that the various factors are independent.

When each of the major event groups has been subdivided into as many variables as have been chosen for the problem in question, the probabilities for the various independent variables are then multiplied together to obtain an overall probability for the occurrence of the particular event under consideration.

Note that so far only two possibilities have been considered; developing the 100 million tons of proven reserves of coal, or developing no reserves. It would really be much more precise to introduce several possible occurrences. The geological variables which may be brought in could relate to the thickness, length, and width of the minable coal seam. Since it would be impractical to consider every possible thickness, the following four cases of variable thickness are used in this example: less than 10 feet (which is here considered uneconomic and is omitted from the table), 10 feet, 20 feet, and 30 feet.

Likewise, variable lengths and widths of minable seam are possible. In this example, we have considered the minable length for three possible situations or events: 5,000 feet, 10,000 feet, and 15,000 feet; and the widths for two possible situations: 2,500 feet, and 5,000 feet. Figure 4 is a flow diagram, which shows a probability assigned to each of these occurrences, and the probability and minable tonnage resulting from each possible event. The diagram is, of course, incomplete because all of the events where the thickness is less than 10 feet, the length less than 5,000 feet, or the width less than 2,500 feet have been omitted. It will be seen that possible amounts of coal-in-place, using the variables chosen are between 15 and 270 million tons, and the probability that one of these events will take place is 0.32. This leaves a probability of 1.00 - 0.32 = 0.68 that none of these events will occur or that the coal-in-place will be less than 15 million tons.

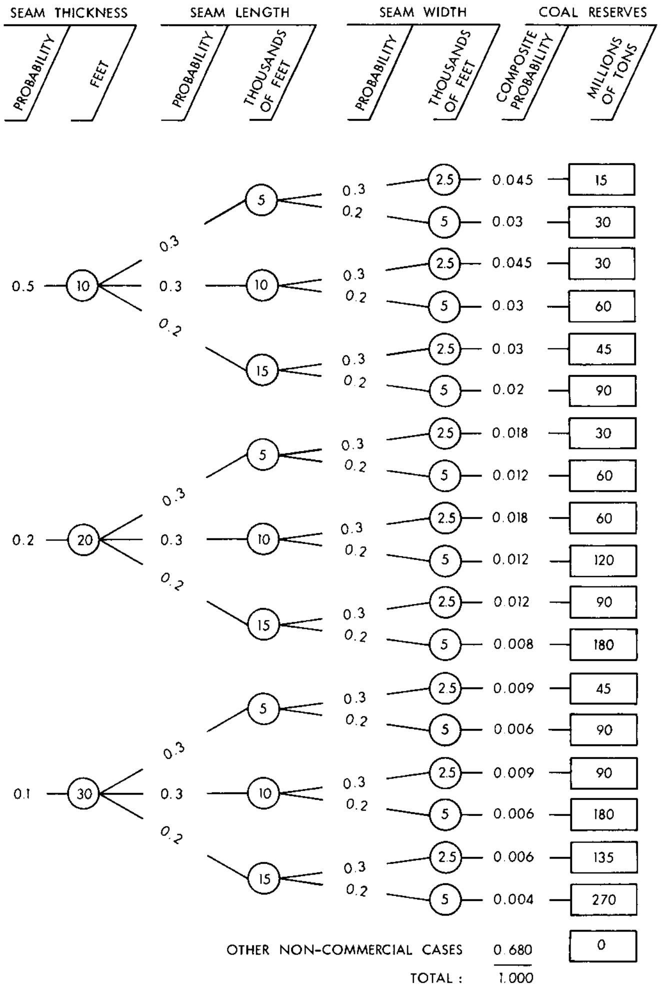

FIGURE 4. Flow diagram showing probabilities of coal discovery in an exploration program.

The present worth of each of the possible cases may now be determined, assuming that nothing less than 60 million tons is economic for mining. A forecast could be prepared for each situation to determine its present worth; however, to simplify the problem, the present worth value per ton that was established for 100 million tons of coal-in-place was used instead. In this example, it was assumed mining would begin in five years, and a present worth value of $0.60 a ton was established based on an 8 per cent discount rate. Consequently, a value of $0.60 a ton has been used throughout the analysis to provide an 8 per cent present worth value of net return for each of the events as shown in table 4. Each event then may be multiplied by the

Table 4. Expected Monetary Values, Exploratory Property

Event (million tons)	Probability	Present Worth ($ million)			
		Net Return at 8%	Net Return at 15%	Expected Value at 8%	Expected Value at 15%
15	0.045	-1.0	-1.0	-0.045	-0.045
30	0.030	-1.0	-1.0	-0.030	-0.030
30	0.045	-1.0	-1.0	-0.045	-0.045
60	0.030	36.0	3.0	1.080	0.090
45	0.030	-1.0	-1.0	-0.030	-0.030
90	0.020	54.0	4.5	1.080	0.090
30	0.018	-1.0	-1.0	-0.018	-0.018
60	0.012	36.0	3.0	0.432	0.036
60	0.018	36.0	3.0	0.648	0.054
120	0.012	72.0	6.0	0.864	0.072
90	0.012	54.0	4.5	0.648	0.054
180	0.008	108.0	9.0	0.864	0.072
45	0.009	-1.0	-1.0	-0.009	-0.009
90	0.006	54.0	4.5	0.324	0.027
90	0.009	54.0	4.5	0.486	0.040
180	0.006	108.0	9.0	0.648	0.054
135	0.006	81.0	6.7	0.486	0.040
270	0.004	162.0	13.5	0.648	0.054
NC	0.680	-1.0	-1.0	-0.680	-0.680
	1.000			7.351	-0.174

probability of its occurrence in order to obtain the expected value of that event.

It must be remembered that an exploration expense has to be allocated to each uneconomic event. For purposes of illustration, the same exploration cost has been used for each event. It is obvious, however, that in practice this cost would vary somewhat – as evidence became available that potential reserves were restricted, much of the exploration cost would be curtailed. If it became apparent that larger reserves could be anticipated, then an increase in the exploration budget would be necessary. In the analysis, an event is also included for the case of discovery of insufficient coal-in-place to be economically recoverable. As previously mentioned, various combinations of events representing non-commercial coal seams have not been shown in figure 4. Since the probabilities shown on the figure total to 0.32, the combined probability of these non-commercial events must be 0.68 (or 1.00 - 0.32). The net return of these events, of course, gives a negative expected value, as do all of the events with less than 60 million tons where an exploration cost is involved. The expected monetary returns for all of the possible events must be added to get what is, in effect, a weighted or expected return from the property and therefore an approximation of the value of the property.

As stated at the beginning, value is, or at least should be, the net amount that may be expected to be returned by the property, taking risk into account and using the appropriate discount rate. In table 4, we have used an 8 per cent discount rate, resulting in a present worth or value to the company of $7.3 million. For comparison, the use of a 15 per cent discount rate is also shown in table 4, giving a value of -$0.174 million. It should be remembered that only the geological risk has been considered in this example.

VALIDITY OF RESULTS

Ideally, the approach to evaluation outlined here has its greatest potential when a company undertakes a large number of investments, just as the amount that may be prudently bet on a roll of the dice or a draw in a poker game has its best application where the action is to be repeated many times. When many properties are being considered, there is an opportunity for each of the events being considered to occur, and the averaging effects give the method its greatest value. Even when only a few properties are considered, the method has its value because it permits a uniform, repeatable, and fair approach to each of the property evaluations.

The validity of the results obtained depends largely, if not entirely, on the accuracy of the information that is used, and particularly on the reliability of the probabilities. The method in no way reduces the need for technical competence in the fields of geology, engineering, marketing, and taxation but, in fact, emphasizes the need for competence in these fields by requiring a mathematical probability assessment of each of a number of events. The geologist, engineer, or economist who is required to state the probability of an event occurring will most likely give the entire problem more careful consideration, and his answer will be more meaningful than if he merely has to state there is a poor, fair, or good chance of it occurring without defining these terms.

It should be emphasized, although it is undoubtedly obvious from the foregoing results, that while the value quoted is the weighted or expected monetary return from the property, there is no assurance of such a return and that an investment should only be made if the investor is prepared to absorb the losses in the case of an unfavorable result.

As properties move closer to the production stage, probabilities can be assigned with more confidence because of the more detailed information available. However, the possibility of losing most or all of one's investment must always be considered.

SUMMARY AND CONCLUSIONS

While the method outlined may appear to some to be over-mathematical in nature, it is no more than a carefully planned and charted formal approach to what is often done informally by the prudent investor, who will decide on his investment by mentally assessing the probability of favorable returns. The main advantage of formal processes, such as have been suggested, over informal processes is that formal processes tend to reduce the chances for error and inconsistent action.

To summarize, the monetary evaluation of properties should be approached in the following manner.

(1) Determine the net revenue to be expected from development of the property.

(2) Discount future net revenue to allow for the time-value of money. Discount rates to be used depend on the financial climate and the purpose of the evaluation.

(3) In the case of unproven properties, the net revenues to be expected for a range of possible events relating to the specific properties must be multiplied by the probability of each event taking place to introduce the degree of risk and to obtain the weighted anticipated net return.

(4) Probabilities should be determined by breaking the problem into as many independent events as possible and by assigning personal probabilities for each event.

In conclusion, the method that we have just discussed permits a uniform, realistic, and consistent approach to the evaluation of proven and unproven properties. Assignment of probabilities forces the evaluator to consider the problem in quantitative terms. Exploration or acquisition costs, past or future, ***per se*** are not a realistic measure of the value of a property. However, consideration of future anticipated costs is an integral part of the evaluation procedure.

REFERENCES CITED

EGGLESTON, W. S. (1965): Estimating fair market value of petroleum properties; Third Symposium on Petroleum Economics and Evaluation, Dallas, Texas.

COMPUTER STORAGE AND RETRIEVAL OF GEOLOGIC DATA ON COAL DEPOSITS

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ABSTRACT

In recent years, a number of sophisticated and extremely versatile data management systems have become available. One such system, SAFRAS, developed in the Geology Department of the University of Western Ontario, has been utilized to construct a file containing mainly data published by the Research Council of Alberta on more than 1500 coal mines in Alberta.

In its present state, the file must be regarded as experimental, incomplete, and preliminary in nature, and as yet does not conform completely to national standards currently being developed for such files. The file has already been used, however, to provide an analysis of the coal deposits of the Alberta Plains (Steiner ***et al.***, 1972), which could only have been obtained at prohibitive cost by other means.

A possible maximum of 67 data items grouped into three categories, were recorded for each of 1693 entries in the file:

(1) index data – location, mine number, type and area, dates of commencement and cessation of operations, total years operating, and last operator's name;

(2) geological data – stratigraphic names and ages of surface bedrock and producing units, number of seams, seam interval, gross thickness of coal, seam thicknesses and elevations, roof and floor lithologies, thickness of cover, bedding attitudes, and elevations of marker horizons below the coal measures;

(3) analytical data – proximate and other analytical data, and production figures.

Data are entered in plain language, easily-understood mnemonic abbreviations or numeric values as appropriate. Construction of the file was begun in April, 1971 and utilization of the file began in August. Retrievals, which are requested by simple statements essentially in plain language, may be used directly or serve as input for other programs which analyze the retrieved data and display the results as maps or other diagrams.

Total cost of the project to the end of October, 1971 is estimated at $2000 to $2500 (exclusive of costs of installing the SAFRAS System and the investigators' time), most of which was in wages for technical assistants. A typical SAFRAS installation costs $3000 to $5000, but once installed is inexpensive to operate. Cost of building a file the size of the one used in this project is in the order of $30 to $40 with simple retrievals less than $5 each.

INTRODUCTION

Geologists, among scientists, have been and in many cases still are reluctant to accept the computer as a fact of modern scientific life and as an extremely valuable tool. Most geologists are not mathematically-oriented and seem to have an inherent resentment towards and distrust of techniques which require extensive manipulation of numbers. Many, if not most, appear to have been convinced that the computer can only deal with information which has been reduced to numbers and codified to the point of having lost its "geological" meaning.

It is undoubtedly true, furthermore, that much geological information is assembled and transmitted in the form of conclusions which have been arrived at more-or-less intuitively, rather than in the form of basic data. It is also apparent that much geologic "data" is descriptive and highly subjective because of scale factors (time, space), lack of precision of measurement, and continuity of objects and concepts. Many geologists are convinced that the inherent nature of geologic information makes the use of computers suspect, and that if geologic information is made to "fit the computer," the geologist's traditional freedom of expression will be restricted with a resultant loss or distortion of information.

Encouragingly, some of this reserve is beginning to dissipate. An Association for Mathematical Geology exists, the IUGS has an active Committee on Storage, Automatic Processing and Retrieval of Geologic Data, the National Advisory Committee on Research in the Geological Sciences (NACRGS) has a subcommittee dealing with computer applications, and as a result of investigations begun by NACRGS in 1964, the Canadian Centre for Geoscience Data was established within the Geological Survey of Canada in 1970.

Since 1968, the Geological Survey of Canada has provided funds to stimulate research into the development and application of computer-processable files of geologic data. The present project was undertaken with financial support from this program through GSC Grant No. 42-66 held by the senior author, and this assistance is gratefully acknowledged.

Acknowledgments

The authors are pleased to acknowledge the assistance of Miss Ann Bartlett-Page, who aided in the installation of SAFRAS at the University of Alberta, and subsequently nursed, cajoled and modified the system to its present high level of efficiency. J. E. Klovan provided much valuable assistance with the analytical aspects carried out at the University of Calgary.

OBJECTIVES

The project was undertaken with two major objectives in mind. The first objective was to develop experience in handling geologic data on coal deposits, to complement the work currently under way on oil and gas pools (Dickie and Williams, in press; Williams and Dickie, in press). Numerous other files of geologic data on metallic mineral deposits are under construction in Canada, and efforts are being made under the auspices of NACRGS to develop minimum national standards for all such data files including files dealing with fossil fuels. Ultimately it is hoped that all Canadian files of geologic data will utilize basic standards pertaining to content and notation and will thereby be linked together in what has been referred to as the Canadian System for Geologic Data (Burk, 1970).

The second objective was to utilize the large amount of data on Alberta coal mines which was published in the form of catalogues by the Research Council of Alberta (Campbell, 1964; 1966), but which had not been applied further, as far as the authors are aware. The attainment of this latter objective is the basis for the companion paper in this volume (Steiner ***et al.***, 1972).

DATA STORAGE AND RETRIEVAL SYSTEM

Some of the first geologic applications of the computer in the field of data storage were the development of well-data systems in the petroleum industry (Stauft, 1966). These early systems were strongly machine-oriented as a consequence of the relative simplicity of the computers which were then available, and the disenchantment which many geologists feel towards computers may be traced to exposure to such primitive systems. As computers have become more sophisticated, they have become more versatile, and it is now no more necessary to be an expert programmer in order to use a computer than it is necessary to be an electronics engineer to tune in the Saturday-night hockey game on the family television set.

In recent years, a number of user-oriented, generalized data-management systems have been developed. Typical of these are GIPSY (***G***eneralized ***I***nformation ***P***rocessing ***SY***stem; Sweeney ***et al.***, 1969), and the MARK IV system (commercially available from Informatics, Inc.). However, most data storage and retrieval systems have been devised for specific projects or computers and as a consequence have limitations of various kinds – either in applicability or cost availability – when applied to other projects.

The storage and retrieval system used for this project is known as SAFRAS (***S***elf ***A***daptive ***F***lexible ***R***etrieval ***A***nd ***S***torage) and was developed by a geologist for geologists (Sutterlin and de Plancke, 1969). It is available commercially from the University of Western Ontario, London, Ontario, for a modest licencing fee. At the time of writing, SAFRAS had been installed or was being installed on a variety of computers at six different institutions (Department of Energy, Mines and Resources, Ottawa – 2 installations; Ontario Department of Mines; Colorado School of Mines; St. Francis Xavier University; University of Manitoba; University of Alberta) in addition to the University of Western Ontario.

The installation at the University of Alberta utilizes an IBM System 360/67 computer running under MTS (Michigan Terminal System) and IBM Operating System. The system can be used in "batch mode" at the central computer site, or from a remote-access terminal, and in either mode only a minimal understanding of the control system is required of the user.

SAFRAS consists of a group of computer routines which themselves are not complete storage and retrieval programs, but which generate a complete system when provided with a list of the items that are to be stored. This list, constructed by the user, specifies the data which are to be included in the file, and their sequence, in effect describing the file to the skeleton library of basic SAFRAS routines (Table 1). The data specifications must include a unique identifier (may be alphabetic, numeric or a mixture of alphabetic and numeric characters) for each station (each unit in the file is termed a "station" – that is, a mine, a borehole, an outcrop, etc.) in addition to the list of names of the data items to be recorded. The name of each data item must be unique and may consist of not more than 30 characters, including dashes which are used to separate individual words in a single name. In addition, for each named data item, the number of characters (space or field width) to be reserved in the file for that item must be specified (there are no restrictions on how much room may

Table 1. Data Specifications Used in Constructing the Coal File

Data Name	Field Width	No. of Decimals	Type of Data[1]	Per cent in File[2]
Index Data: Type *0101				
INSTITUTION[3]	4		A	100
REFERENCE-NUMBER[3]	10		N	100
PROVINCE	4		A	100
COAL-AREA	15		X	100
MINE-NUMBER	4		N	100
MINE-TYPE	2		A	80
MINE-LOC-LSD	38		X	89
MINE-LOC-QUARTER	8		X	7
MINE-LOC-RL	11		X	0
MINE-LOC-SEC	2		N	100
MINE-LOC-TWP	3		N	100
MINE-LOC-RGE	2		N	100
MINE-LOC-MER	1		N	100
MINE-LOC-LAT[3]	8	5	N	100
MINE-LOC-LONG[3]	9	5	N	100
MINE-LOC-OTHER	20		X	0
MINE-LOC-AREA	3		N	100
LAT-LONG-PRECISION	1		N	0
OPERATION-COMMENCED	4		N	63
OPERATION-CEASED	4		N	63
YEARS-OPERATING	2		N	63
OPERATING	1		A	100
LAST-OPERATOR	30		X	100
INDEX-REMARKS	30		X	9
Geologic Data: Type *0201				
SURFACE-BEDROCK-UNIT-NAME[3]	4		A	0
SURFACE-BEDROCK-UNIT-MODIFIER[3]	1		A	0
SURFACE-BEDROCK-UNIT-AGE[3]	3		N	0
SURFACE-ELEV-MIN[3]	4		N	100
SURFACE-ELEV-MAX[3]	4		N	100
PRODUCING-UNIT-NAME	4		A	100
PRODUCING-UNIT-MODIFIER	1		A	73
PRODUCING-UNIT-AGE	3		N	96
NUMBER-OF-SEAMS	2		N	41
SEAM-INTERVAL	4		N	0
THICKNESS-SEAM-ONE-MIN	4	1	N	43
THICKNESS-SEAM-ONE-MAX	4	1	N	43
SEAM-ONE-ELEV	4		N	14
ROOF-LITHOLOGY-ONE	4		A	21
FLOOR-LITHOLOGY-ONE	4		A	18
THICKNESS-SEAM-TWO-MIN	4	1	N	0
THICKNESS-SEAM-TWO-MAX	4	1	N	0
SEAM-TWO-ELEV	4		N	0
ROOF-LITHOLOGY-TWO	4		A	0
FLOOR-LITHOLOGY-TWO	4		A	0
THICKNESS-SEAM-THREE-MIN	4	1	N	0
THICKNESS-SEAM-THREE-MAX	4	1	N	0
SEAM-THREE-ELEV	4		N	0
ROOF-LITHOLOGY-THREE	4		A	0
FLOOR-LITHOLOGY-THREE	4		A	0
GROSS-FEET-COAL	4	1	N	45
COVER-THICKNESS-MIN	4		N	52
COVER-THICKNESS-MAX	4		N	52
DIP-DEGREES-MIN	2		N	0
DIP-DEGREES-MAX	2		N	0
DIP-DIRECTION	3		N	0
ELEV-FIRST-SPECKS[3]	5		N	99
STRAT-REMARKS	30		X	34
Analytic Data: Type *0301				
MOISTURE	3	1	N	5
ASH	3	1	N	5
VOLATILES	3	1	N	5
FIXED-CARBON	3	1	N	5
GROSS-BTU-LB	5		N	5
COKE-BUTTON	1		N	0
GROSS-TONS-MINED[3]	8		N	0
TONS-MINED-70[3]	7		N	1
TONS-MINED-69[3]	7		N	1
ANALYTIC-REMARKS	30		X	0

[1] A - indicates alphabetic data, N - indicates numeric data, and X indicates mixed alpha-numeric data

[2] The proportions of various items actually present in the file based on a uniformly-distributed sample of 100 stations

[3] Data items from sources other than Campbell (1964, 1966)

be reserved for each data item) as well as whether the data are alphabetic, numeric or a mixture of letters and numbers (if numeric and containing decimals, the number of digits to the right of the decimal point must also be specified). For example, an item of data termed "DIP-DIRECTION" would require 3 characters ("field width") if given as an azimuth reading (0-360 degrees) and would be specified as numeric data without decimals. Another item termed "ANALYTIC-REMARKS" could have reserved for it a space several tens or hundreds of characters wide (a field width of 30 characters was specified for remarks in this file solely for sake of economy in file-building) and could contain a mixture of alphabetic and numeric data (Table 1).

The data specifications may be listed in any order, provided the order is always the same for each station in the file; however, for sake of convenience in collecting and editing, the items of data are usually grouped into types (for example, index [location] data, geologic data, and analytical data – Table 1). It is emphasized that each of the data names must be unique, as they form the basis of data retrievals.

The SAFRAS "system generator," when provided with a keypunched list of data specifications, produces "file generator" and "file editor" programs within the computer. A "source document," which is a convenient form to use in collecting data for keypunching, can also be produced (Figs. 1 and 2).

The file generator program, when provided with the actual data, keypunched in the format of the source document, produces the data file in the computer and prints a list of errors which may have been discovered in producing the file (for example, numeric data in a field specified as alphabetic, or more than the specified number of characters in a field). Such errors are normally corrected by replacing the offending data cards and rebuilding the file.

A simply-worded retrieval request (Fig. 3), when provided to the "retrieval generator" with the list of data specifications, produces a detailed retrieval and output program which searches the data file and presents the requested data as printed copy, on punched cards, on magnetic tape or on disc as specified in the retrieval request.

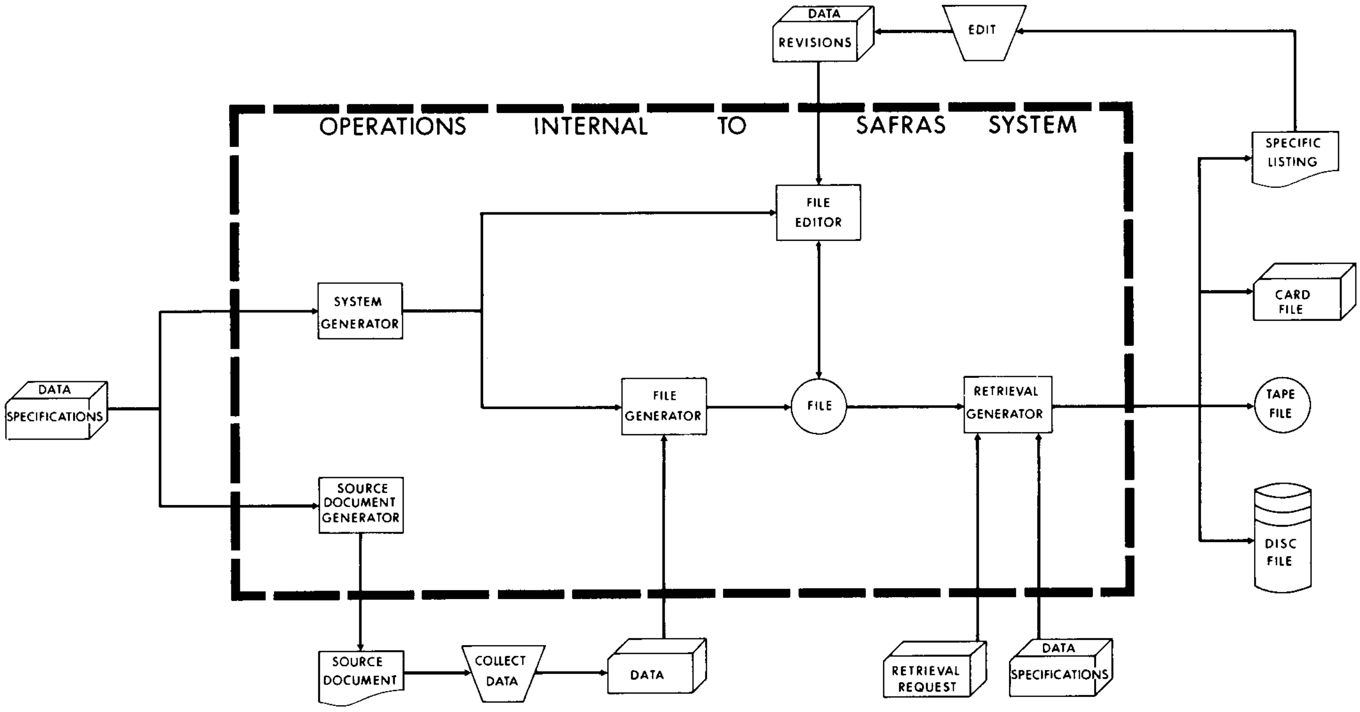

FIGURE 1. Schematic diagram of the SAFRAS System. Operations performed internally by the system are inside the heavy dashed line, with user-provided input and system output outside the heavy line. Card, tape or disc files generated by a retrieval request are normally used as input to analytical or mapping programs.

CODE / INSTITUTION / REFERENCE-NUMBER / PROVINCE / COAL-AREA / MINE-NUMBER / MINE-TYPE /

*0101 / / / / / / /

MINE-LOC-LSD / MINE-LOC-QUARTER / MINE-LOC-RL / MINE-LOC-SEC / MINE-LOC-TWP / MINE-LOC-RGE /

/ / / / / /

MINE-LOC-MER / MINE-LOC-LAT / MINE-LOC-LONG / MINE-LOC-OTHER / MINE-LOC-AREA / LAT-LONG-PRECISION /

/ / / / / /

OPERATION-COMMENCED / OPERATION-CEASED / YEARS-OPERATING / OPERATING / LAST-OPERATOR /

/ / / / /

INDEX REMARKS /

/

CODE / SURFACE-BEDROCK-UNIT-NAME / SURFACE-BEDROCK-UNIT-MODIFIER / SURFACE-BEDROCK-UNIT-AGE /

*0201 / / / /

SURFACE-ELEV-MIN / SURFACE-ELEV-MAX / PRODUCING-UNIT-NAME / PRODUCING-UNIT-MODIFIER / PRODUCING-UNIT-AGE /

/ / / / /

NUMBER-OF-SEAMS / SEAM-INTERVAL / THICKNESS-SEAM-ONE-MIN / THICKNESS-SEAM-ONE-MAX / SEAM-ONE-ELEV /

/ / / / /

ROOF-LITHOLOGY-ONE / FLOOR-LITHOLOGY-ONE / THICKNESS-SEAM-TWO-MIN / THICKNESS-SEAM-TWO-MAX /

/ / / /

SEAM-TWO-ELEV / ROOF-LITHOLOGY-TWO / FLOOR-LITHOLOGY-TWO / THICKNESS-SEAM-THREE-MIN /

/ / / /

THICKNESS-SEAM-THREE-MAX / SEAM-THREE-ELEV / ROOF-LITHOLOGY-THREE / FLOOR-LITHOLOGY-THREE /

/ / / /

GROSS-FEET-COAL / COVER-THICKNESS-MIN / COVER-THICKNESS-MAX / DIP-DEGREES-MIN / DIP-DEGREES-MAX /

/ / / / /

DIP-DIRECTION / ELEV-FIRST-SPECKS /

/ /

STRAT-REMARKS /

/

CODE / MOISTURE / ASH / VOLATILES / FIXED-CARBON / GROSS-BTU-LB / COKE-BUTTON / GROSS-TONS-MINED /

*0301 / / / / / / / /

TONS-MINED-70 / TONS-MINED-69 /

/ /

ANALYTIC-REMARKS /

/

*FIGURE 2. SAFRAS source document for the coal file. Data are entered on alternate lines beneath the appropriate data names in the formats given in the Data Specifications (Table 1), i.e., data entered under INSTITUTION would consist of four alphabetic characters, under REFERENCE-NUMBER, ten numeric characters, etc. Only the alternate lines containing data are keypunched, including all slashes, even when no data are present. Each record type (e.g., *0101, *0201) must start on a new card.*

Retrieval Request:

```
IF ((1905 GE OPERATION-COMMENCED) AND
   (1900 LT OPERATION-COMMENCED))
PUNCH /080/ COAL-AREA MINE-NUMBER MINE-LOC-AREA
   YEARS-OPERATING GROSS-TONS-MINED
IN FORMAT A/15/S/1/N/4/S/2/N/3/S/3/N/2/S/2/Z/8/STOP
```

Translation:

If for any station, 1905 is greater than or equal to the data in category "OPERATION-COMMENCED" and 1900 is less than the data in category "OPERATION-COMMENCED" (i.e., operations commenced between the years 1901 and 1905 inclusive), punch on 80 column cards the data for that station in categories "COAL-AREA" "MINE-NUMBER", "MINE-LOC-AREA", "YEARS-OPERATING" and "GROSS-TONS-MINED" in the following manner:

"COAL-AREA" - 15 alphabetic characters
One blank space
"MINE-NUMBER" - 4 numeric characters
Two blank spaces
"MINE-LOC-AREA" - 3 numeric characters
Three blank spaces
"YEARS-OPERATING" - 2 numeric characters
Two blank spaces
"GROSS-TONS-MINED" - 8 numeric characters (suppress leading zeros) then move to the next station.

FIGURE 3. Typical SAFRAS retrieval request. Conditions to be met are specified by LT (less than), LE (less than or equal to), EQ (equal to), GE (greater than or equal to), GT (greater than), are connnected by AND and OR, and are enclosed in brackets. PUNCH, PRINT and WRITE specify output to be in the form of punched cards, line printer listing, and magnetic tape or disc, respectively.

Proofreading the file for errors normally consists of requesting specific listings of parts of the file and checking these against the original source documents. Errors also may become apparent when specific retrieved data in the form of punched cards or tape or disc files are used as input for analytical or mapping programs. The file editor program is used to replace incorrect items in the file with corrected or revised items.

Figure 1 summarizes the operation of the SAFRAS System as installed at the University of Alberta. As may be seen from the figure, all the programming necessary for file construction, editing and retrieving data from the file is performed internally by the system. The user must provide only a list of the data items, the data to be stored, the corrections for editing purposes, and a statement specifying the data to be retrieved.

A further refinement of the SAFRAS System, known as the MERGE capability, is now undergoing final testing at University of Western Ontario. The MERGE routine will permit revision of file format (change of data specifications), expansion of a file by incorporating data not included in the original specifications, and combination of two files of differing formats into a single file. In each of these cases, all the programming necessary to accomplish the required modifications is performed within the system, with the user providing only the additional (or new) data specifications and data. MERGE is potentially the most powerful and important aspect of SAFRAS because it will permit a dynamic rather than static approach to file construction and use, ensuring that files do not become "stale," and obviating the need for frustrating, expensive and time-consuming system redesign during the course of a project.

FILE CONTENTS

Data items included in the file (Table 1) are mainly those which are available in the existing catalogues (Campbell, 1964; 1966); those few items not obtained from the catalogues are identified in table 1 and in the following discussion. The file contains approximately 1693 entries for the more than 1500 mines listed by Campbell (1964) (because of the listing system Campbell used, many mines appear more than once, and each appearance in Campbell's list constitutes a file entry). A possible maximum of 67 items were recorded for each entry (Table 1); in practice only about 35 to 40 per cent of these were actually available. The restriction in scope of the file has imposed some rather severe limitations on usage and interpretation of the data, as will be discussed below, but was necessitated by practical time considerations. The existing file must be regarded as incomplete and experimental in nature. It is now being expanded and redesigned to accommodate data from diverse other sources and to conform to preliminary national standards for mineral deposits data files which are under discussion by a working subcommittee of the NACRGS.

Data were entered into the file in several forms. Remarks are essentially in plain language, the words being enclosed in quotation marks ' ', or with spaces between words replaced by dashes to conform to system requirements. Many stratigraphic, lithologic and other data were reduced to easily-understood 4-letter mnemonic codes according to the procedure recommended by The American Association of Petroleum Geologists (Cohee, 1967). For example, "Edmonton" becomes EDMN, "Shale" becomes SHLE, and "Sandstone" becomes SNDS. Data which are already in numeric form pose no special problems.

The following comments should be read in conjunction with the list of data specifications provided in table 1. The column entitled "Per Cent in File" in the table is not part of the data specifications, but is an indication of the proportions of the various items actually present in the file, based on a uniformly-distributed sample of 100 stations.

Index Data: Type *0101

These data deal with identification and location of the station, the code "*0101" indicating to the SAFRAS System that this is the first record for a station (*01xx) and that there is only one record of this type (*xx01). The system provides for up to 99 different record types (our file uses 3 types) with up to 99 records in each type (our file uses 1 record for each type).

Data include the organization at which the file was constructed (University of Alberta, Geology Department) and a reference number which identifies year of construction, the number assigned to the particular file by the institution, and an access number for each station in the file, in addition to location and related data. Each mine in Alberta is identified in the file by the unique number assigned by the Provincial Department of Mines and Minerals, and locations are given in the Dominion Land Survey System (Lsd., Sec., Twp., Rge., Mer.). In the catalogues (Campbell, 1964; 1966) some old mines were located only by sections or quarter-sections, and others by river lots (as in the St. Albert Settlement). These latter were converted manually to DLS locations, and then all DLS locations were converted to latitude and longitude (in degrees and decimals), using a computer program which was acquired commercially, and entered into the file. No attempt was made to establish the precision of location, although the file provides space for such data.

Because it was impossible to check the original records and plans for each mine in the file in the time at our disposal, two arbitrary decisions were made which severely affect the accuracy of two items of data in the file. In the first case, the mine area (MINE-LOC-AREA) was considered to be the number of acres represented by the total number of Lsd.'s listed in the catalogues for a particular mine. For example, workings only a few acres in extent that happened to overlap the common corner of four Lsd.'s would be assigned an area of 160 acres (4 x 40 acres); mines located only by quarter-section were assigned 160 acres, and the few that were located only by section were assigned 640 acres.

In the case of operating lifetime (YEARS-OPERATING), all mines were considered to have been in operation for a minimum of one year, even though the mine number may have been issued and cancelled in the same year.

Many numbered "mines" which were assigned areas of 40 acres or more and lifetimes of one or more years may well have consisted only of a few feet of adit into a river bank, worked sporadically to provide a local source of fuel, and some probably existed only on paper in the records of the Department of Mines and Minerals.

Geologic Data: Type *0201

These data deal with the geologic attributes of the mines, insofar as they are known from the catalogues and easily-accessible supplementary data sources. Details of surface bedrock were to be obtained from the most recent geological map of Alberta, but a lack of time prevented their collection. In most cases surface bedrock would be the producing unit which was listed in the catalogues. Minimum and maximum surface elevations were obtained from the 1:50,000 scale topographic maps published by the Government of Canada.

Provision was made for recording data on up to three seams for each mine, whereas as data collection proceeded, it became obvious that only one seam was being exploited in each mine. In the Foothills this may not have been the case. The total thickness of coal reported (GROSS-FEET-COAL) is often greater than the seam thickness, because it was obtained from section logs given in the catalogues and includes thinner, non-mineable beds adjacent to the seam being exploited.

To provide a stratigraphic reference level against which seam elevations could be compared, the elevation of the top of the Colorado Group (ELEV-FIRST-SPECKS) was included in the file. These data were obtained from unpublished 1 inch = 16 mile regional subsurface maps used by Robinson *et al.* (1969).

Analytic Data: Type *0301

These are mainly data on proximate analyses and production, and as may be seen from table 1, very few are available either from the catalogues or readily-accessible alternate sources. Data on production are available from the Provincial Department of Mines and Minerals, but in the time available only annual production figures for those mines operating in 1969 and 1970 were obtained. Data on sulphur content are available for some mines from Stansfield and Lang (1944), but were not included in the file.

APPLICATIONS

In many cases, a simple listing of certain attributes of stations which satisfy specified criteria (for example, all mines in the Edmonton Formation between townships 30 and 55 and between the fourth and fifth meridians) is all that is required from the file. On the other hand, data retrieved from the file in the form of punched cards, or on magnetic tape or disc can serve as input to other programs capable of analyzing the data and producing summaries, graphs or maps as appropriate. It is this latter application which has been emphasized in the present project and which in many cases is the main justification for the construction of large data files. Storage and retrieval is certainly not an end in itself!

Analytical Programs

To demonstrate simple analysis of selected data in the file, two series of retrieval requests were made which produced decks of punched cards in lieu of line-printer listings. The punched cards were taken to the University of Calgary where they were used to create subfiles of the selected data in magnetic disc storage which then served as input to a number of analytical programs on the University of Calgary CDC 6400 computer. These files contain data on year operations commenced, name of coal area, mine number, mine location area, total years operating, producing unit and gross footage of coal.

A simple counting program tabulated data used to draw the histograms of figures 4 and 5. Figure 4 is historically interesting as it documents the surging optimism of the coal industry during the first decades of this century, an optimism which was based upon rapid expansion of the railroads and the prospects of exporting cheap Alberta coal to eastern Canada, and which faltered only slightly during World War I. The optimism disappeared abruptly with the onset of the Depression years, and, except for just before and just after World War II, the number of new mines commencing operations has continued to fall, reflecting a continuing switch away from coal as a fuel. Only four new mines began operations in the ten years from 1961 to 1970. Figure 5 illustrates the distribution of mines by producing unit, and shows the overwhelming dominance of mines which produced from the Edmonton Formation (particularly Lower and Middle Edmonton = Horseshoe Canyon Formation) in central Alberta.

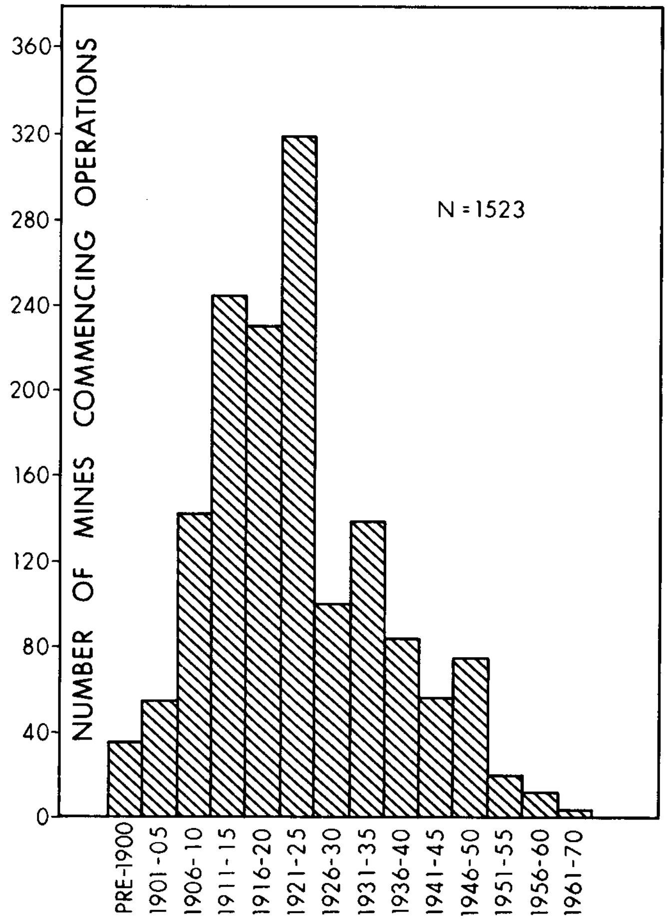

FIGURE 4. Histogram showing numbers of mines in the Alberta Plains commencing operations in each five-year period between 1901 and 1960. Additional categories accommodate those mines which began operations in 1900 or earlier and during the ten years between 1961 and 1970.

A more sophisticated program was used to analyze the data on area, gross thickness of coal, and mine lifetime. The program calculates maximum, minimum and mean values and standard deviations, and constructs frequency histograms and cumulative curves on a line-printer or remote-access terminal. Either arithmetic- or logarithmic-scale ordinates may be chosen for the graphs.

Figure 6 is a frequency histogram of mine areas, drawn with a logarithmic (base 10) ordinate. As discussed above, areas are assigned to each mine on the basis of surveyed units, and the three peaks evident on the histogram probably represent groups of small workings which were located by legal subdivision (Lsd.), quarter-section, and section.

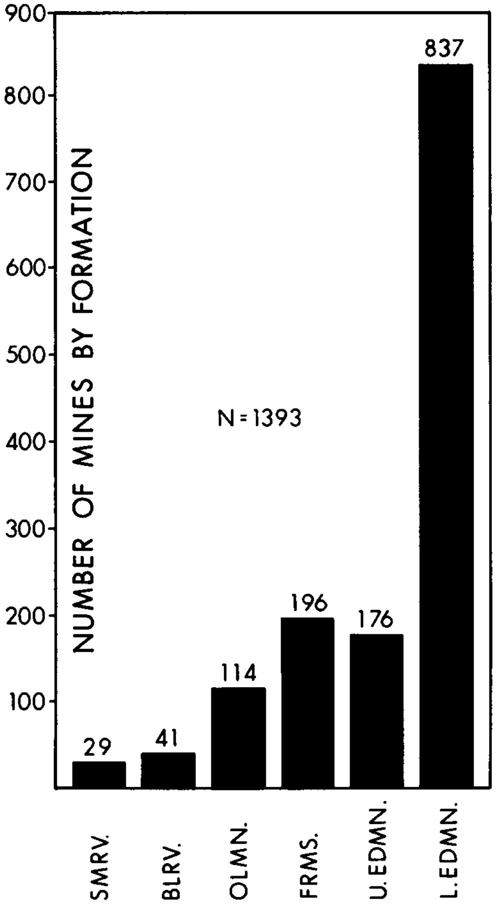

FIGURE 5. Histogram showing distribution of mines in the Alberta Plains by map unit. SMRV = St. Mary River Fm.; BLRV = Belly River Fm. (undifferentiated); OLMN = Oldman Fm.; FRMS = Foremost Fm.; U.EDMN = Upper Edmonton Fm. (Allan and Sanderson, 1945); L.EDMN = Lower and Middle Edmonton Fms. (Allan and Sanderson, 1945).

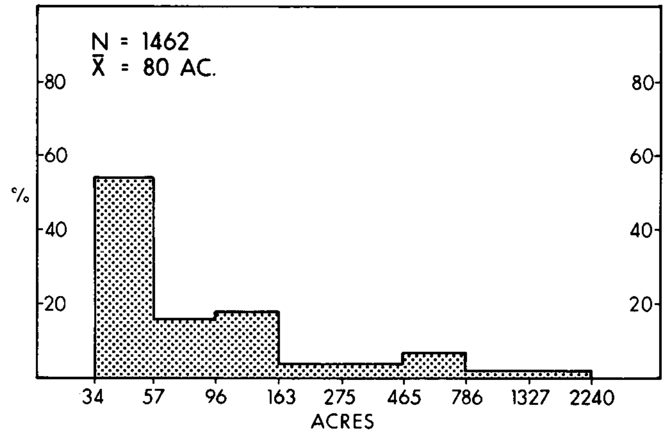

FIGURE 6. Histogram showing distribution of mine areas in the Alberta Plains. The three peaks probably reflect the procedure followed in assigning areas to individual mines (see text). Horizontal scale is logarithmic to base 10.

Beyond illustrating the range of areas encountered, the plot has little value.

Figure 7 illustrates the range of operating lifetimes of mines in Alberta, again utilizing a logarithmic (base 10) ordinate. Approximately 45 per cent of the mines licenced by the Province of Alberta were in operation for three years or less and nearly 30 per cent operated for one year or less. At the other end of the scale, one mine is recorded as having operated for 72 years, the average (logarithmic mean) being 4.3 years.

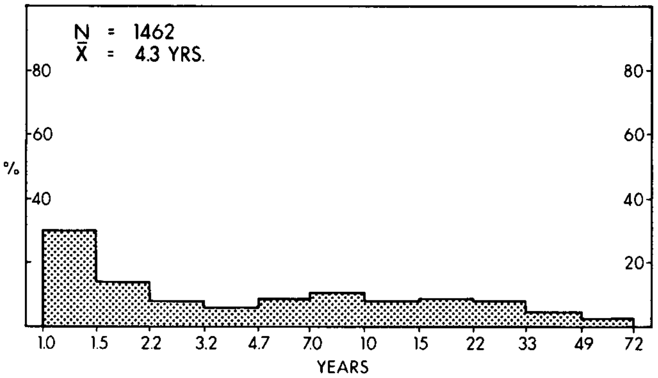

FIGURE 7. Histogram showing distribution of mine lifetimes in the Alberta Plains. Horizontal scale is logarithmic to base 10.

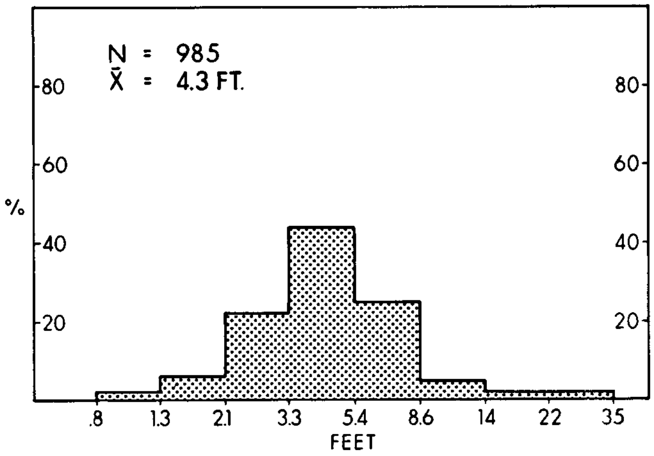

FIGURE 8. Histogram of reported gross thicknesses of coal for mines in the Alberta Plains, irrespective of producing formation. Horizontal scale is logarithmic to base 10.

Data on gross thickness of coal were analyzed by map unit and combined for all mines for which values were available. Figure 8 presents the combined summary data from 985 mines as a histogram with a logarithmic (base 10) ordinate. As may be seen from the figure, thickness values appear to be log normally distributed, having a log mean value of 4.3 feet and a log standard deviation of 1.6 feet. Similar histograms were obtained when gross coal thicknesses were analyzed by formation. Table 2 summarizes all the results of thickness analyses.

Table 2. Tabulation of Reported Gross Footages of Coal by Map Unit for Mines in the Alberta Plains

Map-Unit	No. of Mines	Thickness (ft)			
		Minimum	Maximum	Log Mean	Log SD[1]
"U. Edmonton"	127	0.90	30	5.70	1.64
"L. & M. Edmonton"	596	0.20	26	4.34	1.56
Belly River (undiff.)	24	1.50	35	5.33	2.08
Oldman	84	0.20	15	3.65	1.73
Foremost	138	0.40	14	3.37	1.50
St. Mary River	16	1.20	13	5.61	1.96
All map-units	985	0.20	35	4.31	1.64

[1] Standard Deviation.

Mapping Programs

Geologic data and information are often most clearly and conveniently displayed in the form of maps of various kinds. One of the major difficulties to be overcome in the automated construction of maps on either drum-type or flatbed plotters is the conversion of designated locations into rectilinear plotter coordinates for specific map scales and projections. In this project, mine locations were available from the file either in the Dominion Land Survey system as reported by Campbell (1964, 1966) or equivalent calculated latitude and longitude values. Through the courtesy of A. M. Kelly of the Department of Energy, Mines and Resources, Ottawa, a group of programs was obtained to convert locations given as latitude and longitude into X and Y coordinates on Universal Transverse Mercator, Polyconic or Lambert Conformal Conic map projections at any required scale. Selected data from the file or values calculated from file data by intermediate programs were plotted in this way using the 30-inch CALCOMP drum-type plotter in the University of Alberta Computer Centre. Where desirable and appropriate, plotted values could have been contoured using one of the contouring programs available from the Centre's program library.

In practice, retrieval requests were written to obtain output on magnetic tape, in formats which were acceptable as input to the intermediate data reduction and mapping programs. All the basic work maps for figures 2 to 8 and figures 10 to 24 in the companion paper by Steiner *et al.* (1972) were machine-produced at scales of 1:500,000 and 1:1,000,000 with outlines, formation boundaries, contours, and in some cases additional values added manually.

For example, values of fixed carbon and volatile matter from proximate analyses were retrieved from the file along with corresponding locations in terms of latitude and longitude and used to create a subfile on magnetic tape. This subfile was used as input for the programs which converted latitude and longitude into X and Y coordinates and for a simple program which calculated fixed carbon percentages on an ash- and moisture-free basis. Locations, now in rectilinear coordinates for a 1:1,000,000 scale Universal Transverse Mercator map projection, and recalculated values of fixed carbon were placed in a second subfile on magnetic tape which was then used to create on the plotter the work map for figure 4 in Steiner *et al.* (1972).

It is convenient and quite simple, therefore, to retrieve data from the file, use these data as the basis for additional calculations if required, and plot either the data or the results of the calculations as maps on convenient scales rapidly and without resorting to manual processing at any stage.

TIME AND COST ANALYSIS

Work on the project began in April 1971 with the hiring of two technical assistants to transcribe data from the published catalogues and topographic and subsurface maps to source documents in preparation for keypunching. Data from mines on the Plains were ready for keypunching by mid-June, and the file was constructed, edited and usable by the end of July. Retrievals for mapping purposes began in August, revealing many errors which were not apparent in the original editing, and which required correction before the file could be used effectively. Collection of data on mines from the Foothills was complete by the end of October, but these have not yet been entered into the file. Use of the file as the basis for this and the accompanying paper by Steiner ***et al.*** was complete by mid-October.

Total cost of the project to the end of October 1971, exclusive of costs incurred in installation of the SAFRAS System and the time of the authors, is estimated at $2000 to $2500, mostly in wages to technical assistants involved in data collection, keypunching and editing. The SAFRAS storage and retrieval system typically costs between $3000 and $5000 to install but once installed is very inexpensive to operate. A file the size of the one built for this project would cost between $30 and $40 to build, depending upon the size of the computer, with simple retrievals less than $5 each. Each of the maps produced in this study cost an estimated $10 in computer time, and total cost of all the frequency analyses performed was less than $50.

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COAL DEPOSITS OF THE ALBERTA PLAINS

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ABSTRACT

The composition, stratigraphy, and structure of the Cretaceous coal measures of the Alberta Plains south of latitude 55 (township 70) are summarized on a series of computer-generated regional maps based on a file of published data from approximately 1500 to 1600 mines. These maps cover the major near-surface coal horizons in the following stratigraphic units:

lower, middle, and upper Edmonton Formations
St. Mary River, Eastend, and Frenchman Formations
Foremost and Oldman Formations.

Maps presented include:

known minimum overburden thickness
gross coal thickness
structure contours on coal horizons
isopachs from coal horizons to top of Colorado Group
calorific value
fixed carbon (ash and moisture-free)
moisture content
ash content
sulphur content
regional rank distribution.

Clustering of data in small areas is quite common. Where this occurs values have been averaged, and such averages have been labelled and given greater weight for contouring purposes. Most maps are contoured, but in some cases only the raw data are shown.

The two major shortcomings and difficulties in attempting to present a regional picture such as this centre around the correlation of coal seams among mine areas and the reliability of available data. The authors have assumed that all seams in each of the stratigraphic units are correlative and have generally accepted the remaining data as published by Stansfield and Lang (1944) and Campbell (1964, 1966).

INTRODUCTION

Most of the Upper Cretaceous stratigraphic units of the Alberta Plains are coal-bearing (Fig. 1). The barren marine units comprise the Upper Colorado Group, the Lea Park-Pakowki and Bearpaw Formations, plus the Drumheller marine tongue of the Edmonton Group. The coal is a soft, low-sulphur coal, ranging in rank from lignite to high volatile C bituminous. This study, employing both the present stratigraphic nomenclature (Irish, 1970) and the traditional units of the coal industry (Allan and Sanderson, 1945) (Fig. 1), is based on a computer file (Williams ***et al.***, this volume) of some 1500 to 1600 Alberta coal mines (Fig. 2), as reported by Campbell (1964, 1966).

Acknowledgments

The authors are indebted to A. Bartlett-Page for assistance with the computer aspects of this study, and to E. Grillmair for help with the evaluation of data and preparation of maps. This study was made possible by financial support from the Geological Survey of Canada and the National Research Council.

ANALYTICAL DATA

The analytical data from approximately 300 calorific and proximate analyses of Alberta coals (Campbell, 1964, 1966) are summarized in figures 3 to 6. Foothills and Mountain data, which include Lower Cretaceous coals, are also contoured. Clustering of data in small, formerly active mining centres is quite common. Where this occurs values have been averaged, and such averages have been given greater weight for contouring purposes in order to emphasize the regional trends and suppress local anomalies. Some of the anomalies are no doubt due to varying sampling and laboratory techniques over the past twenty-five years.

The gross calorific values in BTU's per lb (Fig. 3) range from just over 7000 in the Cypress Hills, to nearly 14,000 in the Mountains. Fixed carbon (moisture and ash free) varies from 50 per cent in the eastern Plains to 86 per cent in the Canmore basin near Banff (Fig. 4). The contour map of fixed carbon displays a minor, linear "high" in the centre of the Alberta Plains which parallels the mountain front. The trough between this "high" and the increasing values in the Foothills is independent of lignite occurrence in the Paskapoo Formation (pre-1970 terminology), which crops out in this general area. As is to be expected, the moisture content (Fig. 5) decreases from 35 per cent in the eastern Plains to 2 per cent in the Mountains.

The ash content (Fig. 6) displays the greatest variability of all the analytical data, but regional trends can be clearly delineated. Individual analyses range from as high as 30 per cent in the Crowsnest area, to as low as 4 per cent in the eastern Plains. The average ash content ranges from 15 per

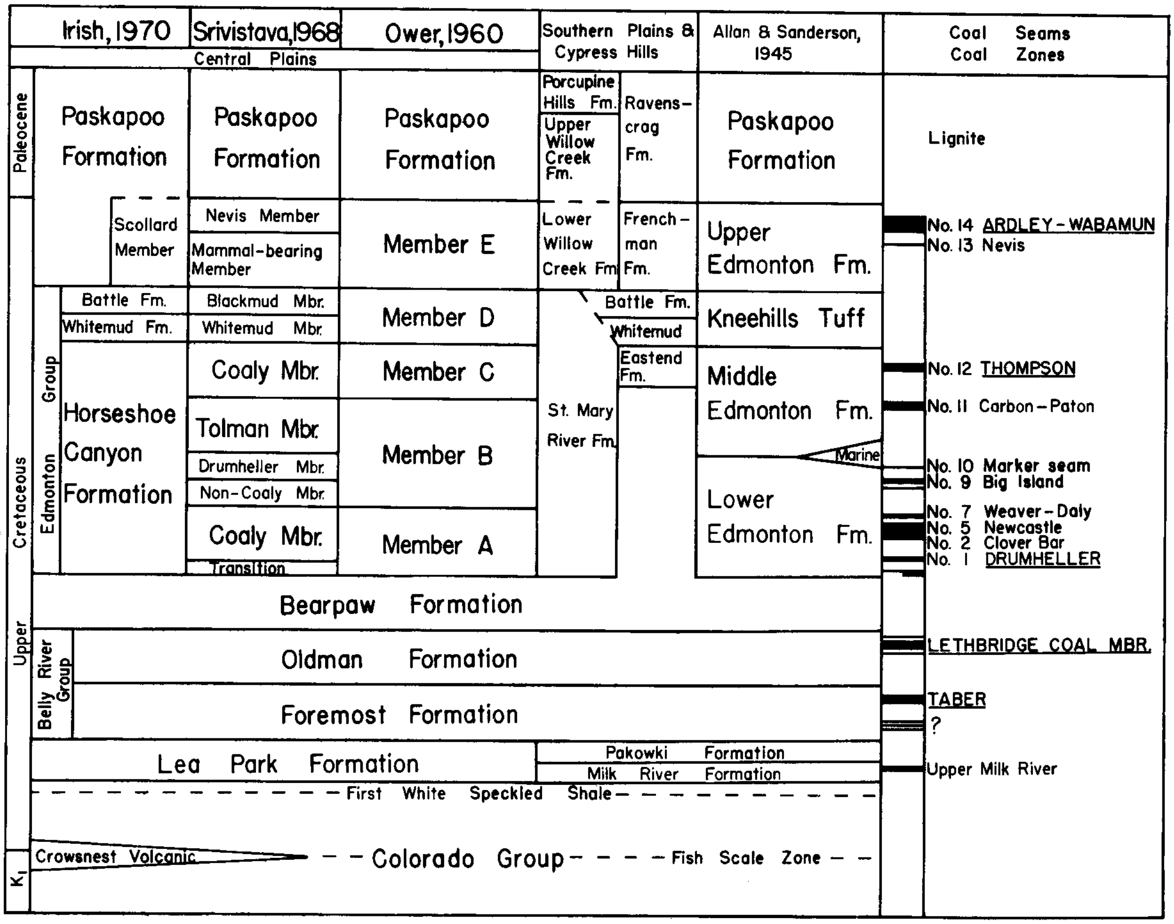

FIGURE 1. Upper Cretaceous rock-units and coal seams of the Alberta Plains.

cent in the southwestern Mountains and Foothills to 6 per cent in the eastern Plains. The coals in the western and particularly the southwestern part of Alberta have consistently higher average ash content than those farther east, as indicated in figure 6. The standard deviation decreases from 5.6 to 2.4 per cent in a similar manner. Present data would permit drawing alternative division lines somewhat more parallel to the mountain front than shown in figure 6.

The sulphur content of ultimate analyses has been averaged by Alberta coal areas (Allan, 1940) and taken from Stansfield and Lang (1944). Averages range from 1.0 to 0.3 per cent, but individual analyses vary from 1.2 to 0.2 per cent. Present data permit distinguishing two characteristic regions (Fig. 7). The southwestern region centering around the Crowsnest Pass includes all coal areas with an average sulphur content of higher than 0.5 per cent. In the northeastern region, including the Cypress Hills and the central and northern Plains and Foothills, the average sulphur content is equal to or less than 0.5 per cent.

On the basis of the above data, the regional rank distribution (ASTM, independent of weathering characteristics) of Alberta coal is shown on figure 8. As is well known, the rank increases toward the Mountains. The validity of the slices shown in the Foothills and Mountains is dependent on the geographic distribution of analyses, as shown in figures 3 to 5.

DISCUSSION OF ANALYTICAL DATA

Disregarding the lignite in the Paleocene part of the Paskapoo Formation, the major governing variable controlling the regional trends of all analytical data is proximity to the mountain front (Figs. 3 to 8). Strati-

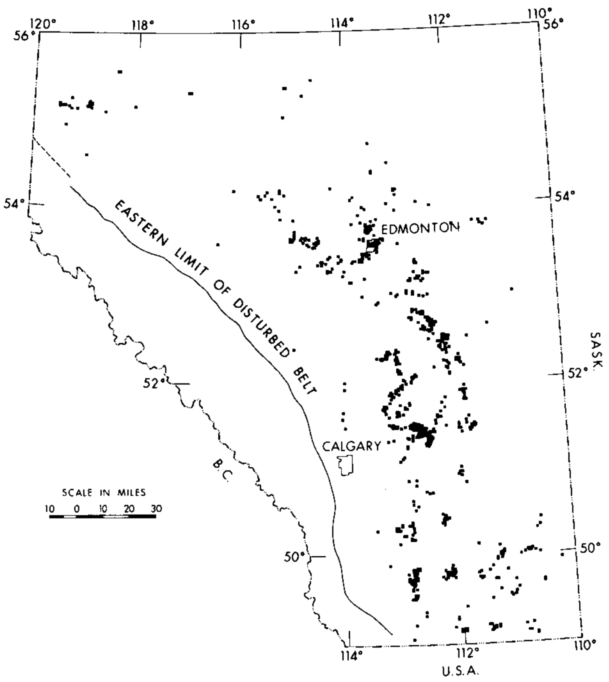

FIGURE 2. Coal mines of Alberta, 1895 to 1971.

graphic position appears to be only a subsidiary, superimposed variable. The Belly River coals of the northeastern Plains of Alberta are characterized by a degree of organic metamorphism which is equal to or less than that of the overlying lower Edmonton Group coals which crop out toward the west. Stansfield and Lang (1944) list analyses of these Belly River coals; however, the data have not been included in the computer file, since no precise locations are given other than coal area and stratigraphic unit.

The regional distribution of ash content appears to be related to the record of Early Cretaceous volcanism in the Crowsnest area. The Cretaceous paleolatitude of Alberta was somewhat north of the horse latitudes, which implies a prevailing wind direction from the southwest. Prevailing winds apparently carried ash from the centres of Cretaceous volcanism in the northwestern United States, British Columbia, and the Crowsnest area, to the coal swamps of the Alberta Plains (Fig. 6). Local conditions of run-off redistributed some of the airborne ash and sulphur and locally concentrated them in specific subenvironments, which may account for the great variability of these components in certain areas and stratigraphic levels. Frequent, periodic volcanism also may be responsible for some of the variations noted. Coal seams are in many cases interbedded with volcanic ash beds, some of which have been dated by the potassium-argon method, as discussed below.

The regional distribution of sulphur in Alberta coals also appears to be directly related to synchronous volcanism in the same manner as ash content (Fig. 7). Explanations put forward for other regions relied on marine waters being primarily responsible for the distribution and concentration of sulphur (Geological Society of America, 1971); this mechanism is not denied here, except that the ultimate source of the sulphur appears to be nearby volcanic activity.

DEFINITION OF COAL ZONES

Allan's (1943) terminology of coal seams of the Red Deer River valley has been adopted (Fig. 1), and this study will attempt to show that equivalent coal seams occur in similar stratigraphic positions and successions over wide areas. Thus, regionally valid coal zones may be defined on the basis of these original coal seam designations. Table 1 lists the major Upper Cretaceous coal zones of the Alberta Plains.

The stratigraphic positions of the lignite horizons of the Paleocene part of the Paskapoo Formation are not known. Allan's coal seam No. 14 forms part of the economically most important zone of the Alberta Plains, and defines the Ardley coal zone of the Scollard Member. This seam also is referred to as the Wabamun or Pembina or "Big" seam.

The No. 12 seam represents the uppermost seam in the upper part of the Horseshoe Canyon Formation some 50 feet below the Whitemud Formation, and defines the Thompson coal zone. Some 100 feet below No. 12 occurs the No. 11 seam, which constitutes the Carbon coal zone in the upper part of the Horseshoe Canyon Formation.

There are at least ten coal seams in the lower part of the Horseshoe Canyon Formation (Fig. 9), and three major coal zones may be differentiated. Figure 9 illustrates the correlation of Allan's (1943) Red Deer River valley coal seams with those of the Edmonton area according to Beach (1934). Most minor and all major coal seams correlate over distances of 90 to 150 miles. The Big Island coal zone comprises Allan's No. 8 to No. 10 seams, covering a stratigraphic interval of some 90 feet and includes the Marker seam, the Big Island-High Level Bridge seam, and the Whitemud Creek seam. Some 100 to 120 feet below the

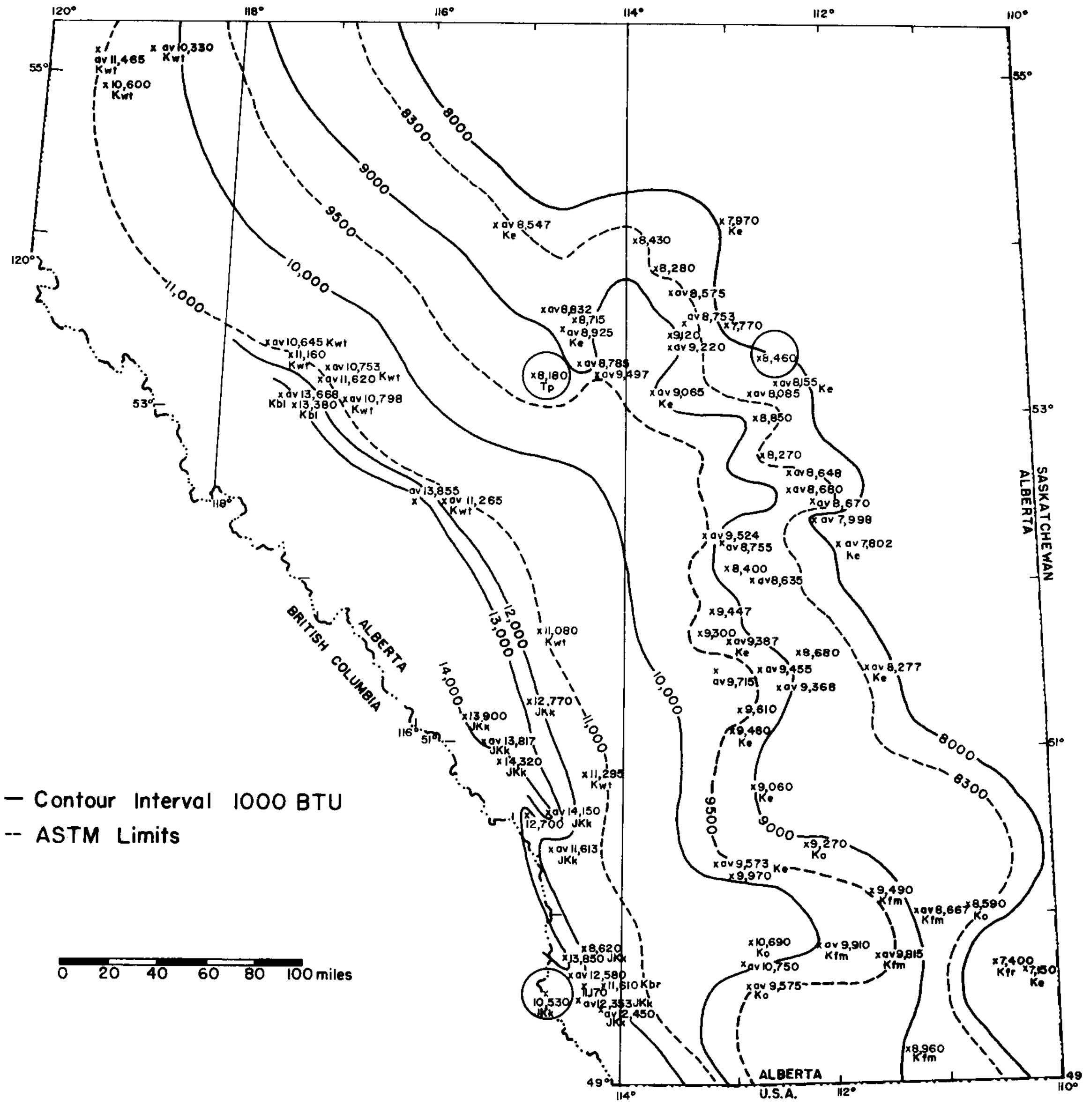

FIGURE 3. Gross calorific values of Alberta coals in BTU/lb. (Circled determinations not honored in contouring). Tp = Paskapoo Formation (Paleocene), Ke = Edmonton Group and Scollard Member, Kfr = Frenchman Formation, Kea = Eastend Formation, Ko = Oldman Formation, Kf = Foremost Formation, Kbr = undifferentiated Belly River Group, Kwt = undifferentiated Wapiti Group, Kbl = Blairmore Group, JKk = Kootenay Formation, Not labelled = Edmonton Group and Scollard Member, av. = average of two or more determinations.

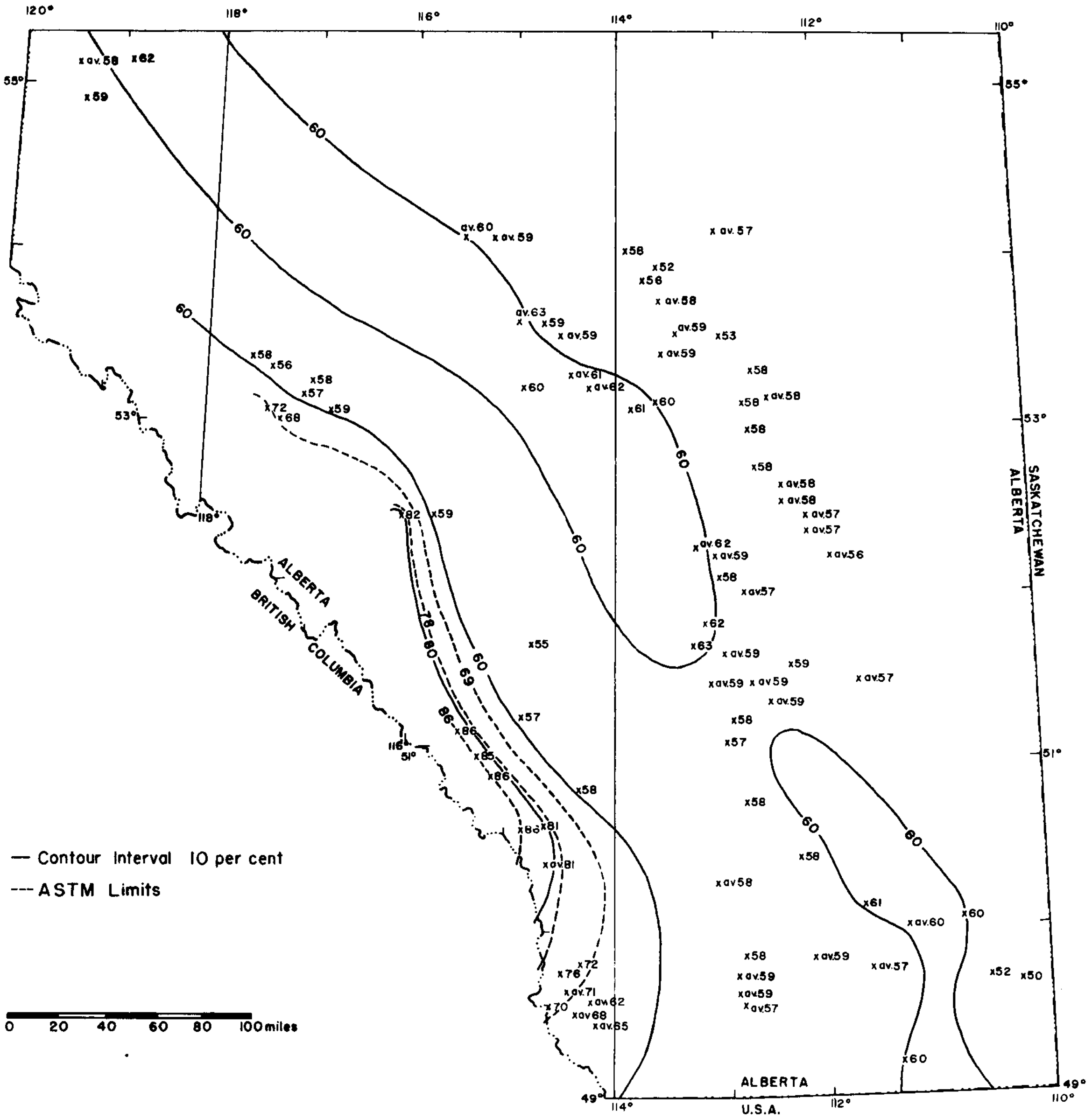

FIGURE 4. Fixed carbon (moisture and ash free) values of Alberta coals in percentages (av. = average of two or more analyses).

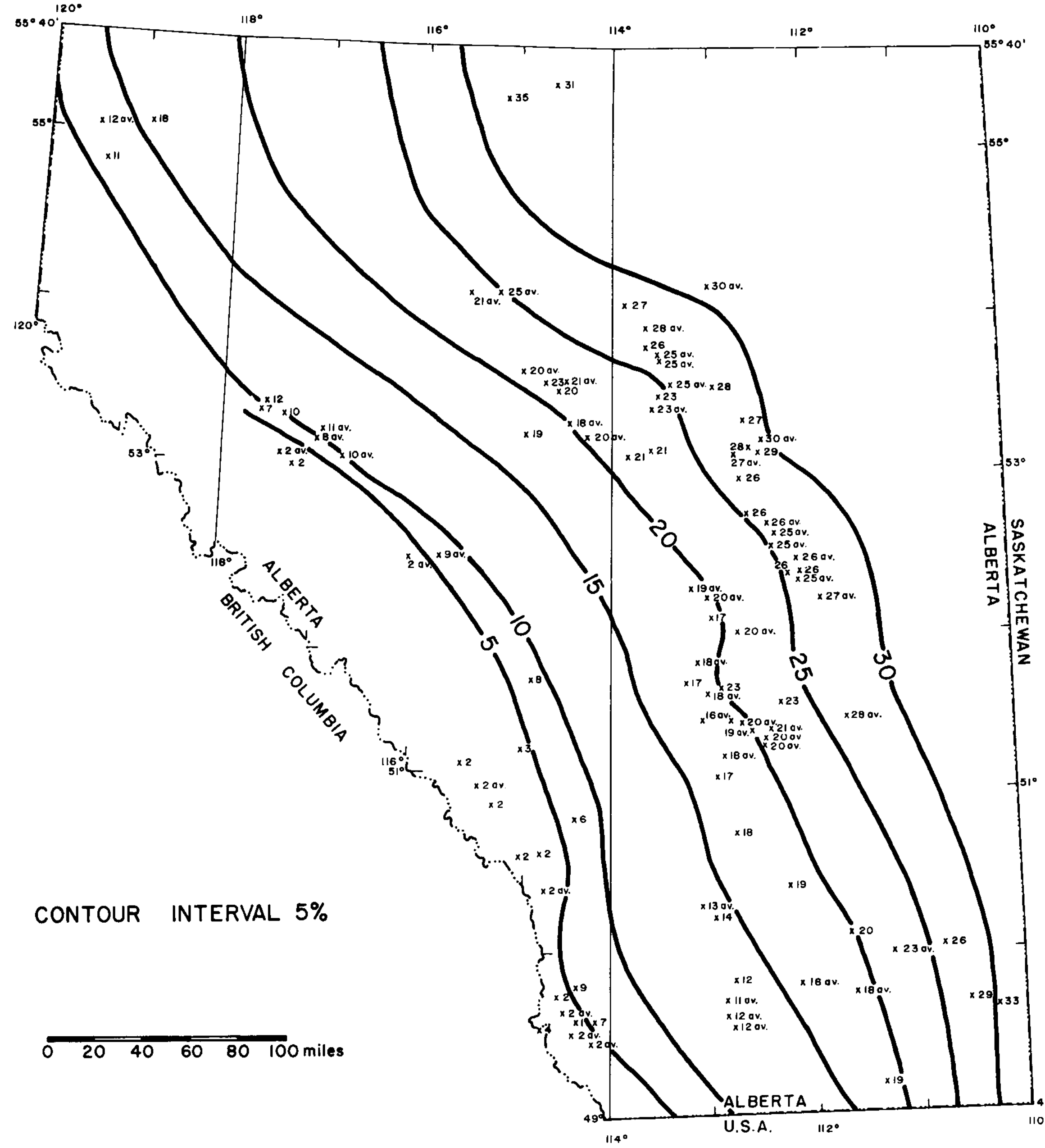

FIGURE 5. Moisture contents of Alberta coals in percentages (av. = average of two or more analyses).

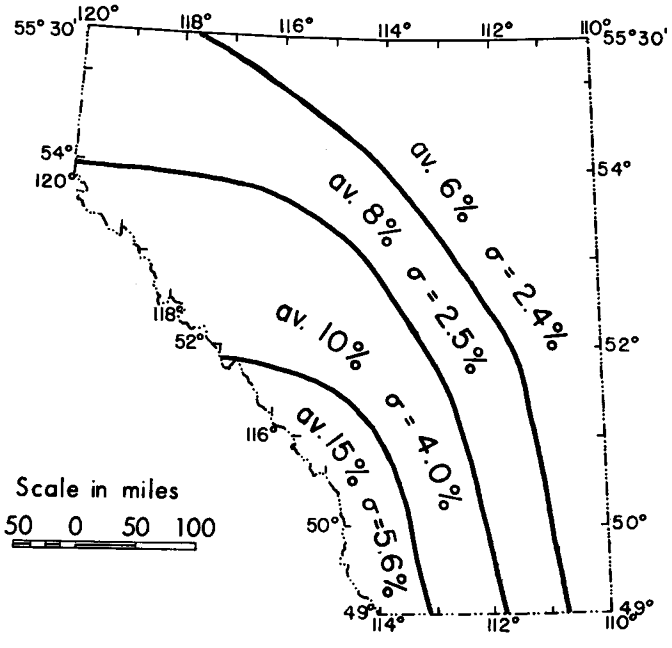

FIGURE 6. *Ash contents of Alberta coals in percentages. Kootenay Formation 15 per cent; Oldman Formation 15 per cent; Foremost Formation 9 per cent; Scollard Member 9 per cent; Horseshoe Canyon Formation 8 per cent. (Data permit drawing alternative division lines more parallel to the mountain front than shown. In this case averages, av., and standard deviations, σ, are slightly different from those shown above, but all values decrease toward the northeast).*

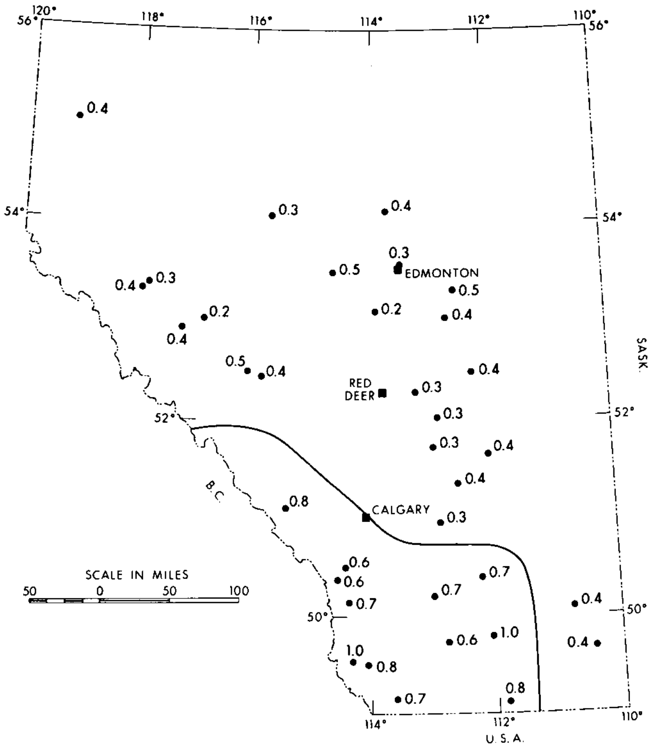

FIGURE 7. *Sulphur contents of Alberta coals in percentages (average per coal area). Line separates regions of high and low sulphur contents. In the southwestern region the sulphur content is more than 0.5 per cent; in the northeastern region the sulphur content is equal to or less than 0.5 per cent.*

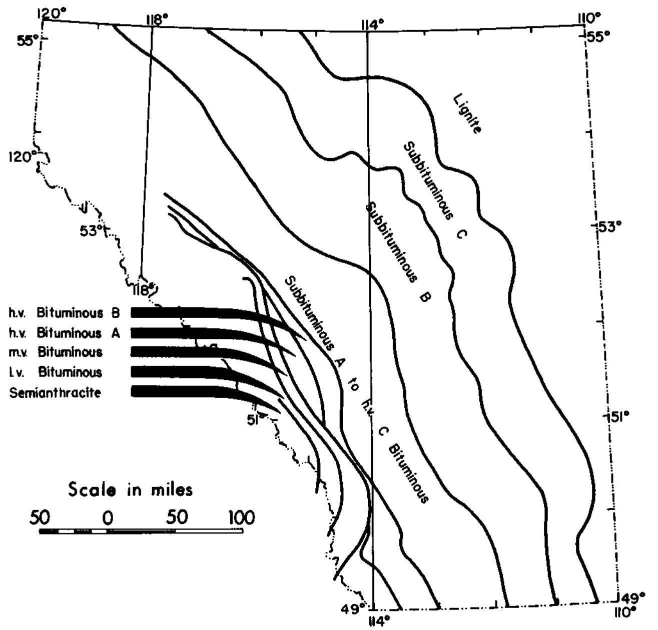

FIGURE 8. *Regional rank distribution of near-surface Alberta coal according to ASTM classification, but independent of weathering characteristics.*

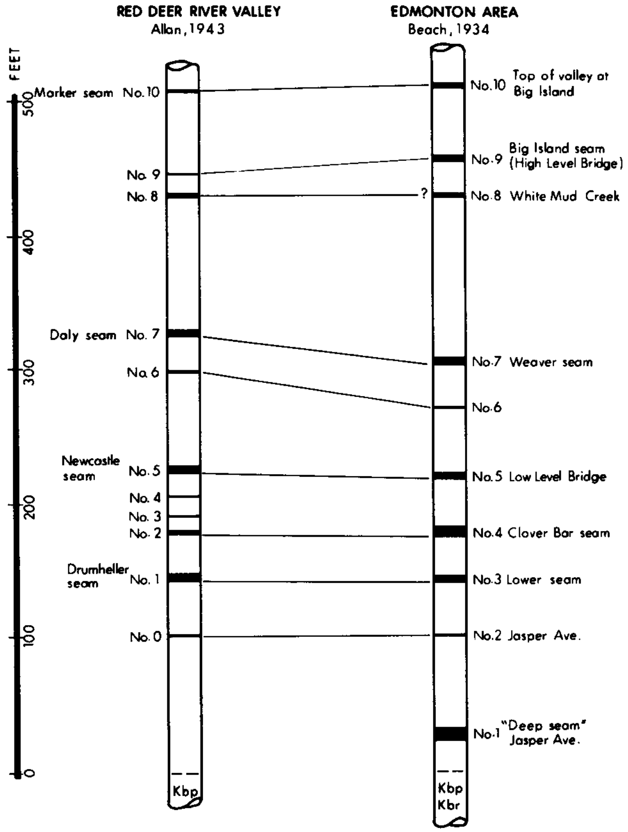

FIGURE 9. *Correlation of coal seams in lower part of Horseshoe Canyon Formation (lower Edmonton Formation). Kbp = Bearpaw Formation, Kbr = Belly River Group.*

Table 1. Major Coal Zones of the Alberta Plains.

Irish (1970)	Allan & Sanderson (1945)	Allan (1943)	Coal Zones (this paper)
Paskapoo Formation - Paleocene	Paskapoo Formation	Several lignite horizons of unknown stratigraphic position	
Paskapoo Formation - Scollard Member	Upper Edmonton Formation	No. 14	Ardley
Horseshoe Canyon Formation (upper part)	Middle Edmonton Formation	No. 12	Thompson
		No. 11	Carbon
Horseshoe Canyon Formation (lower part)	Lower Edmonton Formation	No. 8 to No. 10	Big Island
		No. 6 and No. 7	Weaver–Daly
		No. 1 to No. 5	Drumheller–Clover Bar
Upper Oldman Formation	Upper Oldman Formation	Lethbridge Coal Member	Lethbridge
Upper Foremost Formation	Upper Foremost Formation	Taber Coal	Taber
Lower Foremost Formation	Lower Foremost Formation	Possibly Lower Foremost coal horizons	
Upper Milk River Formation	Upper Milk River Formation	Coal horizons of limited areal extent in Alberta	

base of the Big Island coal zone, the 30-foot Daly-Weaver coal zone consists of No. 6 and No. 7 seams, of which only No. 7 has been mined. Some 50 to 70 feet below the base of the Daly-Weaver zone the top of the complex 60-foot Drumheller coal zone is defined. This coal zone consists of at least five seams which have been mined as the Newcastle-Low Level Bridge seam, the Clover Bar seams, and the Drumheller and lower seams of the Edmonton area. Beach's basal 8-foot No. 1 seam has no equivalent seam in the Red Deer River valley. The occurrence of this "Deep seam" in the Edmonton area may be the result of the southward withdrawal of the Bearpaw sea, which gave rise to coal-forming conditions at an earlier stage in the north.

The Lethbridge coal zone and the Taber coal zone occur near the top of the Oldman and Foremost Formations, respectively. The correlation of the coal seams of the undifferentiated Belly River Group of northeastern Alberta with the Lethbridge and Taber coal zones of the southern part of the province is uncertain.

The coal in the Upper Milk River Formation just north of the 49th parallel is of limited areal extent in Alberta and has not been included in this study.

SUBSURFACE MAPS OF COAL ZONES

Seam elevations and gross thicknesses of coal are known for only a number of mines shown in figure 1. In the preparation of the maps, the computer file was augmented by data from a variety of sources, such as Pearson (1959, 1960, 1961), Campbell and Almadi (1964), and Campbell (1967a,b). The file includes surface elevations for all mines, taken from NTS 1:50,000 scale topographic map-sheets. Elevations on the top of the Colorado Group have been estimated on the basis of the "first white-speckled shale" map of Robinson *et al.* (1969). The outcrop patterns of the Battle, Whitemud, and Horseshoe Canyon Formations and Scollard Member of the Paskapoo Formation have been kindly supplied by Dr. R. Green, Research Council of Alberta.

The outstanding feature of the approximate structure contour map on top of the Ardley coal zone of the Scollard Member (Fig. 10) is a pronounced southwestward swing of the structure contours south of Red Deer, reflecting the influence of the post-Cretaceous Sweetgrass Arch. In this area the structure contours on the top of the Colorado Group shale are roughly north-south. The isopach map from the top of the Ardley coal zone to the top of the Colorado Group (Fig. 11) shows westward thickening, which is characteristic of most of the Cretaceous strata of Alberta. Gross thicknesses of coal mined are indicated in figure 12, which shows only three areas where thickness is in excess of 10 feet. The mean and maximum thicknesses reported from the Ardley coal seam are 5.7 feet and 30 feet, respectively.

The Thompson coal zone has been selected as representative of the coal deposits in the upper part of the Horseshoe Canyon Formation. The regional structure contour map on top of the Thompson coal zone (Fig. 13) displays a southwestward swing of the contours south of Red Deer, similar to the map of the Ardley zone. The isopach map from the top of the Thompson coal zone to the top of the Colorado Group (Fig. 14) is roughly consistent with the known configuration of the Alberta Basin. Both maps distinguish between mines of the Thompson and Carbon coal zones in the upper part of the Horseshoe Canyon Formation.

The lower part of the Horseshoe Canyon Formation includes mines of three coal zones, and these coal zone assignments, which are based on structural and stratigraphic position, are indicated in figures 15 and 16. The structure contour map of the Drumheller coal zone (Fig. 15) is characterized by a southwestward swing of the contours northeast of Calgary, similar to maps of the other coal zones. The structure contour map is based on the stratigraphic level of the Drumheller-Clover Bar seams. The isopach map from the Drumheller coal zone to the top of the Colorado Group (Fig. 16) appears more complex and shows an isolated "thin" (1800 ft) approximately 100 miles northeast of Calgary. This anomaly may be related to a 50 to 100-foot anomalous "high" on the "first white-speckled shale" in this general area, and possibly to erroneous coal zone assignments.

The mean and maximum thicknesses of coal seams in the Horseshoe Canyon Formation are 4.3 feet and 26 feet, respectively. The known coal seam thicknesses as mined are summarized and interpreted in figure 17. This map probably has no specific paleogeographic meaning, since it includes at least ten coal seams, plus those of the equivalent St. Mary River and Eastend Formations. The map does show general areas in which coal-forming conditions are thought to have persisted for longer periods during the deposition of the Horseshoe Canyon Formation.

The structure contour map (Fig. 18) and isopach map (Fig. 19) of the Lethbridge coal zone at the top of the Oldman Formation is consistent with the known structure of the Sweetgrass Arch. The anomaly in the vicinity of Lethbridge appears to be related to the Monarch fault zone some 7 to 10 miles to the west. A southwesterly-dipping surface thrust has also been mapped south of Lethbridge, as indicated. The mean and maximum gross thicknesses of coal reported are 3.7 feet and 15 feet, respectively, and the areal distribution and thickness interpretation of the seam thickness of the Lethbridge Coal Member is summarized in figure 20. Coal seams between 10 and 15 feet have been mined in only one area 20 miles southwest of Brooks.

The main coal zone near the top of the Foremost Formation is designated the Taber coal zone. Allan (1943) suspected that lower coal seams were present in the Foremost Formation, but their existence cannot be resolved without additional stratigraphic field work. Known seam elevations (Fig. 21) and isopach values (Fig. 22) can be contoured smoothly, but this does not rule out the possibility of lower coal seams. Thickness data of the Foremost coal seams are summarized in figure 23, which shows six widely scattered areas where seams of 5 to 10 feet have been reported. Mean and maximum thicknesses are 3.4 feet and 14 feet, respectively.

DISCUSSION OF COAL ZONES

The Ardley coal zone and the coal zones of the Horseshoe Canyon Formation are undoubtedly diachronous, as indicated by the southwesterly swing of the structure contours south of Red Deer (Figs. 10, 13, 15). Considering the structure contours of the Ardley coal zone and the isopach map from this coal zone to the top of the Colorado Group, the zone in the Red Deer River valley appears to be at a higher stratigraphic level than in the Whitecourt area to the northwest of Edmonton. This diachronous nature of the Ardley coal zone is tentatively supported by five sanidine potassium-argon age dates of interbedded volcanic ash. The Pembina coal bentonite at Whitecourt yields an age of 64 m.y., while the upper Ardley bentonite of the Red Deer River valley is dated as 62 m.y. (Folinsbee *et al.*, 1965). The 2 m.y. age difference may be significant since Shafiqullah ***et al.*** (1964) quote a standard deviation of approximately l m.y.

The southwesterly change in trend of the structure contours of the Horseshoe Canyon Formation and Scollard

Member coal zones is related to penecontemporaneous and post-depositional positive movement of the Sweetgrass Arch, indicating that the influence of the arch extended much farther north toward the close of Late Cretaceous time. Williams and Buck (1964) previously reported similar data with regard to the underlying stratigraphic units of the Upper Cretaceous succession farther south.

The Lethbridge coal zone is probably as synchronous or diachronous as the base of the overlying Bearpaw Formation (Folinsbee ***et al.***, 1965). On the basis of present data it is not possible to decide whether the Taber coal zone is restricted to the top of the Foremost Formation, or whether it diachronously includes coal seams in the lower part of the Foremost Formation in the extreme southern part of the province. Alternatively, there could be more than one coal zone, as suggested by Allan (1943).

It may be significant that the isopach maps of the intervals from the top of the Colorado Group to the coal zones in the Foremost and Oldman Formations (Figs. 19 and 22) indicate easterly thickening, whereas intervals to the coal zones in the Horseshoe Canyon and Paskapoo Formations thicken towards the west (Figs. 11, 14, 16). This suggests that the locus of coal-forming environments shifted eastward during deposition of the regressive Foremost and Oldman Formations. Similar conditions may have prevailed during Edmonton and Paskapoo time, but the rate of westerly thickening of these deposits is much greater, thus obliterating any effects of diachronous coal deposition.

It is concluded that the coal zones, particularly those of the Scollard Member and the Horseshoe Canyon Formation (formerly the Edmonton Formation) as defined here, are regionally valid, since the subsurface maps (Figs. 10 to 17) are consistent with known structures of the Alberta Syncline. The regional validity of the Ardley coal zone particularly has been assumed previously and documented by Pearson (1959) and Campbell (1967a).

MINIMUM OVERBURDEN

The known minimum overburden of coal mines in the Alberta Plains is summarized in figure 24. This map does not mean that coal is present at all locations of a given range of overburden. The range of overburden, subject to variation in local topographic relief, refers to the stratigraphic level at which coal is known to occur in neighbouring areas. In order to estimate the probable overburden in a specific location, figure 24 would have to be read in conjunction with a recent large-scale bedrock map of the Province of Alberta. The structure contour maps, together with the surface elevation in a particular locality, can also be used to estimate the overburden of the stratigraphic level of the various coal zones.

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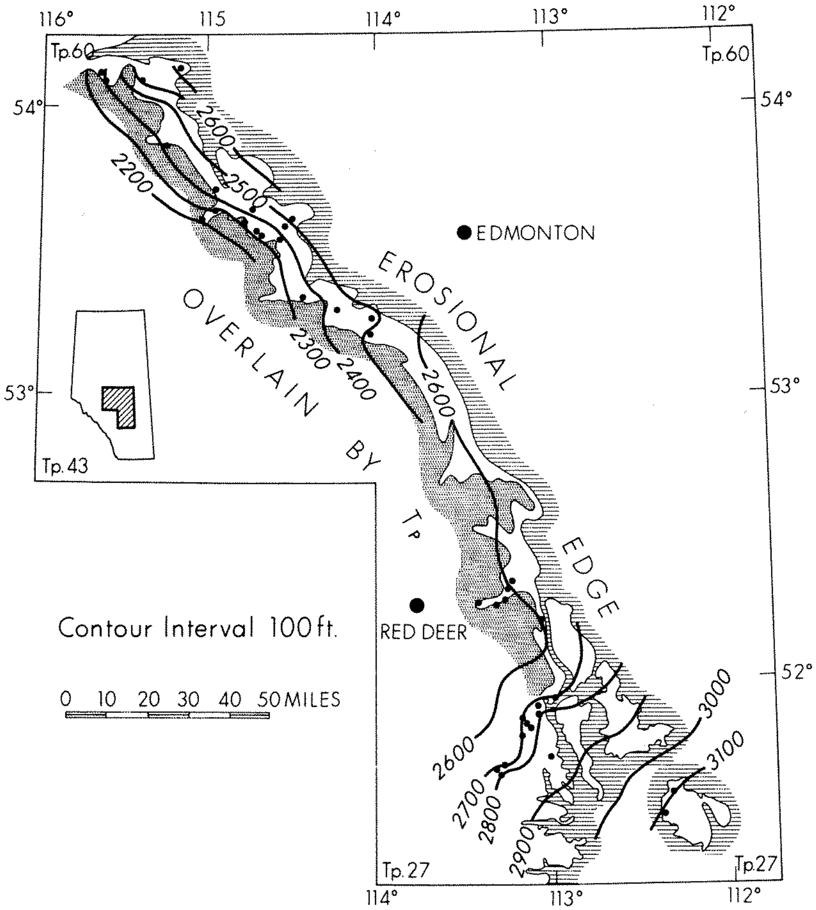

FIGURE 10. Structure contour map on top of the Ardley coal zone of the Scollard Member, Paskapoo Formation (formerly upper Edmonton Formation). Map shows outcrop distribution of the Scollard Member with the erosional edge to the east. Tp = Paskapoo Formation (Paleocene).

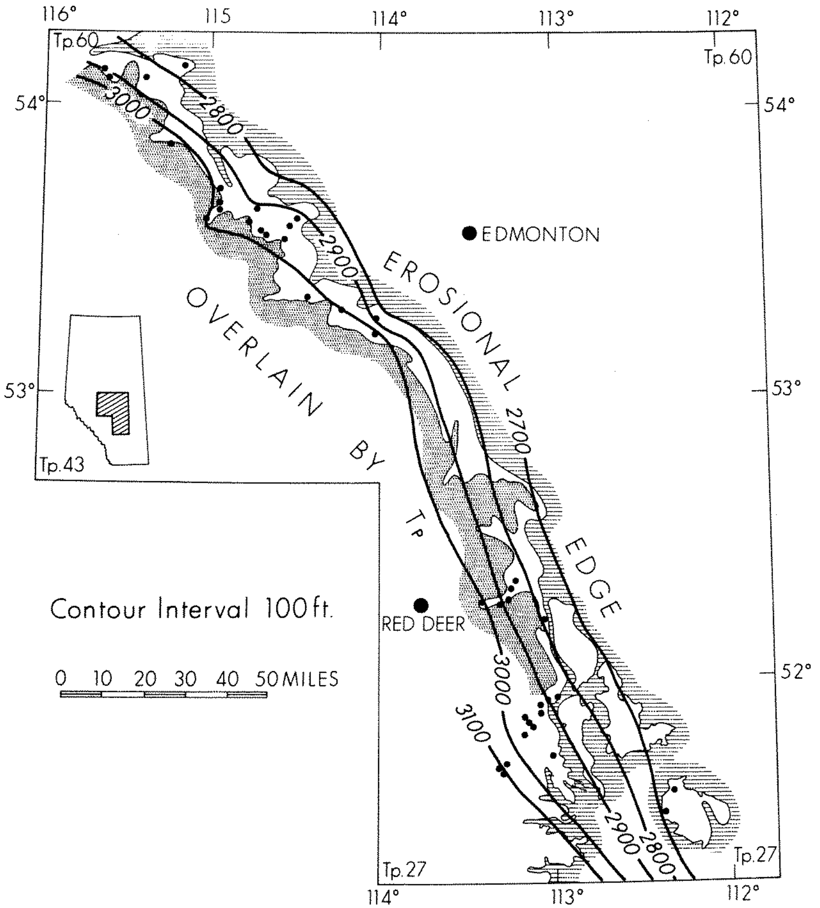

FIGURE 11. Isopach map from the top of the Ardley coal zone to the top of the Colorado Group. Map shows outcrop distribution of the Scollard Member, Paskapoo Formation (formerly upper Edmonton Formation) with the erosional edge to the east. Tp = Paskapoo Formation (Paleocene).

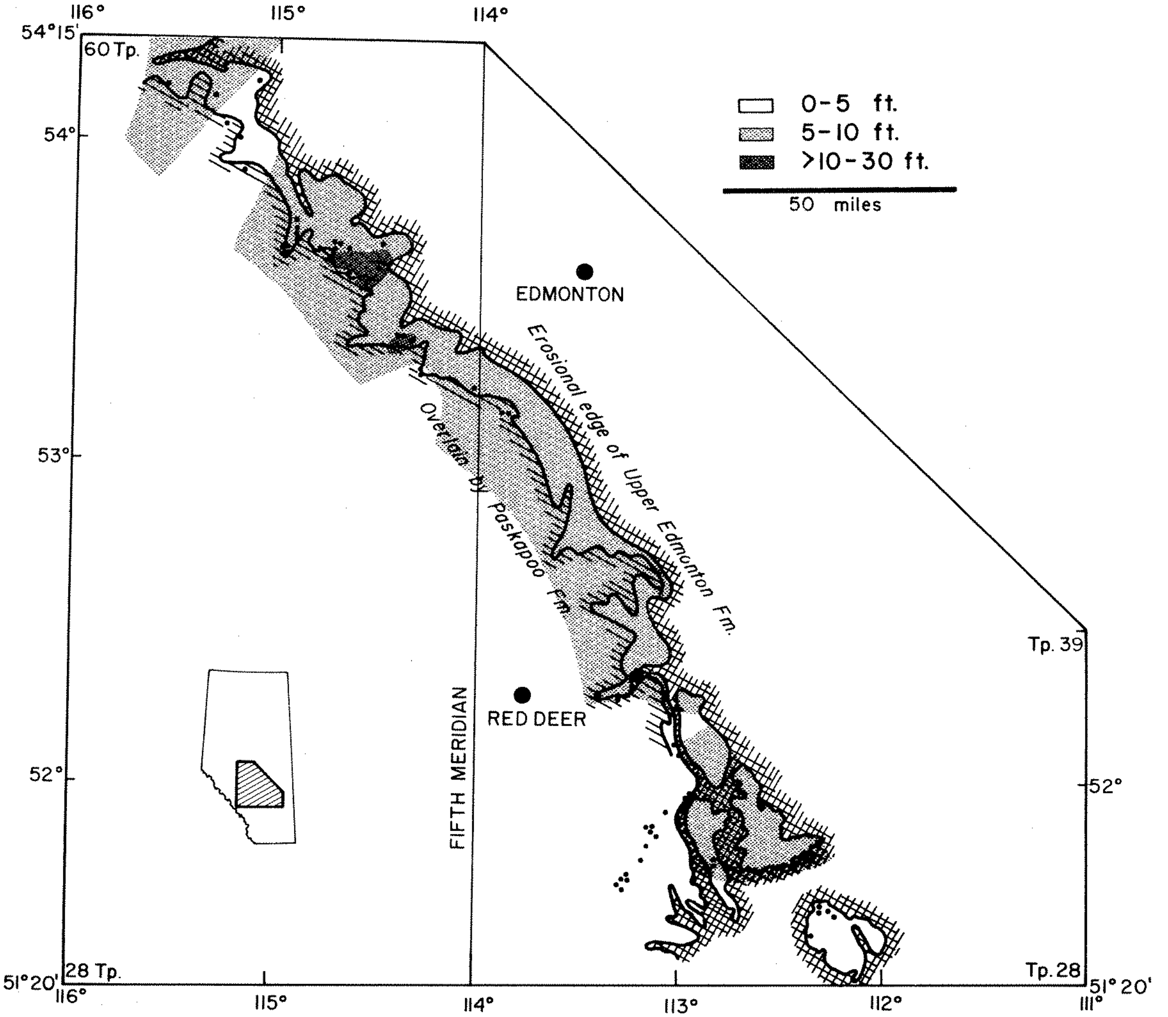

FIGURE 12. Gross coal thicknesses mined in the Ardley coal zone. Map shows outcrop distribution of the Scollard Member, Paskapoo Formation (formerly upper Edmonton Formation). A few coal mines in the equivalent Frenchman Formation lie outside the map-area.

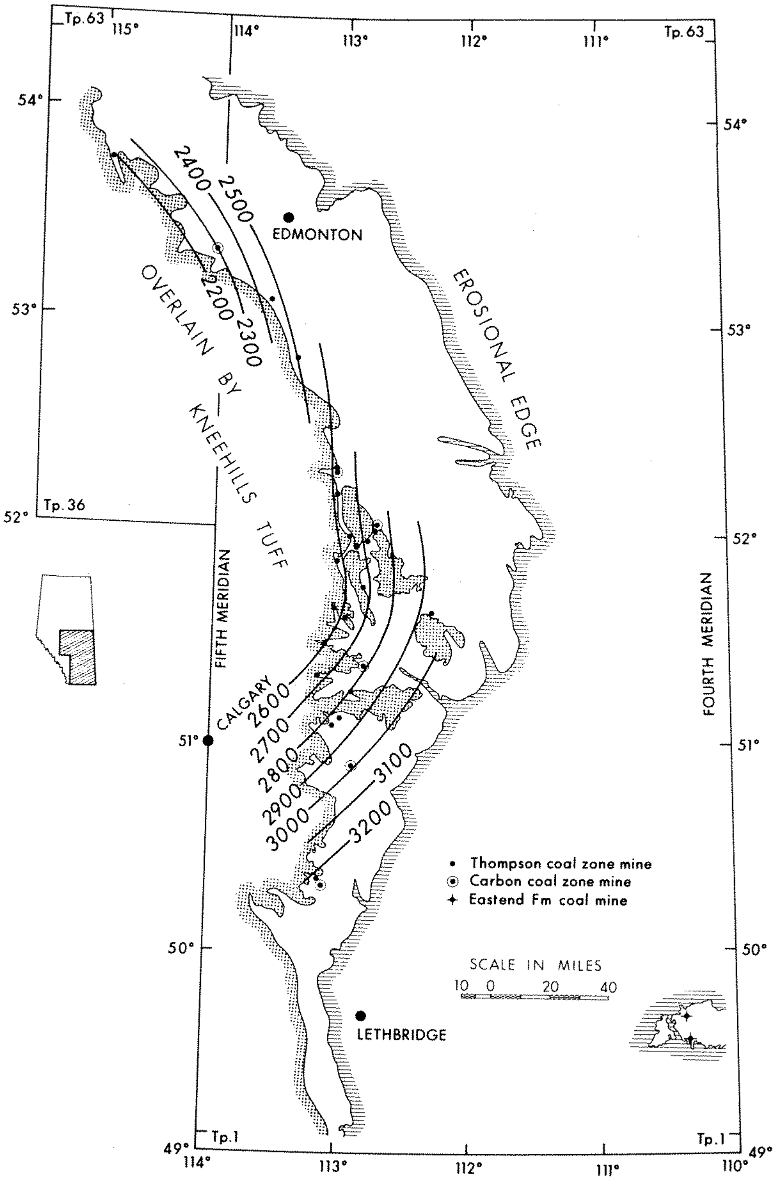

FIGURE 13. Structure contour map on top of the Thompson coal zone in the upper part of the Horseshoe Canyon Formation. Map shows outcrop distribution of the Horseshoe Canyon Formation (formerly middle and lower Edmonton Formations) and equivalent St. Mary River and Eastend Formations. The Horseshoe Canyon Formation is overlain to the west by the Whitemud and Battle Formations (formerly Kneehills Tuff).

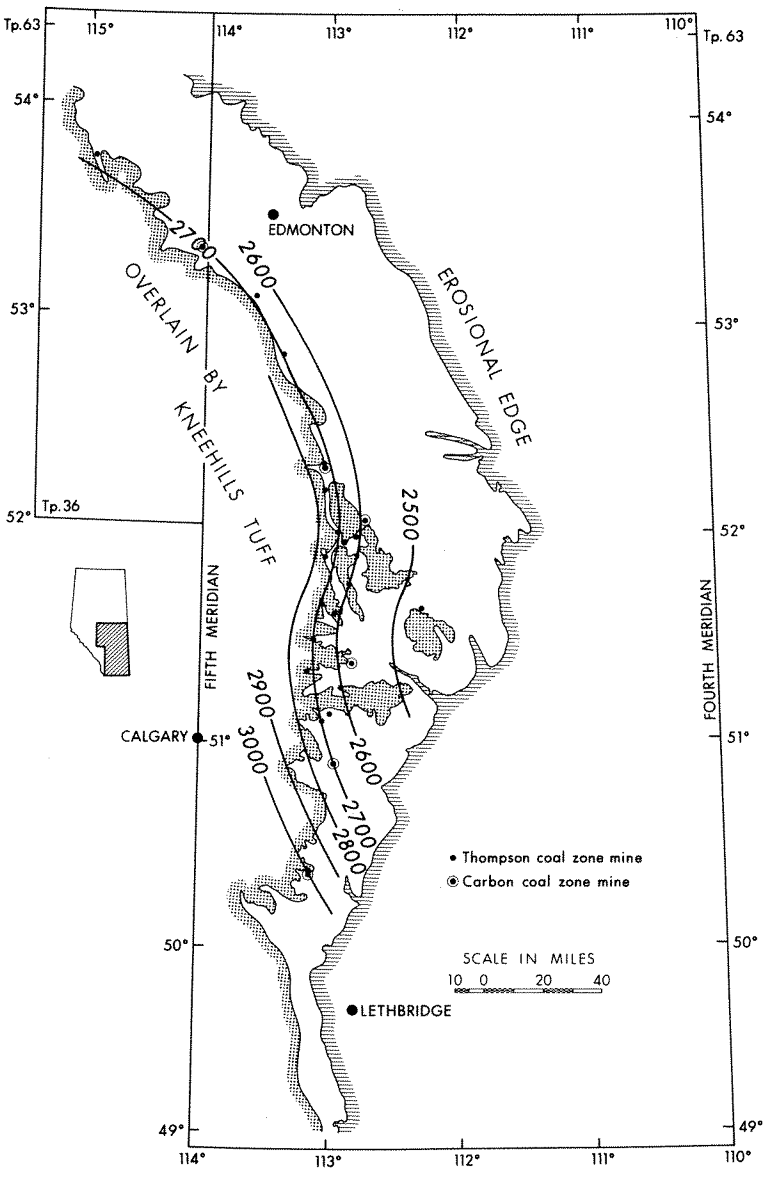

FIGURE 14. Isopach map from the top of the Thompson coal zone to the top of the Colorado Group. Map shows outcrop distribution of the Horseshoe Canyon Formation (formerly middle and lower Edmonton Formations) and equivalent St. Mary River Formation. The Horseshoe Canyon Formation is overlain to the west by the Whitemud and Battle Formations (formerly Kneehills Tuff).

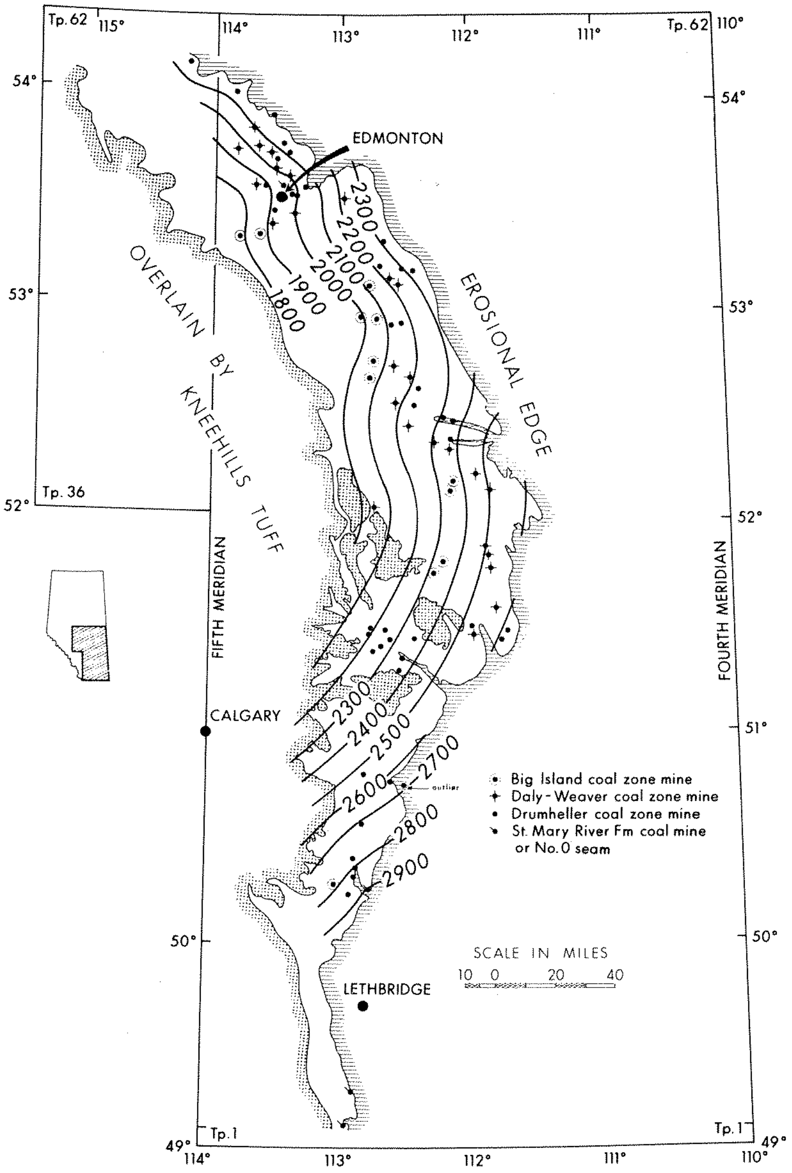

FIGURE 15. Structure contour map on top of the Drumheller coal zone in the lower part of the Horseshoe Canyon Formation. Map shows outcrop distribution of the Horseshoe Canyon Formation (formerly middle and lower Edmonton Formations) and equivalent St. Mary River Formation. The Horseshoe Canyon Formation is overlain to the west by the Whitemud and Battle Formations (formerly Kneehills Tuff).

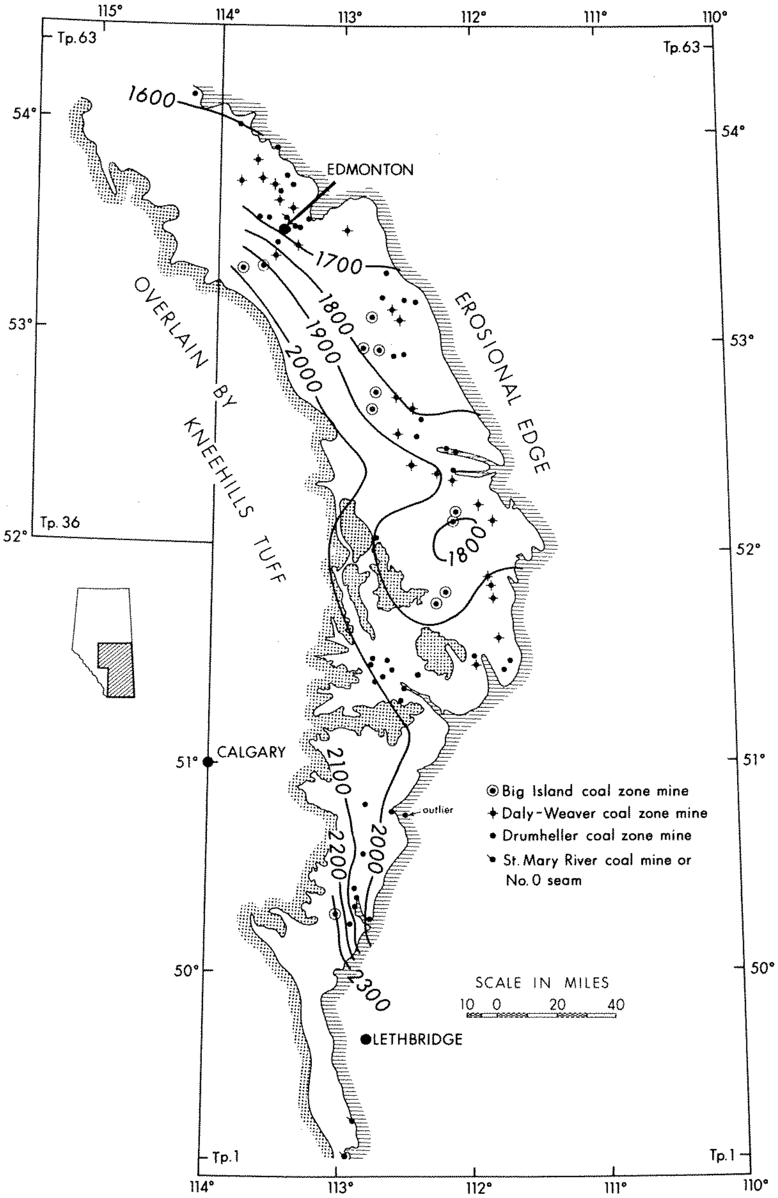

FIGURE 16. Isopach map from the top of the Drumheller coal zone to the top of the Colorado Group. Map shows outcrop distribution of the Horseshoe Canyon Formation (formerly middle and lower Edmonton Formations) and equivalent St. Mary River Formation. The Horseshoe Canyon Formation is overlain to the west by the Whitemud and Battle Formations (formerly the Kneehills Tuff).

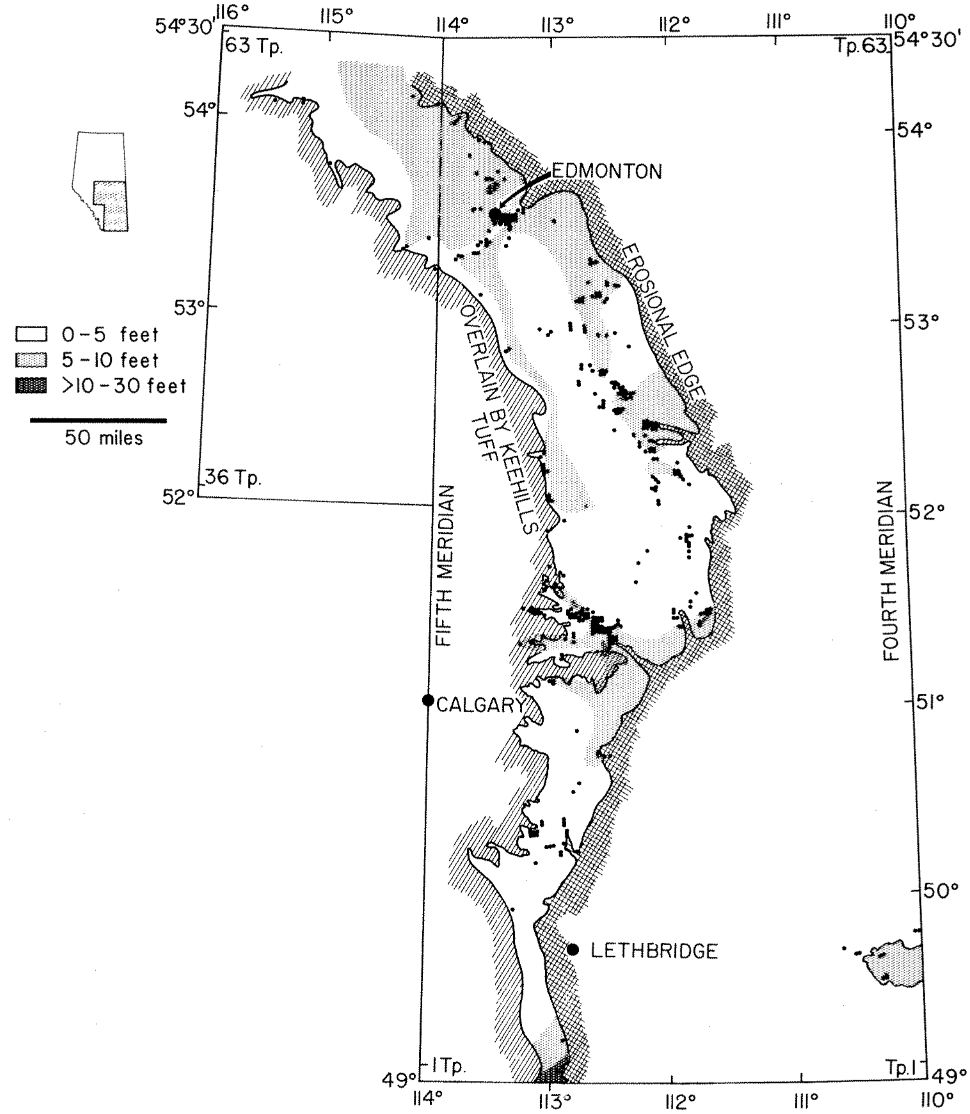

FIGURE 17. Gross coal thickness mined in the Horseshoe Canyon Formation (formerly middle and lower Edmonton Formations) and the equivalent St. Mary River and Eastend Formations.

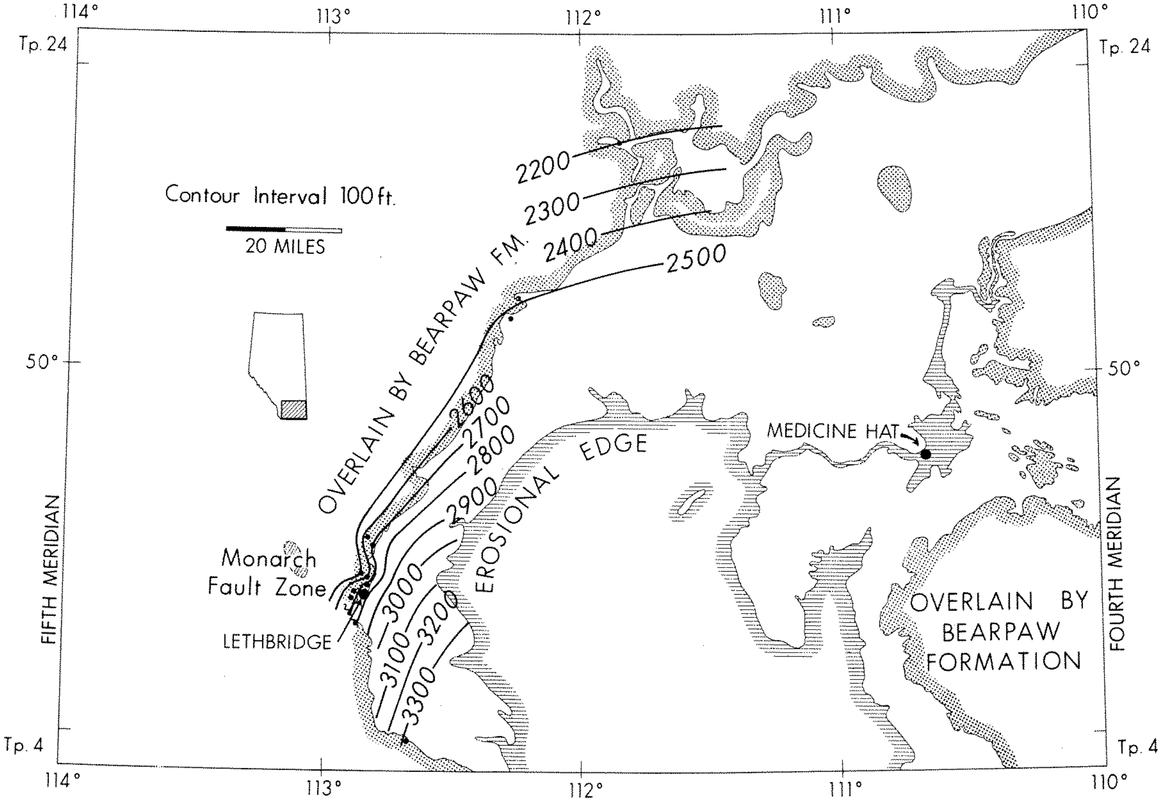

FIGURE 18. *Structure contour map on top of the Lethbridge coal zone in the Oldman Formation. Map shows outcrop distribution of the Oldman Formation in southern Alberta. Monarch fault zone is indicated as a shaded area west of Lethbridge.*

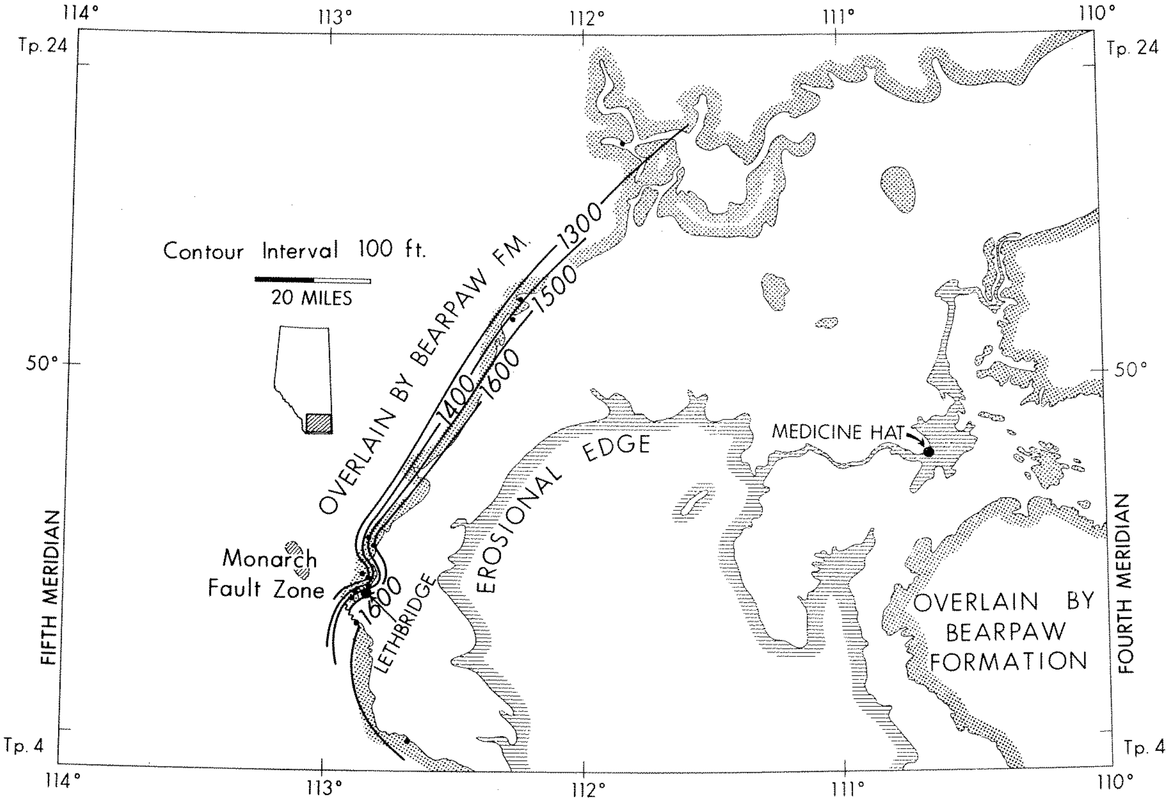

FIGURE 19. Isopach map from top of the Lethbridge coal zone to the top of the Colorado Group. Map shows outcrop distribution of the Oldman Formation in southern Alberta. Monarch fault zone is indicated as a shaded area west of Lethbridge.

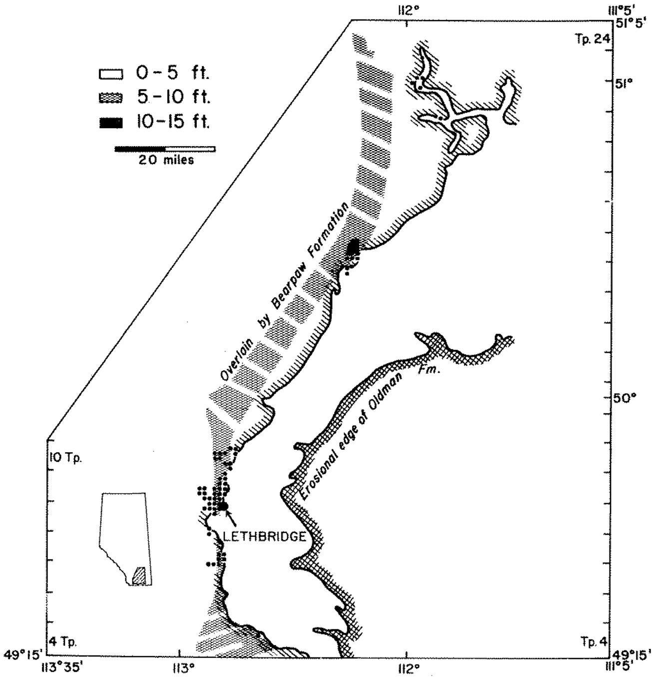

FIGURE 20. Gross coal thicknesses mined in the Lethbridge coal zone of the Oldman Formation. Possible equivalent coal-bearing strata in northeastern Alberta are indicated on figure 24 as Belly River Group.

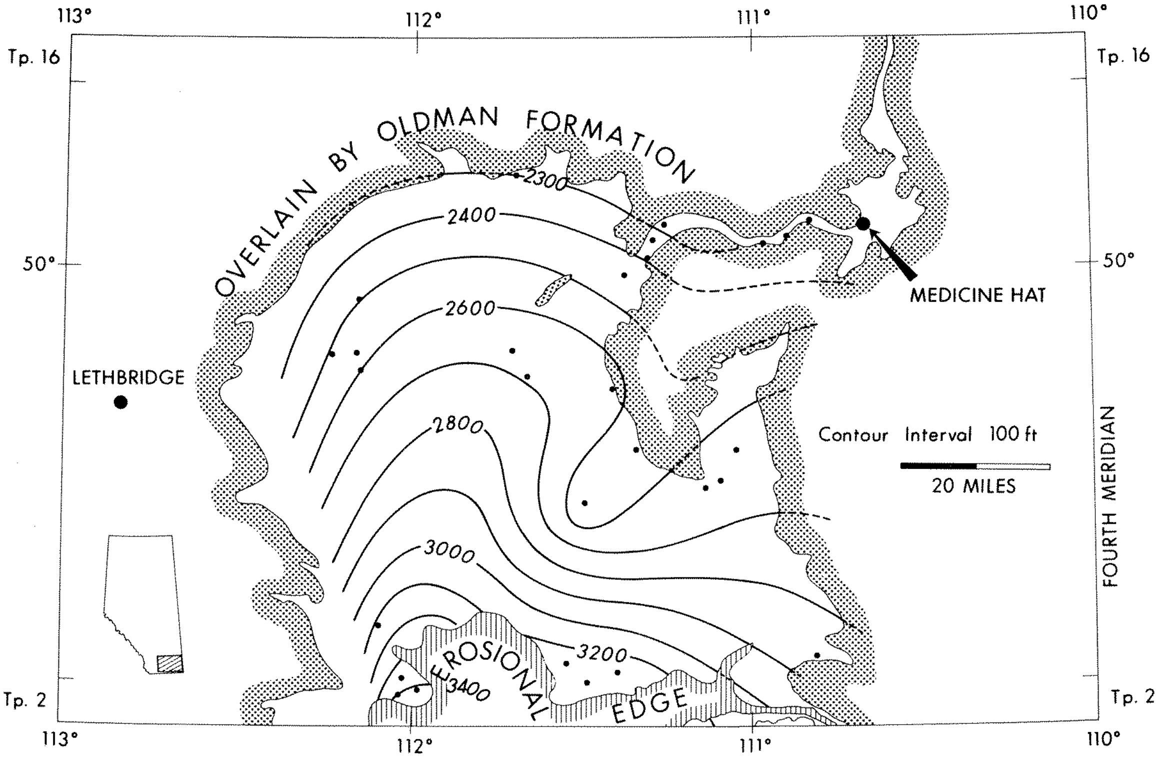

FIGURE 21. Structure contour map on top of the Taber coal zone in the Foremost Formation. Map shows outcrop distribution of the Foremost Formation in southern Alberta.

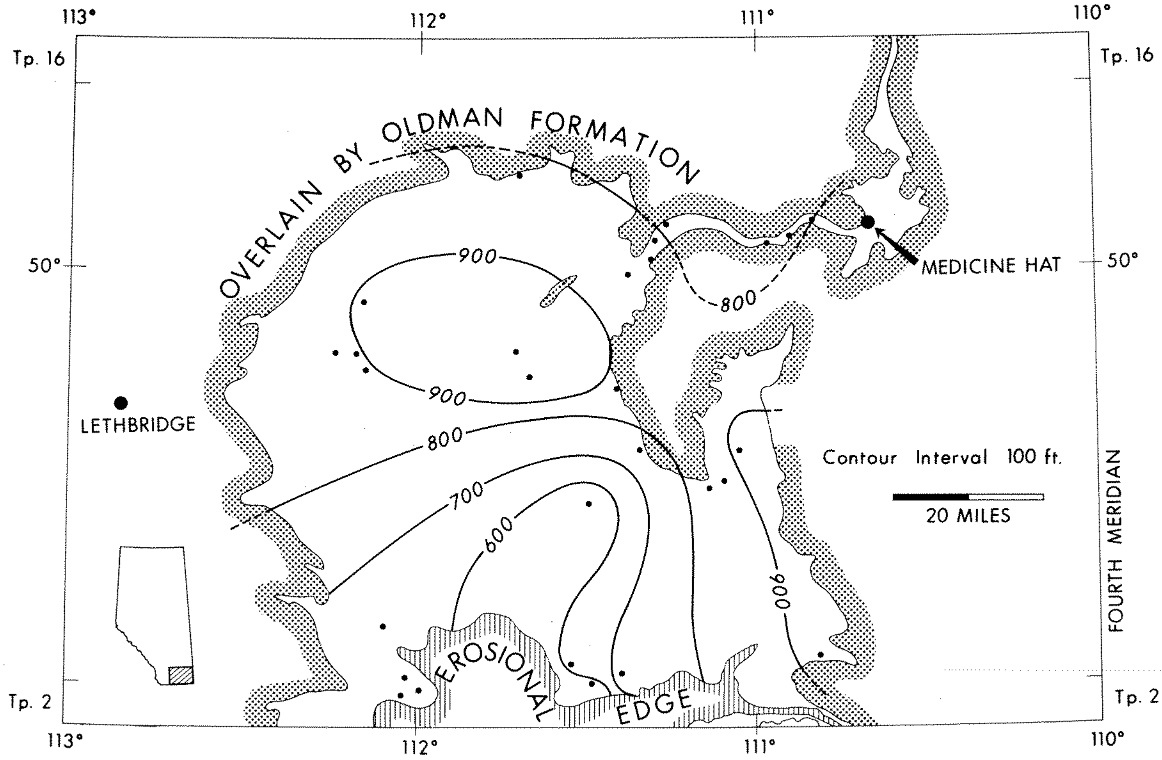

FIGURE 22. Isopach map from the top of the Taber coal zone to the top of the Foremost Formation in southern Alberta. Map shows outcrop distribution of the Foremost Formation in southern Alberta.

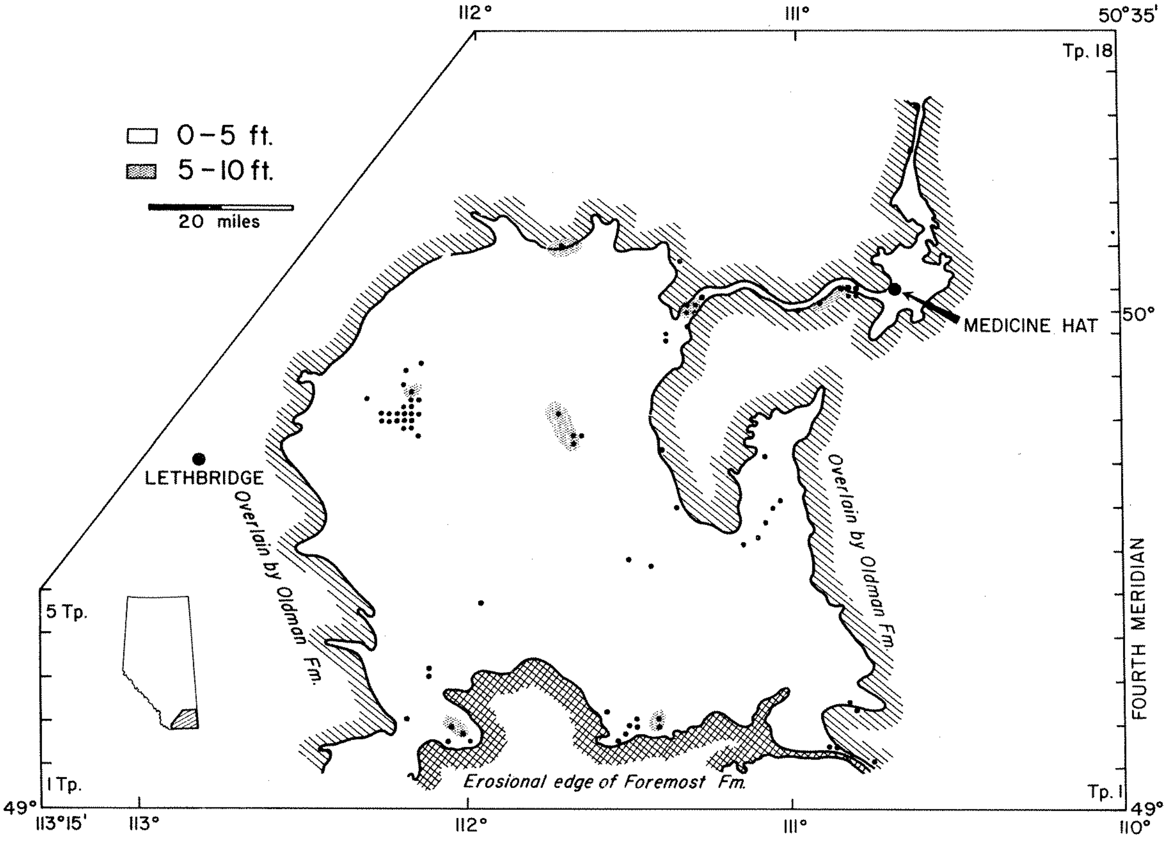

FIGURE 23. Gross coal thicknesses mined in the Taber coal zone of the Foremost Formation. Possible equivalent coal-bearing strata in northeastern Alberta are indicated on figure 24 as Belly River Group.

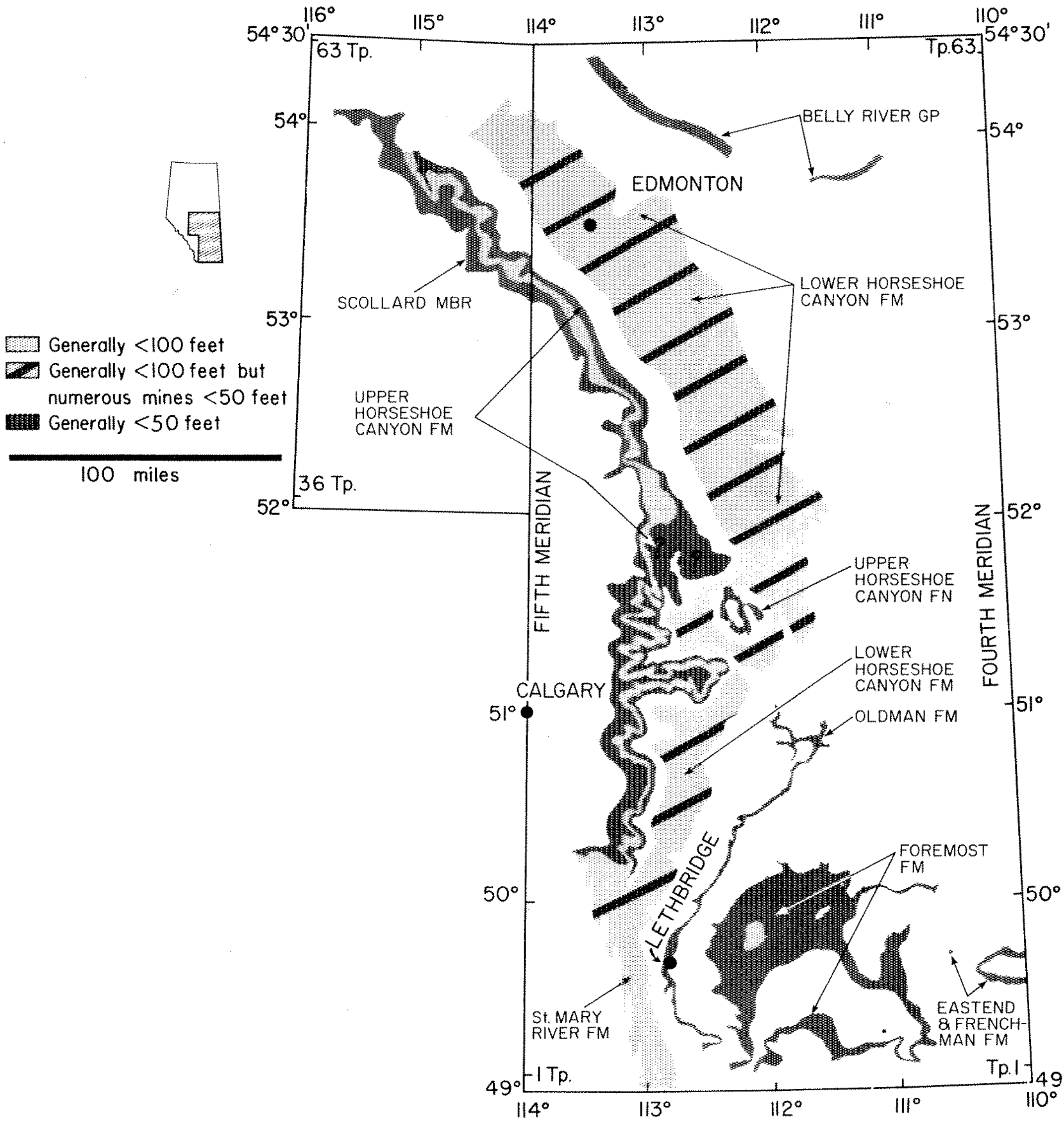

FIGURE 24. Interpretive summary of known minimum overburden of coal mines in the Alberta Plains.

UPPER CRETACEOUS-PALEOCENE COAL-BEARING STRATA, NORTHWEST-CENTRAL ALBERTA PLAINS

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ABSTRACT

Coal-bearing strata of Late Cretaceous age outcrop over a large area in northwest-central Alberta, a region of approximately 18,000 square miles which extends eastward from the British Columbia border along the southern margin of the settled Peace River district. The area, part of the dissected Alberta Plateau, is underlain by gently dipping nonmarine sandstones and mudstones of Late Cretaceous and Paleocene ages which merge to the southwest with folded and faulted Cretaceous strata of the Foothills. Bedrock outcrops are discontinuous, and much of the area is overlain by thick deposits of glacial origin.

Although coal is found throughout the nonmarine Wapiti Group of inferred Cretaceous age, the thickest and most widespread coal exposures are confined to the upper part of the succession, correlative with the Ardley coal interval of south-central Alberta. The Ardley-equivalent interval extends about the flanks of the Swan Hills near the eastern edge of the area, across the lowlands adjacent to the Little Smoky River and westward to the Simonette River Thick coal seams exposed near the junction of the Kakwa and Smoky Rivers and about the flanks of Nose Mountain near the Foothills also are believed to correlate with the Ardley interval.

The coal, concentrated in intervals up to 15 feet thick, grades in rank from subbituminous in the east to high volatile bituminous in the west near the Foothills margin. Preliminary assessment of the data indicates that several potentially large coal deposits are present at shallow depths along the projected outcrop belt of Ardley-equivalent strata, which could provide a major future source of energy for Alberta.

INTRODUCTION

Nonmarine strata of Late Cretaceous and Early Tertiary ages underlie a large area in the western Alberta Plains, extending as a broad belt of gently dipping beds along the margin of the Foothills from the Peace River district in the north to the Crowsnest Pass in the south. Although the broad geologic framework in which these strata are found has been known for many years, especially for southern Alberta, their stratigraphy and economic potential have been outlined in detail in relatively few localities. Consequently, the Research Council's Geology Division carried out a helicopter-supported survey in 1969 and 1970 designed to subdivide and map the Upper Cretaceous-Tertiary succession of the west-central Plains, from the North Saskatchewan River in the south to 55 degrees latitude in the north (Fig. 1). Approximately 300 outcrop localities were described and sampled, and drill cuttings and logs from several hundred exploratory oil wells have been examined subsequently.

This paper summarizes the stratigraphy, structure, and lithology of the coal-bearing strata in the northern part of the area, with emphasis on the distribution and correlation of potential coal deposits.

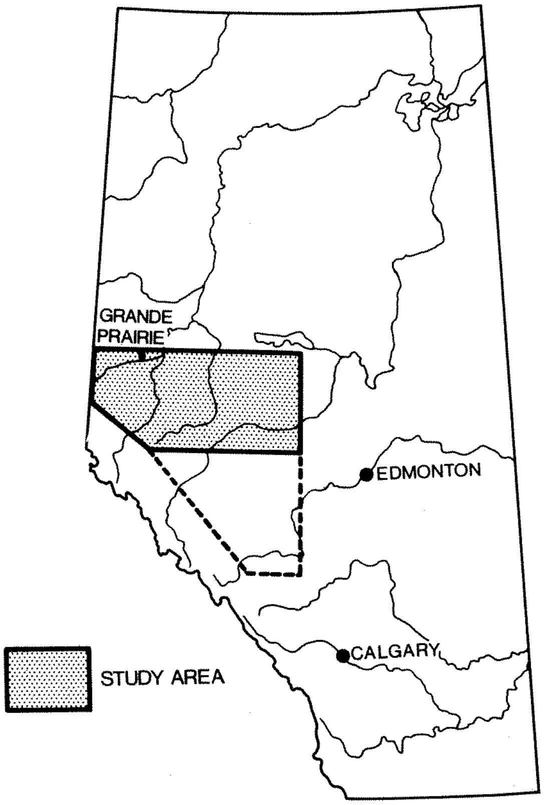

FIGURE 1. Location of study-area. Dashed line indicates additional area covered by bedrock mapping program.

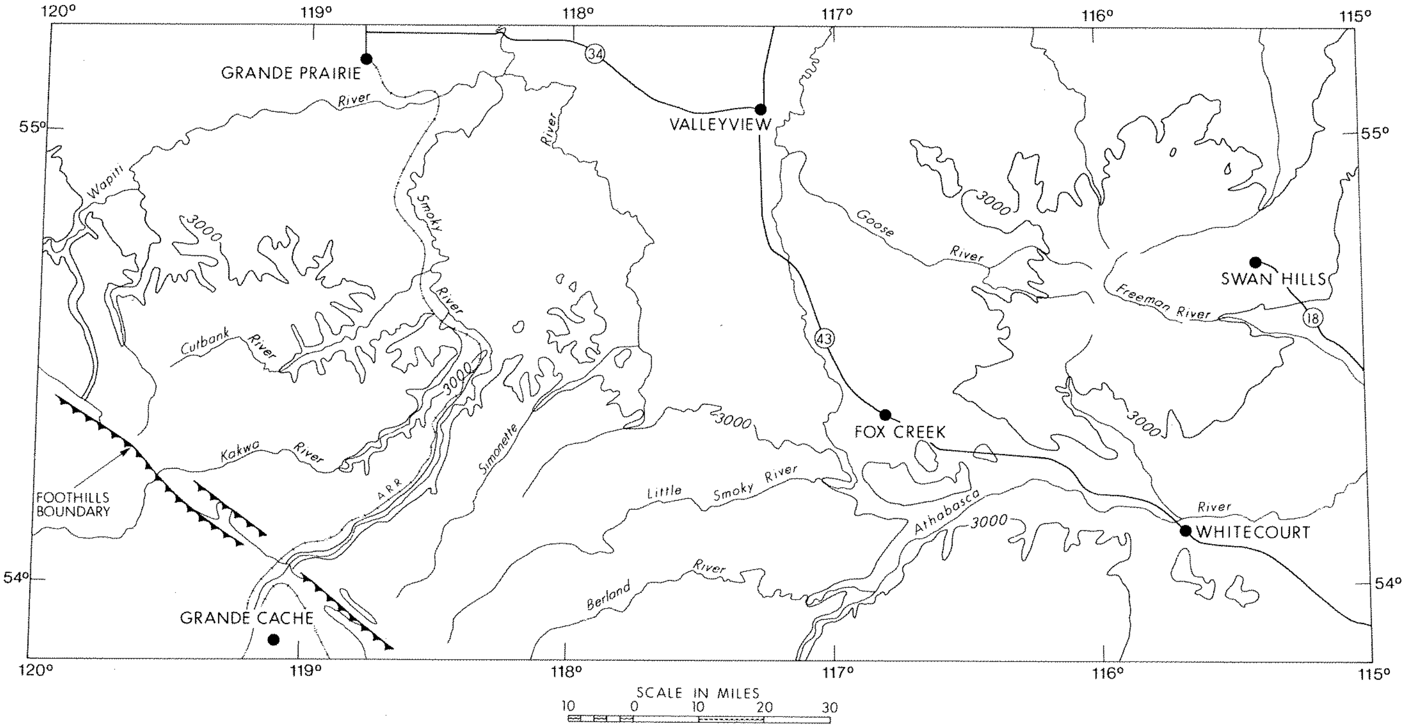

FIGURE 2. Physiographic divisions and major access routes, northwest-central Alberta Plains.

Location and Access

The map-area is located in northwest-central Alberta, extending from the British Columbia border on the west to the Swan Hills on the east, and covers approximately 18,000 square miles. Although the region is sparsely populated, access to much of it has increased substantially during the past decade, mainly due to exploration for natural resources. In the southwest (Fig. 2) the Alberta Resources Railway extends north from the coal-mining town of Grande Cache to the city of Grande Prairie. Provincial Highways 43 and 34 traverse the central and northern parts of the area respectively, and Highway 18 extends into the Swan Hills on the east. In addition, a number of trunk roads maintained by the Alberta Forest Service and service roads built by oil companies provide access to many parts of the region.

Previous Work

The first geological accounts of this region were made by officers of the Geological Survey of Canada. A. R. C. Selwyn was the first to report on this region in 1877 (***see*** Dawson, 1881), and was followed by G. M. Dawson in 1881, who visited parts of the northern and central portions of the area. Dawson (1881) named several of the rock units, including two of the stratigraphic units still in use. In 1918 J. A. Allan studied the geology of the area between the Swan Hills and Lesser Slave Lake. J. F. Caley (Evans and Caley, 1929) explored much of the Wapiti River and the extreme western portion of the region. More recently, Allan and Carr (1946) mapped the bedrock and coal exposures in the area between the Wapiti and Cutbank Rivers, and Greiner (1955) mapped a small area along the eastern edge of the Foothills, near the confluence of the Narraway and Torrens Rivers. Elsewhere, over most of the region formational units and boundaries have remained obscure.

PHYSIOGRAPHY

The area forms part of the dissected Alberta Plateau with elevations ranging from 2000 feet in the north to approximately 5000 feet along the margin of the Rocky Mountain Foothills in the southwest (Fig. 2). In a general way, the region is divisible into three topographic elements, the boundaries of which are outlined approximately by the 3000-foot topographic contour (Fig. 2).

(1) A deeply dissected tableland is located in the southwestern part of the area, consisting of a series of flat-topped ridges separated by incised valleys of north- and northeast-trending rivers. The tableland merges with the Foothills on the southwest, and extends across the southern part of the area in subdued form adjacent to the Athabasca River.

(2) A lowland region extends across the northern and central parts of the area. This is a region of generally low relief, meandering streams, and thick glacial deposits. Bedrock outcrops are scarce, and the few that are present have been contorted in many cases by glacial action.

(3) The Swan Hills, which is a deeply dissected upland consisting of concordant flat-topped ridges separated by wide glaciated valleys.

The area is drained by the components of two major river systems. The western and central parts are traversed by a number of generally northerly-flowing rivers which ultimately empty into the Peace River. The southern and eastern parts are drained by the Athabasca River and a number of smaller tributary streams.

Most of the region, except possibly the high flat-topped ridges in the southwest, was glaciated during Late Pleistocene (Wisconsin) time. As a result, glacial deposits (till, outwash, lake sediments) cover bedrock in most of the region, being thickest in the central lowland area and about the flanks of the Swan Hills. In addition, the flat upper surfaces of the Swan Hills and the high ridges in the southwest near the Foothills are capped in many places by preglacial quartzite gravels of probable Tertiary age.

Over most of the area, bedrock outcrops are confined to the deeper river valleys, although a few exposures are found along the upper slopes of the Swan Hills and the high ridges near the Foothills in the southwest. Generally, away from the Foothills margin, bedrock slopes tend to be unstable, and large scale slumping is a common feature along the larger stream and river valleys and in the Swan Hills.

GEOLOGY

Stratigraphy

Except for a small area in the northeast, the region is underlain by a thick succession of nonmarine sandstones, silty mudstones, and coal beds which is approximately equivalent to the Belly River, Bearpaw, Edmonton, and Paskapoo Groups and Formations of south-central Alberta (Fig. 3). However, the marine Bearpaw Formation, which separates the Belly River Group from the overlying Edmonton Group in the Red Deer River area of south-central Alberta, thins to the north by grading laterally into nonmarine beds in the lower part of the Edmonton Group. Thus, the Bearpaw Formation is absent as a mappable unit in northwest-central Alberta, with the result that the nonmarine Belly River- and Edmonton-equivalent strata cannot be distinguished on the basis of lithology alone.

Although the base of the combined Edmonton-Belly River Groups can be defined as the contact with the marine shales of the Smoky Group, the upper boundary is difficult to distinguish. In south-central Alberta the upper boundary of the Edmonton Group has been placed at the top of a thin but widespread bentonitic shale unit (Battle Formation), which contains a siliceous tuff bed (Kneehills Member) in the upper part (Carrigy, 1970; Irish, 1970). In northwest-central Alberta the Battle Formation is elusive in outcrop and in the western part of the area does not provide a useful marker bed. Consequently, discriminating between Edmonton-equivalent and Paskapoo-equivalent strata is difficult. However, over most of the region, a general distinction can be made between beds similar to the "classical" Paskapoo Formation (Paleocene) of south-central Alberta (pre-1970 terminology, Fig.3) and the underlying coal-bearing strata of latest Cretaceous age on the basis of the same criteria used by Allan and Sanderson (1945).

Therefore, the writers propose tentatively to use a twofold terminology in describing the major bedrock units of the northwest-central Plains (Fig. 3) with the understanding that additional studies may lead to a more consistent basis for subdividing and mapping the nonmarine succession in this area. Thus, the Wapiti Group is equivalent to the Belly River Group, Bearpaw Formation, Edmonton Group and lower member of the Paskapoo Formation (Scollard Member; Irish, 1970) of south-central Alberta, and the "Paskapoo" Formation is equivalent to the "classical" Paskapoo Formation of south-central Alberta.

Structure

The regional structure of the area is that of a broad, asymetrical syncline (Alberta Syncline) in faulted contact along the southwest margin with steeply dipping beds of the Foothills. This feature is demonstrated by structure

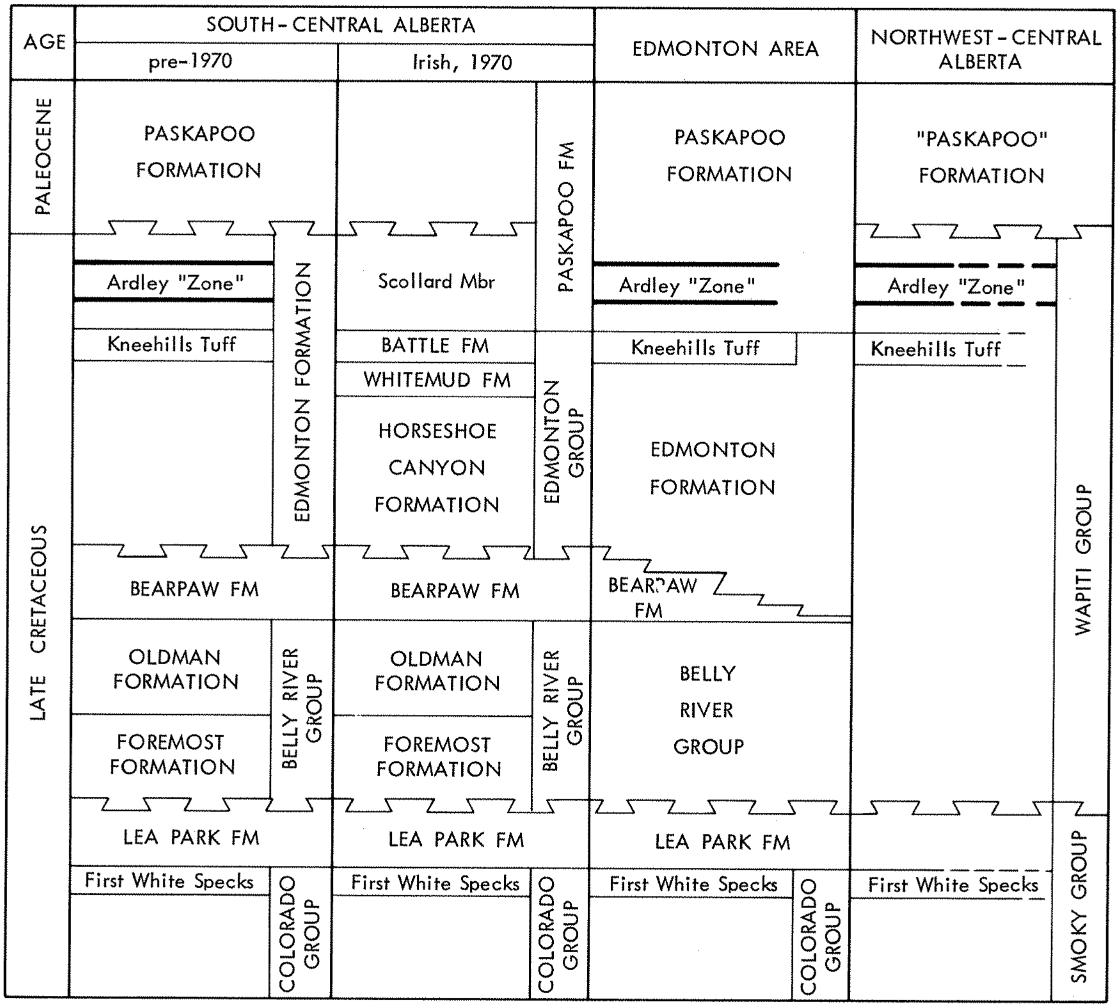

FIGURE 3. Correlation of Upper Cretaceous and Paleocene formations in central Alberta.

contours drawn on the upper boundary of the "first white-speckled shale," a reliable subsurface marker bed in the upper part of the marine Smoky Group (Fig. 4). Over most of the region the beds dip slightly (up to 2°) to the south or southwest, although local undulations may exist.

Correlation of younger nonmarine Cretaceous and Paleocene strata based on outcrop data yields the same broad picture of regional structure (Fig. 5). The only measurable attitudes on these strata – which tend to be quite lenticular and hence not traceable over even short distances – are near the Foothills margin, where they dip from 5° to 15° to the northeast, towards the synclinal axis which presumably parallels the Foothills front a few miles out from the margin of the disturbed belt itself. Elsewhere, strata mapped as Wapiti Group and "Paskapoo" Formation tend to appear flat-lying, an effect that may be enhanced by the propensity of these beds to thin (and thus converge) in a northeast direction. This may account for the fact that the Wapiti-"Paskapoo" boundary parallels the 3000-foot contour over the central part of the area, from the Simonette River to the east flank of the Swan Hills.

Rock Units

Figure 5 is a geological map of the northwest-central Plains showing the areal distribution of major rock-units based on preliminary interpretation of outcrop and shallow subsurface data. The general stratigraphic and structural relationships of the beds are indicated by the cross section in figure 6, which extends across the strike of the beds from the Foothills in the southwest to the Swan Hills in the northeast.

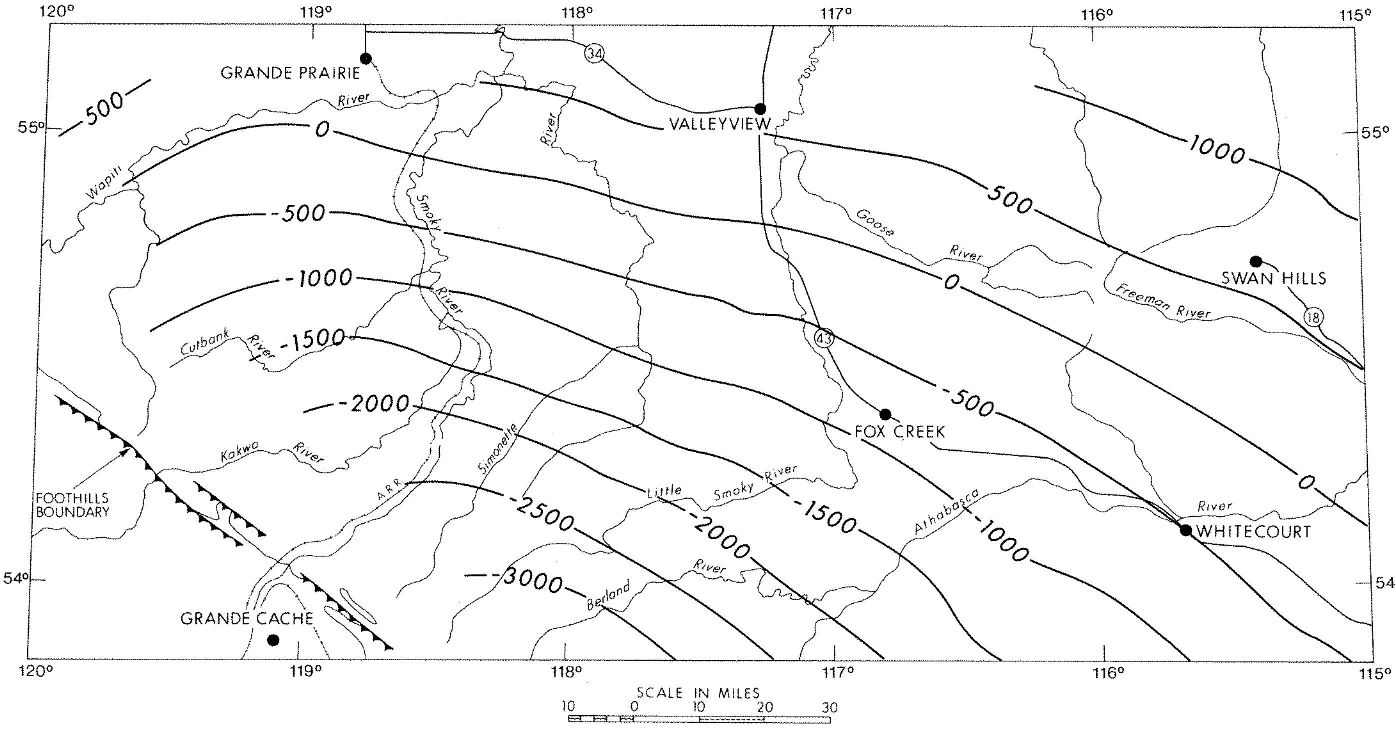

FIGURE 4. Structure contour map of "first white-speckled shale" marker bed, Smoky (Colorado) Group, northwest-central Alberta Plains. (Contour interval = 500 feet)

Smoky Group

Only the uppermost portion of the Smoky Group is exposed, along the East Prairie River, at the northern end of the Swan Hills. The beds consist mainly of soft, dark grey or brown shale.

Wapiti Group

The Smoky Group is overlain conformably by the Wapiti Group, which underlies most of the northern half of the area and varies in thickness from approximately 2500 feet in the Swan Hills region to more than 4500 feet near the Foothills. The Wapiti Group is a succession of nonmarine fluviatile deposits consisting of thick, pale grey, crossbedded, bentonitic sandstones with scattered conglomerate beds, and medium to dark grey, laminated siltstones and blocky mudstones with locally developed coal seams. The strata are lenticular and contain in places scattered thin bentonite and tuff beds.

In oil-well logs the lower 1000 to 1500 feet of Wapiti strata contain more sandstones than the upper part. This lower sandy interval also contains a number of thin (generally less than 5 feet) coal seams which formerly were mined in the Grande Prairie district on the northern margin of the map-area. Although paleontological evidence is lacking, on the basis of lithology these beds may correlate with the Belly River Group of south-central Alberta.

The middle part of the Wapiti Group as observed in oil-well logs is less arenaceous than the lower beds and contains fewer and thinner coal seams. Bentonite beds become more common near the top of the succession, which is marked in the central and eastern parts of the area by the base of the Kneehills Tuff (Battle Formation) marker bed. These strata may correlate with the Bearpaw Formation and revised Edmonton Group of south-central Alberta.

The upper part of the Wapiti Group, from the Kneehills Tuff marker bed to strata shown as "Paskapoo" in figure 5, is approximately correlative with the lower (Scollard) member of the revised Paskapoo Formation in south-central Alberta (Irish, 1970). The unit is shown in cross section (Fig. 6) to be from 500 to 800 feet thick, but the upper boundary is difficult to place consistently owing to the marked lenticularity of the fluviatile sandstones and associated mudstones near the base of the "Paskapoo"

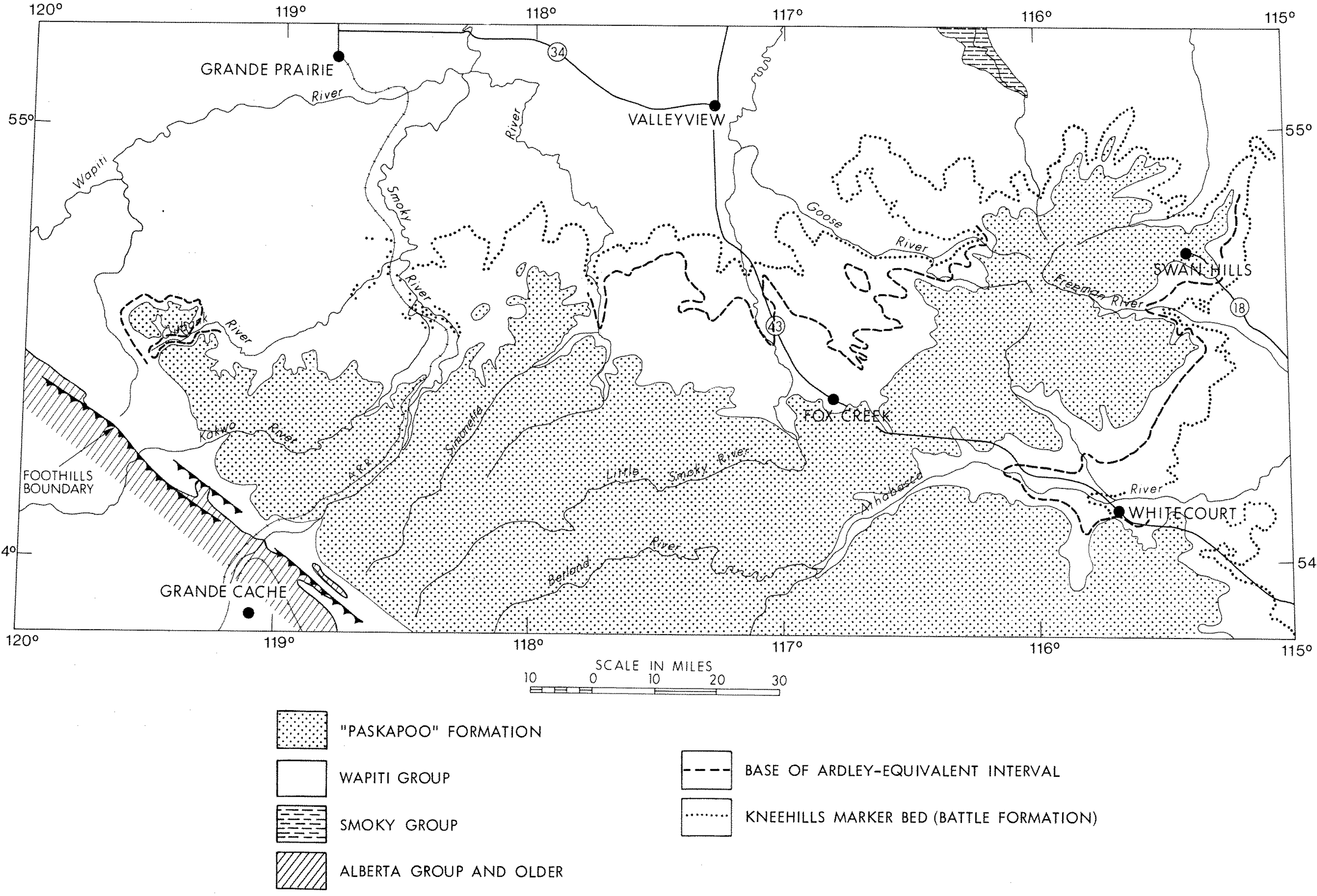

FIGURE 5. Preliminary bedrock geology map, northwest-central Alberta Plains.

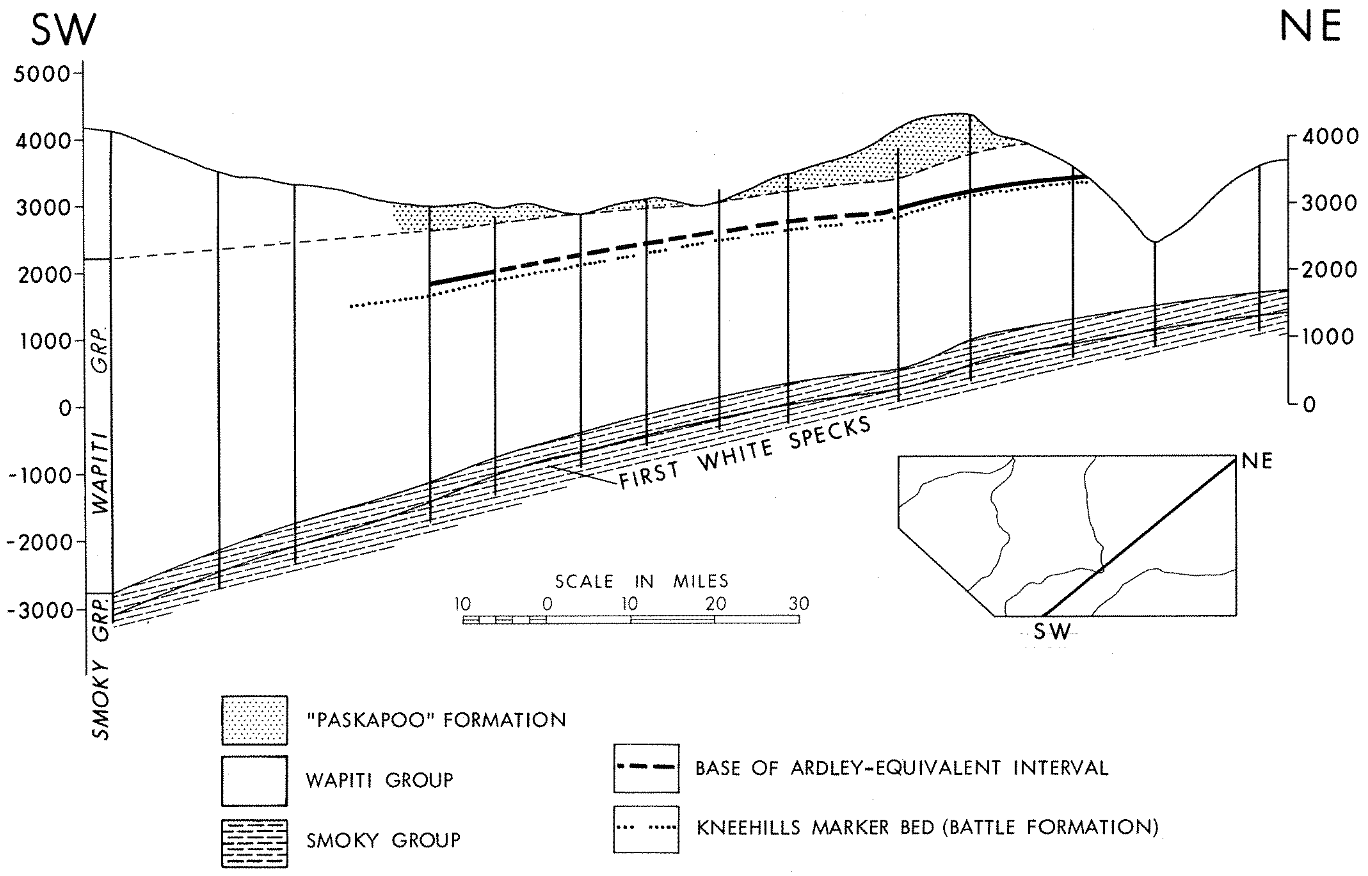

FIGURE 6. Schematic cross section through Upper Cretaceous and Paleocene rock units, northwest-central Alberta Plains.

succession. The strata are similar in lithology to the underlying middle Wapiti beds, except for the abundance of coal seams described below.

The Kneehills Tuff interval (Battle Formation) varies in thickness from 30 to 40 feet in well logs, disappearing westward as a mappable subsurface unit in the vicinity of the Smoky River. It is composed largely of bentonitic shale containing a thin silicified tuff bed and has a widespread distribution in central Alberta. Exposures of this interval are difficult to identify in northwest-central Alberta, and the outcrop pattern shown in figure 5 is based mainly on projection to surface of well-log determinations. However, this projection undoubtedly is inaccurate in some localities owing to the widely varying drift thicknesses over much of the area. To the west, towards the Foothills, the Kneehills loses its distinctive character on well-log profiles partly as a result of thickening of the total section. Also, other tuff and bentonite beds enter the succession; these have similar electric-log properties and make identification of the Kneehills difficult.

Approximately 100 to 200 feet above the Kneehills marker bed, a relatively thick, laterally persistent coal-bearing interval is found in the upper part of the Wapiti Group, which correlates in stratigraphic position with the Ardley "coal zone" of south-central Alberta. This interval is not completely exposed at any one locality but can be identified in well logs in some parts of the area. In the Swan Hills region the Ardley interval varies in thickness from 50 to 100 feet and contains several coal seams, commonly confined to the upper and lower thirds of the interval. To the west, near the junction of the Simonette River and Deep Valley Creek, on the Smoky River, and near the headwaters of the Cutbank River, several thick coal seams or intervals (up to 15 feet) are found in the upper part of the Wapiti succession interbedded with grey bentonitic sandstone, carbonaceous mudstone, and thin bentonite beds. These coal-bearing strata are correlated tentatively with the Ardley interval of the Swan Hills region on the basis of stratigraphic position, lying in close proximity to the thick, cliff-forming, buff-weathering sandstones that mark the approximate base of the "Paskapoo" succession in this area.

"Paskapoo"

The youngest bedrock strata in northwest-central Alberta, designated as "Paskapoo" in figure 5, correlate on the basis of stratigraphic position and gross lithology with the "classical" Paskapoo Formation of south-central Alberta. The beds cap the high ridges adjacent to the Foothills in the southwest, extending across the southern margin of the area and northward to cap the Swan Hills. The beds are thickest in the southwest, being truncated in a northeasterly direction by the post-Paleocene erosion surface. The strata are characterized in the lower part by thick, buff-weathering, pale grey, crossbedded sandstones which, although lenticular, tend to form cliffs that are useful for regional mapping purposes. The upper part of the succession is composed of soft, pale grey sandstone interbedded with blocky green and grey siltstone and silty mudstone associated in places with thin (less than 2 feet) coal and carbonaceous shale beds. The strata are markedly calcareous in the southwest and contain in places freshwater pelecypods and gastropods which locally form coquina beds.

The succession is overlain disconformably in the Swan Hills and in some of the high ridges in the southwest by unconsolidated quartzite gravels of presumed Mid to Late Tertiary age.

COAL DEPOSITS

Historical Review

Coal mining is not new to the area; at least fifty mines have operated in northwest-central Alberta between the First World War and the early 1960's when the last mine closed in 1963 (Campbell, 1964). Owing to the relatively sparse population, most of these mines have operated in two areas:

(1) the Halcourt coal area (Allan, 1924) in the northwest, in the general vicinity of Grande Prairie, which is near the southern margin of the settled Peace River district;

(2) the Whitecourt coal area (Allan, 1924) in the southeast, on the northwest margin of the settled area in central Alberta.

Both underground and surface mines have operated in the two coal areas.

Figure 7 shows graphically the coal production in each of these areas. Prior to 1925, all of northern Alberta was included in the Peace River coal area, and individual coal production records for the Halcourt and Whitecourt coal areas were not kept. In the Halcourt area production was from thin (less than 3.5 feet) seams in the basal part of the Wapiti Group (Belly River-equivalent of central Alberta). The coal is ranked as high volatile C bituminous (Stansfield and Lang, 1944, p. 127-9), and total production from 1925 to 1963 was 53,782 tons. In the Whitecourt area production was from Ardley-equivalent seams up to 8 feet thick. The coal is ranked as subbituminous B (Stansfield and Lang, 1944, p. 173-4), and total production from 1925 to 1961 was 9,267 tons. Analyses of coals from these two areas can be found in Stansfield and Lang (1944) and Campbell (1964).

Most if not all of the production from these coal mines was for domestic consumption by a sparse, widely scattered population, and the small production is hardly indicative of the potential coal reserves of the area.

Distribution of Coal

Figure 8 shows the locations of the thicker coal intervals[1] observed in measured outcrop sections. Fifty-eight locations have intervals less than 5 feet thick, although two of the sections along the Smoky River have two or more coal intervals in close proximity with aggregate thicknesses of more than 5 feet (6 and 10.75 feet, respectively). Similarly, in the western part of the area Allan and Carr (1946) measured several sections along the Cutbank River which have aggregate coal thicknesses of 5 to 10 feet. However, individual seams are thin (less than 3 feet), being separated by clay and shale interbeds.

Of more interest are the coal intervals greater than 5 feet thick for which pertinent data are summarized in table 1. In

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[1] The term coal "interval" is used here in lieu of coal seam or bed, since time did not permit detailed trenching and examination of many of the coal beds during the field survey. Thus, some of the coal intervals for which the locations are indicated in figure 8 may contain beds of coaly clay or shale, or thin bentonite beds intercalated among individual coal seams.

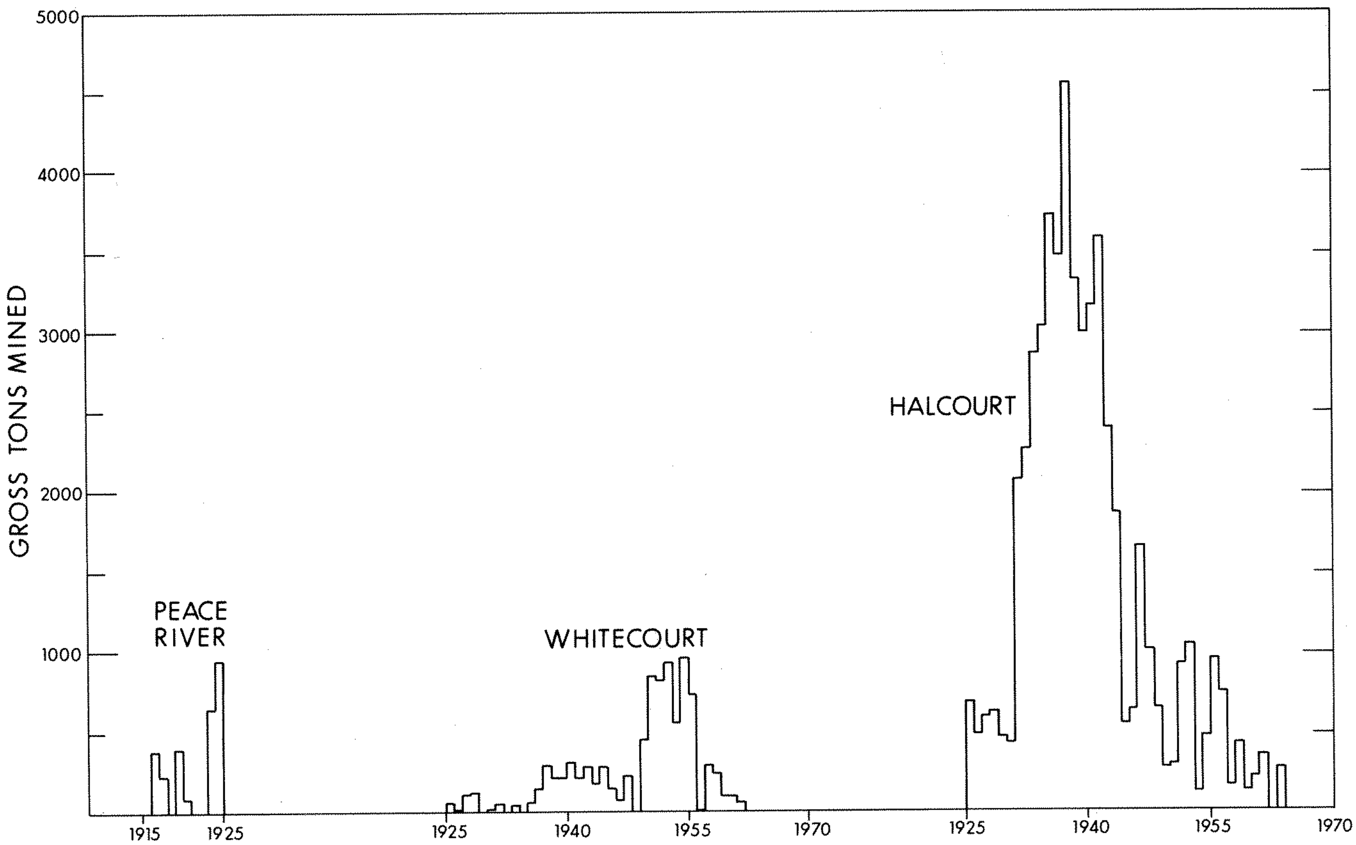

FIGURE 7. History of coal production in the Halcourt, Peace River, and Whitecourt coal areas (data from Annual Reports, Mines Division, Alberta Department of Mines and Minerals, 1915-65).

the Nose Mountain area near the Foothills margin, three sections containing 5-, 8-, and 15-foot coal-bearing intervals were measured. In addition Allan and Carr (1946) described a section on the southwest face of Nose Mountain (in township 64, range 11, west of the 6th meridian) in which the total thickness of coal is 11 feet 2 inches over an interval of 15 feet 6 inches. Whether these coal-bearing intervals are correlative is uncertain.

To the east, a 6-foot thick coal interval is exposed near the confluence of the Kakwa and Smoky Rivers. About 130 feet lower in the same section a 4-foot coal interval associated with coaly shale beds is found. Examination of sample cuttings and logs from wells drilled on Simonette Ridge to the southeast show thick coal-bearing intervals 1000 to 1600 feet below ground level which probably are correlative with the coal beds exposed along the Kakwa and Smoky Rivers just above the junction of the two rivers.

Near the junction of the Simonette River and Deep Valley Creek several coal-bearing sections are exposed. One section contains a 7-foot coal interval separated by 14 feet of siltstone from an overlying coaly interval 10 to 20 feet thick. A second section contains a 13-foot thick coal-bearing interval with thin bentonitic clay interbeds; the base of the seam is below river level.

Farther east, in the lowlands adjacent to the Little Smoky and Iosegun Rivers, two thick coal outcrops were observed. On the Little Smoky River a 10-foot coal interval is separated from an overlying 3-foot interval by 2 feet of silty mudstone. The other, just north of Iosegun Lake, exposes a 7-foot coal interval. At both localities surficial deposits directly overlie the coal. In 1967 and 1968 the Research Council's Groundwater Division drilled several test wells in the Smoke Lake area in connection with a groundwater survey for industry, one of which bottomed in a coal-bearing succession 49 feet thick. Subsequently, the

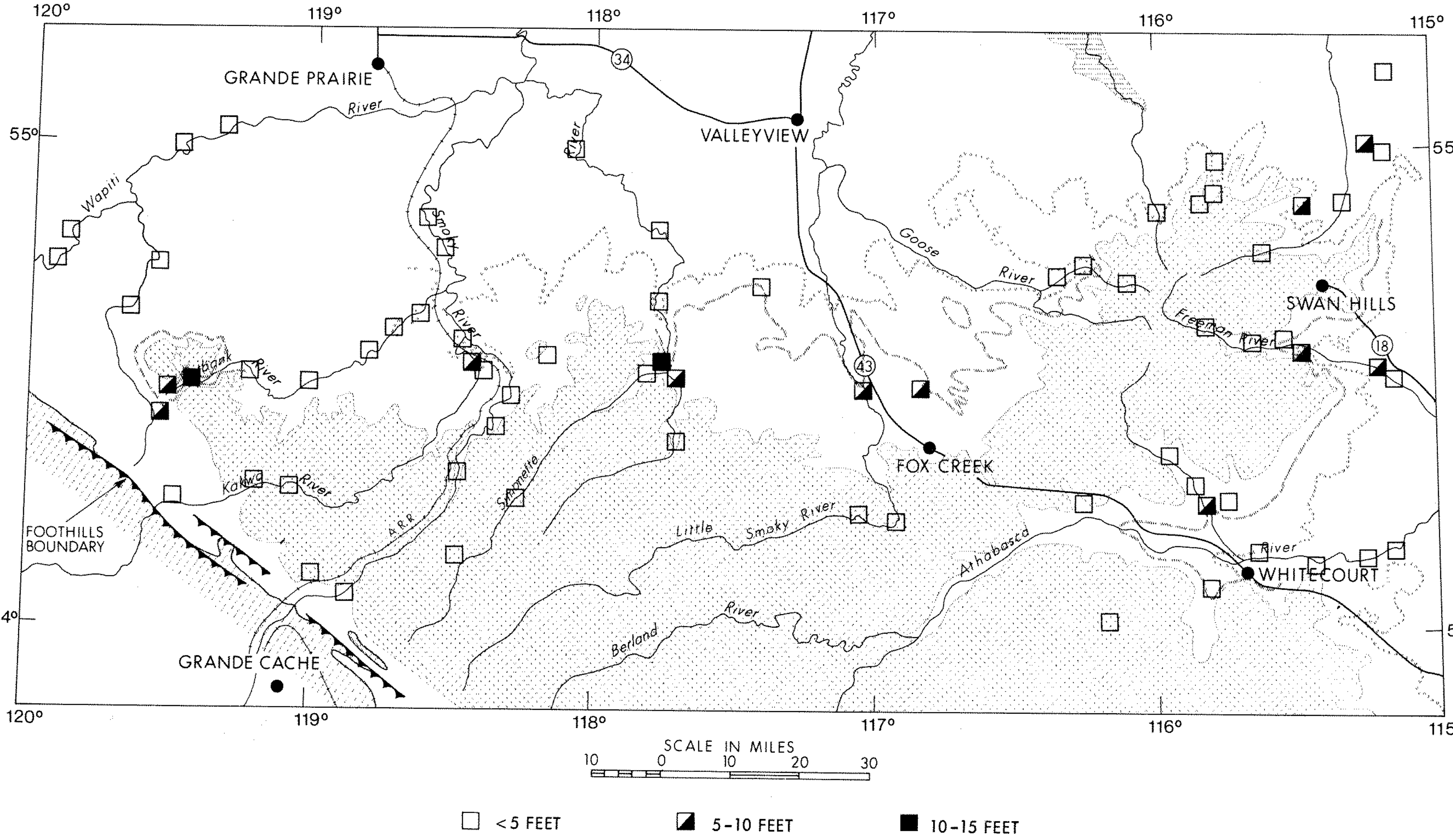

FIGURE 8. Locations and thicknesses of major coal intervals observed in outcrops, northwest-central Alberta Plains.

Table 1. Locations and Thicknesses of Major Coal Intervals, Northwest-Central Alberta Plains

Area	Location (Sec - Tp - R Mer)	Thickness (in feet)
Nose Mountain	12-63-11 W.6	8*
Cutbank R.	31-63-10 W.6	5*
Cutbank R.	3-64-10 W.6	15*
Kakwa R.	30-64- 3 W.6	6* + 5*
Simonette R.	29-64-25 W.5	13*
Deep Valley Cr.	16-64-25 W.5	7*
Little Smoky R.	1-64-21 W.5	10*
Fox Creek	8-64-19 W.5	7*
Swan Hills	12-61-13 W.5	5
Swan Hills	9-68-10 W.5	5 1/2
Swan Hills	31-64-10 W.5	8*
Swan Hills	25-69- 8 W.5	5*
Swan Hills	18-64- 8 W.5	10+*

*See Table 2 for analysis

Research Council's Coal Division carried out a detailed drilling program for near-surface coal deposits in the Fox Creek area, proving up an inferred 350 million tons of strippable coal (Campbell, in press).

About the flanks of the Swan Hills several thick coal-bearing sections were examined. Two 5-foot thick coal intervals are exposed along the Moosehorn River and Boulder Creek in the northern part of the Swan Hills. South of the town of Swan Hills, along the Freeman River, an 8-foot coal-bearing interval was measured, and further downstream a contorted interval containing 10 feet of coal-bearing beds was observed. Northwest of Whitecourt, along the Sakwatamau River, several coal-bearing intervals are exposed, the thickest of which is a 5-foot coal interval.

All but three of these thicker (5 feet or greater) coal intervals probably are contained within that interval of strata correlative with the Ardley coal interval of central Alberta, that is, above the Kneehills Tuff (Battle Formation) marker bed and beneath thick, lensing, buff-weathering sandstones that mark the base of the "classic" Paskapoo succession in central Alberta. From the Simonette River westward, the Kneehills Tuff is absent as a mappable unit; nevertheless, the thicker coal beds are seemingly restricted to the uppermost part of the Cretaceous (Wapiti Group) succession on the basis of stratigraphic position.

Coal Rank

The approximate rank of the coal deposits in northwest-central Alberta is discussed with the following qualifications in mind:

(1) the analyses are from outcrop samples; thus BTU values are probably lower than for subsurface samples due to oxidation and weathering effects;

(2) BTU values may be affected by losses in moisture content between sampling and analysis, even though the samples were collected in plastic bags.

Nevertheless, some general trends in variation in coal rank show up, which can be correlated with similar geographic changes in the composition and physical properties of the associated strata.

Approximate rank of the samples was calculated from analyses performed by a commercial laboratory using the approximation formula given in the A.S.T.M. Handbook (1970, p. 69). Sulphur content was ignored in these calculations: where sulphur values are available, they range from 0.22 to 0.33 per cent. Table 2 gives the results of these analyses.

Figure 9 shows the aerial distribution of analysed samples and their approximate rank, classified as subbituminous or high volatile bituminous. The salient feature of the distribution is that subbituminous coals are confined to the eastern part of the area, defined approximately by a line drawn parallel to the Foothills in the vicinity of the Simonette River. West of this line, all of the coal samples are classed as high volatile bituminous.[1]

Figure 10 is a scatter diagram showing the correlation between moist, mineral-matter-free calorific values obtained from outcrop coal samples and "across-strike" distance from the eastern margin of the Foothills, irrespective of the assumed stratigraphic position of the samples. The least-squares curve is linear with a correlation coefficient (r) of 0.59. That is, approximately 35 per cent ($r^2 \times 100$) of the variation in calorific value of the coal deposits in the area can be associated with distance from the Foothills, which factor presumably relates in turn to the intensity of diagenetic or low grade metamorphic effects to which the strata were subjected.

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[1] Some of the coal samples from the western part of the area could be classified as subbituminous A coals. However, because of weathering effects, it is felt that these samples should be assigned to the high volatile bituminous rank.

Table 2. Analyses and Classification of Coal Outcrop Samples, Northwest-Central Alberta Plains

Sample Number	Location (Sec – Tp – R Mer)	Seam Thick. (ft)	Water Content (%)	Ash Content (%)	Vol. Matter (%)	Fixed Carbon (%)	Gross BTU/lb	MMMF BTU/lb	Approximate Rank
BM 69-19	12-63-11 W.6	8	4.9	6.6	37.7	50.8	10,090	10,880	High Vol. C/Subbitum. A
BM 69- 6	3-64-10 W.6	15	5.2	20.2	29.8	44.8	9,830	12,638	High Vol. C Bitum.
WH 69- 5	31-63-10 W.6	5	5.1	12.1	32.7	50.1	10,560	12,181	High Vol. C Bitum.
BM 70- 9	18-61-10 W.6	3	7.8	54.2	17.5	20.5	4,349	10,770	High Vol. C/Subbitum. A
BM 69- 9	10-61- 7 W.6	3	4.3	55.3	18.3	22.1	5,065	12,931	High Vol. C Bitum.
JK 70- 9	21-59- 7 W.6	1+	4.1	35.6	29.0	31.4	7,991	13,134	High Vol. B Bitum.
WH 69- 8	17-65- 5 W.6	3	6.2	34.1	24.8	34.9	7,550	12,082	High Vol. C Bitum.
BM 69- 4	6-68- 4 W.6	1 1/2	6.5	16.6	31.8	45.1	9,435	11,543	High Vol. C Bitum.
BM 69- 2	12-65- 4 W.6	4	6.8	34.5	23.5	35.2	7,542	12,155	High Vol. C Bitum.
BM 69-13	1-62- 4 W.6	6	5.4	41.6	24.5	28.5	6,320	11,652	High Vol. C Bitum.
WH 69-11A	30-64- 3 W.6	6	9.0	8.1	30.6	52.3	10,380	11,395	High Vol. C/Subbitum. A
WH 69-11B	30-64- 3 W.6	5	6.4	12.0	32.1	49.5	10,090	11,624	High Vol. C Bitum.
BM 69-14A	31-63- 2 W.6	2	7.4	18.1	29.0	45.6	9,634	12,029	High Vol. C Bitum.
MC 69- 7	28-69- 1 W.6	2	7.5	11.5	34.7	46.3	10,008	11,457	High Vol. C/Subbitum. A
MC 69- 2	14-64-26 W.5	<5	6.6	33.8	26.1	33.5	6,810	10,840	High Vol. C/Subbitum. A
JK 71- 7	29-64-25 W.5	13	16.4	30.2	21.5	32.0	6,518	9,760	Subbitum. B
BM 69-30	16-64-25 W.5	7	10.5	39.2	24.8	25.5	5,360	9,423	Subbitum. C
MC 69- 3	32-62-25 W.5	5	7.2	15.3	33.3	44.3	9,738	11,709	High Vol. C Bitum.
JK 71- 5	21-66-23 W.5	2	22.8	14.9	25.6	36.7	7,502	8,973	Subbitum. C
MC 69-27	1-64-21 W.5	10	14.7	11.0	30.6	43.7	9,220	10,489	Subbitum. B
JK 71- 6	8-64-19 W.5	7	25.9	6.7	28.3	39.1	7,796	8,416	Subbitum. C
MC 69-10	28-66-16 W.5	4 1/2	9.1	17.1	33.4	40.4	8,820	10,863	High Vol. C/Subbitum. A
MC 69-16	18-62-13 W.5	<5	14.7	23.3	28.2	33.8	7,190	9,668	Subbitum. B
BM 69-50	27-61-13 W.5	3	9.6	9.8	31.1	49.6	9,104	10,204	Subbitum. B
BM 69-75	32-68-12 W.5	1	8.8	14.2	35.8	41.3	9,091	10,774	High Vol. C/Subbitum. A
BM 69-68	6-65-11 W.5	1 1/4	5.8	40.4	27.4	26.4	5,747	10,343	Subbitum. B
BM 69-67	31-64-10 W.5	8	7.5	16.6	36.4	39.5	8,780	10,741	High Vol. C/Subbitum. A
BM 69-83	25-69- 8 W.5	5	9.0	19.7	35.2	36.1	7,840	10,009	Subbitum. B
BM 69-66	18-64- 8 W.5	10+	4.8	49.4	25.0	20.8	4,620	10,118	Subbitum. B

The large amount of "unexplained" variation in calorific values (that is, the 65 per cent of total variation not attributed to the regression curve) may be due to several factors: sampling (analytical) errors, variation in depths of burial, inherent (stratigraphic or geographic) differences in coal composition, "random" effects.

Diagenesis

Related to regional variation in coal rank are changes in the composition of the detrital sediments themselves, particularly well exemplified by variation in the degree and kinds of sandstone cements. This is indicated in summary fashion in figure 11.

East of a line trending approximately parallel to the Foothills through the centre of the map-area, the sandstones – with the exception of hard carbonate-cemented lenses – tend to be partly or largely uncemented: intergranular porosity is high, and the main authigenic minerals are scattered patches of kaolinite or montmorillonite cement associated in a few of the rocks with intergranular crystals of clinoptilolite, a low temperature Ca-Na zeolite.

To the west of this line, which corresponds approximately to the eastern limit of coals classed as subbituminous, intergranular sandstone porosity diminishes markedly. Kaolinite, montmorillonite, and calcite are the dominant

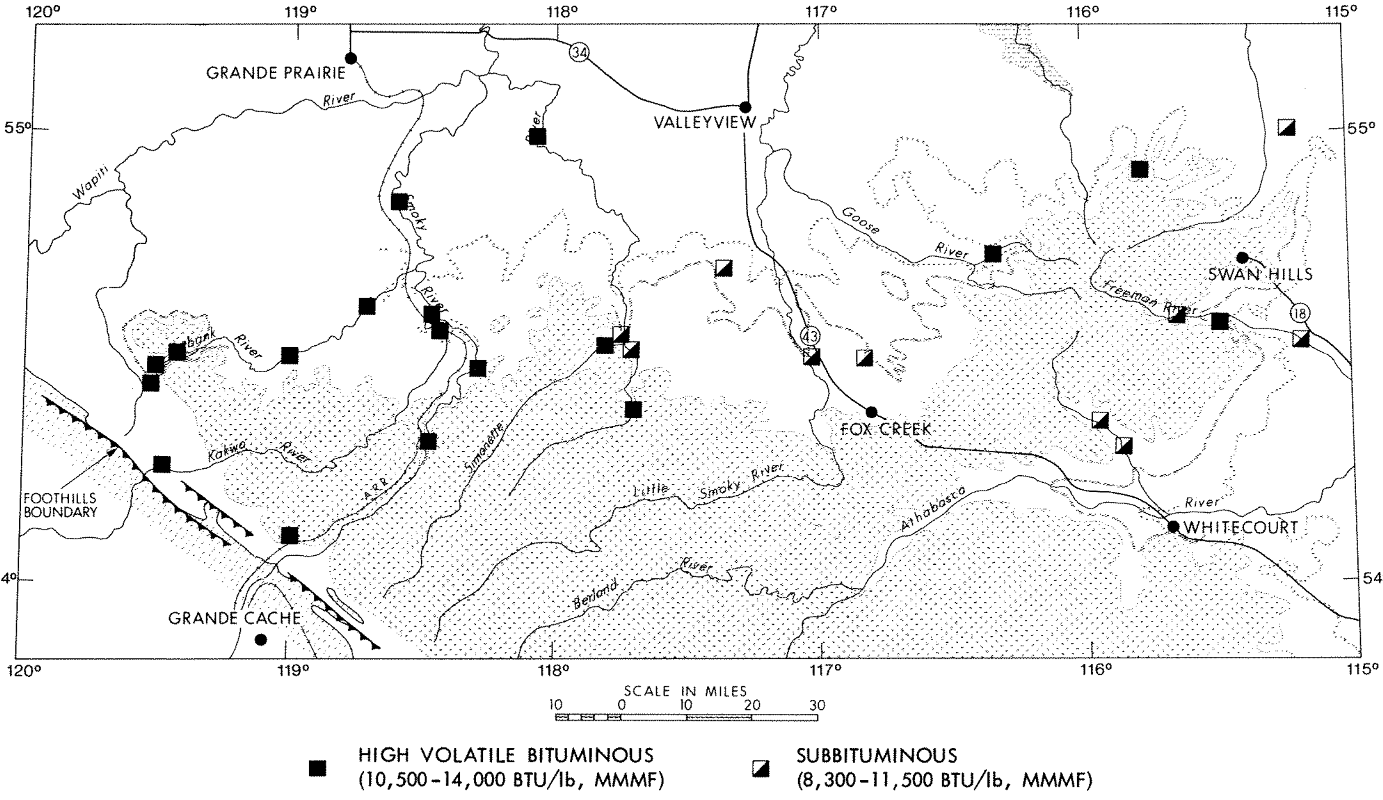

FIGURE 9. Locations and approximate rank of analysed coal outcrop samples, northwest-central Alberta Plains.

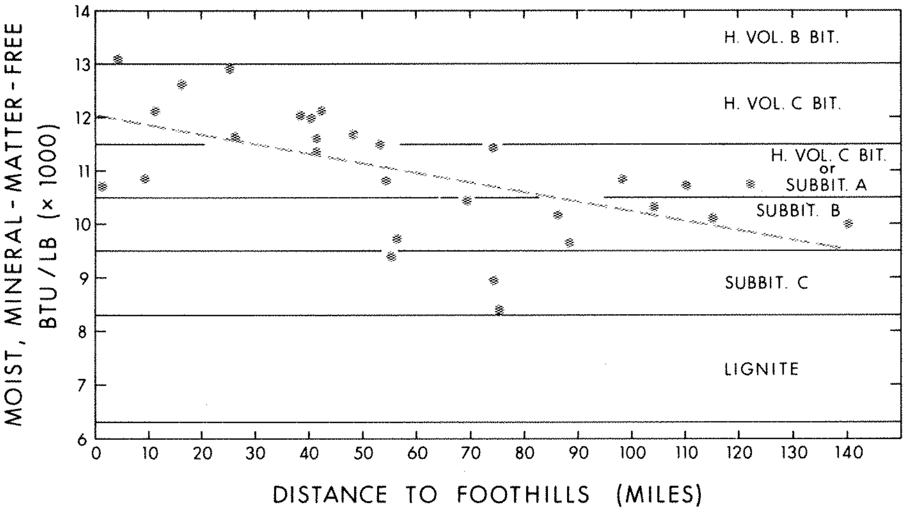

FIGURE 10. Variation in rank (moist, mineral-matter-free BTU/lb) with distance across strike from Foothills margin, coal outcrop samples, northwest-central Alberta Plains.

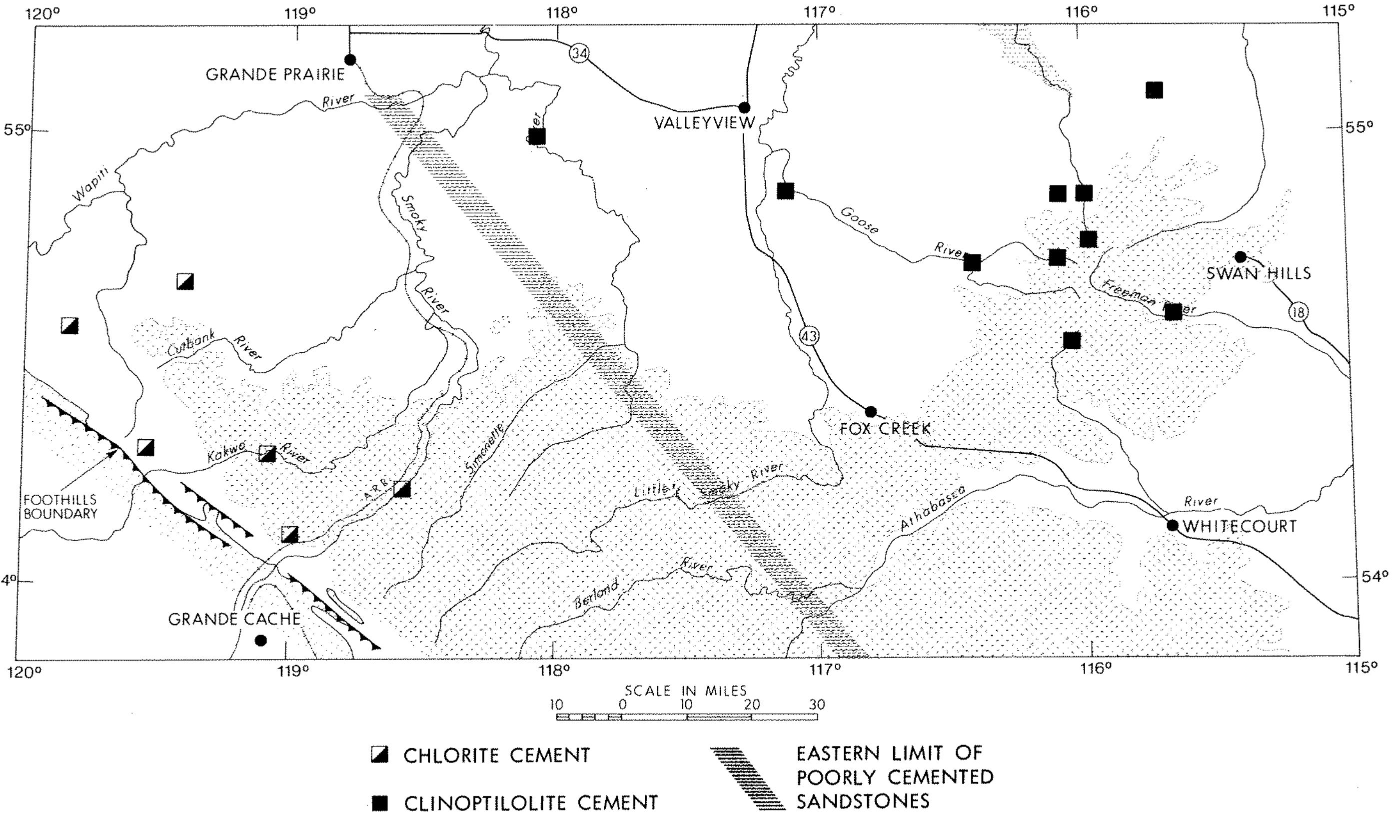

FIGURE 11. Types and distribution of sandstone cements, northwest-central Alberta Plains.

cementing minerals, forming up to 20 per cent by volume of the total rock constituents. Further west, towards the edge of the Foothills, chlorite cement is found in some of the sandstones, imparting a greenish tinge to the rocks. The distribution of chlorite is interpreted as marking the boundary of a regional zone of low grade metamorphism in which the original authigenic constituents of the rocks have undergone moderate chemical alteration and recrystallization to form chlorite rather than montmorillonite cement.

ECONOMIC GEOLOGY

Figure 12 shows five areas which appear on the basis of outcrop data to have potentially large reserves of coal at shallow depths and therefore may warrant further examination by drilling in the future. These areas are Nose Mountain, Simonette River-Deep Valley Creek, Fox Creek, and the southern and eastern flanks of the Swan Hills.

The large block in the Fox Creek area has been drilled in some detail by the Research Council of Alberta's Coal Division. The results of this drilling show that approximately 350 million tons of inferred shallow (100 feet of overburden – mainly drift) coal reserves exist in seven blocks in an area of about 66 square miles (Campbell, in press). The area is accessible with good water supplies; on the other hand, the near surface geology is complex due to thick (up to 200 feet) but variable amounts of glacial drift (St. Onge, 1966) and to the widespread presence of ice-contorted bedrock.

The other four areas indicated on the map remain unexplored in detail, although the coal deposits in all are presumed to be contained within the Ardley-equivalent interval, as are the Fox Creek deposits. The Nose Mountain area is one of moderate relief with some potential structural complexities; it also is relatively inaccessible at present with no large water supply in the vicinity. The Simonette River-Deep Valley Creek exposures appear relatively thick,

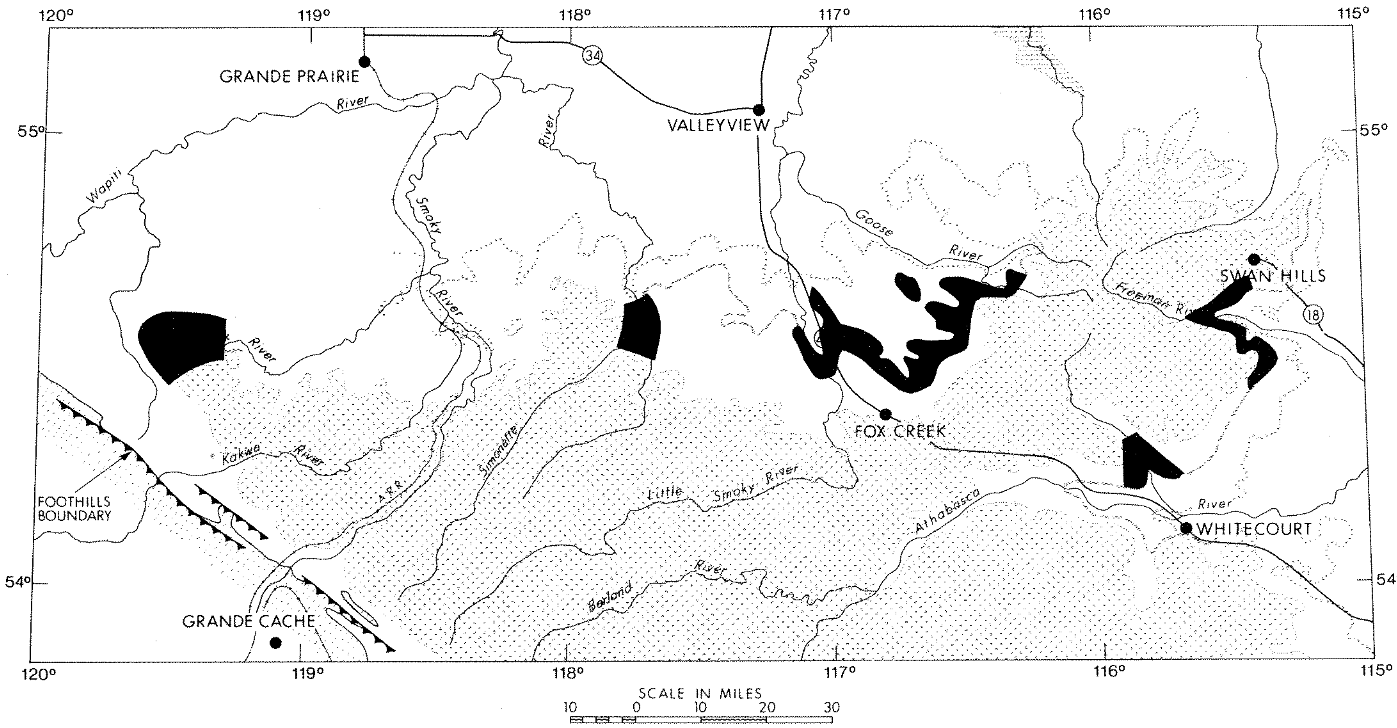

FIGURE 12. Areas inferred to be underlain by potentially economic coal deposits at shallow depths, northwest-central Alberta Plains.

the relief is lower than to the west, and the Simonette River itself provides a potential source of water. Potential reserves around the southern and eastern flanks of the Swan Hills are associated with the same problems as those near Fox Creek: thick glacial deposits and ice-contorted bedrock. Also, surface water supplies are scarce in this area.

In summary, outcrop and drilling data suggest that substantial deposits of subbituminous and high volatile bituminous coal are to be found at relatively shallow depths in uppermost Cretaceous strata of northwest-central Alberta. Although the development and utilization of these deposits does not appear to be of immediate concern, they represent a major future source of energy for the Province of Alberta.

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GEOLOGY OF THE LUSCAR (BLAIRMORE) COAL BEDS, CENTRAL ALBERTA FOOTHILLS

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ABSTRACT

Coal-bearing strata of Early Cretaceous age outcrop extensively along the strike of the central Alberta Foothills between the Clearwater and Athabasca Rivers, a distance of 150 miles. The strata form part of the dominantly nonmarine Blairmore Group, divisible at this latitude into two major formational units characterized by differences in sandstone composition and gross lithology.

Commercial coal seams varying in thickness from 5 to 30 feet and in number from 2 to 5 are restricted to the lower part of the upper unit (Beaver Mines Formation). The coal is interbedded with thick, crossbedded, pale grey, feldspathic sandstones and grey, sideritic, silty shales (Luscar facies), which in the Cadomin area overly a thin tongue of marine shale correlative with the Moosebar Formation of the northern Foothills. To the south, in the vicinity of Clearwater River, the Luscar beds grade laterally into green chloritic sandstones and shales which lie conformably on the calcareous beds at the top of the lower Blairmore unit (Gladstone Formation). These beds form the nonmarine fluviatile facies of the Beaver Mines Formation, being contiguous with the Mountain Park beds above the Luscar coal measures in the northern part of the area.

INTRODUCTION

Coal-bearing strata of Early Cretaceous age are exposed along the strike of the Alberta Foothills from near Clearwater River in the south to the Alberta-British Columbia border in the north, a distance of approximately 250 miles. Within the southern part of this area – between the Athabasca and North Saskatchewan Rivers – coal mining has been carried out since the early 1900's at several localities. Peak production was achieved in the late 1950's when combined annual production of 1 1/2 million tons was reported, representing 27 per cent of the bituminous coal mined in Alberta at that time. Mining temporarily ceased shortly thereafter owing to diminishing markets, but renewed interest in Foothills bituminous coals for coking purposes has led recently to the reopening of operations at one locality (Luscar) and to intensive exploration for additional reserves throughout the central Foothills region.

This paper is concerned with the Luscar coal-bearing beds in the central Alberta Foothills, defined as the belt of folded strata extending along the eastern margin of the Rocky Mountains between the Bow River in the south and the Athabasca River in the north (Fig. 1). The objective of the study is to define the distribution, lithology, and depositional environment of these strata, which form part of the Lower Cretaceous Blairmore Group.

Acknowledgments

The writers thank the managements of Mesa Petroleum Company and Rio Alto Exploration Limited for permission to include data from two wells drilled in the Clearwater River area.

REGIONAL GEOLOGY

Distribution

Blairmore Group and correlative strata form a blanket of predominantly clastic sediments deposited over the site of the Alberta Foothills and much of the Plains during Early

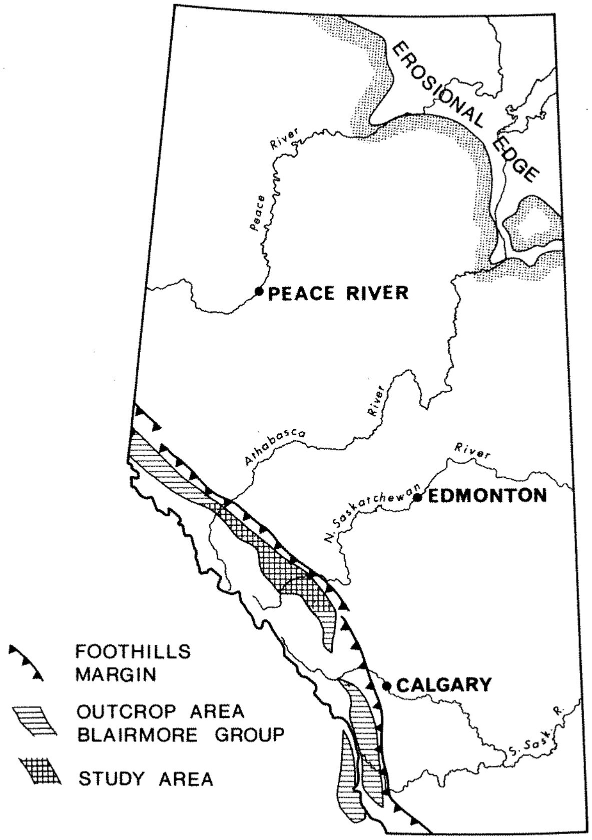

FIGURE 1. Location of study-area.

Cretaceous time. Within the Foothills these strata form a wedge-shaped body of rock that ranges in thickness from 1200 feet near the eastern edge of the outcrop belt to more than 3000 feet on the west. Undoubtedly, prior to uplift and subsequent erosion of the Rocky Mountains during Tertiary time, Blairmore strata extended much farther west than the present outcrop pattern indicates, although the approximate position of the western margin of the depositional basin during Early Cretaceous time is speculative.

Within the central Foothills, from just north of the Bow River to the Athabasca River, Blairmore strata — including the Luscar coal beds — are now exposed along a series of northwest-trending fault blocks and associated folds, giving rise to the outcrop pattern indicated in figure 2. The southwest margin of the outcrop area is marked in this region by the trace of the McConnell thrust fault, which denotes the eastern limit of the Rocky Mountain front ranges. The northeast margin is defined approximately by a series of ***en echelon*** faults associated with large folded anticlinal structures exposing Upper Paleozoic strata in their cores (Clearwater, Brazeau, and Nikanassin structures). Locally, structurally incompetent Blairmore strata — especially the coal-bearing Luscar beds — are faulted and in places strongly folded where they are exposed along the strike of major structural features. Thus, local structural complexities, combined with the generally discontinuous nature of outcrops in much of the central Foothills, make detailed comparison and correlation of even relatively closely spaced sections difficult.

Stratigraphy and Correlation

Lower Cretaceous coal-bearing strata of the central Foothills have been the subject of attention since the beginning of the century, when the first attempts were made to map and evaluate the coal deposits for use in steam locomotives.

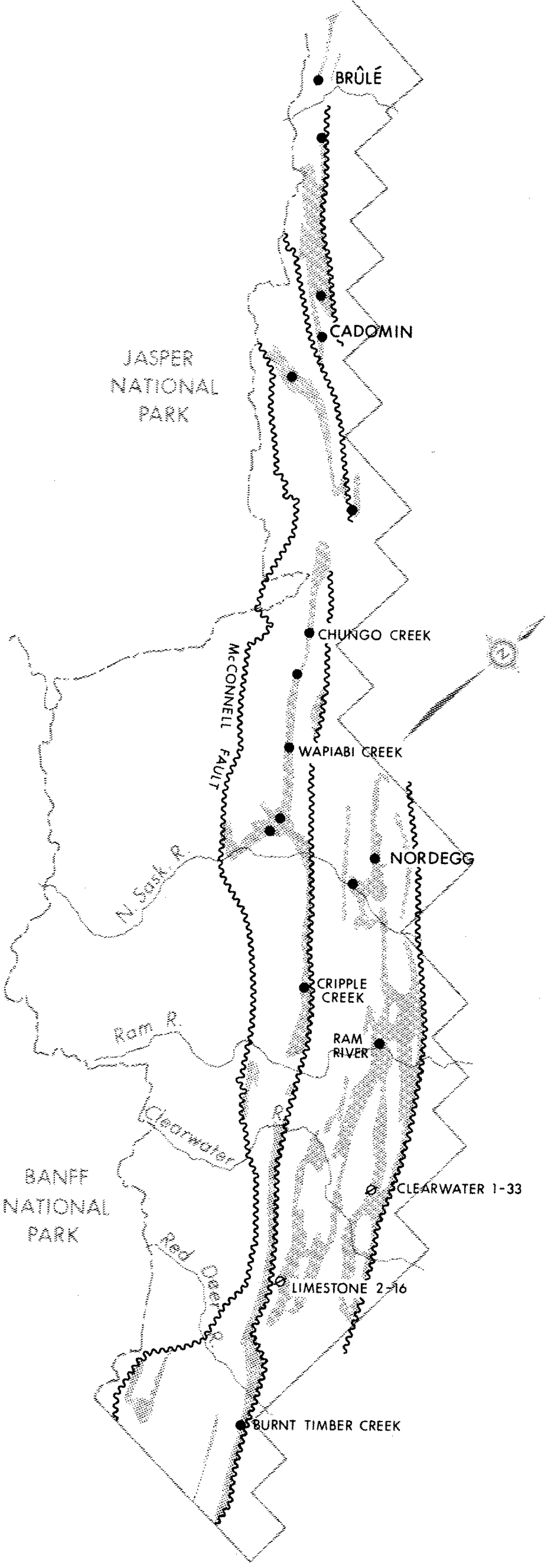

FIGURE 2. Location of measured sections, central Alberta Foothills.

Originally these strata were correlated with the coal-bearing Kootenay Formation of the southern Foothills, now known to be of Late Jurassic age, at least in part. More detailed investigations by B. R. MacKay in the 1920's in the northern part of the central Foothills showed that the coal-bearing beds there contain a fossil flora which is distinctly younger than that found in the Kootenay Formation of the southern Foothills, correlating with the flora found in the lower part of the non-coal-bearing Blairmore Group to the south.

MacKay (1929a, 1930) subsequently divided the nonmarine Lower Cretaceous succession of the north-central Foothills into four lithologic units which he named, in ascending order (Fig. 3):

Nikanassin Formation: hard grey sandstone and dark grey shale with thin coaly beds in the upper part;

Cadomin Formation: thin resistant chert and quartz pebble conglomerate;

Luscar Formation: grey sandstone and dark grey shale with commercial coal beds in the upper part;

Mountain Park Formation: coarse-grained, green, ridge-forming sandstone and greenish-grey shale with scattered lenses of chert pebble conglomerate.

The Cadomin Formation, although relatively thin, is widespread throughout the Foothills and serves as an excellent marker bed for differentiating the Nikanassin and Luscar units. However, the boundary between the Luscar and overlying Mountain Park Formations has remained difficult to define owing to its gradational nature. MacKay himself was unable to distinguish between the two "formations" in the Brûlé coal basin north of Cadomin (MacKay, 1929b), and most investigators in adjacent parts of the central and northern Foothills, with the notable exception of Douglas (1955, 1958), have not recognized the Mountain Park Formation as a distinct lithologic unit, preferring to include correlative strata with the underlying Luscar Formation for mapping purposes.

Subsequent to MacKay's work in the north-central Foothills, the exact relationship between the Luscar-Mountain Park beds and the Blairmore Group of the southern Foothills remained obscure. However, on the basis of detailed lithologic and paleontologic studies, Mellon (1967) recently proposed a revised stratigraphic framework for the Blairmore Group and correlative strata of the Alberta Foothills, shown schematically in figure 4. Mellon divided the Blairmore Group of the southern Foothills into three formational units distinguished by differences in gross lithology, sandstone composition, and fossil floras. The formations are bounded by regional disconformities (that is, breaks in sedimentation) of variable magnitude which correspond approximately to time-datum planes.

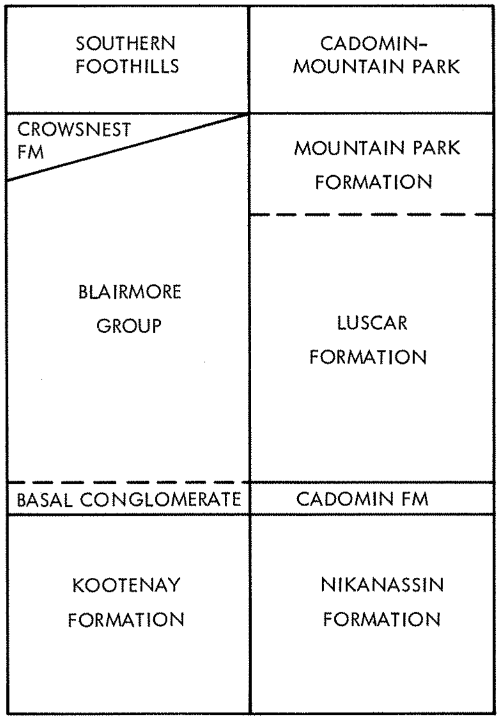

FIGURE 3. Stratigraphic nomenclature chart, Lower Cretaceous strata, Alberta Foothills.

The lower unit, the Gladstone Formation, is from 200 to 500 feet thick in the southern Foothills, comprising:

(1) a basal quartzite and chert pebble conglomerate (Cadomin Conglomerate);

(2) an intermediate succession of thinly bedded varicolored shales and fine-grained, grey, siliceous sandstones;

(3) an upper "calcareous" member composed of fossiliferous freshwater limestone and black calcareous shale.

The average thickness of the unit increases in a northerly direction along the strike of the Foothills, in which direction certain facies changes also take place:

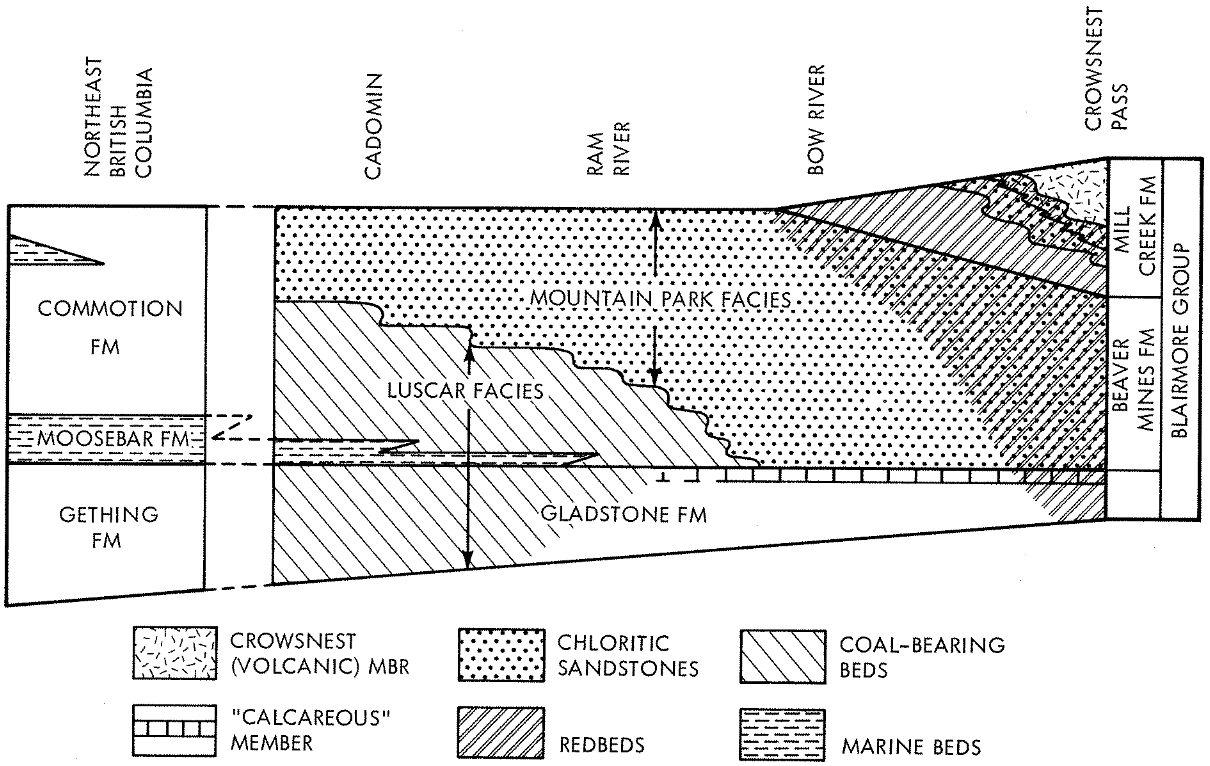

FIGURE 4. Relationship of facies to formational units, Blairmore Group, Alberta Foothills.

(1) the "calcareous" member grades laterally into black silty shale and fine-grained sandstone north of the Bow River;

(2) carbonaceous shale and thin coal beds become increasingly more common in sections north of the Ram River.

In summary, the lithology and faunal content of the formation change from a distinctly nonmarine aspect in southern Alberta to a less well defined aspect in the central Foothills, indicative of closer proximity to marine conditions of deposition there.

The middle Blairmore unit in the southern Foothills, the Beaver Mines Formation, is approximately 900 to 1200 feet thick along the eastern outcrop margin. It consists of thick crossbedded green sandstones, interbedded with dark green siltstones and red, green, and grey silty shales associated in places with thin bentonite and finely crystalline tuff beds. The sandstones contain a high proportion of reworked volcanic detritus – feldspars, biotite, rock fragments – and in places are interbedded with lenses of igneous pebble conglomerate. Their green color is due to the presence of chlorite cement, deposited as a coating about the detrital grains together with a variety of other authigenic constituents. In this respect Beaver Mines strata differ markedly from the quartzose, cherty rocks of the older Gladstone and Kootenay Formations and the overlying cherty sandstones of the Mill Creek Formation.

The Beaver Mines Formation can be traced along the strike of the Foothills from the Crowsnest Pass region to north of the Bow River without any major change in gross lithology or composition, except that the red mottled shales common in the southernmost Foothills are replaced in a northerly direction by drab green and grey shales. However, north of the Red Deer River, in the vicinity of the Clearwater River, coal seams of commercial thickness are found in the lower part of the Beaver Mines Formation, extending northward along the strike of the Foothills into northeastern British Columbia. Associated with the presence of coal beds in the lower part of the Beaver Mines Formation at this latitude are a number of other lithologic and compositional changes:

Table 1. Lithologic Attributes of Blairmore Group Facies, Central Alberta Foothills

Attribute	Facies		
	Lower Luscar [1]	Upper Luscar [2]	Mountain Park [3]
Color	Banded: grey and white, "salt-and-pepper" type	Pale to medium grey, buff-speckled in many cases	Pale greyish-green to medium green
Bedding	Thick (lower part) to thin (upper part); microcrossbedding and ripple marks common	Thick, crossbedded	Thick, crossbedded, few mud pebbles
Detrital Composition (Granular Constituents)	Quartz, chert, clastic carbonates	Mixed: volcanic detritus, clastic carbonates, quartz, chert; siderite pellets common	Abundant volcanic detritus: angular quartz, feldspars, rock fragments, biotite
Cement Composition (Authigenic Constituents)	Quartz, kaolinite, calcite	Illite, kaolinite, quartz, calcite	Chlorite, illite, quartz, calcite

[1] Gladstone Formation

[2] Beaver Mines Formation (lower part)

[3] Beaver Mines Formation (upper part)

(1) the characteristic greenish color of the sandstones changes to pale grey, denoting the change from chlorite cement to kaolinite or illite;

(2) thin sideritic ironstone beds and nodules become abundant in both the shales and sandstones. and the sandstones take on a reddish-brown speckled appearance due to the abundance of bedded siderite pellets;

(3) a thin tongue of dark grey marine shale carrying a microfauna found in the Moosebar Formation of northeastern British Columbia is present at the base of the formation in the Cadomin area.

Additional differences in lithologic attributes associated with facies changes within the Blairmore Group are summarized in table 1.

These coal-bearing strata correlate with the upper part of MacKay's and Douglas' "Luscar Formation," distinguishable in the north-central Foothills from the underlying Gladstone (Gething) Formation on the basis of lithology and sandstone composition. However, the upper part of the Beaver Mines Formation — corresponding to MacKay's "Mountain Park Formation" — maintains the same gross lithologic attributes in the north-central Foothills observed throughout the formation south of the Clearwater River (green chloritic sandstones, lack of coal beds), although the contact with the underlying Luscar succession remains gradational and therefore difficult to map consistently, particularly in areas of poor exposures (Douglas, 1955, 1958).

In summary, the Luscar and Mountain Park beds are interpreted as laterally interfingering facies of the middle part of the Blairmore Group in the central Alberta Foothills, deposited about the margin of a shallow boreal sea that transgressed from the north into central Alberta during Early Cretaceous (Albian) time (Fig. 5). The Mountain Park beds are the nonmarine fluviatile facies skirting a highland source region on the southwest margin of the depositional basin, whereas the Luscar beds represent the coastal plain deposits marginal to the marine beds to the north. A similar facies distribution exists in the underlying Gladstone Formation (lower Luscar beds), which is correlative with the coal-bearing Gething Formation of northeastern British Columbia. However, in the central Foothills commercial coal beds appear to be confined to the upper part of the Luscar succession, above the marine tongue, associated with the regressive near-shore deposits.

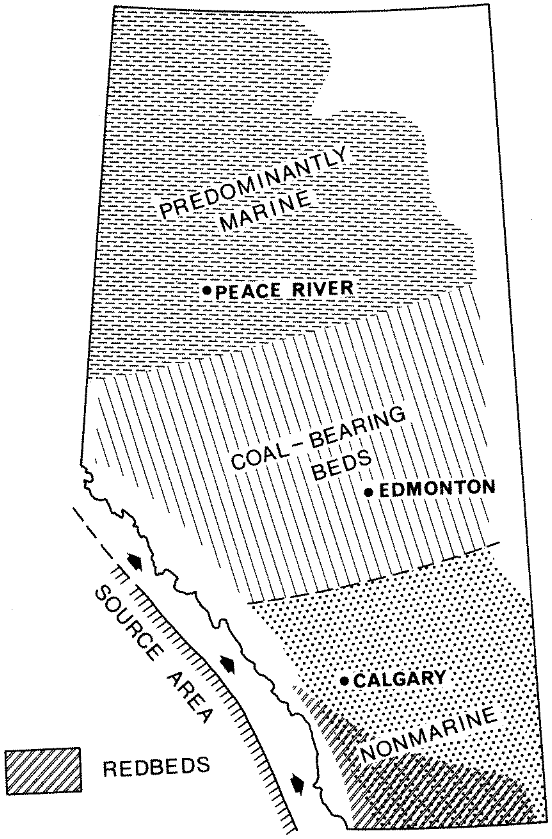

FIGURE 5. Generalized distribution of Blairmore Group depositional facies during Early Cretaceous time.

COAL GEOLOGY

Distribution and Correlation

The restricted stratigraphic distribution of coal-bearing strata in the Blairmore Group of the central Foothills is of considerable help in mapping and exploring for economic coal deposits, but correlations of individual seams, even over short distances, is made difficult by two factors:

(1) the inherent lensing nature of the coal-bearing beds; and

(2) the complexly folded and faulted structure of the "inner" Foothills strata, especially true of shaly or coal-bearing successions.

In addition, outcrops are scarce or lacking in many areas due to the presence of glacial or alluvial deposits, and to thick forest cover.

Figure 6 presents a series of columnar sections through the coal-bearing upper Luscar beds along the strike of the central Foothills, from Brûlé in the north to Burnt Timber Creek, a tributary of the Red Deer River, in the south. In this area Blairmore Group strata range in thickness from approximately 1200 feet near the eastern margin of the outcrop belt to more than 3000 feet near the western edge, defined by the Front Ranges of the Rocky Mountains proper (McConnell thrust fault, Fig. 2). Several generalizations can be made concerning the thicknesses, distribution, and regional correlation of Luscar coal seams in the central Foothills:

(1) commercial coal seams are restricted to the lower part of the Beaver Mines Formation, above the marine tongue or correlative strata;

(2) number and thicknesses of coal seams varies from section to section;

(3) lithologic associations (assemblages) of the coal-bearing succession are highly variable;

(4) no reliable basis exists for correlating individual seams over any distance.

The potentially commercial coal seams of the Blairmore Group in the central Foothills are restricted to the "upper Luscar" interval, above the marine tongue or equivalent strata which mark the base of the Beaver Mines Formation in this area. Below this datum coal beds are generally few and thin (less than 3 feet thick), reflecting basic differences in the conditions of sedimentation which prevailed during the deposition of the lower and upper Luscar beds. The marine tongue, which contains a microfauna of Middle Albian age (Mellon and Wall, 1963), extends as a distinct marker bed northward along the strike of the Alberta Foothills into northeastern British Columbia, where it is mapped as the Moosebar Formation of the Fort St. John Group (Stott, 1963, 1968). At Cadomin the marine interval consists of approximately 20 feet of dark grey shale with a thin fossiliferous ironstone bed at the base, lying conformably on silty ostracode-bearing shales and fine-grained calcareous sandstones of the Gladstone (Gething) Formation (Mellon, 1967). The overlying interval, between the marine shales and the thick crossbedded sandstones associated with the Jewel seam mined at Cadomin, is largely covered and possibly folded; thus, the nature of the transition to the nonmarine upper Luscar coal-bearing strata is uncertain.

On Ram River, about 100 miles south of Cadomin near the eastern edge of the inner Foothills (Tps. 37, 38, R. 12,

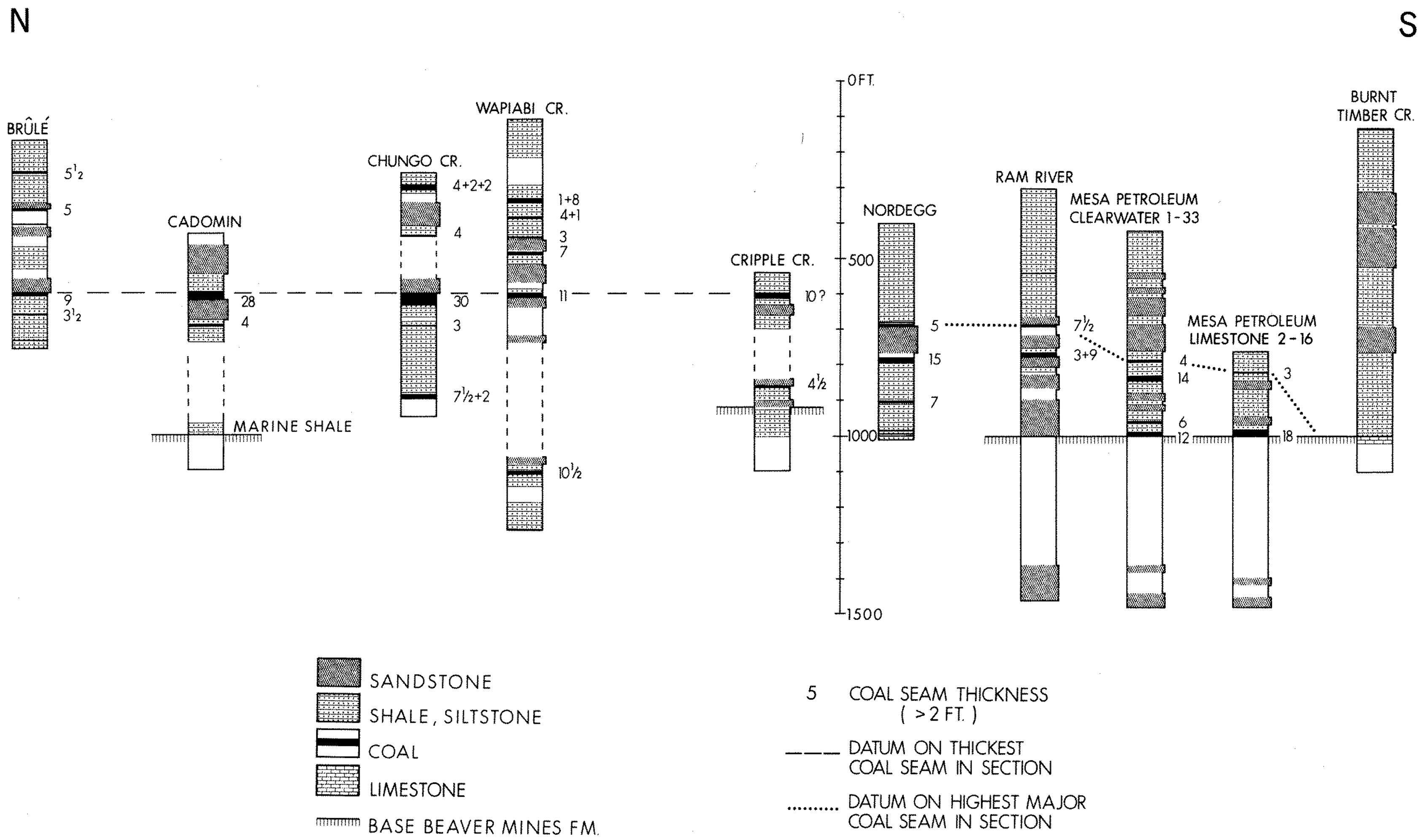

FIGURE 6. Columnar sections, Blairmore Group, central Alberta Foothills, showing coal seam distribution and thicknesses. See figure 2 for section locations.

W.5th Mer.), the marine beds are replaced by a thick crossbedded sandstone unit containing lenses of ironstone concretion conglomerate. There is no clearcut evidence of marine sedimentation at this locality, but the sandstone, which is present about 100 feet below the coal-bearing beds, is interpreted as a shoreline deposit marking the southern extent of the Moosebar Sea at this latitude. To the west, on Cripple Creek (Tp. 37, R. 14, W.5th Mer.), the base of the Beaver Mines Formation is placed at the base of a 15-foot thick grey carbonaceous sandstone about 100 feet above dark grey, ostracode-bearing, silty shale and 40 to 50 feet below a 4- to 5-foot thick sheared coal bed. The thick "shoreline" sandstones present at the base of the Beaver Mines Formation on Ram River appear to be absent at this locality, and the ostracode species indicate nonmarine conditions of deposition (J. H. Wall, pers. comm.). However, an interpretation of the lithologic succession across the formational boundaries is difficult owing to local structural complexities and the poor quality of outcrops.

Farther south, in the vicinity of the Clearwater River, several coal-bearing intervals were penetrated in two wells drilled by Mesa Petroleum Company in Blairmore Group strata on the flanks of large faulted anticlinal structures. Four coal intervals are present in the Mesa Clearwater well (in Lsd. 1-33-35-10 W.5th Mer.), the lowest of which lies at or just above the base of the Beaver Mines Formation. In the southernmost well, Mesa Limestone 2-16 (in Lsd. 2-16-33-10 W.5th Mer.) only two coal seams or "zones" are found, the thickest and lowest of which also lies at or near the base of the Beaver Mines Formation Thus, it appears that the coal-bearing upper Luscar interval thins in the vicinity of the Clearwater River, by progressive replacement of potential coal-bearing beds in the upper part of the interval by non-coal-bearing beds. In the vicinity of the Red Deer River, the coal-bearing facies has virtually disappeared by lateral gradation into fluviatile chloritic strata similar to the Mountain Park "formation" farther north; these beds in turn rest directly on the nonmarine "calcareous member" at the top of the Gladstone Formation, which extends as a distinct marker bed throughout the Blairmore Group of the southern Foothills (Glaister, 1959).

Number and Thicknesses of Coal Seams

The number and thicknesses of coal seams in the upper Luscar interval varies widely from section to section. For example, MacKay (1930, Fig. 5) shows nine seams exceeding 2 feet in thickness in the Luscar succession at Mountain Park, whereas only two seams are recognized a few miles to the northeast at Cadomin (some allowance should be made for structural foreshortening between the two areas, which are separated by the Nikanassin thrust fault). In the eight coal-bearing upper Luscar successions illustrated schematically in figure 6, the number of seams exceeding 2 feet in thickness ranges from two to six, although there may be repetition of seams due to faulting in some sections and possibly omission of seams due to lack of exposures in others. Similarly, observed thicknesses of upper Luscar coal seams undoubtedly are exaggerated in some cases by local folding, which may account in part of the apparent bimodal character of the seam thickness frequency histogram in figure 7.

Depositional Facies

Local variations in the succession of gross lithologic units associated with the upper Luscar coal seams provide a very general pattern of cyclic sedimentation on which a depositional model can be based. This is illustrated in figure 8 in which the ideal "cycle" of upper Luscar sedimentation is compared with those for other parts of the Blairmore Group and correlative strata.

The upper Luscar cycle ideally consists of (from the base up):

(1) a thick crossbedded sandstone unit which becomes progressively finer-grained towards the top;

(2) dark grey carbonaceous siltstone and silty shale with thin ironstone (siderite) partings and concretions;

(3) coal and coaly shale.

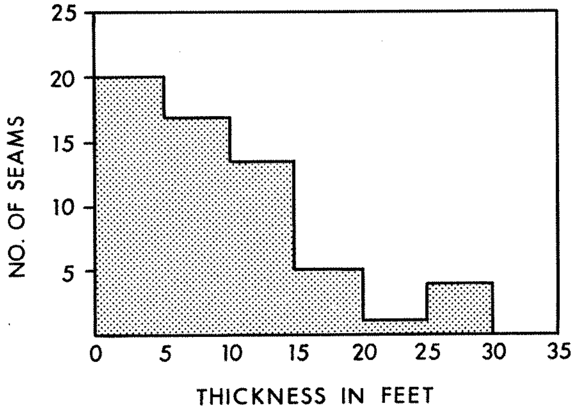

FIGURE 7. Frequency distribution of coal seam thicknesses in upper Luscar strata, central Alberta Foothills (from sections and wells shown in figure 2).

The sandstone, which varies widely in thickness, is interpreted as a channel deposit on a broad alluvial floodplain sloping towards the coastal sediments margining the Moosebar Sea. The associated silt-shale complex represents interfluvial sediments on which organic deposits — now coal — formed in low-lying, poorly drained areas. In gross aspect, the upper Luscar succession suggests a depositional model similar in many respects to that described by Allen (1970) for the modern Niger delta.

In practice, considerable variation exists in the successions of gross lithologic units observed in the field when these are compared to the idealized upper Luscar succession shown in figure 8. For example, coal seams can be found directly above or beneath thick "channel" sandstones, or intercalated among relatively thick siltstone-shale successions some distance from the base or top of the nearest "channel" sandstone. This apparent irregularity in the stratigraphic-lithologic distribution of Luscar coal seams is not difficult to comprehend, if the exceedingly complex areal distribution of the component depositional phases of modern sedimentary systems is translated into a vertical (stratigraphic) succession of lithologies. Alluvial and deltaic systems of sedimentation are particularly complex, consisting of a series of interlensing lithologic units, the distributions of which are highly sensitive to slight variations in sea level, topography, and sediment influx. Thus, it is expected that the upper Luscar coal measures will exhibit numerous deviations from any idealized depositional model, and that the local, lensing nature of individual lithologic units will preclude correlation of coal seams over even moderately large areas. Field evidence seems to support this hypothesis.

Comparision of the upper Luscar depositional model with those inferred for other facies of the Blairmore Group brings out some similarities and also some obvious differences in lithologic assemblages (Fig. 8). The Mountain Park sedimentary cycle is similar in many respects to that of the upper Luscar, except that coal is absent and redbeds are found in the shaly mudstones at the top of the cycle in the southern Foothills. Consequently, the Mountain Park facies is interpreted to represent fluviatile deposition on the

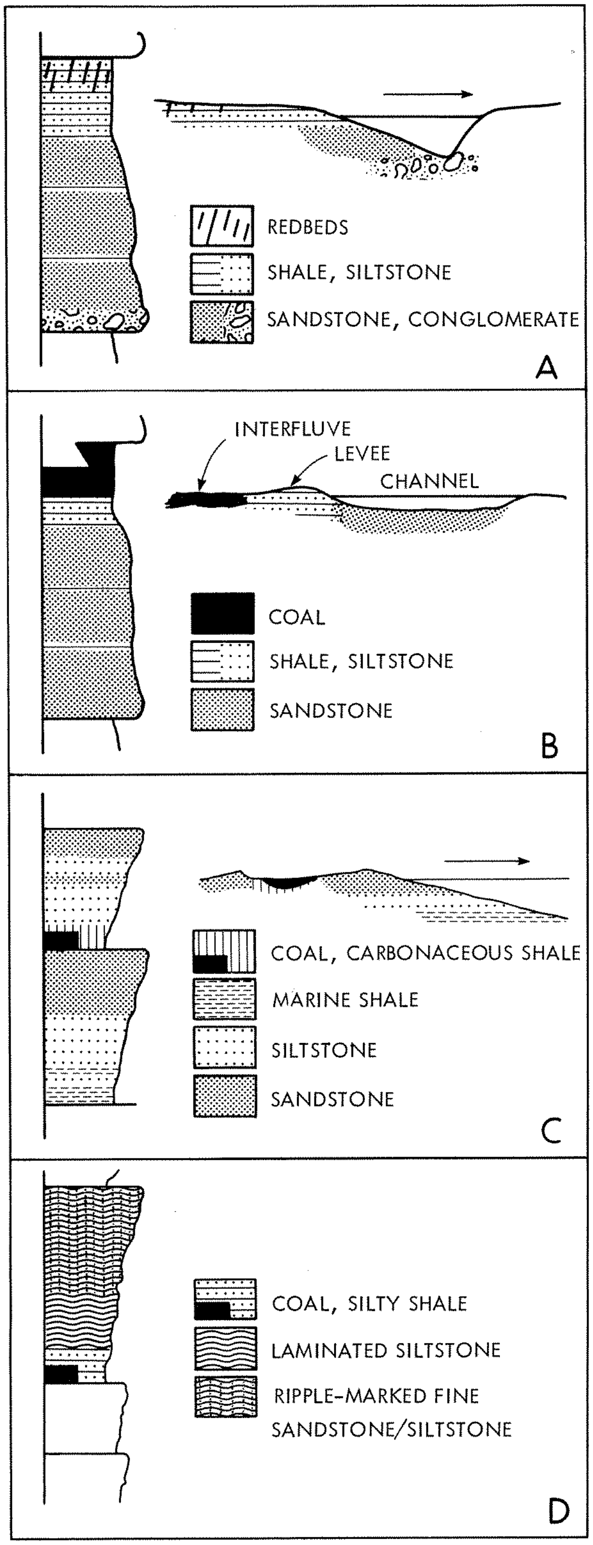

FIGURE 8. Idealized depositional models for Blairmore Group and equivalent strata, Alberta Foothills. A, Mountain Park facies; B, upper Luscar facies; C, Moosebar-Commotion succession; D, lower Luscar facies.

higher, better drained portions of the alluvial plain, closer to the sediment source area. Thick lenses of pebble and cobble conglomerate are present in some of the sandstones; this also indicates closer proximity to a highland source area undergoing active erosion. In contrast, the lower Commotion-Moosebar succession observed on Belcourt Ridge in northeastern British Columbia (Mellon *et al.*, 1963) suggests a shoreline locus of deposition in which organic material accumulated in lagoonal or tidal swamps behind a sandy barrier ridge, analogous to the depositional model proposed for the basal Kootenay Formation of southwestern Alberta (Jansa, this volume). Thus, the lithologic cycle is reversed in the lower Commotion succession; the shales and siltstones (and coal) are at the base and the coarser-grained sandstones at the top.

A similar type of "reversed" cyclicity is found in the lower Luscar (Gladstone Formation) beds of the central Alberta Foothills, except that the strata are finer-grained and tend to be more thinly bedded. However, the apparent lack of distinctly marine fossils in the lower Luscar succession raises some puzzling questions concerning the actual depositional environment, for the pattern of cyclic sedimentation suggests a marine or tidal flat model.

COAL RANK AND PRODUCTION

The Blairmore Group (Luscar) coals of the central Alberta Foothills vary in rank from low volatile bituminous to high volatile bituminous A (Stansfield and Lang, 1944). The average gross calorific values of coals from the area between Brûlé and Nordegg range between 12,000 and 14,000 BTU/lb, but there is considerable local variation in composition and related properties which tends to mask any regional trends that might be present. Whether these variations in coal type and quality are due to depositional or orogenic factors, or both, is uncertain on the basis of existing data; needless to say, much work remains to be done on the effects of geologic agencies on the composition and rank of Foothills coal deposits.

Although Blairmore (Luscar) coal-bearing strata have a wide distribution in the central Alberta Foothills, commercial production of coal has been confined to three areas (Fig. 2): the Brûlé-Pocahontas area adjacent to the Athabasca River in the north; the "Coal Branch" area, which includes Mountain Park, Cadomin, and Luscar; and the Nordegg area near the North Saskatchewan River.

Mining in the Brûlé area began about 1911 and continued at Brûlé and Pocahontas until the 1920's. During this period production was less than 200,000 tons per year; it ceased owing to severe structural conditions within the coal beds, which are situated along the complexly folded and faulted western margin of the Foothills.

The "Coal Branch" area contains complexly folded and faulted Luscar strata extending for some distance along the southwest and northeast flanks of the Nikanassin Range, a faulted block of Paleozoic strata bounded by a low-angle thrust fault on the northeast. As many as five mines have been in simultaneous production in this area, the first of which was opened in 1911. Production reached a peak in the 1940's at which time more than 1 million tons of bituminous coal a year were mined. Production dropped rapidly during the 1950's, coinciding with the change from steam to diesel engines in the railways, and the last mine (Luscar) closed in 1959. More recently, mining operations were resumed at Luscar, and production of approximately 1 million tons was achieved in 1971.

Mining in the Nordegg area began in 1914 and continued until 1955 when declining markets and financial difficulties forced the operations to cease. Production reached its maximum level in the 1940's during which period more than 300,000 tons a year were mined.

The combined total production of coal from the Luscar beds of the central Foothills averaged approximately 1 million tons a year between 1920 and the early 1950's, forming from 25 to 35 per cent of the total Alberta bituminous coal production for any one year (Fig. 9). The

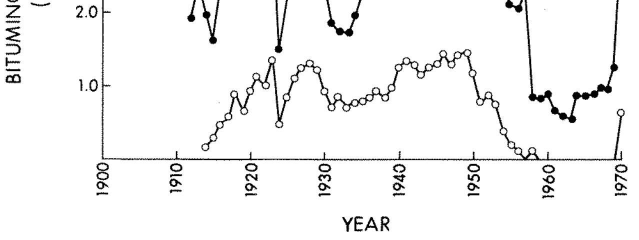

FIGURE 9. Bituminous coal production, central Alberta Foothills (compiled from Dominion Bureau of Statistics and Mines Branch reports, Ottawa).

only current commercial production of Lower Cretaceous bituminous coal in the central Foothills is from open pit mines at Luscar, where Cardinal River Coals Limited has a contract to provide 15 million long tons of coking coal for export to Japan (Fayram and Raymond, 1969). However, exploration for coking coals has been extremely active throughout the Alberta Foothills during the past several years, and it appears likely that production in the central Foothills will increase substantially during the next decade, depending on the availability of export markets.

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CRETACEOUS STRATIGRAPHY, NORTHEASTERN BRITISH COLUMBIA

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ABSTRACT

Jurassic and Cretaceous sediments occur in three major cyclic, clastic sequences in which marine shales grade laterally and vertically into deltaic and alluvial sediments. Each cycle has a maximum thickness of about 9,000 feet (2,700 m). The occurrence of coal beds within each sequence is dependent on the interrelationships of the various facies.

The lowest sequence, formed by the Jurassic Fernie Formation and the Lower Cretaceous Minnes Group, contains a thick sequence of cyclic carbonaceous sediments but appears to lack thick coal seams. The middle sequence, consisting of the Lower Cretaceous Bullhead and Fort St. John Groups and the Upper Cretaceous Dunvegan Formation, contains major deposits of low to medium volatile bituminous coal. The coal seams, occurring mainly in the Gething Formation and Gates Member of the Commotion Formation, appear to be best developed south of Peace River. The upper sequence, formed by the Upper Cretaceous Smoky Group and Wapiti Formation, contains subbituminous coal.

INTRODUCTION

Cretaceous rocks of northeastern British Columbia embrace a thick succession of intertonguing marine shale and sandstone and alluvial-deltaic coal-bearing sediments. These strata have been of economic interest since the end of the eighteenth century when Alexander Mackenzie (1801) first noted "bituminous substance" in the Peace River canyon. However, the coal deposits of Peace River region were examined in any detail only after the beginning of this century (Robertson, 1907; Galloway, 1913, 1915; McLearn, 1923; Galloway, 1924; McLearn and Irish, 1944; Mathews, 1947; Hughes, 1964, 1967), and the coal-bearing sequences in less accessible parts of the region have been studied only within the last 15 to 20 years (Zeigler and Pocock, 1960; Irish, 1970; Stott, 1968a).

An understanding of the interrelationships of the various facies of Cretaceous strata in northeastern British Columbia is essential in the determination of the vertical and areal distribution of coal beds.

Acknowledgments

Field studies were carried out in conjunction with other geological studies undertaken by B. R. Pelletier and G. C. Taylor. The fossil flora and fauna were identified and dated by E. T. Tozer, Hans Frebold, J. A. Jeletzky, T. P. Chamney, W. A. Bell, F. M. Hueber, and D. C. McGregor.

STRATIGRAPHY

The western limit of Cretaceous exposures is sharply defined by major faults of the Rocky Mountain system (Fig. 1), and the westernmost margin of the basin is not preserved. The maximum composite thickness of the succession totals almost 28,000 feet (8,400 m), but such a thickness does not occur at any one locality because the axis of maximum subsidence migrated progressively eastward during the Cretaceous Period.

The development of the basin and its infilling with clastic sediments are related to tectonism in the Columbian Orogen and subsidence in the elongate Alberta Trough. The Nevadan Orogeny in British Columbia has sometimes been considered a short, although profound, geological event at the end of the Jurassic Period, but evidence within the Lower Cretaceous succession suggests that uplift along the Omineca Geanticline occurred periodically and extended well into the Cretaceous Period. Continued uplift along the geanticline in Late Cretaceous time culminated in the late phases of the Laramide Orogeny.

The sediments were deposited as part of three major transgressive-regressive sequences in which shale of marine origin grades laterally and vertically into sandstone, carbonaceous mudstone, conglomerate, and coal of deltaic and alluvial origin (Fig. 2). The lowest sequence is formed by the Fernie Formation and the overlying Minnes Group. The middle sequence contains the Bullhead and Fort St. John Groups and the Dunvegan Formation at the top. The third sequence contains the Smoky Group and Wapiti Formation. Several large-scale cycles are represented within each of these major sequences, and numerous minor cycles occur throughout.

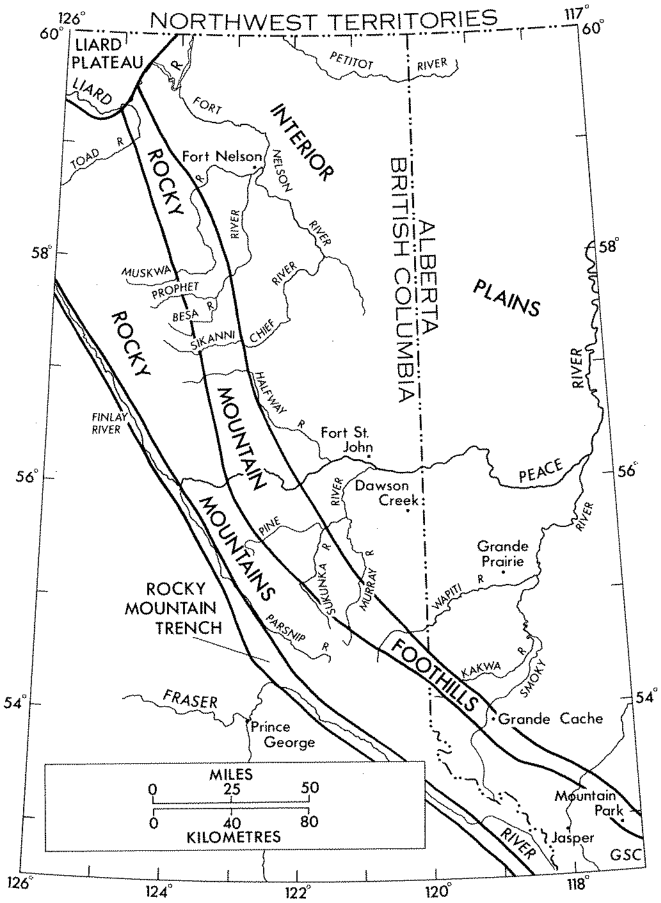

FIGURE 1. Index map showing location of main geographic features and physiographic divisions, northeastern British Columbia.

Fernie - Minnes Sequence

The oldest sequence, consisting of the Fernie Formation and Minnes Group, forms a major sedimentary unit that reaches its maximum development in the western Foothills between Smoky River and Carbon Creek (Fig. 3). The sequence attains a thickness of about 9,000 feet (2,700 m) but decreases to an erosional edge eastward in the Plains and also northward along the Foothills (Stott, 1967a, 1967b).

Within this region, the sequence lies unconformably on beds of Triassic age.[1] It is bevelled by pre-Bullhead erosion and throughout the region is overlain unconformably by the Cadomin Formation or equivalent basal Gething beds. In the northern part of the region, the Jurassic-Cretaceous boundary lies within transitional beds between Fernie shale and massive Monteith quartzose sandstone. Continental deposition began earlier farther south in the Alberta Foothills where the boundary apparently lies within the Kootenay Formation. Several minor hiatuses occur within the Fernie Formation, indicated mainly by the lack of diagnostic ammonite zones. No major break is recognized within the Minnes succession itself, although disconformities representing short time gaps may be present locally.

Fernie Formation

The lower part of the sequence, included in the Fernie Formation (Frebold, 1957; Frebold and Tipper, 1970), comprises dark shale that was deposited under marine conditions that existed in the Alberta Trough throughout most of the Jurassic Period. In general, the total thickness of Jurassic shale does not exceed 1,000 feet (300 m) but thicknesses in the order of 3,000 feet (900 m) occur in the western Foothills. Lithological units within the Fernie Formation are remarkably persistent along the depositional strike, and most can be traced throughout the region (Stott, 1967a).

Nikanassin Formation

Alternating units of fine-grained sandstone and dark grey shale, generally included in the Nikanassin Formation, overlie the Fernie Formation in the vicinity of Mountain Park (Fig. 3). The formation is only 930 feet (280 m) thick at Folding Mountain east of Jasper but is as much as 2,000 feet (600 m) thick or more in westerly exposures (Mountjoy, 1962; Irish, 1965). Although the Nikanassin Formation in the eastern Foothills does contain units of carbonaceous sediments and a few thin layers of coal (Irish, 1965; Zeigler and Pocock, 1960), the formation appears to be mainly of marine origin. The alternating sandstone and shale beds resemble the transitional beds between the Fernie shale and continuous sandstone succession of the Minnes Group in the region between Smoky and Peace Rivers.

Minnes Group

The regressive sequence is more complete from Berland River northward where a thick succession of sandstone, conglomerate, shale, and coal-bearing beds lying between Jurassic Fernie shale and massive Cadomin conglomerate is included in the Minnes Group (Fig. 3). The group has a

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[1] See Figure 2, The Cretaceous Gething Delta, northeastern British Columbia, by D. F. Stott, published in this volume.

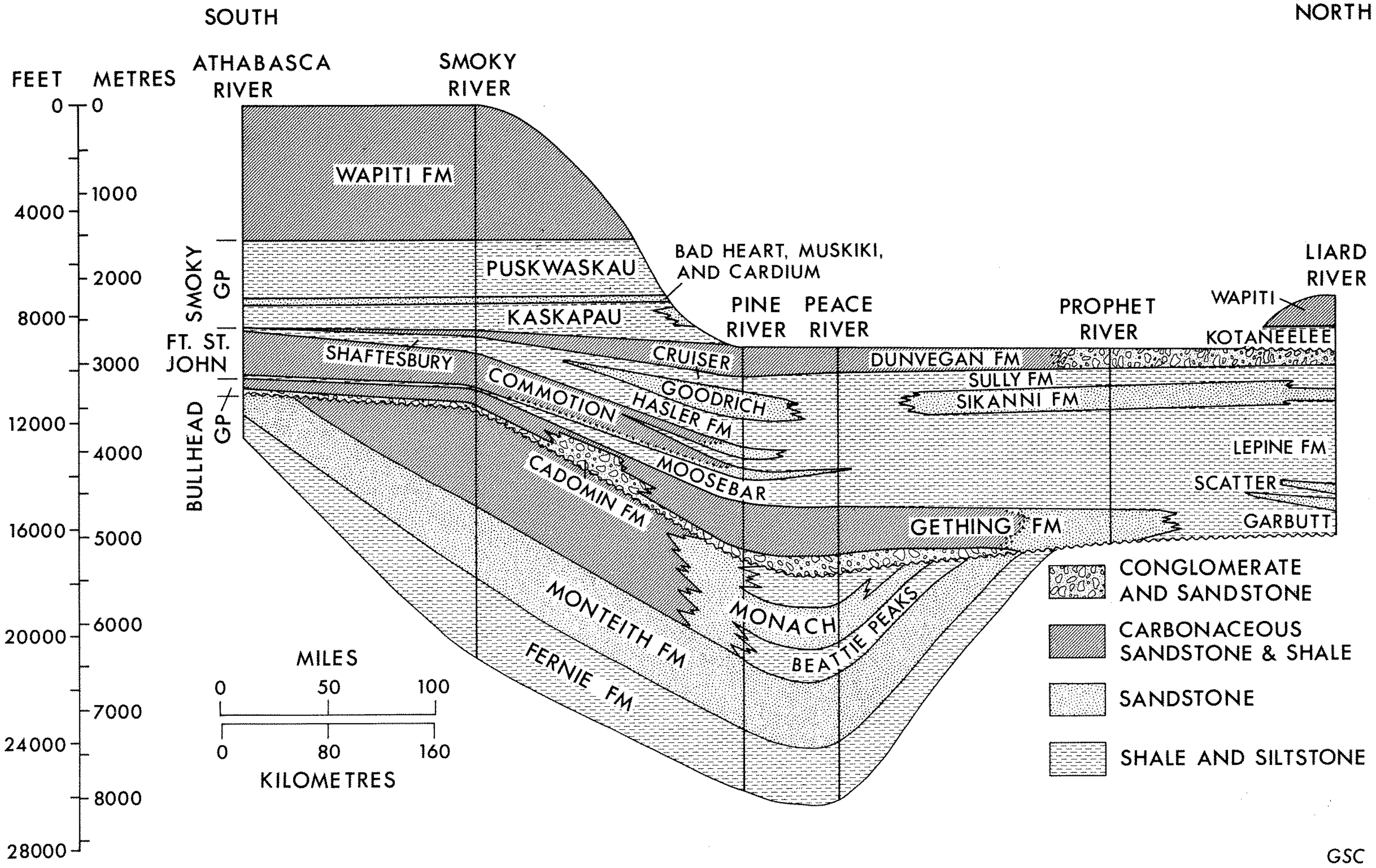

FIGURE 2. Major rock-units in Jurassic and Cretaceous strata of northeastern British Columbia.

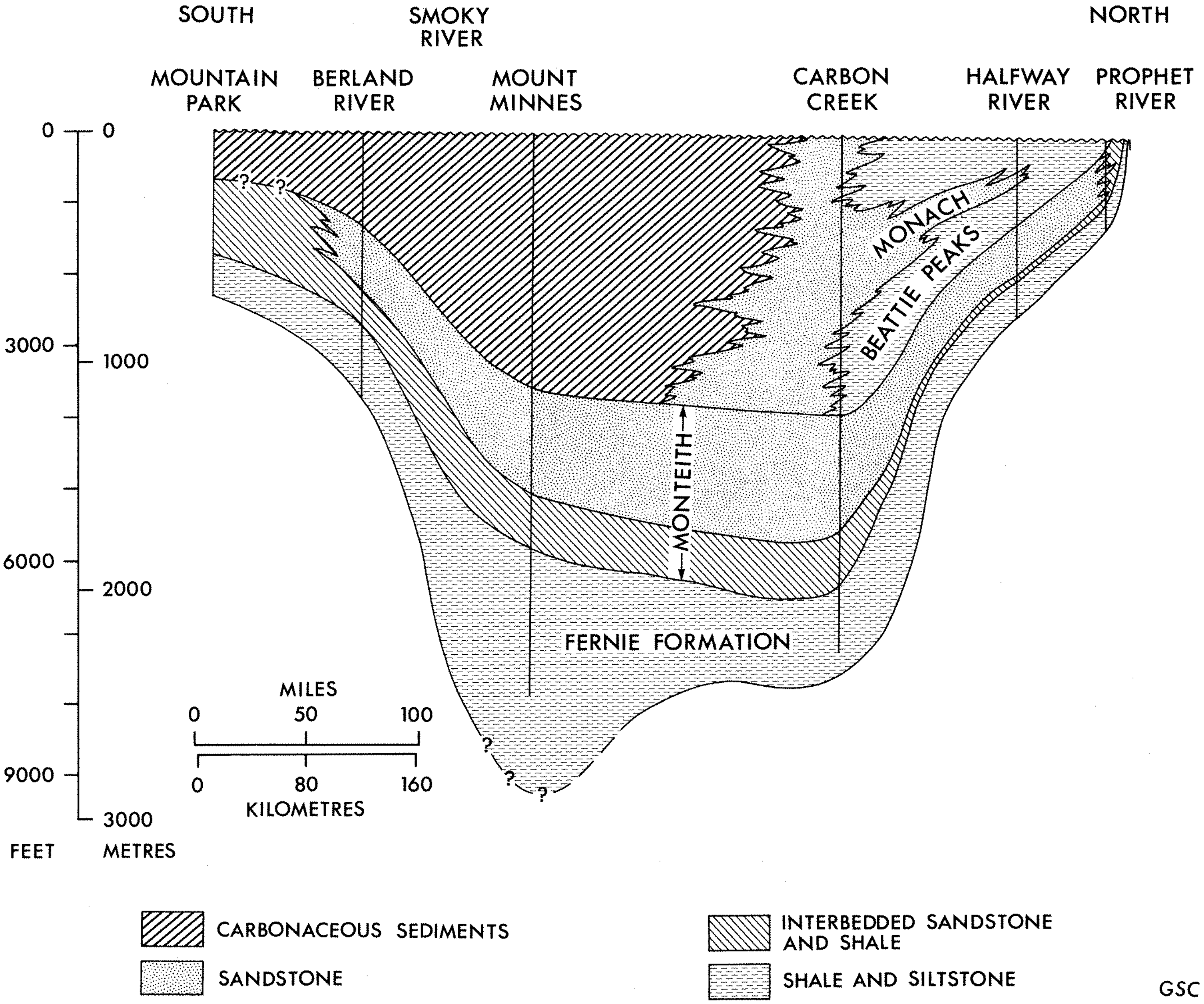

FIGURE 3. Fernie - Minnes succession along the Foothills between Mountain Park and Prophet River.

maximum thickness of 7,000 feet (2,100 m) between Smoky and Peace Rivers (Zeigler and Pocock, 1960; Stott, 1967a). Although basal Minnes beds may be equivalent to the Nikanassin Formation to the south, much of the group is younger. The basal sandstone, extending from Berland River to Prophet River, attains a maximum thickness of 2,000 feet (600 m). It was derived in Late Jurassic and earliest Cretaceous time from the rising Omineca Geanticline and was deposited under nearshore conditions. An overlying coal-bearing succession is presently preserved in the region between Berland and Sukunka Rivers.

The carbonaceous unit grades northwesterly between Murray and Pine Rivers into marine sandstone, which in turn grades north of Pine River into marine mudstone and siltstone (Fig. 3). As a result of these facies changes, three formations have been defined within the Minnes succession of the Peace River region; in ascending order, the Monteith, Beattie Peaks, and Monach Formations (Mathews, 1947; Hughes, 1964, 1967; Stott, 1967a). In addition, a fourth unit occurs between the Monach and Cadomin Formations but is not named at present (Stott, 1962, 1967a). The marine shale and siltstone of the Beattie Peaks Formation

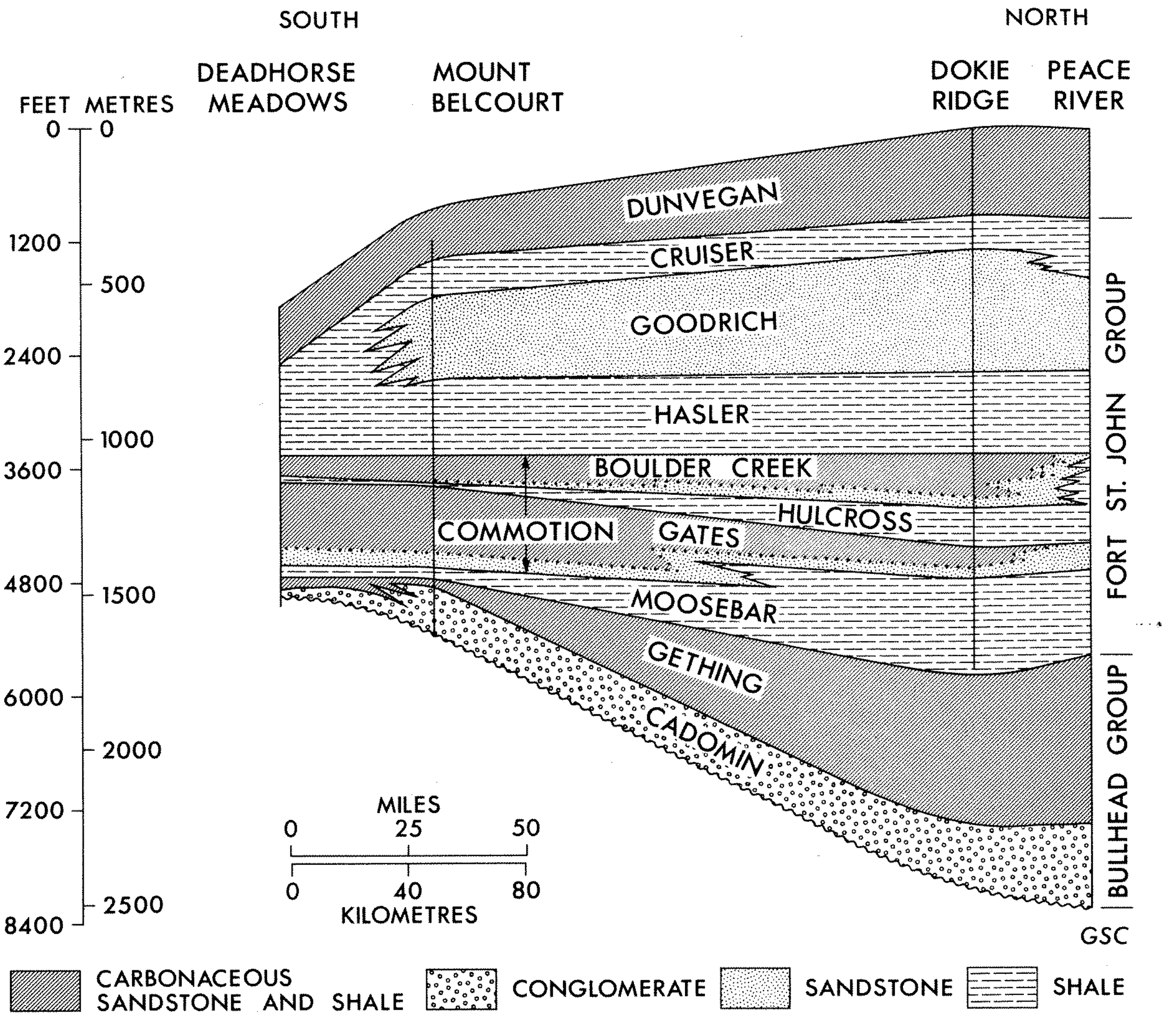

FIGURE 4. Bullhead - Fort St. John - Dunvegan succession along the Foothills between Kakwa and Peace Rivers.

are delta-front deposits. The quartzose sandstone of the Monach Formation, similar to the Monteith Formation, represents prodelta deposits and is locally developed near Peace River. The succession above the Monach Formation consists mainly of alternating units of marine sandstone and mudstone, but it also includes some carbonaceous units and thin coal seams.

Coal Deposits

Although the carbonaceous facies of the Minnes Group between Berland and Sukunka Rivers is in the order of 4,000 feet (1,200 m) thick, no major coal seams were observed and to the writer's knowledge, none has been reported. The sandstone is commonly very carbonaceous, and coaly plant hash is abundant in the mudstone and siltstone. Many of the cycles include thin coal seams ranging from less than 1 inch to 2-3 feet thick. In the Peace River region, thin coal seams are present in the beds between the Monach and Cadomin Formations, particularly in the region around Mount Bickford. Similarly, coal layers are found in upper Minnes strata north of Peace River (Stott, 1967a). However, throughout the entire region, there is no indication of substantial coal seams, and the prospects of major discoveries within the Minnes succession are not promising.

Bullhead - Fort St. John - Dunvegan Sequence

The middle transgressive-regressive sequence, 1,500 to 7,500 feet thick (450 - 2,100 m), developed during Late Neocomian to Cenomanian time, and consists of the Bullhead and Fort St. John Groups and Dunvegan Formation (Fig. 4). Large quantities of clastic material derived from the Omineca Geanticline were deposited in the Rocky Mountain exogeosyncline. South of Pine River, much of the sediment was deposited on a broad, low-lying alluvial plain which bordered a boreal embayment (Stott, 1968a). Several large deltas developed along the embayment and were overriden at various times by the expanding seaway. In addition to the initial invasion recorded within the Bullhead Group, four additional major transgressions, marked by shale, with succeeding regressive nearshore to deltaic deposits, are recognized in the Fort St. John Group and Dunvegan Formation. It is within these regressive sediments that the major coal deposits of northeastern British Columbia occur.

The major break in the sedimentary record of Cretaceous rocks occurs between beds of Middle to Late Valanginian age and those of Barremian-Aptian age (Stott, in press). This erosional unconformity lies at the base of the Cadomin conglomerate or equivalent basal Gething sandstone and truncates successively older beds northward from Peace River along the Foothills and eastward into the Plains. Minor disconformities may occur at the base of each transgressive shale but are not well documented. Toward the centre of the basin, the marine Fort St. John shales were deposited with only minor or no hiatus.

Bullhead Group

The base of the sequence is marked by a distinctive conglomerate, the Cadomin Formation (McKay, 1929, 1930), which occurs throughout the Foothills as far north as Peace River (Stott, 1968a). It consists predominantly of massive conglomerate containing well-rounded pebbles, cobbles, and boulders of resistant rocks deposited in the piedmont alluvial plain environment. The conglomerate shows a rapid eastward gradation in maximum size and thickness. The conglomerate grades laterally into finer sandstone north of Peace River.

The overlying succession in the region south of Smoky River has been assigned to the Luscar Formation (McKay, 1929, 1930) or to the Gladstone and Beaver Mines Formations of the Blairmore Group (Mellon, 1967).

In the region between Smoky and Peace Rivers, the Cadomin conglomerate is overlain by and grades laterally into alternating units of sandstone, carbonaceous shale, and coal that are included in the Gething Formation (Fig. 5). The major facies of conglomeratic sandstone and the coal-bearing succession grade laterally northward from Peace River into fine-grained sandstone, which in turn grades into dark silty mudstone. The northern limit of coal seams appears to lie near Sikanni Chief River. The main development of the fine-grained sandstone facies is concentrated between Sikanni Chief and Besa Rivers. Beyond there, dark grey marine mudstone and siltstone become more abundant.

The maximum thickness of the Bullhead Group is about 2,500 feet (750 m) at Peace River, but it decreases along the Foothills both north and south of there and also eastward beneath the Plains. The isopach map[1] of combined thickness of the Cadomin and Gething facies indicates two major lobes, one centred at Peace River and the other in the vicinity of Mount Belcourt and Wapiti River. The general trend parallels the ancient Peace River structure.

Fort St. John Group

The second transgression of the middle sequence is recorded in marine shales of the Moosebar, Buckinghorse, and Garbutt Formations of the Fort St. John Group (Figs. 4, 5). The boreal embayment advanced westward beyond the present Foothills and during its early phase extended southward beyond Athabasca River at least as far as Cadomin (Mellon and Wall, 1961). As subsidence within the basin was exceeded by increased sedimentation, related to uplift in the source region, the shoreline prograded northeastward and the widespread Gates sandstone of the basal Commotion Formation was deposited. The upper part of the Gates Member, or the main part in the more southerly sections, is a cyclic succession of carbonaceous sandstone, mudstone, siltstone, coal, and some conglomerate. The maximum thickness of the Moosebar-Gates succession is about 1,300 feet (390 m) between Pine and Peace Rivers (Fig. 6). Maximum sedimentation was along the same trend as the ancient Peace River Arch. The depositional sequence grades vertically and laterally southward from Peace River from marine shale into nearshore sandstone and then into sediments of the delta and floodplain environments.

The third marine advance of the middle sequence is recorded in the Hulcross Member of the Commotion Formation south of Peace River (Fig. 5). That embayment did not extend so far south as the Moosebar sea, its southwestern margin lying near Belcourt Creek. The shales

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[1] See Figure 3, The Cretaceous Gething Delta, northeastern British Columbia, by D. F. Stott, published in this volume.

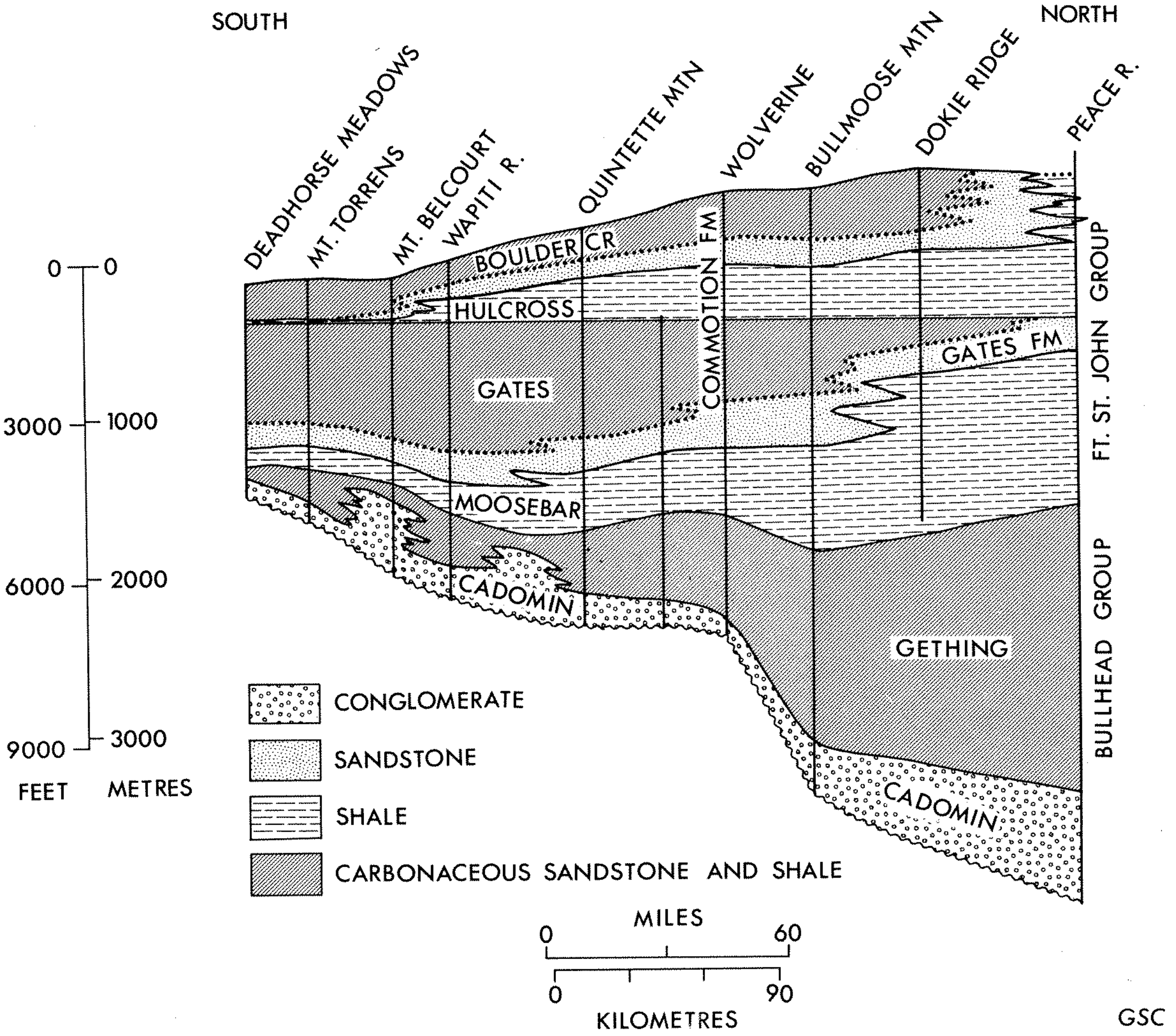


FIGURE 5. Bullhead - Moosebar - Commotion succession along the Foothills between Kakwa and Peace Rivers.

grade vertically and laterally into well-sorted marine sandstone of the basal Boulder Creek and Cadotte Members, and they in turn grade into alluvial-deltaic plain sediments (Figs. 5, 7). This sequence, having a maximum thickness of 940 feet (280 m), has its main trend centred between Pine and Peace Rivers and parallel to the ancient Peace River Arch (Stott, 1968a).

The two sandstone wedges of the Commotion Formation disappear at Peace River, and northward beyond there, the Lower Cretaceous Albian sequence is represented by a more continuous sequence of marine shale included in the Buckinghorse Formation (Stott, 1967b, 1968b).

Farther north in the vicinity of Liard River, sandstones of the Scatter Formation are part of another major delta the history of which is similar to that of the Commotion Formation (Fig. 2; Stott, 1968b). In that area, the lower cycle of Garbutt shales and basal Scatter sandstone is about 1,350 feet (405 m) thick, and the upper cycle, formed by the middle Scatter shale and upper Scatter sandstone, is 700 feet (210 m) thick. Unlike the Commotion succession, only marine sandstones are present there, and the alluvial-deltaic sequence apparently is no longer preserved.

The fourth transgression of the middle sequence, recorded in the Hasler, Buckinghorse and Lepine Formations,

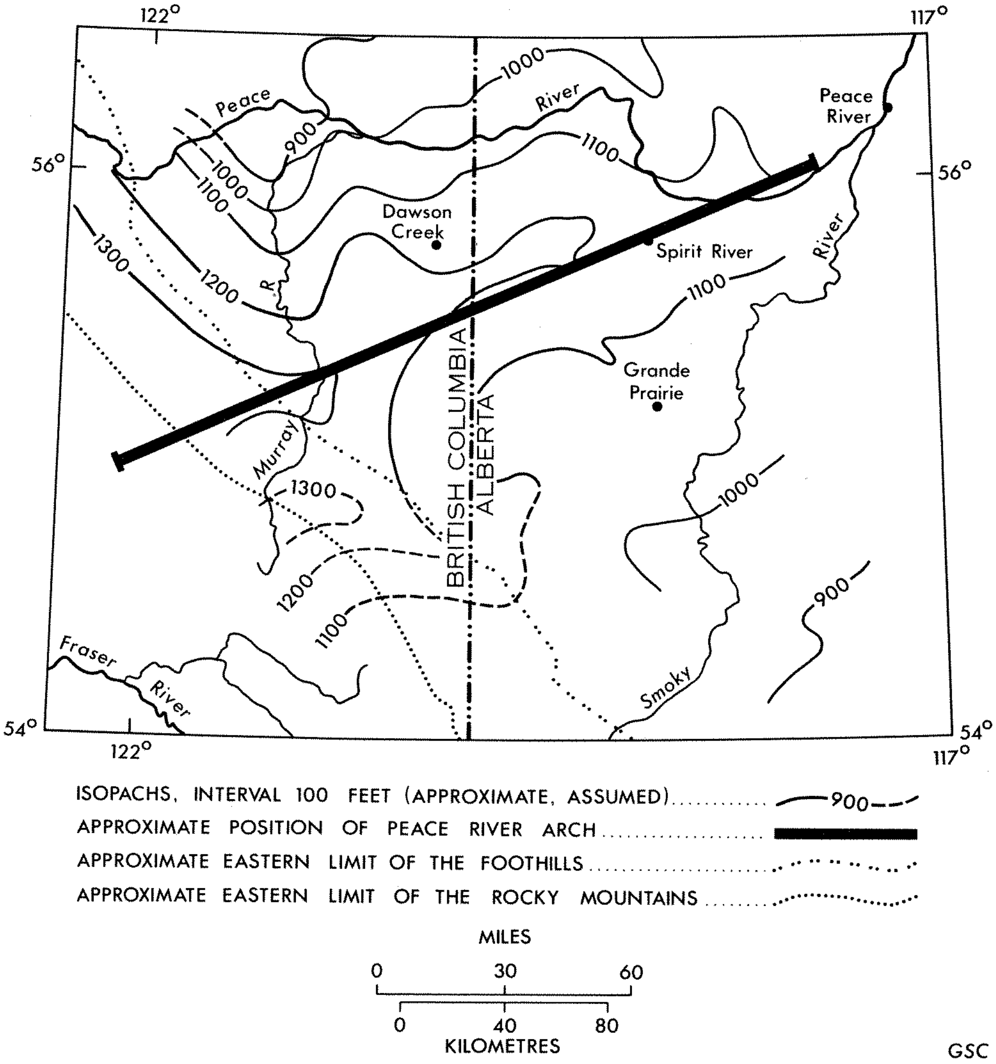
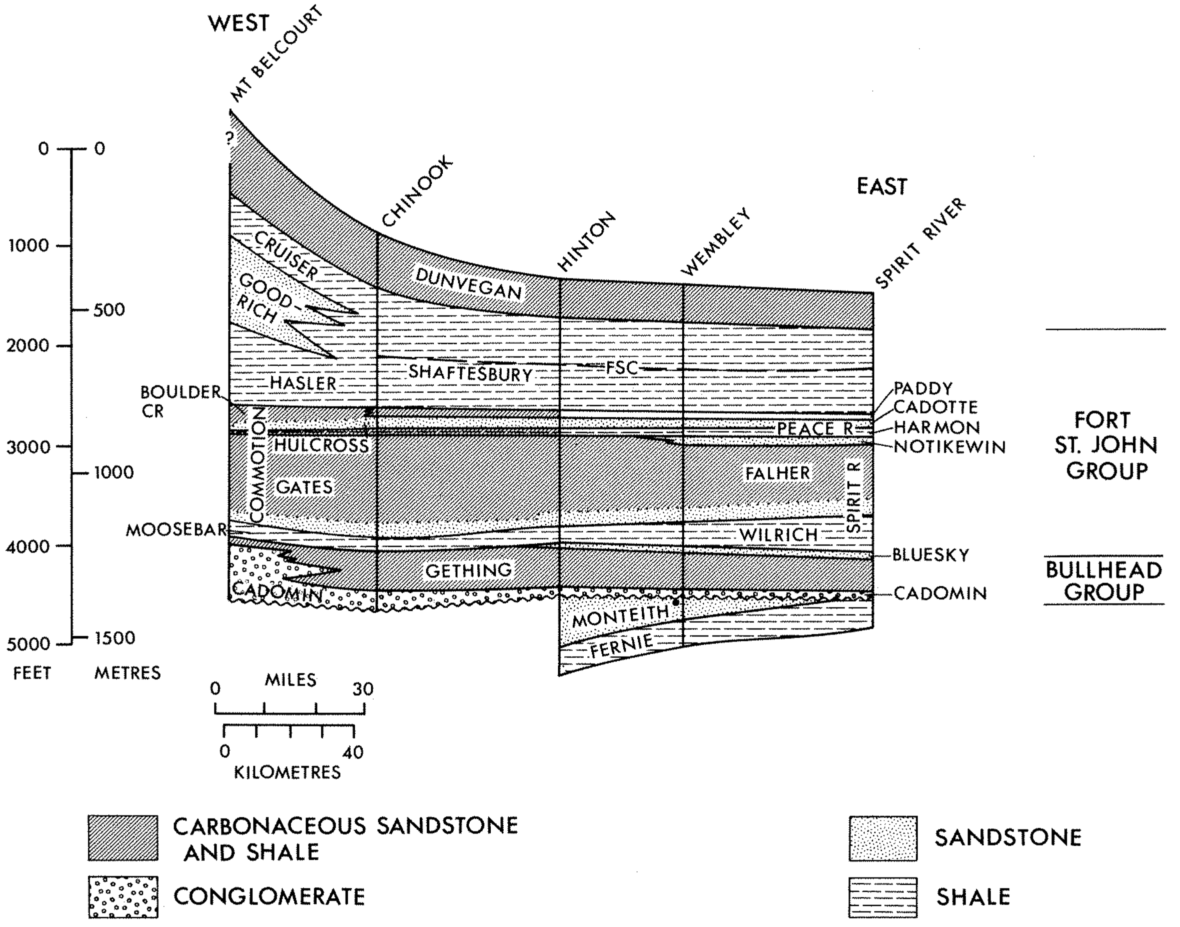


FIGURE 6. Isopach map of Moosebar, Commotion, and Spirit River sediments.

produced another thick marine shale succession that grades upward into epineritic Goodrich and Sikanni sandstones (Fig. 4). These sandstones represent nearshore deposits formed during Late Albian (*Neogastroplites*) time. The sandstones have maximum thicknesses of 1,300 feet (390 m) but grade eastward into shale (Figs. 7, 8; Stott, 1968a, 1968b).

Southward beyond Mount Belcourt and eastward from the Foothills, the overlying Goodrich sandstone grades laterally into shale, and the beds between the Commotion and Dunvegan Formations merge into one continuous shale succession (Figs. 4, 7, 8). The Hasler Formation becomes inseparable from the overlying strata, and equivalent beds are then included in the Shaftesbury Formation (McLearn and Henderson, 1944). The only area in which relatively thick carbonaceous sediments occur within either Goodrich or Sikanni strata is at Mount Belcourt. No seams of coal are exposed there.

The last transgression of Early Cretaceous time is recorded by the Cruiser and Sully shales which grade transitionally upward into Cenomanian (earliest Late Cretaceous) alluvial and deltaic conglomeratic sandstone of the Dunvegan Formation (Fig. 4). The deltaic and fluvial environments finally advanced well into the middle of the basin, bringing to an end the deposition of marine sediments in the present Foothills region of northeastern British Columbia.



GSC

FIGURE 7. Bullhead - Fort St. John - Dunvegan succession in the Foothills and Plains, northeastern British Columbia and northwestern Alberta.

Coal Deposits

Before the Dunvegan Formation is described, the potential coal horizons of the Bullhead and Fort St. John Groups will be reviewed.

Several coal seams, ranging from 10 to 25 feet, occur within the Gething Formation between Kakwa and Murray Rivers. Coal is commonly found above the top of the Cadomin Formation from Kakwa River northward in the eastern Foothills, to Belcourt and Kinuseo Creeks and Quintette Mountain, and as far north as Bullmoose Mountain. Coal also occurs above other conglomeratic beds in this region. At Bullmoose Mountain the upper part of the formation has been extensively drilled and the main seam occurs in the upper 200 feet (60 m) of the formation. Seams ranging from 6 to 20 feet have been trenched in Gething strata within the Fisher Creek syncline along Pine River and also in the region of Hasler Creek (Spivak, 1944; McKechnie, 1955). Low to medium volatile, bituminous coal was mined from Gething strata at Peace River for many years, although the maximum seam reported is only 5 feet thick (McLearn, 1923; McLearn and Irish, 1944; McLearn and Kindle, 1950; Irish, 1970). Although some coal occurs within the Gething Formation as far north as Sikanni Chief River, the main development of Gething coal appears to be limited to the area south of Halfway River.

A major coal seam occurs above the basal Gates sandstone of the Commotion Formation, apparently extending from the Kakwa region at least as far north as Mount Belcourt, and is present above the basal Gates sandstone at Quintette

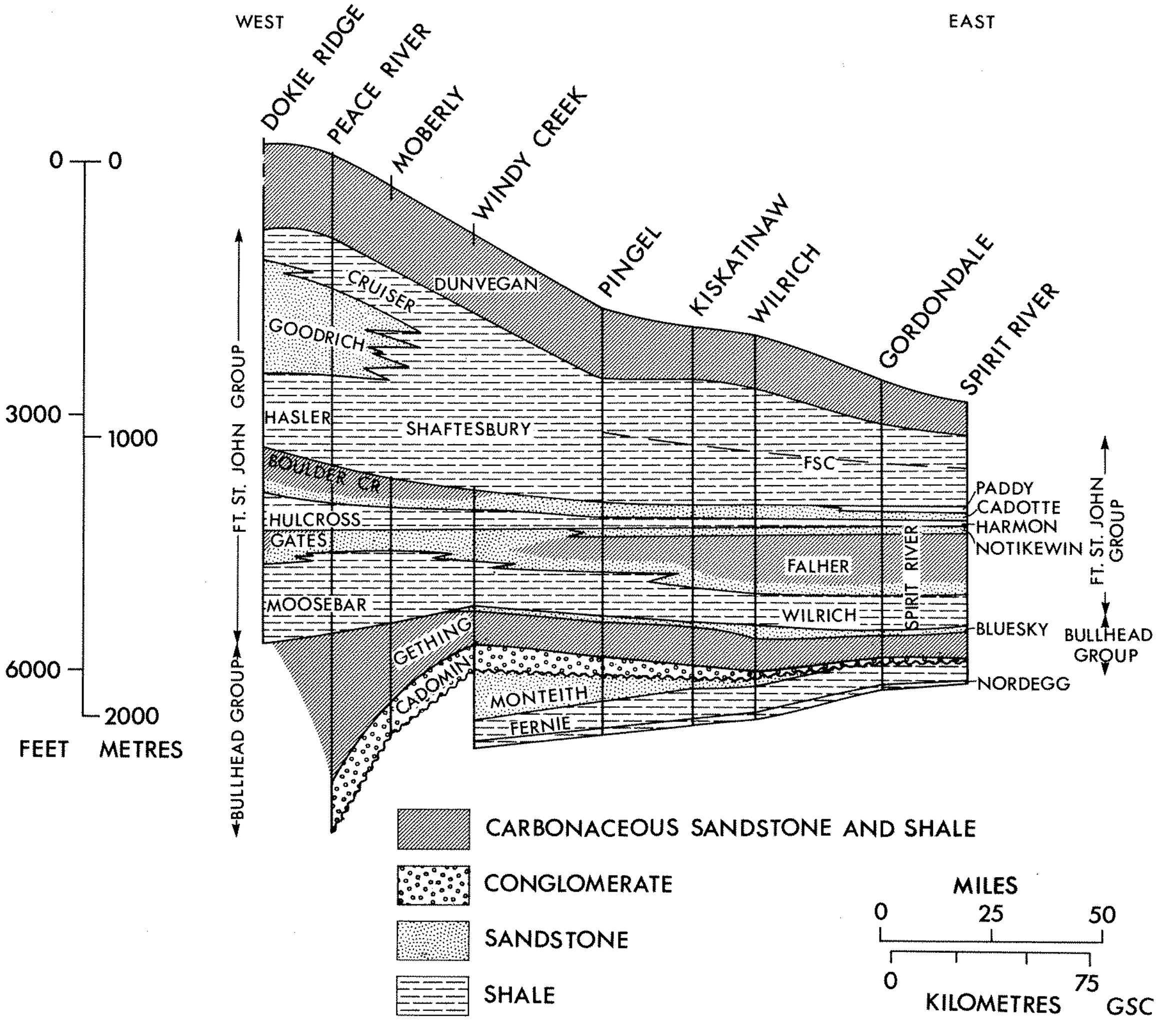


FIGURE 8. Bullhead - Fort St. John - Dunvegan succession at latitude of Peace River.

Mountain, north of Wolverine River, and on Bullmoose Mountain. Coal in a similar stratigraphic position forms one of the main seams at Grande Cache. It is interesting to note similar relationships at Cadomin where a major seam overlies beds equivalent to the basal Commotion sandstone. The stratigraphic position of the coal does not necessarily imply that the same seam extends throughout the region. It does imply that a favourable environment developed on the lower deltaic plain landward of marine, prodeltaic sandstones, and, as a result of progradation, coal swamps advanced seaward, covering the older marine sediments. Other coal seams occur higher within the Gates Member. Although the upper part of the Boulder Creek Member contains a relatively thick carbonaceous unit and some coal, no major seams were noted.

Coal is not present within the epineritic or prodelta Goodrich and Sikanni sandstones.

Dunvegan Formation

The Late Cenomanian Dunvegan Formation occurs along the eastern Foothills between Smoky and Peace Rivers. In the most southern part of the region it consists mainly of fine-grained sandstone and interbedded shale of prodeltaic origin. Those beds grade northward into carbonaceous sediments that were deposited in alluvial-deltaic environments. The formation varies in thickness, being approximately 500 feet (150 m) thick throughout much of the southern region but increasing to more than 1,200 feet (360 m) in the western Foothills near Peace River.

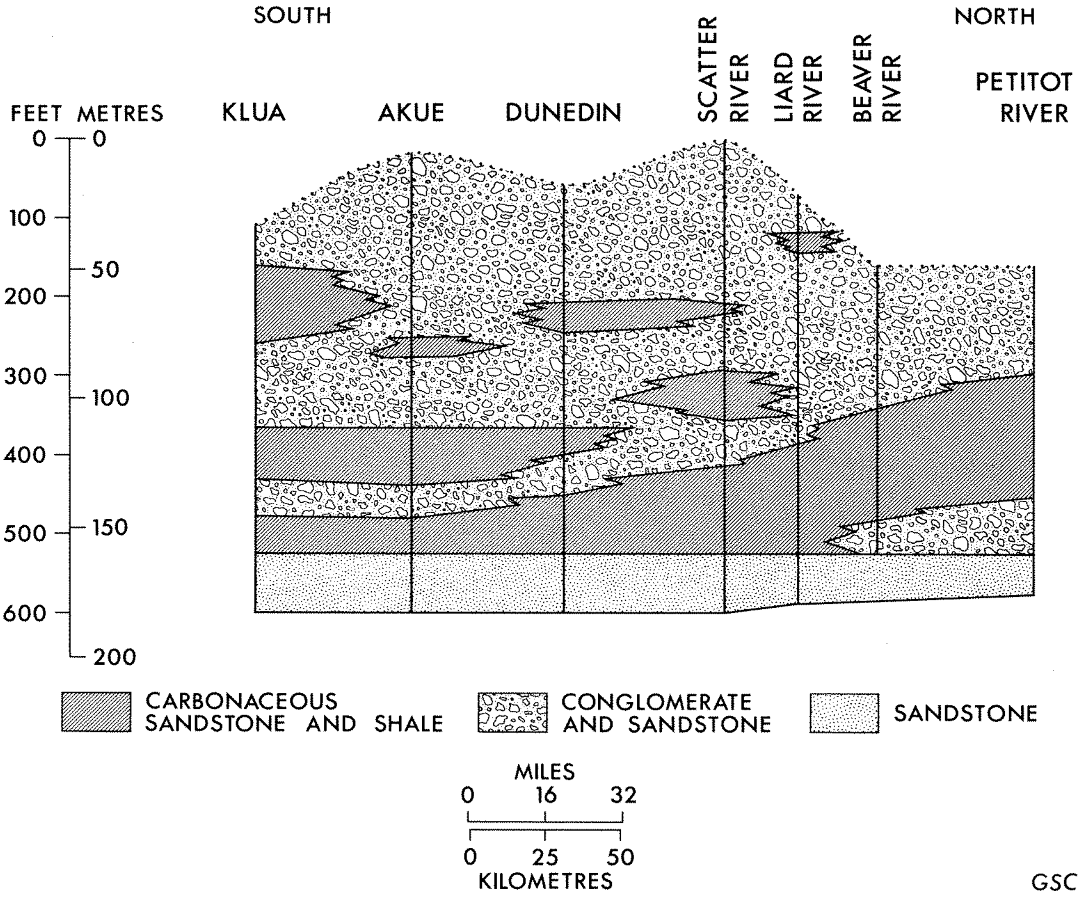


FIGURE 9. Dunvegan Formation in northern British Columbia.

The Dunvegan Formation north of Sikanni Chief River comprises a basal sandstone overlain by cycles of carbonaceous mudstone, massive conglomerate, and coarse-grained sandstone (Fig. 9). Within those cycles, there is some variation from one locality to another in thickness and number of conglomeratic units (Stott, 1968b). The basal unit consists of fine-grained, siliceous, thick-bedded to massive sandstone. The conglomeratic units contain rounded to well-rounded pebbles, dominantly of quartz, quartzite, and chert of various shades of green, blue, grey, white, and black, ranging from 1/8 inch to 6 inches in diameter. The average pebble size is much reduced east of the Alaska Highway.

The recessive beds between the massive conglomerates appear to contain carbonaceous mudstones and siltstones, but no thick coal seams were observed.

The upper surface of the formation throughout much of the northern region lies immediately below glacial deposits, and, in most places, some of the uppermost beds have probably been removed by erosion. The formation is 570 feet (170 m) thick north of Kledo Creek on the Alaska Highway and decreases to 491 feet (150 m) at the headwaters of Klua Creek (Stott, 1968b).

Coal Deposits

The possibility of finding major coal deposits within the Dunvegan Formation is somewhat limited. To the south in the Smoky River region, the formation comprises mainly marine sandstone and shale of the prodeltaic and delta-front facies in which coal does not commonly occur. The region between Murray and Pine Rivers presumably contains sediments of the lower deltaic plain. As that environment is most favourable for coal development, that region holds the most promise for Dunvegan seams. From Prophet River northward, most of the Dunvegan sediments were deposited in the upper deltaic or alluvial plain environment where conditions probably did not favour the development of thick coal deposits.

Smoky - Wapiti Sequence

The third major sequence in northeastern British Columbia developed entirely within Late Cretaceous time and is formed by the Smoky Group and Wapiti Formation (Fig. 2). That sequence occurs in the region south of Peace River between the Foothills and Dawson Creek (Stott, 1967c). Its northern limit there is erosional. The original extent of the basal marine beds is unknown but the upper part of the marine succession and the overlying alluvial beds reappear in the broad Liard Syncline north of the Alaska Highway (Stott, 1968b; Taylor and Stott, 1968).

In the region south of Dawson Creek, the Smoky Group lies gradationally on the Dunvegan Formation without a major break. However, in the extreme northeastern corner of British Columbia, Upper Cretaceous Kotaneelee marine shales, equivalent in age to the upper Smoky shale, unconformably overlie the Dunvegan Formation, and the hiatus represents all of the Turonian and Coniacian stages. Minor disconformities may occur at the top of the Cardium and Bad Heart Formations and may be present locally within the Wapiti Formation.

The dominant marine succession included in the Smoky Group records two main marine cycles separated by the thin littoral to epineritic sandstones of the Cardium and Bad Heart Formations (Stott, 1967c). A lateral change occurs within the Kaskapau Formation between Wapiti and Pine Rivers where mid-basin shale grades into epineritic or prodelta sandstone, the northwestern edge of which is erosional. It is possible that some alluvial-deltaic beds included in the Dunvegan Formation at Mount McAllister south of Peace River may be equivalent in part to the basal Kaskapau shale and sandstone.

The major regressive succession of the Wapiti Formation, lying gradationally on the Smoky marine beds, is dominantly continental sandstone, shale, and coal. These beds, ranging in age from Campanian to Maestrichtian, form a thick wedge of clastic sediments that extends from the Foothills across the Plains. The beds are more than 5,000 feet (1,500 m) thick in the west but decrease to a few hundred feet in the east. Only a small area south of Dawson Creek is underlain by Wapiti strata and it has not been examined in any detail (Stott, 1961). In adjacent areas of Alberta, described by Kramers and Mellon elsewhere in this volume, subbituminous to high volatile bituminous coal is reported by them and also by Allan and Carr (1946) to be most abundant in the middle to upper part of the Wapiti Formation, where seams range from 2 to more than 10 feet thick.

Within the Liard Syncline, the upper sequence consists of the Kotaneelee Formation and the overlying Wapiti Formation (Stott, 1968b). Shale of the Kotaneelee Formation is dark grey to black and weathers rusty. The Wapiti Formation of this region consists of a succession of medium-grained sandstone and conglomerate with interbeds of carbonaceous mudstone and siltstone. A seam of low grade coal, 15 inches thick, was reported by Hage (1945, p. 23) from equivalent beds on Liard River north of the British Columbia boundary.

SUMMARY

The main coal deposits of the Foothills occur within the Bullhead and Fort St. John Groups and are concentrated in the region from Peace River southward. The northern limit of coal development is closely related to the structural feature commonly known as the Peace River Arch. In the Plains, the near-surface coal occurs in the Wapiti Formation which has a restricted areal distribution, occurring southwest of Dawson Creek and also within the Liard Syncline.

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THE CRETACEOUS GETHING DELTA, NORTHEASTERN BRITISH COLUMBIA

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ABSTRACT

A major deltaic complex, comprising the Cadomin and Gething Formations of the Bullhead Group, developed in the vicinity of Peace River during an Early Cretaceous (Late Neocomian) phase of a boreal marine embayment. The western margin of the narrow embayment was largely controlled by the Omineca Geanticline, but a northeasterly element, related to the ancient Peace River Arch, played a major role in the development of the deltaic complex.

The succession attains a maximum thickness of 2,500 feet at Peace River but thins northeastward to a depositional edge. The basal conglomeratic sequence, included in the Cadomin Formation, represents deposits of the piedmont alluvial plain environment. The overlying and, in part, laterally equivalent Gething Formation contains deltaic sediments at Peace River which interfinger northward with shallow marine sandstone and shale, and those, in turn, grade into offshore shale and siltstone. To the south, the sequence consists mainly of floodplain sediments.

The sequence contains the "Lower Blairmore-Luscar" flora and a previously unreported marine microfauna of Late Neocomian to Early Albian age. Deposits of subbituminous to bituminous coal occur within the sequence between Smoky and Sikanni Chief Rivers.

INTRODUCTION

Sediments of a major deltaic complex of Early Cretaceous age are included in the Bullhead Group of northeastern British Columbia. They were deposited within a prograding succession during the early transgressive phase of an advancing boreal sea which culminated in the widespread marine inundation of Albian time. As these rocks contain deposits of good coking coal, a knowledge of the distribution, thickness, lithology, and facies variations is essential for exploration and exploitation. This report, based on stratigraphic, sedimentologic, and petrologic studies of the Bullhead Group, describes the succession between Smoky and Tuchodi Rivers.

Thirty-six outcrop sections were examined (Fig. 1), and data concerning the unconformity at the base were obtained from more than 20 additional sections. Mechanical logs, samples, and cores of approximately 50 boreholes were examined also.

Acknowledgments

Field studies were carried out in conjunction with other geological studies undertaken by B. R. Pelletier and G. C. Taylor. The fossil flora and fauna were identified and dated by D. C. McGregor, W. A. Bell, J. A. Jeletzky, Hans Frebold, and E. T. Tozer, of the Geological Survey of Canada. T. P. Chamney undertook a detailed study of the microfauna from the Gething shales, thus providing additional documentation of a previously unknown marine transgression. Analyses of the clay components of the Gething sediments were provided by A. E. Foscolos.

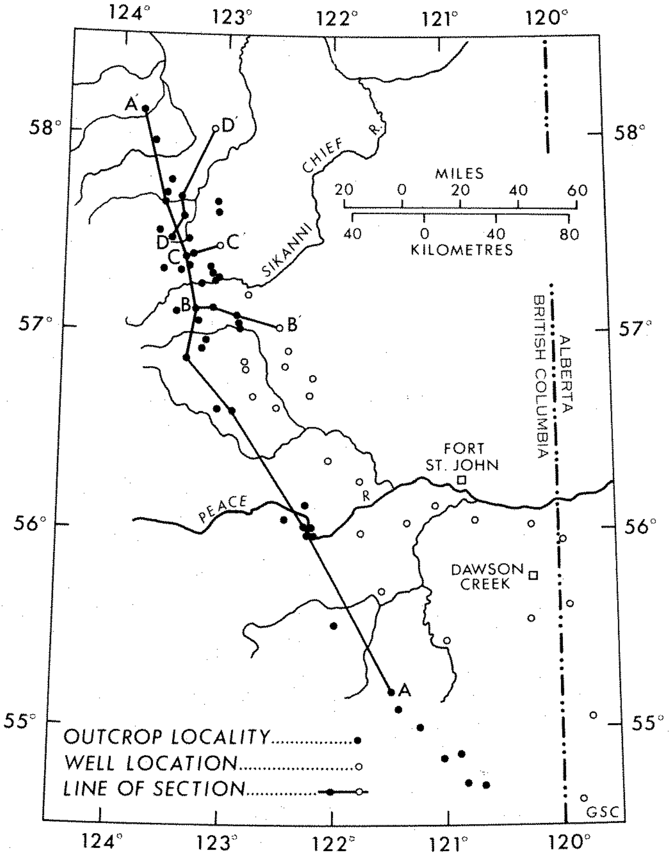

FIGURE 1. Locations of sections, Lower Cretaceous Bullhead Group.

BULLHEAD GROUP

The Bullhead Group, originally defined at Peace River (McLearn, 1918, 1923) comprises the Cadomin and Gething Formations (Fig. 2; Stott, 1968; in press). Northward beyond Graham River, the massive conglomeratic Cadomin Formation grades laterally into fine-grained sandstone and carbonaceous sediments similar to that of the Gething Formation, and it becomes impractical to map more than one unit (Stott, 1967a). The group is recognized as far south as Smoky River, and the boundaries of the equivalent stratigraphic interval are easily defined at Cadomin south of Athabasca River.

Contacts

Basal conglomerate or sandstone of the succession lies on successively older beds in the Foothills both northwesterly and southeasterly from Peace River and also easterly into the Plains (Fig. 2). Between Pine and Peace Rivers, the Bullhead Group lies on Minnes beds of middle to late Valanginian age. From Peace River to Sikanni Chief River, the succession overlies successively older Minnes beds. North of Besa River, basal sandstone lies on Jurassic Fernie shale and beyond Prophet River, on sediments of Triassic age. A similar truncation of underlying beds occurs eastward where Bullhead sediments lie unconformably on lowermost Cretaceous beds, then on Jurassic, and finally on older strata. The lower contact of the Cadomin conglomerate with the Minnes succession is distinct and abrupt at most localities. In addition to the regional relationships, evidence of unconformable relationships is provided by channelled surfaces and local angular relationships.

The contact between the Cadomin and Gething Formation is drawn at the top of the conglomeratic sandstone. This boundary lies at no persistent stratigraphic horizon but occurs at the top of different sandstones from one locality to another.

The Gething Formation is overlain by dark grey to black mudstone of the Fort St. John Group (Stott, 1967a, 1968). Those shales are assigned to the Moosebar Formation from Peace River southward and to the Buckinghorse Formation from Peace River northward. The Gething-Fort St. John contact is probably disconformable, representing a hiatus of short duration.

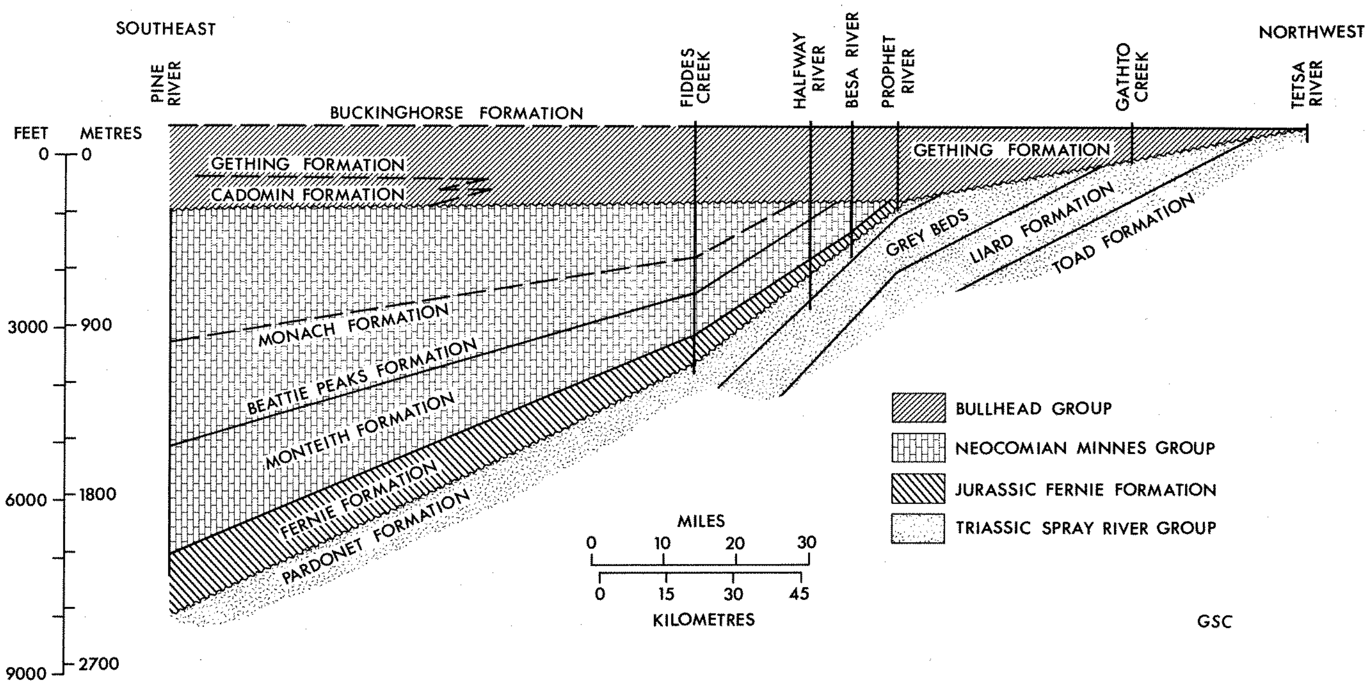

FIGURE 2. Unconformity below Cadomin and Gething Formations between Tetsa and Pine Rivers, northeastern British Columbia.

Thickness and Distribution

The succession is well exposed in the Foothills between Smoky and Tuchodi Rivers, a distance of more than 300 miles. The outcrop belt is about 25 miles wide, but the Bullhead Group extends beneath the Peace River Plains for a much greater distance. The group attains its maximum thickness of 2,500 feet at Peace River canyon but decreases to only a few hundred feet in the subsurface of Peace River Plains and to a zero depositional edge north of Fort St. John (Fig. 3). The isopach pattern of the combined Cadomin-Gething succession shows two lobes, a southern one with a depocentre between Mount Belcourt and Wapiti River and a northern one with depocentre in the vicinity of Peace River Canyon. The northern lobe, which forms the main Gething delta, extends for about 150 miles along the western margin of the embayment and for a similar distance eastward into the basin. Its areal distribution matches some of the largest Recent deltas (*see* Rainwater, 1966, Fig. 1), including those of the Mississippi and Nile Rivers. The northeasterly trending axis of greatest sedimentation parallels the ancient Peace River Arch. To the north, the isopachs are deflected to the north and northwest, becoming subparallel to the structural trends of the present Rocky Mountains. The zero isopach marks the western margin of a large island that separated the region of Gething deposition from that of McMurray deposition along the western edge of the craton (Rudkin, 1964).

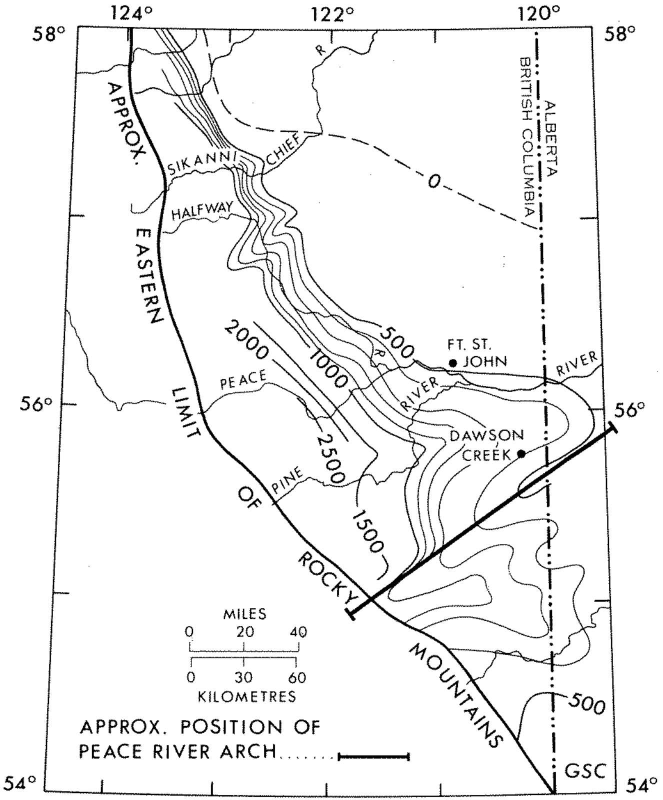

FIGURE 3. Isopach map of Bullhead Group.

Lithology and Facies Variation

The Bullhead succession represents an accumulation of sediments deposited in various environments associated with a major delta. It is a heterogeneous stratigraphic unit containing several distinct but genetically related lithofacies (Fig. 4). These include (1) chert pebble conglomerate and conglomeratic to coarse-grained sandstone, (2) a cyclical coal-bearing succession, (3) fine-grained sandstone, and (4) dark grey marine siltstone and mudstone with a subfacies of glauconitic argillaceous sandstone, siltstone, and mudstone. These lithofacies developed within the alluvial piedmont, alluvial-deltaic, prodelta (littoral and nearshore) and delta-front to midbasin marine depositional environments.

Conglomeratic Sandstone Facies

The main conglomeratic facies, occurring above the unconformity, is included in the Cadomin Formation (MacKay, 1929, p. 9B; 1930, p. 477). The basal conglomerate has an extensive distribution, extending along the Foothills from Graham River in the north to the Blairmore region of southern Alberta (Fig. 4; Norris, 1964; Mellon, 1967). In the region between Smoky and Pine Rivers, the facies consists dominantly of massive conglomerate with minor beds of fine-grained sandstone and carbonaceous mudstone. In the Peace River region, it consists of thick units of coarse-grained conglomeratic sandstone. The number of conglomeratic units varies from one locality to another: two are common in the vicinity of Smoky and Kakwa Rivers, three to four occur in the western Foothills south of Pine River, and numerous conglomeratic units occur in the Peace River region.

The conglomeratic facies is concentrated in two major depositional lobes centered near Mount Belcourt and Peace River. The maximum thickness in the southern lobe is 530 feet, and in the northern lobe is in the order of 750 to 800 feet. The thickness of conglomerate and conglomeratic sandstone decreases to less than 50 feet in the subsurface of Peace River Plains.

The massive conglomerate consists of pebbles, cobbles, and boulders. Boulders as much as 15 inches in diameter occur

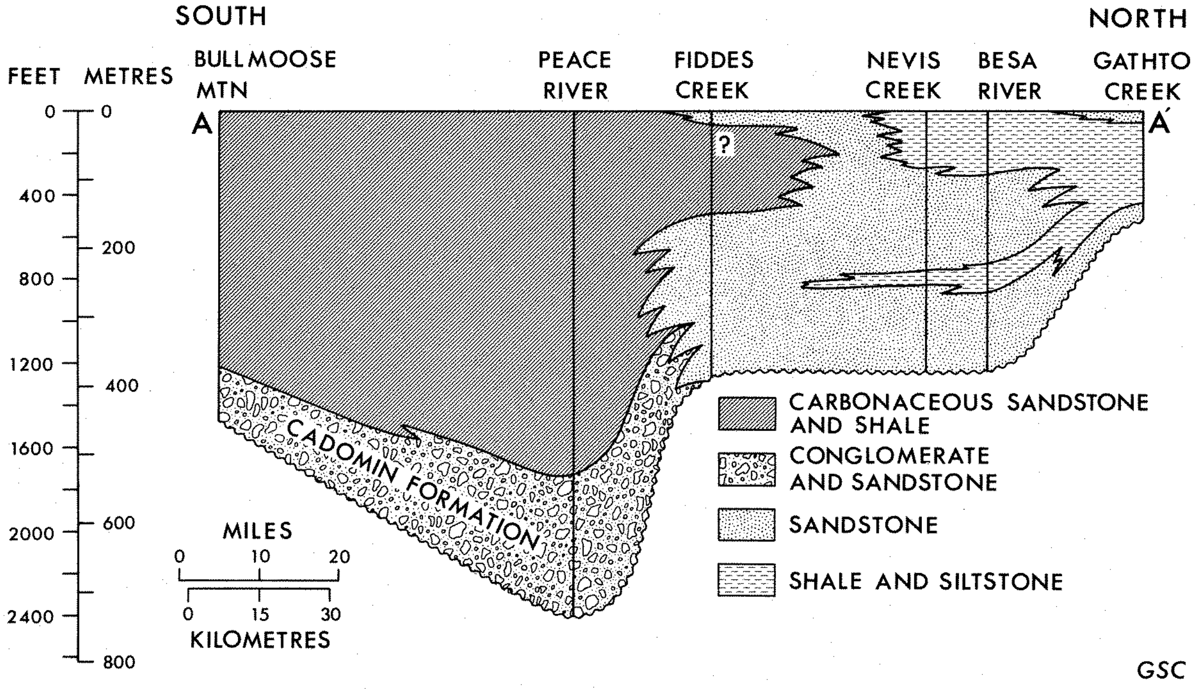

FIGURE 4. Schematic diagram of Cadomin and Gething Formations along a southeast-northwest line, Foothills of northeastern British Columbia.

in the southern delta. Between Sukunka and Burnt Rivers, the maximum diameter is in the order of 6 inches. Cobbles with a diameter of 3 inches were found within the conglomeratic facies in the Carbon Creek basin, but maximum sizes decrease to an inch or less at Peace River Canyon.

Most of the clasts are chert, quartzose sandstone, quartzite, and some quartz. Limestone pebbles and cobbles are relatively abundant between Kakwa and Wapiti Rivers but become less numerous northward. Most of the chert is white, grey, or black, but some is bluish-grey and pale green. Pebbles of light pink quartzitic sandstone are common in the southern part of the region. The clasts are subangular to rounded.

The conglomerates, with their fair to good sorting, stratified nature, festoon cross-stratification, lenticular bedding, scoured and channelled lower contacts are typically fluvial and are comparable with deposits of streamfloods in wet regions (Blissenbach, 1954; McKee, 1954). The decrease in maximum size of boulders and gradation of conglomerate into coarse-grained sandstone eastward and northeastward indicate a rapid decrease in the carrying power of the transporting agent. The intertonguing of these coarse clastic sediments both along and across the depositional strike with carbonaceous mudstone, siltstone, and coal reveals the presence of forested and swampy areas between the major alluvial fans. The fluvial origin, the erosional unconformity at the base of the conglomerate, and widespread but thin sheet-like distribution of coarse material, and the phenoclasts of durable rocks are all suggestive of development in a piedmont alluvial plain environment.

Coal-bearing Facies

The conglomeratic facies grades laterally and vertically into a heterogeneous assemblage of fine- to coarse-grained sandstone, carbonaceous siltstone, coal, and thin marine shale (Fig. 4). This facies was described as the Gething Member by McLearn (1923, p. 4B) and subsequently raised to formational status by Beach and Spivak (1944). This facies attains its maximum development near Peace River, being concentrated in the main northern lobe and forming the Gething delta (Fig. 3). The total thickness of the Gething Formation at the type locality on Peace River is approximately 1,800 feet. The facies decreases to 1,264 feet at Bullmoose Mountain and to only 260 feet at Mount Torrens. Between Peace and Halfway Rivers, the formation averages about 1,100 feet thick with a maximum thickness of 1,300 feet in the western Foothills. The formation thins rapidly eastward beneath the Plains.

In the southern part of the region, the succession includes the typical fining-upward cycles of alluvial origin (Allen, 1962, 1964, 1965; Beerbower, 1964). In these cycles, the thicker sandstone with large- and small-scale cross-strata, ripple lamination, irregular basal surface, and lenticular nature represent channel deposits. The sediments are brownish-grey to grey, fine- to coarse-grained lithic arenites and chert conglomerates. Such sandstones commonly grade upward into silty sandstone with horizontal laminae and bedding, deposited under lower energy conditions of the floodplain after the channel system had been abandoned. Overlying dark mudstone with abundant plant debris probably accumulated on the deltaic plain in interfluve areas as the result of overbank flood-flow or lacustrine conditions. Many clayey siltstones and silty clays with organic debris, including rootlets, tree roots and stumps, are similar to modern floodbasin deposits (*see* Bernard *et al.*, 1962; Allen, 1965). The associated coal and coaly shale are deposits of the marshes and swamps of the deltaic plain. That environment favoured the deposition of peat and subsequent development of thick coal seams. At Peace River, thin interbeds of marine shale appear within the cycle and indicate that the sediments in that region were deposited at the outer margin of the delta. Foraminifera obtained from the shale are representative, according to T. P. Chamney (*in* Stott, in press), of environments ranging from fairly open marine to very nearshore restricted. The shales represent the distal prodelta clay to proximal prodelta silt and clay deposited as the delta advanced into the basin. Fine- to coarse-grained sandstone associated with these sediments represent delta fringe and distributary channel deposits. The development of thick coals at the margin of the delta is not favoured owing to the influx of great quantities of clastic material and to continued subsidence with repeated flooding by marine water.

The cumulative thickness of conglomerate and conglomeratic sandstone within the carbonaceous and sandstone facies was plotted for each described section north of Peace River (Fig. 5). Four fairly well-defined belts of conglomerate trend northeasterly across the basin, being more or less perpendicular to the regional depositional strike. They appear to represent channel deposits of major distributaries, although the most northerly belt contains only a thin deposit of 10 feet or less.

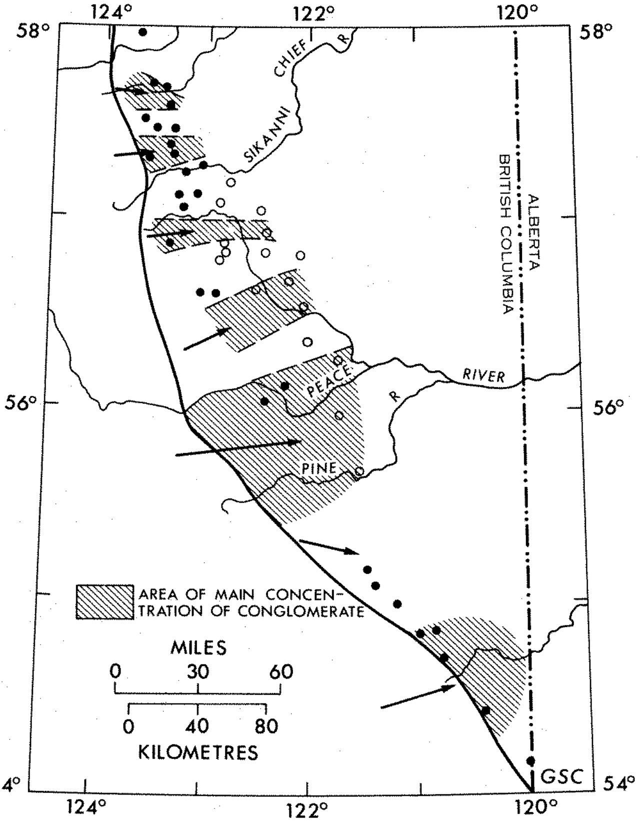

FIGURE 5. Conglomerate in Cadomin, Gething, and Bluesky Formations.

Fine-grained Sandstone Facies

The conglomeratic and carbonaceous coal-bearing facies grade northward into a fine-grained sandstone facies. This facies is concentrated in the region between Halfway and Besa Rivers (Fig. 4). The sand-shale ratio was calculated for the Gething sections north of Peace River (Fig. 6). In general, the sandstone is concentrated along the western side of the trough, and the shale content increases eastward. Four major lobes of sandstone occur in the region, the axis of each trending more or less perpendicular to the regional depositional strike. The axes correspond to a remarkable degree with the four major accumulations of conglomerate.

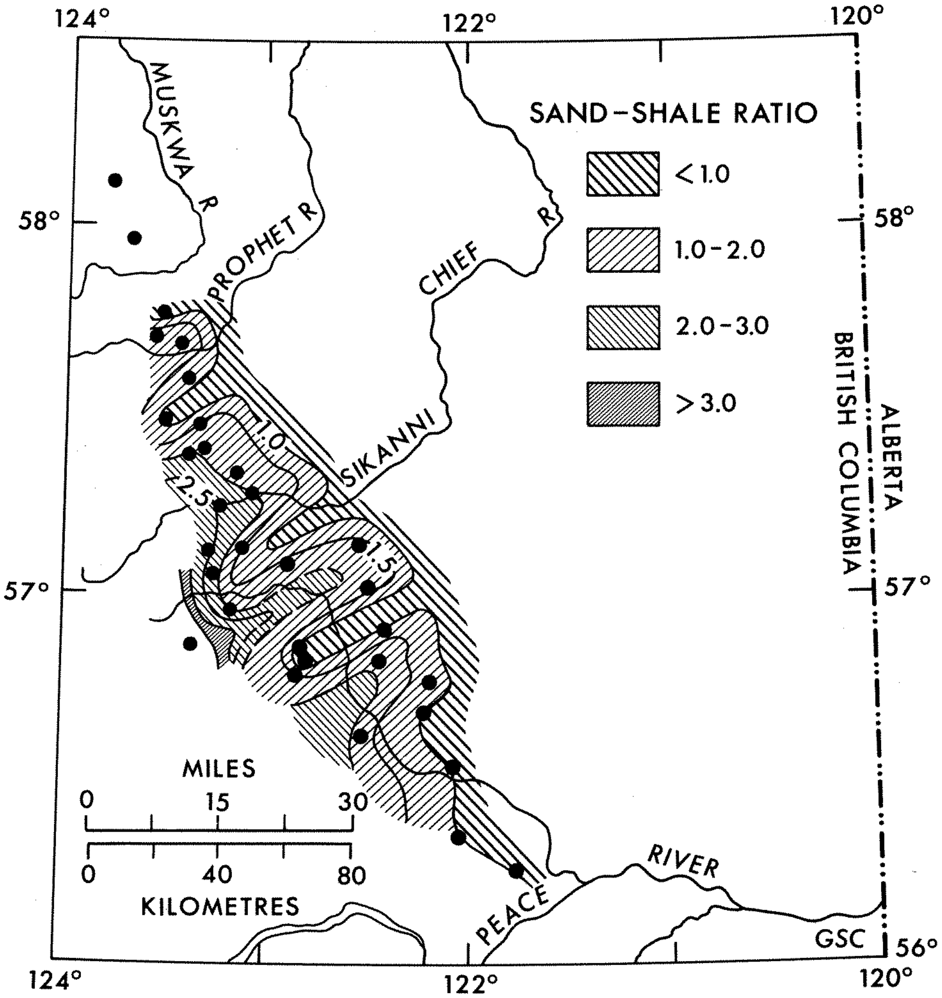

FIGURE 6. Sand-shale ratio, Gething Formation.

This facies has a thickness in the order of 1,100 to 1,300 feet near Besa River but thins both eastward and northward. In an east-west cross section at about the latitude of Halfway River, this facies is dominant although tongues of the carbonaceous facies appear within the formation at some localities (Fig. 7). Farther north, beyond Sikanni Chief and Besa Rivers, almost the whole formation consists of the fine-grained sandstone facies, the carbonaceous facies has disappeared and thin interbeds of marine shale and siltstone containing foraminifera make their appearance (Fig. 8).

The detrital constituents of the sandstones include quartz, chert, lithic fragments, and carbonate grains. Quartz ranges from 20 to 100 per cent of the detrital grains and is most abundant in the eastern sections near Prophet River. Chert ranges from 1 to 65 per cent. Considerable carbonaceous material occurs in some samples. The carbonate content, although never large, appears to be greater within the more carbonaceous sandstone. The matrix is composed of clay, fine silt, and clay-size detritus. The stable composition, good sorting, and relatively uniform grain size are indicative of current action and shallow water origin.

Sedimentary structures include small-scale crossbedding, oscillation and current ripple marks, flow rolls, fine laminations, worm burrows, and mottling typical of reworking by various organisms.

Although these sandstones appear to be sheet-like, they may be a composite of smaller sand bodies. Such shallow marine deposits are similar to delta-front sands (Visher,

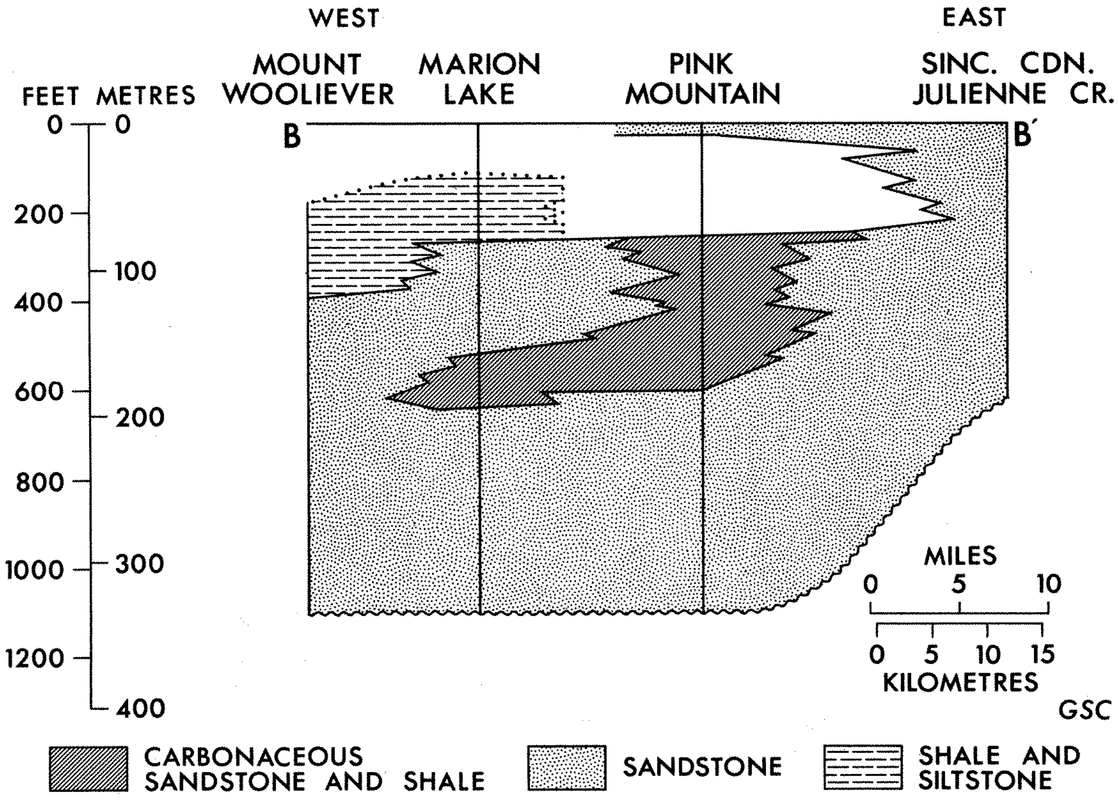

FIGURE 7. Schematic diagram of Gething Formation at latitude of Halfway River.

1965; Moore, 1966), delta-front sheet sands (Gould, 1970, p. 11), and tidal and barrier island sand bodies (Van Straaten, 1954a, 1954b; McKee, 1954; Shepard and Moore, 1955; Potter, 1967).

Mudstone-siltstone Facies

Marine mudstone and siltstone become abundant near the top of the Gething Formation at Sikanni Chief River. The facies forms about one-third of the formation between Halfway and Besa Rivers but becomes more prominent north of Prophet River. In an east-west cross section, the greater thickness occurs in the Foothills, with a marked decrease of total section eastward beneath the Plains (Fig. 9).

These mudstones are dark grey to black, weather rubbly to blocky, and contain reddish weathering sideritic concretions. Three distinct layer lattice silicate assemblages were identified by A. E. Foscolos (*in* Stott, in press) who recognized three assemblages. They are, in ascending order, (1) illite only, (2) illite, chlorite or septochlorite, with or without kaolinite, and (3) illite-chlorite. The significance of these assemblages and their relationship to source and depositional environments are still being investigated.

Sideritic material may be present in both mudstone and siltstone, occurring as nodules, beds, or grains. The mudstone commonly lacks good bedding, although bedding is commonly defined by layers of concretions or by thin beds of siltstone. Layers and laminae of siltstone and very fine-grained sandstone occur within the mudstone. The content of siltstone increases upward in cyclic units which may grade into sandstone. Small-scale cross-laminations occur within the sandier beds, and a few small slump structures, flow rolls and small channel structures are present.

A unit of glauconitic silty mudstone, siltstone, and sandstone occurs in the region of Prophet River, representing some part of the Bluesky Formation of the Peace River Plains. These sediments grade southwesterly into glauconitic sandstone, conglomeratic sandstone, and

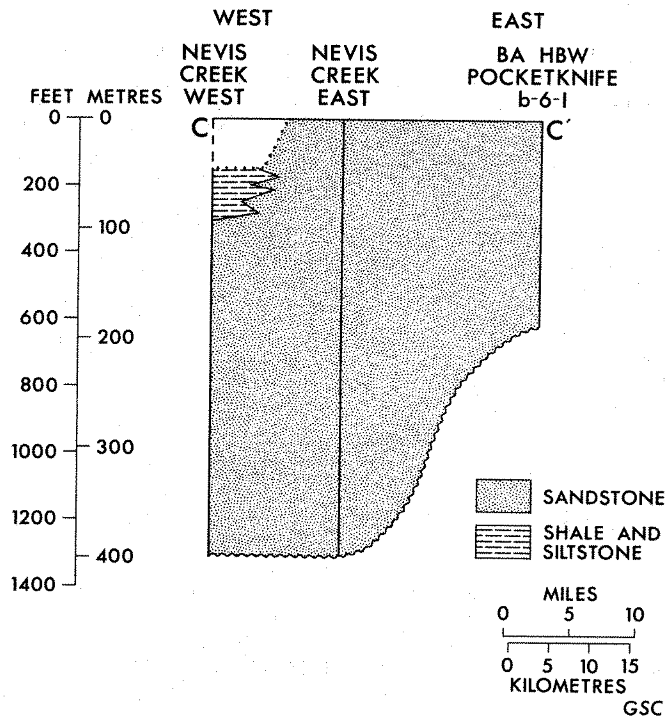

FIGURE 8. Schematic diagram of Gething Formation at latitude of Nevis Creek.

conglomerate. In some places the uppermost beds of this unit, marking the top of the Gething Formation, are highly concretionary.

The laminated, argillaceous siltstone and silty mudstone with organic material are characteristic of recent prodelta slope to bottomset beds (Scruton, 1955, p. 35-38; Allen, 1964, p. 31; Donaldson ***et al.***, 1970, p. 122; Allen, 1970, p. 149). The dark coloration of these sediments is caused by very fine carbonaceous fragments and disseminated iron sulphides indicative of reducing conditions below the sediment-water interface. The occurrence of glauconite and siderite are indicative of marine deposition (Krumbein and Garrels, 1952; Burst, 1958; Shepard and Moore, 1955; Van Andel and Postma ***et al.,*** 1954), and the abundance and variety of foraminifers also provides additional evidence of open marine conditions.

Age

The Bullhead Group lies on strata of the Minnes Group that contains a marine fauna of middle to late Valanginian age (Hughes, 1964, 1967; Stott, 1967b). It is overlain by Fort St. John shales of early Albian age and so on the basis of stratigraphic position can be dated as Hauterivian to early Albian. The macroflora comparable with the Lower Blairmore flora was dated by Bell (1956) as Aptian and/or early Albian and the microflora was dated by McGregor (*in* Stott, 1968) as Valanginian to Aptian. On the basis of microfauna, consisting predominantly of foraminifera, Chamney (*in* Stott, in press) gives an age assignment of late Neocomian (Barremian-Aptian) to early Albian.

Source and Tectonism

The marked increase in thickness and general increase in coarseness of sediments to the west and southwest indicates a source area in that direction (Fig. 3, 10). The detritus, dominated by quartz and chert and lacking typical metamorphic grains and abundant feldspar, is derived from a sedimentary terrain. The metasedimentary suite of quartzite, quartzose sandstone, minor argillite, and limestone was apparently derived from Paleozoic to Precambrian rocks, presently well represented in the western ranges of the Rocky Mountains. Chert is typical of many Paleozoic carbonate formations, and the abundant black chert may be derived from upper Carboniferous rocks. In addition to the western borderland, another source was the eastern island underlain by relatively flat-lying Paleozoic to earliest Cretaceous sediments (Fig. 10). Recycled quartz, concentrated on the eastern side of the basin, probably was derived from lowermost Cretaceous and older quartzose sandstone exposed on the island.

The western borderland from which the Bullhead sediments were derived was part of the Omineca Geanticline. Movements along the geanticline were not continuous but were episodic, with several strong pulses during Cretaceous time. The widespread basal conglomerate is strongly indicative of major uplift along the geanticline. The sediments were carried into the basin by several rivers, the deltas of which coalesced, thus forming a deltaic complex rather than a single delta. A primary control of the development of the major Gething delta was the structural zone generally referred to as the Peace River Arch. During Early Cretaceous time, subsidence continued along the north side of the structure. The continuous subsidence of that region not only funnelled in large volumes of terrigenous material derived from the geanticline but also favoured the development of poorly drained, swampy regions ideal for the accumulation of plant debris and the development of coal seams.

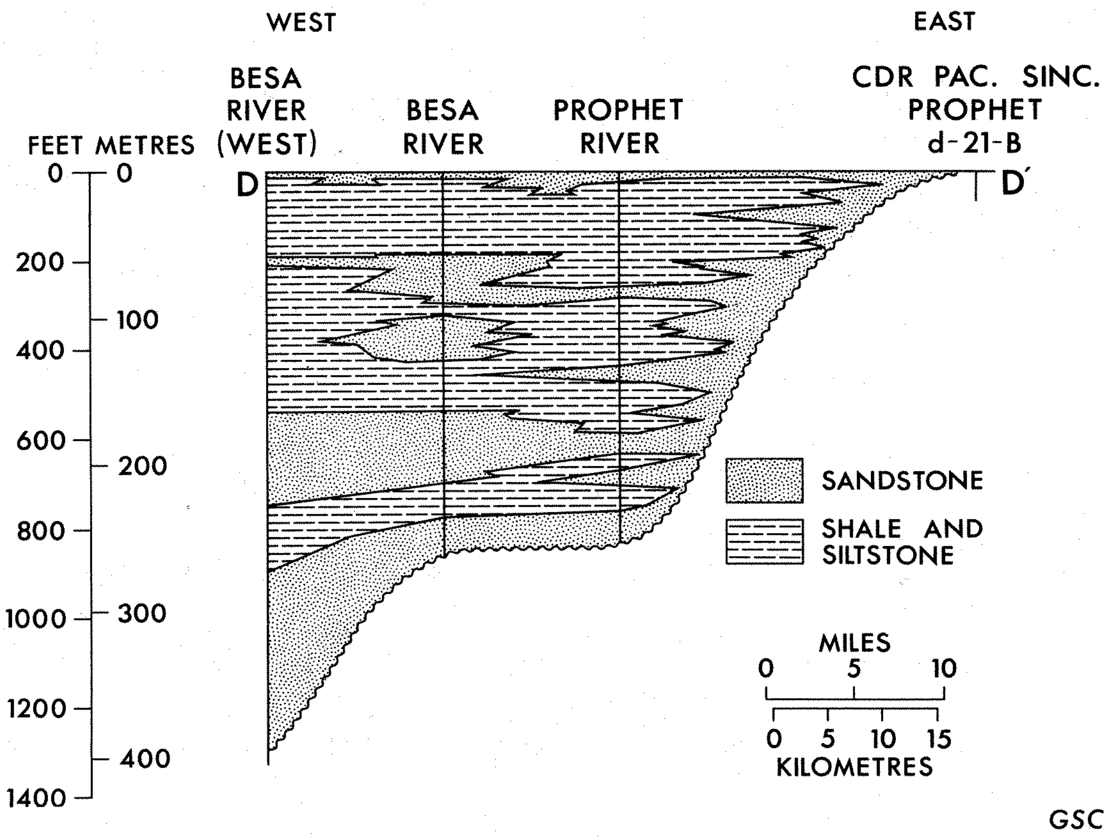

FIGURE 9. Schematic diagram of Gething Formation at latitude of Besa River.

The gradual decrease in thickness of the conglomeratic deposits and the increase in fine silt, mudstone, and coal provide evidence that the highland was being eroded gradually and that succeedingly smaller amounts of detritus were being carried into the basin. As the source area was reduced in elevation, ever-decreasing amounts of detritus were being contributed to the continually subsiding basin, and eventually the marine embayment transgressed over the floodplain of the Gething delta.

COAL OCCURRENCES

Coal occurs within recessive carbonaceous sediments that separate massive beds in the conglomeratic facies. Such occurrences have been noted in the eastern Foothills in the vicinity of Narraway River and Belcourt Creek where the thick conglomerate of the Belcourt delta grades laterally eastward into the carbonaceous facies. Similar occurrences are found in the Peace River region.

Thick seams, ranging from 10 to 25 feet or more, occur within the main carbonaceous facies between Kakwa and Murray Rivers. Coal commonly occurs at the top of the Cadomin Formation. A seam 11 to 15 feet thick is present above the Cadomin in the Kakwa River region and coal occurs above the Cadomin along the eastern Foothills between Narraway River and Quintette Mountain. Coal occurs above other thick conglomeratic beds higher within the Gething Formation.

A recent exploration program at Bullmoose Mountain has outlined the distribution of several seams in the upper 200 feet of the Gething Formation. The main seam averages 9 feet thick and reportedly is of good metallurgical coking quality. Other coal occurrences in the Gething Formation have been observed in that region, particularly in the beds overlying the Cadomin Formation.

Low to medium volatile coal with fair to good coking characteristics has been reported from the Pine River region

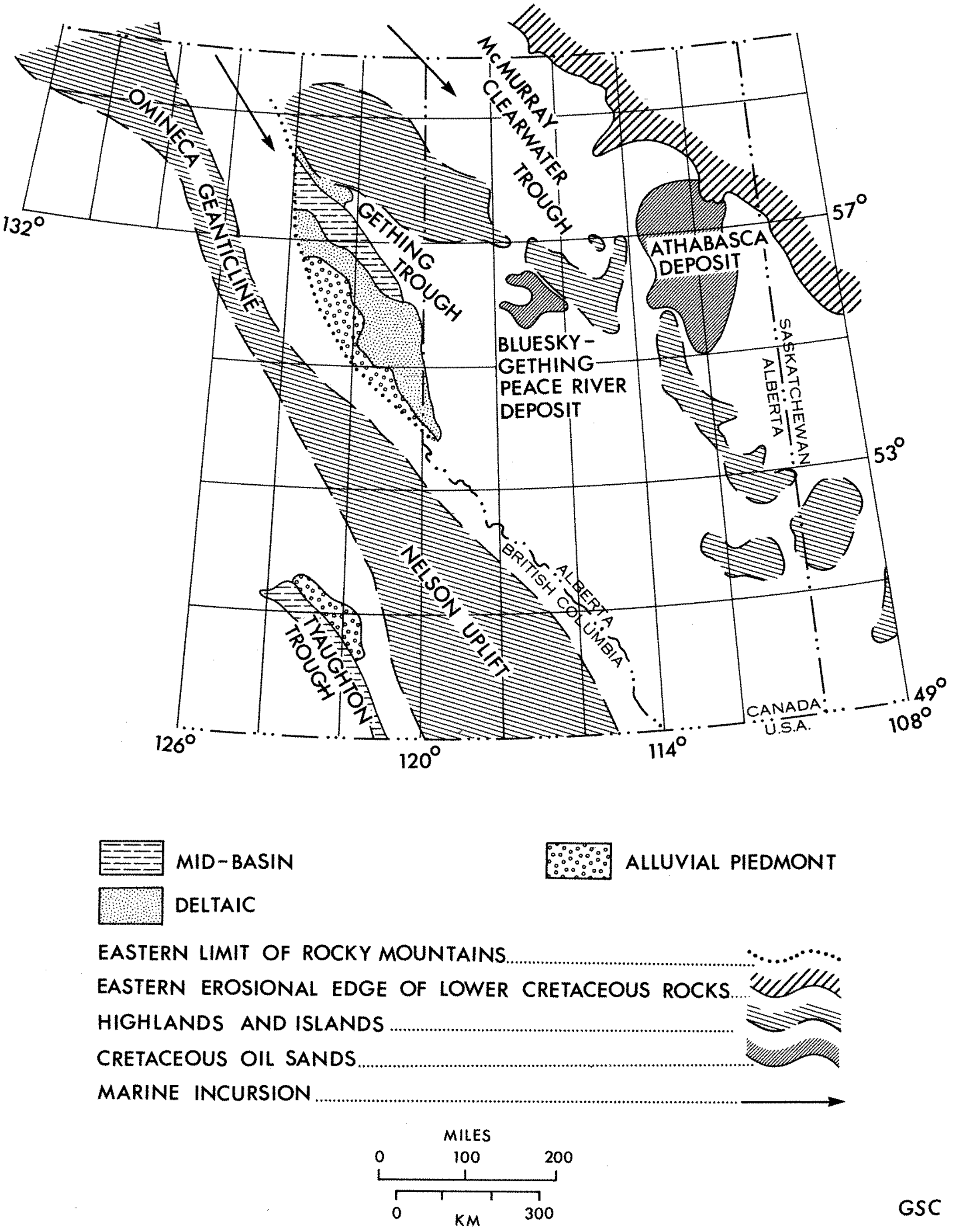

FIGURE 10. Paleogeographic map of Bullhead Group (modified after Rudkin, 1964).

(Spivak, 1944; McKechnie, 1955). These include two seams of 4 feet thickness and one of 6 feet thickness. Nine seams ranging from 6.5 feet to 20 feet have been described at Willow Creek, and seams as much as 20 feet thick are present on the north side of Pine River.

The main coal-bearing succession in the Carbon Creek region between Pine and Peace Rivers lies within the Gething Formation. Seams ranging from 4 to 17 feet were reported by Mathews (1947) from that area, but the thicker ones may be structurally thickened.

The coal mined at Peace River was obtained from the Gething Formation and is reported to be low to medium volatile bituminous (McLearn and Kindle, 1950). Although many seams are present in the canyon, the maximum thickness of any one seam is reported to be between 5 to 6 feet. At that locality, the coal was deposited at the outer margin of the delta where subsidence and influx of large quantities of clastic sediments resulted in rapid shifts of environments. As a result, individual coal seams are not thick and probably not extensive.

Exposures between Peace and Halfway Rivers are poor and the presence of thick coal deposits is questionable. A structurally thickened seam lies above conglomerate at the south end of Pink Mountain and one 4-foot seam and coaly shale occurs about 400 feet below the top of the Gething on the western flank. Only a few thin coaly shale beds and coal are exposed at Sikanni Chief River.

From Sikanni Chief River northward, the Gething consists of prodelta sandstone and delta front to mid-basin siltstone and shale. Coal did not develop in these marine environments, and although minor beds of carbonaceous debris might have accumulated in shallow lagoons and bays behind the sand barriers, no major deposits are likely to be present in that region.

In summary, Gething coal is widely distributed throughout the region but its northern development is controlled by its relationships to the prodeltaic sandstone facies at Sikanni Chief River. Current exploration and development work give promise of new mines obtaining production from Gething strata between Smoky and Peace Rivers.

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LIGNITE COAL RESOURCES OF SASKATCHEWAN

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ABSTRACT

Lignite coal deposits in Saskatchewan are present in the Ravenscrag Formation of Paloecene age, in the Belly River Series of Upper Cretaceous age, and in the Swan River Group of Lower Cretaceous age. The Belly River contains no known economic coal deposits and the prospects of locating such deposits are poor. Data on the Swan River coals are limited, but the prospects for economic deposits are somewhat better than for the Belly River. Ravenscrag lignites overshadow all other deposits, and the prospects for large reserves are excellent.

The centre of Ravenscrag deposition in Saskatchewan occurred in the Estevan area, where the formation is thickest and the coal seams are more numerous, thicker on the average, and of better quality than those in south central and southwestern areas of the province.

Proximate analyses reveal an increase in ash content and a decrease in thermal quality of the lignites from east to west. Average thermal values range from about 7800 BTU/lb in the Estevan coal field to about 5000 BTU/lb for the lignites in the Shaunavon area.

The lignites in southern Saskatchewan are favorably located in relation to deposits of other industrial minerals, and the prospects for the development of a complex of industries based on lignite as a raw material and energy source are good.

INTRODUCTION

Saskatchewan's known coal resources are all of lignitic rank. The reserves which are known to be economic are found in the Ravenscrag Formation of Paleocene age, which is present only in the extreme southern parts of the province.

In western Saskatchewan thin coal seams of Late Cretaceous (upper Belly River) age have been penetrated by numerous water wells. Most known occurrences are in an area where the Oldman Formation of the Belly River Series is overlain directly by relatively thin glacial drift. These occurrences are of minor importance and will be considered briefly in this paper.

In the Lac La Ronge-Wapawekka Lake area of central Saskatchewan, coal of lignitic rank has been observed in several localities in outcrop and in boreholes. The seams are part of the Lower Cretaceous Swan River Group and also are considered briefly.

Figure 1 shows the locations of the three coal-bearing areas described above.

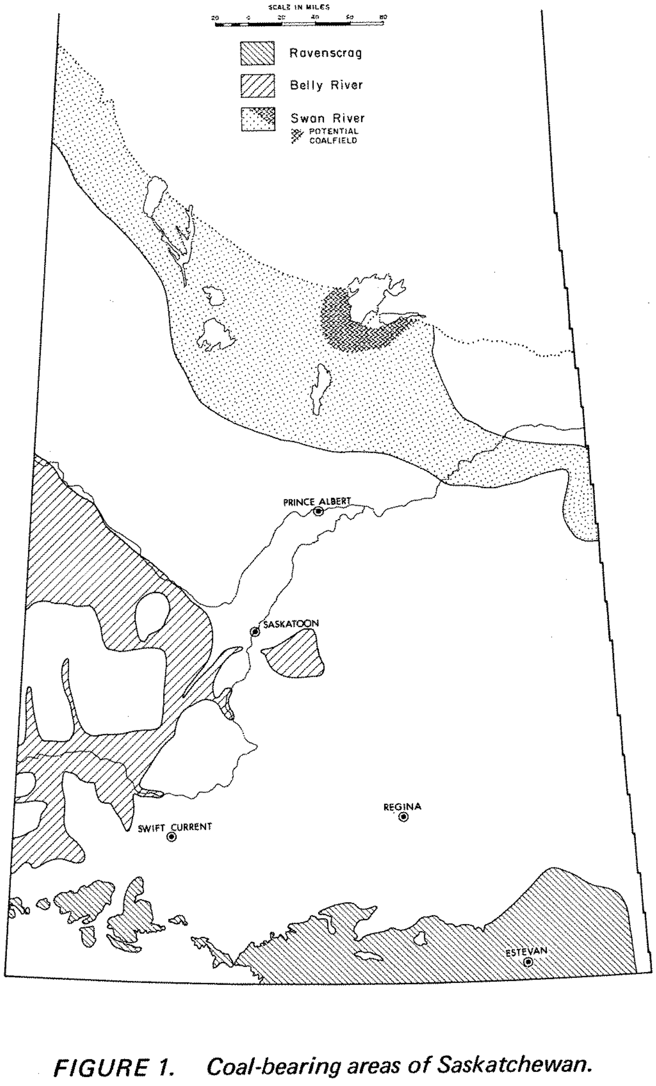


FIGURE 1. Coal-bearing areas of Saskatchewan.

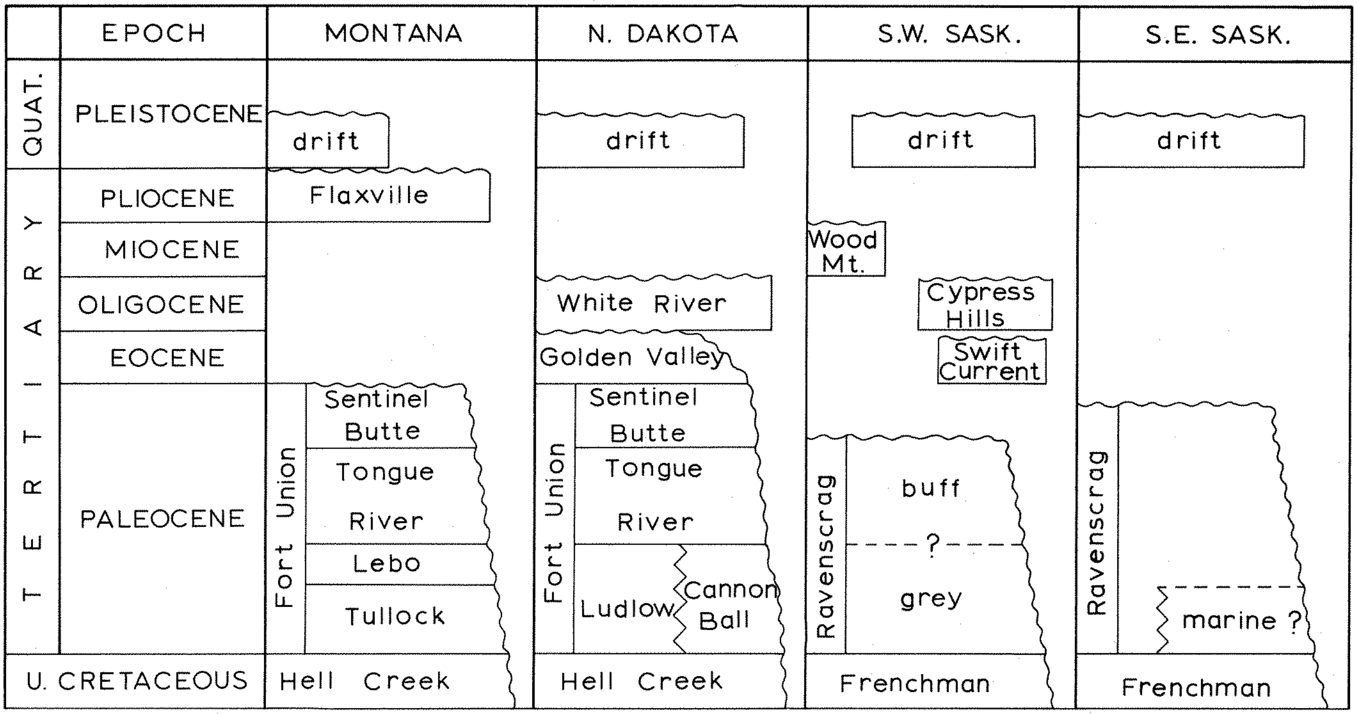


FIGURE 2. Stratigraphic correlation chart, southern Saskatchewan and adjacent areas.

RAVENSCRAG LIGNITES

Historical Sketch

Deposition of the Ravenscrag sediments during the Paleocene epoch and those of the related Fort Union Formation south of the International Boundary represents one of the last major events in the most recent chapter of the long history of the Williston Basin, which began perhaps as early as Precambrian or Early Paleozoic time. The Williston Basin has been reshaped several times during its history by epeirogenic and orogenic episodes in western North America, the most recent of which was the Laramide orogeny during Late Cretaceous and Early Tertiary times.

Continental deposition dominated the sedimentary history of the Ravenscrag in southern Saskatchewan. There is a distinct possibility, however, that the Early Paleocene Cannonball Sea extended from eastern North Dakota northward into part of southeastern Saskatchewan. Fraser *et al.* (1935) discussed the problem of the age and origin of a succession of 185 feet of blue clays and sands immediately below coal-bearing Ravenscrag beds in the Taylorton area. If these beds are of Early Paleocene age they may well represent a northern extension of the Cannonball Sea (Fig. 2).

The original distribution of the Ravenscrag Formation in southern Saskatchewan has been considerably modified by post-Paleocene erosion. Its maximum areal extent was likely almost double the present extent. It covers approximately 10,000 square miles of southern Saskatchewan and represents the northern limit of a vast area, centered in North Dakota and Montana, which periodically nurtured the coal-forming, low-lying, forested areas of the Paleocene epoch (Fig. 3).

Later deposition, on an eroded Ravenscrag surface, is represented by the Oligocene Cypress Hills Formation which caps the highest parts of the Cypress Hills area. Evidence of the youngest Tertiary deposition is found in the Wood Mountain area, where the Wood Mountain Formation of Miocene age is present only as isolated remnants capping the highest areas. The final major episode in the depositional history of southern Saskatchewan was the widespread Pleistocene glaciation which left a mantle of drift of varying thickness everywhere except in the very highest parts of the Cypress Hills.

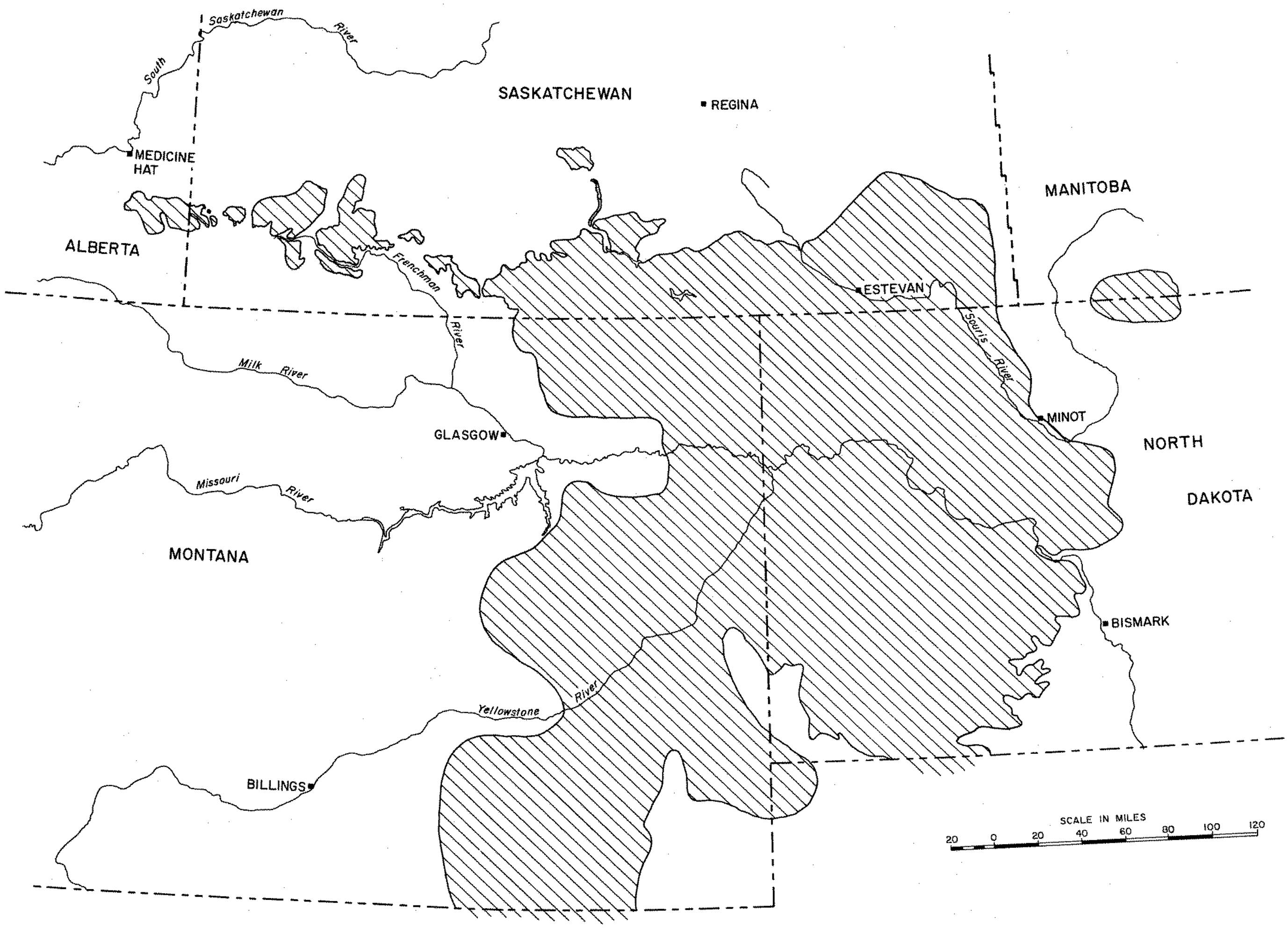


FIGURE 3. Present limits of Paleocene coal basin, southern Saskatchewan and adjacent areas.

Distribution of Reserves and Coal Analyses

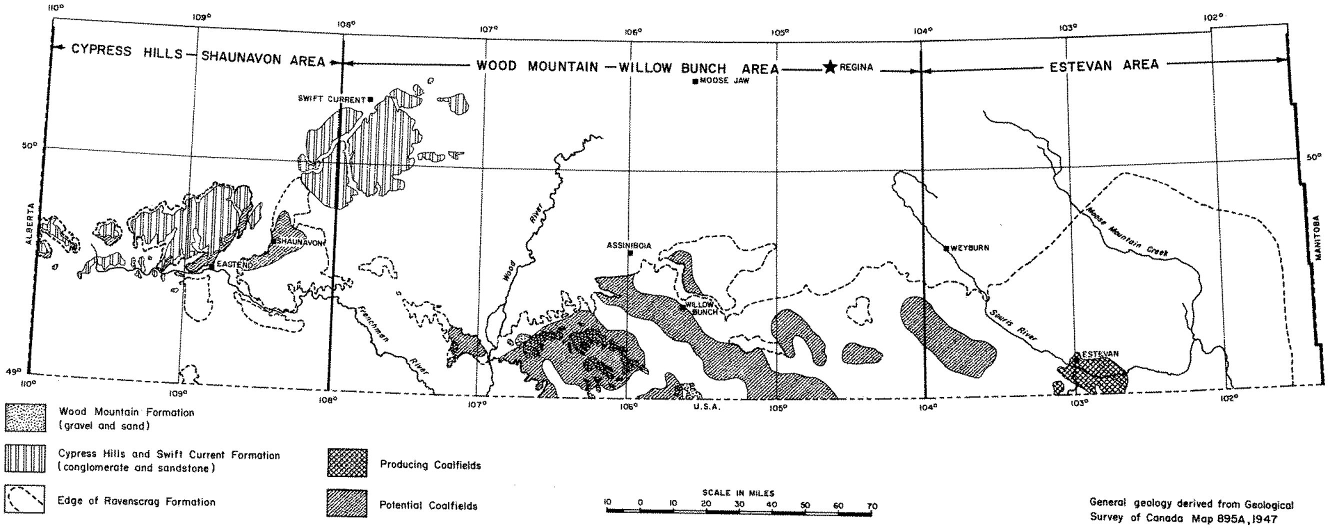
Three major coal fields are recognized in southern Saskatchewan. These are, from east to west, in the following areas: Estevan, Wood Mountain-Willow Bunch, and Cypress Hills-Shaunavon. Figure 4 illustrates the producing and potentially productive coal fields in southern Saskatchewan.

Estevan Area

Although eight major lignite seams are found in the Estevan area within a stratigraphic interval of about 750 feet, only four of these have been mined. Only two of these four seams are of economic significance in any one locality in the Estevan coal field. The average thicknesses of the four upper seams are, in descending order, 5, 5, 7, and 10 feet (MacKay, 1947). Locally, some seams may reach thicknesses of 13 to 15 feet.

The stratigraphic relationship between the Estevan coal seams and those of the Wood Mountain-Willow Bunch area to the west is uncertain, due to lack of reliable drillhole information. It is believed, however, that the seams of the Estevan area are younger than those in the areas farther west.

Latour and Chrismas (1970) made reserve estimates for the Estevan coal field in three categories as follows: measured, 291.5 million short tons; indicated, 1,044.4 million short tons; and inferred, 487.2 million short tons. These figures will probably increase as more exploratory work is done, as technological advances are made in deep stripping



General geology derived from Geological Survey of Canada Map 895A, 1947

FIGURE 4. Existing and potential coal fields, Ravenscrag Formation.

techniques, and as the demand for energy grows sufficiently to make some of the deeper and thinner seams economically attractive.

Maximum, minimum, and average values for 22 proximate analyses of lignite from various seams and localities in the Estevan coal field are presented in table 1. The data are based on figures published by Swartzman (1953) and Swartzman and Tibbets (1955).

Wood Mountain-Willow Bunch Area

In the Wood Mountain-Willow Bunch area the Ravenscrag Formation attains a maximum thickness of about 500 feet. Numerous lignite seams are unevenly distributed throughout the section and do not persist laterally throughout the area. The stratigraphic relationships among the seams are not fully understood. At least five major seams are present in the area and average about 5 or 6 feet in thickness. Locally, some seams may attain thicknesses of 18 to 20 feet.

Table 1. Proximate Analyses of Estevan Coals (as received)

	Minimum	Maximum	Average
Moisture (per cent)	31.0	35.0	-
Ash (per cent)	5.3	10.2	7.1
Volatile matter (per cent)	26.2	28.5	27.3
Fixed carbon (per cent)	31.6	36.1	34.2
Calorific value (BTU/lb)	7260	7920	7840
Ash softening temp. (°F)	2090	2480	2180

Data from several hundred recent shallow drillholes, water wells, old mine records, and the work of Pearson (1962) were useful in developing a general picture of lignite coal distribution in the area. The interpretations are presented in figure 4, and it should be stressed that data for certain areas are either scarce or nonexistent; consequently the distribution of potential coal areas is in part a reflection of the availability of data. As more data is accumulated the interpretations very likely will change. The areas not shown as potential coal fields, particularly where drift thicknesses are relatively thin, should not be disregarded in lignite exploration programs.

MacKay (1947) subdivided this area (from longitude 104 to 108 degrees west) into four separate blocks, each being one degree of longitude in width, and Latour and Chrismas (1970) calculated lignite reserves for each of these four blocks. If their figures for the four blocks are combined, the indicated reserves are 5.375 billion tons and the inferred reserves are 3.909 billion tons.

The lignites of the Wood Mountain-Willow Bunch area vary widely in ash content. The average is somewhat higher than that for the Estevan lignites, and consequently the heat

Table 2. Proximate Analyses of Wood Mountain-Willow Bunch Coals (as received)

	Minimum	Maximum	Average
Moisture (per cent)	34.6	49.4	39.7
Ash (per cent)	5.8	17.1	9.75
Volatile matter (per cent)	21.3	28.8	24.6
Fixed carbon (per cent)	18.2	30.4	25.9
Calorific value (BTU/lb)	4260	6550	5780

value is lower. Minimum, maximum, and average values for proximate analyses of lignites from various localities in the area are presented in table 2. The data are based on 17 analyses published by Pearson (1962).

Recent analyses of lignite samples from the central part of the Wood Mountain-Willow Bunch area, on an "as received" basis, indicate an average moisture content of 50 per cent, an average ash content of 6 per cent, and an average heat value of 4900 BTU/lb. The higher moisture content may reflect efficient waterproof packaging techniques, a very short duration between coring and analysis, and the addition of water from the drilling mud.

Cypress Hills-Shaunavon Area

In the Cypress Hills-Shaunavon area (Fig. 4), about 1300 square miles of Ravenscrag sediments are present in isolated erosional remnants. About 400 square miles of this area are overlain disconformably by Eocene or Oligocene deposits. Drift thicknesses in the area are generally less than 100 feet.

Two or three of the numerous lignite seams in the upper 150 feet of the formation reach sufficient thicknesses to be considered economic. Seam thicknesses are generally thinner than those of the areas to the east, but locally (particularly near Shaunavon) they may be 10 to 15 feet thick.

The lignites in the vicinity of Eastend and Shaunavon are of slightly poorer quality than those of the Wood Mountain-Willow Bunch area. Table 3 provides minimum, maximum, and average values for 50 proximate analyses of lignites from the Shaunavon-Eastend vicinity.

Estimates of lignite reserves by Latour and Chrismas (1970) for the Cypress Hills area (a combination of the Eastend and Cypress Lake blocks of MacKay, 1947) are: indicated, 603.6 million short tons; and inferred, 302.4 million short tons.

In the western half of the Cypress Hills-Shaunavon area drilling data are scarce. There is some evidence, however, that lignite deposits of economic value are present along the perimeters of some of the Ravenscrag outliers and in places where the overlying Oligocene deposits are relatively thin.

Table 3. Proximate Analyses of Shaunavon-Eastend Coals (as received)

	Minimum	Maximum	Average
Moisture (per cent)	27	60	50
Ash (per cent)	4	27	8
Volatile matter (per cent)	23*	59*	45*
Fixed carbon (per cent)	11	54	30
Calorific value (BTU/lb)	2848	5949	5000

*Data determined on a dry basis

BELLY RIVER COAL

Widespread deposits of nonmarine sandstones and clays of Upper Cretaceous age are present in western Saskatchewan. These clastic deposits are correlative with the Oldman Formation of the Belly River Series of Alberta. Erosion of younger strata has exposed these sediments over a large area (Fig. 1), and they are now overlain directly by glacial drift, with the exception of a few isolated exposures.

Coal of uncertain rank (lignitic to subbituminous) has been reported in many localities by early workers. In particular, water well borings have been reported to penetrate up to 10 feet of coal in some areas. However, recent drilling programs and the fieldwork of Hudson (1965) have shown that early reports of thick coal seams are highly exaggerated due to misidentification of samples or poor sampling techniques, or both factors. The coal seams vary from a few inches to about 2 feet thick. They are discontinuous and have been subjected to considerable distortion by glacial action.

The prospects of locating economic coal deposits in this area are poor judging from present data. It is stressed, however, that the area is large, and relatively little reliable drilling information is available.

SWAN RIVER COAL

Outcrops of the Lower Cretaceous Swan River sandstones are found at several localities near the northern perimeter of the sedimentary basin. The most important of these, in terms of coal deposits, are those present in the Lac La Ronge-Wapawekka Lake area (Fig. 1). Coal of lignitic rank has been found at several localities in this area in outcrop and in drillholes.

Exposures of coal have been observed on the south shore of Wapawekka Lake; on the Bow River southwest of Lac La Ronge; at Egg Lake west of Lac La Ronge; and on MacKenzie Creek, about 300 yards east of mile 67.75 on Highway No. 2 (Pearson 1961). In boreholes on the east side and south end of Montreal Lake, coal-bearing zones 14 and 30 feet thick were encountered at depths of 630 and 720 feet, respectively. Boreholes near Highway No. 165 in Lsd. 3-22-65-17 W. 2nd Mer. and in the northeast quarter of Sec. 33-66-20 W. 2nd Mer. encountered zones of interbedded coal and sand at depths of 630 to 705 feet and 40 to 170 feet, respectively. Observed seam thicknesses in outcrops and boreholes range from a few inches to about 5 feet.

Proximate analyses of four samples, one by the Department of Energy, Mines and Resources, Ottawa, and three by the Chemistry Department, University of Saskatchewan, Saskatoon, are presented in table 4.

Table 4. Proximate Analyses of Four Samples of Swan River Coals

	1	2	3	4
Moisture (per cent)	11.23	13.06	11.07	9.90
Ash (per cent)	23.00	29.45	27.37	19.93
Volatile matter (per cent)	30.97	35.99	45.93	34.83
Fixed carbon (per cent)	34.80	21.50	15.63	35.34

LIGNITE UTILIZATION

With the exception of limited production of lignite char and the associated by-product, creosote, and limited usage in the sodium sulphate industry, Saskatchewan lignites are primarily utilized for ultimate conversion to electrical energy, both inside and outside the province. This usage of the province's lignite resources is limited in scope. With present technology and some additional research, it seems conceivable that lignite could form the basis of a complex of integrated industrial processes, particularly in southern Saskatchewan where a variety of other industrial minerals are present. Some products arising out of a broader use of lignite also may have a bearing on industrial development and water pollution control in northern areas.

Some suggestions for greater diversification in the use of lignite coal in Saskatchewan are listed below.

(1) Improvement of lignite destined for export by:
  (a) reduction of ash content;
  (b) reduction of moisture content;
  (c) reduction of sodium content.

(2) Recovery of the by-products of combustion of lignite:
  (a) rare elements such as gallium, germanium and yttrium which are present in some lignite deposits;
  (b) fly ash which is useful as a lightweight aggregate and is proving extremely effective in water and effluent purification.

(3) Use of thermal energy and in certain cases electrical energy, for the processing of raw materials found in the proximity of lignite deposits, e.g., clays, potash, carnallite, pumicite, sodium sulphate and leonardite.

(4) Production of organic chemicals, and liquid and gaseous fuels from lignite.

(5) Agrobiological application of lignite and leonardite derivatives.

(6) Production of lignite char for the metallurgical and metal extraction industry.

(7) Production of activated carbon for water purification.

This list is far from complete but serves to stress the potential of Saskatchewan's lignite reserves. Figure 5 illustrates the present and potential uses of lignite and figure 6 presents the geographical relationship between lignite deposits and nearby deposits of various industrial minerals.

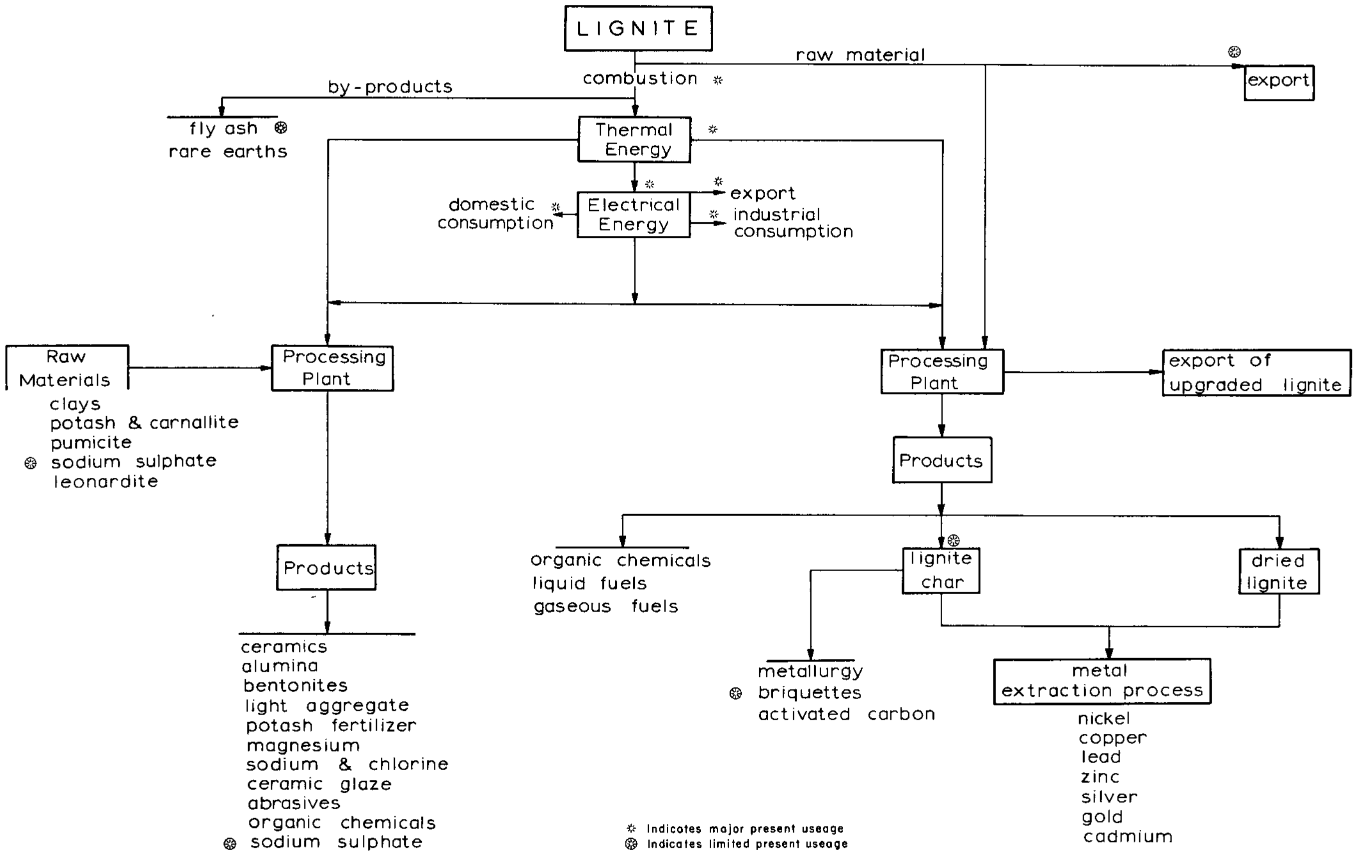


FIGURE 5. *Existing and potential uses of Saskatchewan lignite deposits.*

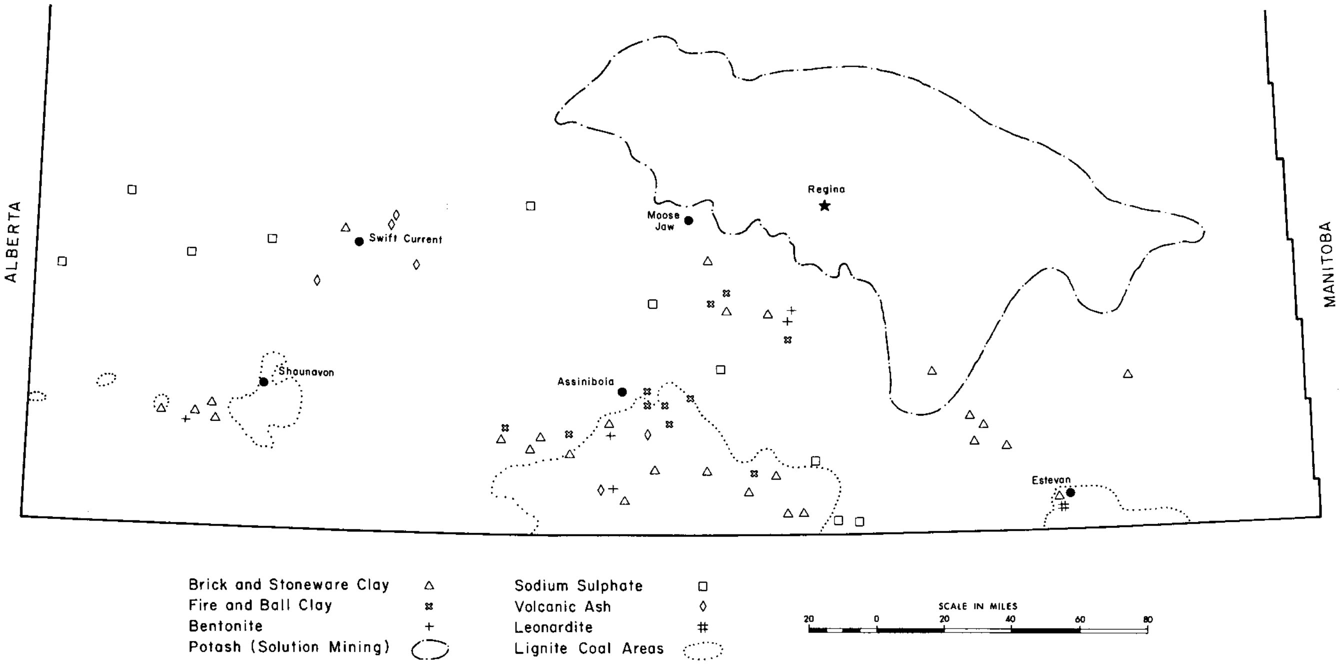


FIGURE 6. *Distribution of lignite and potential industrial mineral deposits of southern Saskatchewan.*

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COAL SEAMS OF THE ESTEVAN AREA, SOUTHEASTERN SASKATCHEWAN

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ABSTRACT[2]

Five lignite seams are present in the Tertiary Ravenscrag Formation in the Estevan area, at depths of 100 feet or less. They are named, in ascending order: the Boundary, Estevan, Souris, Roche Percée, and Short Creek seams. A total succession of approximately 250 feet is represented by the coal beds and interstratified clays, silts, and sands. Strata dip to the southeast at 25 feet per mile or less and strike northeast-southwest.

Large areas underlain by coal seams at shallow depths are delineated. Reserve calculations are dependent on detailed information on seam thicknesses and feasible strip-mining depths.

The stratigraphically higher seams on the average are thinner than the lower seams. This, together with the increase in the average grain size of the clastic detritus in higher strata, suggests the progressive withdrawal of a marine margin to the south during the deposition of the coal seams and associated strata in Paleocene time.

INTRODUCTION

The Estevan area is located 125 miles southeast of Regina and immediately north of the International Boundary (Fig. 1). The region is a flat to gently rolling prairie environment dissected by the Souris River and its tributaries, Long Creek and Short Creek. Elevations range from less than 1750 feet within the valley of the Souris River to more than 1950 feet on the surrounding plain (Fig. 2).

Study of the lignite seams is based on data from approximately 1200 wells, the majority of which were drilled to depths of less than 100 feet by numerous coal companies. The wells are located along the edges of sections in townships 1 and 2, ranges 6, 7, 8, and 9 west of the second meridian. All the wells were incorporated into preliminary cross sections to verify correlations for mapping purposes. Information is available for approximately 1800 additional drill holes but was not used in this study.

The purpose of this paper is to demonstrate the regional relationships of the coal seams with respect to stratigraphy, structure, and depth of burial.

The writer is indebted to the Saskatchewan Department of Mineral Resources for permission to publish this paper. Much of the preliminary compilation work was carried out while in the employ of the Department.

STRATIGRAPHY

Mineable lignite seams in the Estevan area are located in the upper beds of the Tertiary Ravenscrag Formation, on the northeast flank of the Ravenscrag basin. The strata dip gently to the south to a regional basin center in western North Dakota. Outcrops of coal and associated sands, silts, and clays are common in the Souris River valley between Estevan and east of Roche Percée, as well as in the valleys of Short and Long Creeks. Many wave-cut exposures of Tertiary bedrock have formed along the edges of the reservoir created by the damming of Long Creek by the Saskatchewan Power Corporation.

Interest in the commercial exploitation of the lignite dates back to the 1880's. Soon after the turn of the century several small mines were in operation. The earliest stratigraphic work of major consequence was carried out by MacLean (1918), who compiled a composite section from well data available at the time which included three seams at depths of less than 150 feet and four deeper seams, the deepest of which is more than 700 feet (Fig. 3). Among the three shallow seams, the uppermost was designated the "H" seam. The seam below was recorded as the "J" seam and locally was known as the "second workable" or "upper Estevan" seam by mine operators. Below this is the "L" or "third workable" seam, also variously known as the Wooloomooloo, Anderson, Shand, Bienfait, and Taylorton seam. Dowling (1920) briefly considered the mining potential of the lower seams, and Lee (1927) recognized four shallow seams — designated as Numbers 1 to 4, in descending order — discussing the areal extent and workability of each. Frazer ***et al.*** (1935) also reported four seams which they called, in ascending order, the Taylorton (or Lower Estevan), Upper Estevan, Roche Percée, and Frayne seams. None of the early work included map presentations of seam distribution, depths, thicknesses, or structure.

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[1] Formerly with the Department of Mineral Resources, Regina, Saskatchewan.

[2] This contribution is a slightly modified version of a paper published in The Canadian Mining and Metallurgical Bulletin Vol. 65, 1972, No. 724, p. 61-71.

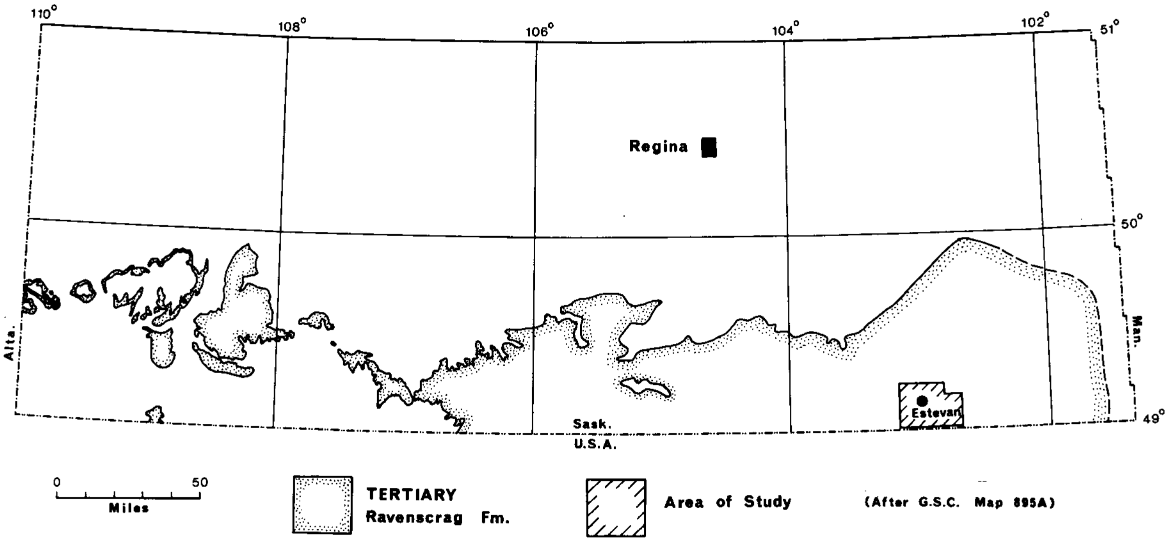


FIGURE 1. Location map, southeastern Saskatchewan.

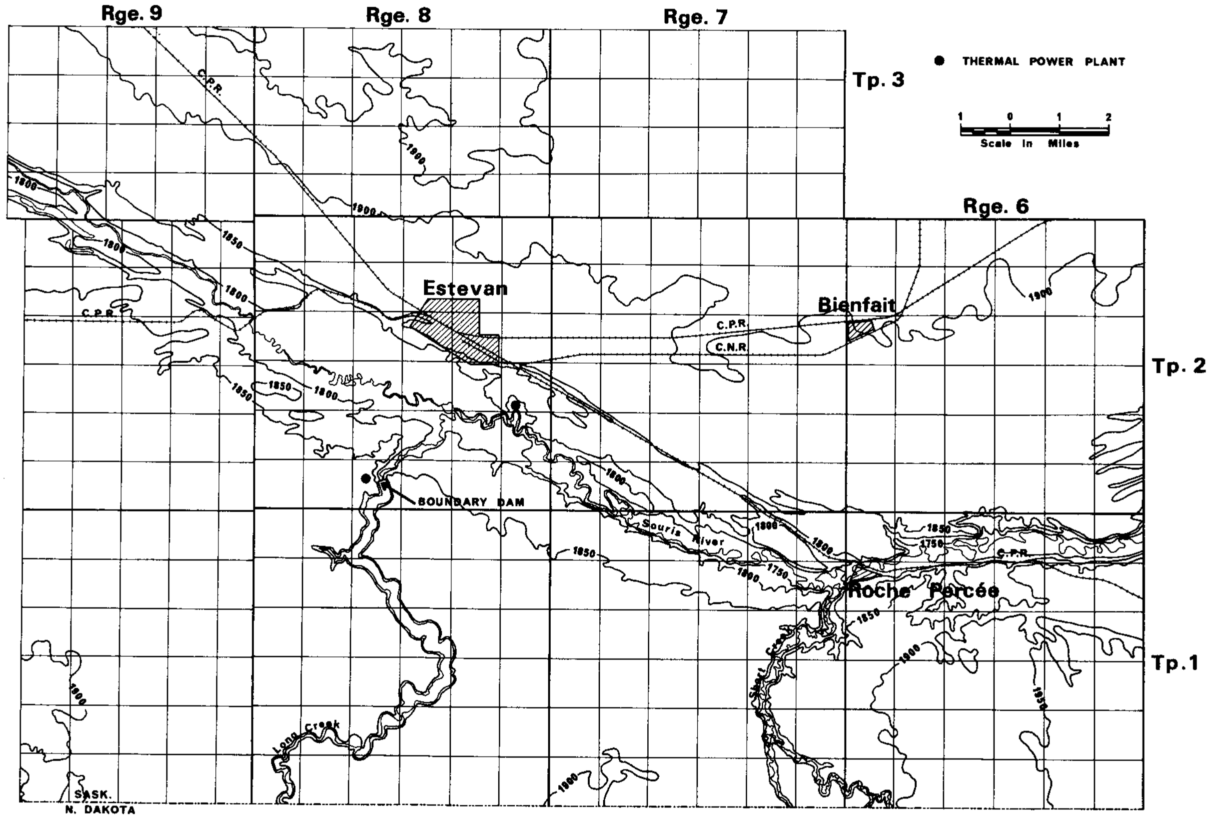


FIGURE 2. Topographic map of the Estevan area.

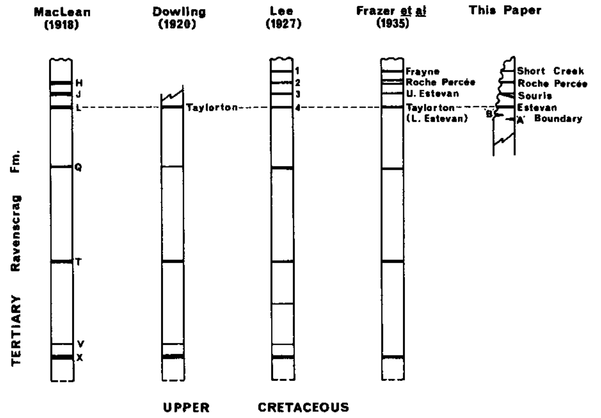


FIGURE 3. Seam nomenclature, Estevan area.

Six cross sections serve to illustrate adequately the number and distribution of coal seams (*see* Fig. 4 for lines of sections and Figs. 5 and 6 for cross sections). Each is presented in simplified form: all seams less than 1 foot thick and all wells which display anomalies are excluded.

The Boundary seam is the lowest and occurs below the seam previously called the Taylorton and herein designated the Estevan. The Boundary seam may represent two seams; however, the lack of continuity across the region, best shown in figure 6, precludes the possibility of establishing relative stratigraphic relationships of the units. Following in succession above the Boundary seam are the Estevan, Souris, Roche Percée, and Short Creek seams. The Souris seam demonstrates two interesting developments: firstly, a tendency to pinch out laterally in many areas and, secondly, to split into two major seams in an easterly direction (Fig. 5).

Each of the seams subcrop in a northerly and easterly direction, below a thin mantle of glacial drift. A total succession of approximately 250 feet is present between the Boundary and Short Creek seams, each seam being separated from the one above or below by about 60 feet of strata. All of the seams, with the exception of the Boundary seam, outcrop in stream valleys where erosion has progressed through the drift cover to bedrock.

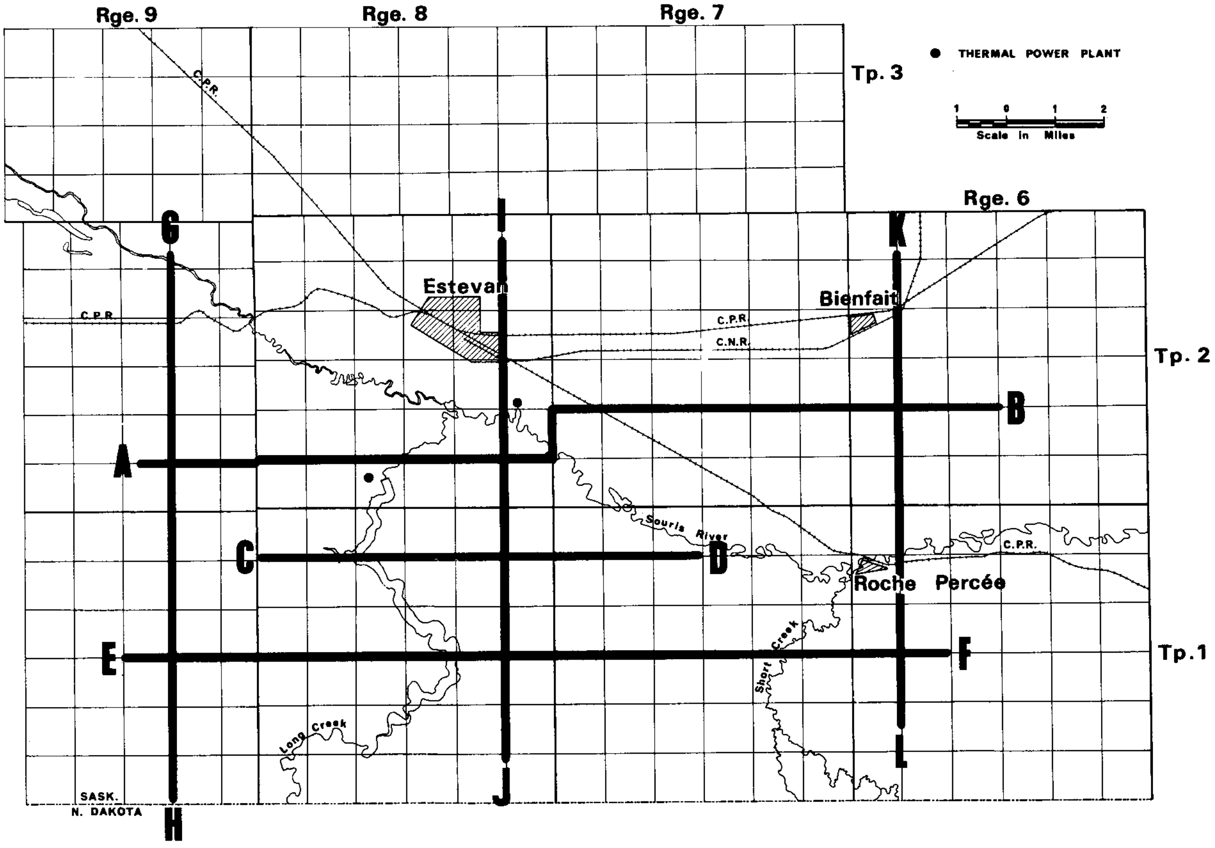


FIGURE 4. Location of cross sections.

DISTRIBUTION AND STRUCTURE

The Boundary seams have been penetrated in wells west of Long Creek and have been delineated no further east than the 100-foot depth of drilling allows (Fig. 7). The coal beds strike northeast-southwest and dip southeast at 25 feet or less per mile. By comparison of verified and projected contours, the "B" seam appears to be structurally and thus stratigraphically lower than the "A" seam.

The overlying Estevan seam has the greatest areal distribution of any seam in the area (Fig. 8). Structure contours reveal local flexures of low amplitude and the regional southeasterly dip noted above. The strike of the beds changes to west northwest-east southeast in the eastern part of the study area.

The Souris seam is restricted mainly to an area south of the Souris River and east of Long Creek (Fig. 9). Mapping was carried out on the lower, more laterally persistent beds, east of the point at which the seam splits.

Figures 10 and 11 illustrate the tendency of the subcrop margins of the Roche Percée and Short Creek seams to extend farther east and south of lower seams. Similar structural elements noted above are prevalent.

Normal faulting involving 20 feet or less of throw has been observed in mining operations. In some cases faulting between drill holes cannot be confirmed but appears the most favorable interpretation for reconciling structural discrepancies.

DEPTH

The Boundary "B" seam varies from less than 50 feet to greater than 100 feet deep. The "A" seam is somewhat deeper on the average, varying between slightly less than, to greater than 100 feet in depth (Fig. 12).

Over much of the area the Estevan seam lies beneath less than 50 feet of overburden (Fig. 13). For this reason it has been extensively mined and is presently exploited west of the Boundary Dam by the Saskatchewan Power Corporation, east of Estevan by Battle River Coal Company, and south of Bienfait by the Manitoba and Saskatchewan Coal Company. Large reserves of coal remain in place in the Estevan seam at depths greater than 50 feet.

Figure 14 shows that a considerable area is underlain at shallow depths by the Souris seam. Depths were mapped on the basis of overburden on the lower part of the seam; thus, some adjustment must be made for even more shallow scattered lenses of lignite in the upper part of the seam. To date, there has been little commercial development of the seam.

Thin overburden on the Roche Percée seam north, south, and west of Roche Percée has resulted in extensive mining of this unit (Fig. 15). The Manitoba and Saskatchewan Coal Company is presently mining the Roche Percée seam south of Bienfait.

The Short Creek seam, as thus far delineated by drilling, is less than 75 feet below the surface (Fig. 16). Lee (1927) reports that this seam has been worked in one mine, but it is generally thin and not laterally persistent.

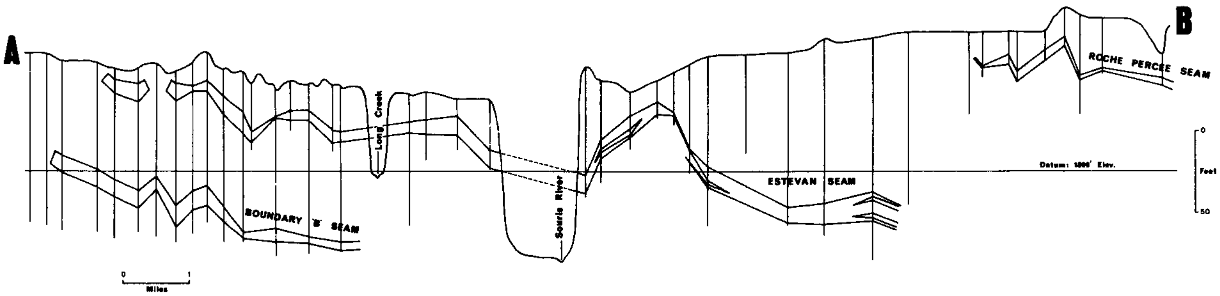
PALEOENVIRONMENT

Certain generalizations following from the foregoing discussion are worthy of note with regard to environment of deposition. The observation is made that higher seams are somewhat thinner than lower ones. This is thought to be a reflection of the retreat of the Gulfian sea southwards in early Tertiary (Paleocene) time, resulting in continental rather than a marginal marine environment in the Estevan area. Outcrop information tends to verify this with the noticeable change from clays and calcareous silts in the western part of the area, where lower strata are exposed, to crossbedded sandstones in stratigraphically higher beds farther east in the Roche Percée area. The clays and silts are interpreted to represent marginal marine swamp deposits in contrast to the sandstones which indicate a prograding deltaic facies.

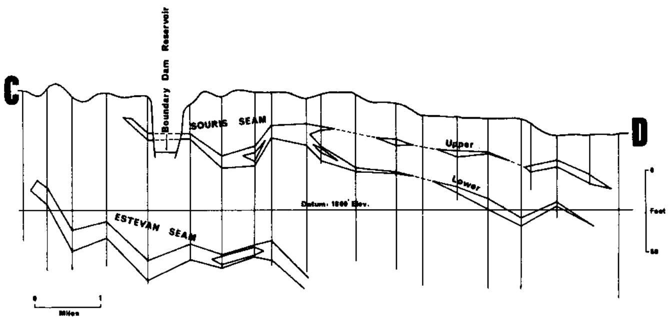
Recent petrographic work by Broughton (1972) and Cameron and Birmingham (1971) establish that the Estevan seam, which is associated with fine clastics, was largely developed on a forest-moor environment with some indication of reed-moor and open-water influences.

CONCLUSIONS

A proper evaluation of the lignite reserves in southeastern Saskatchewan requires knowledge of at least two basic parameters: (1) detailed information on the thicknesses of seams; (2) a definite depth cut-off for mining as determined from strip-ratios and stripping equipment limitations. Neither of these factors have been adequately defined herein. However, with a proper appreciation of the distribution of the seams and the regional stratigraphic relationships outlined above, it is to be hoped that a realistic appraisal of reserves and subsequent development approaches may follow.



SECTION A-B



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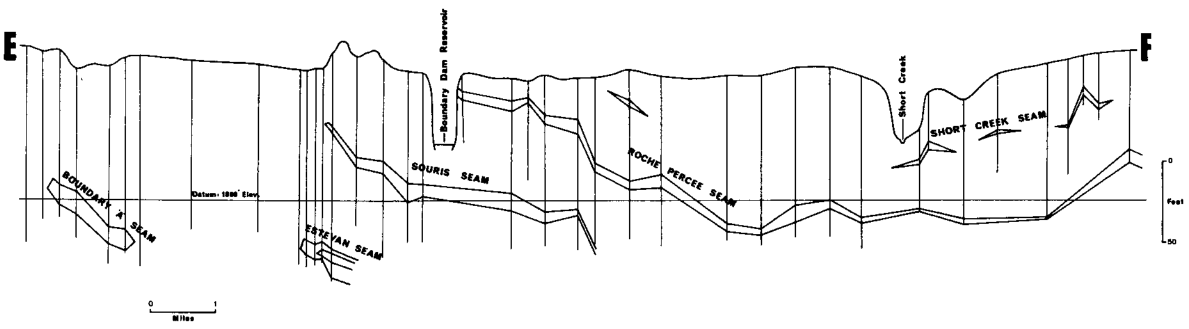
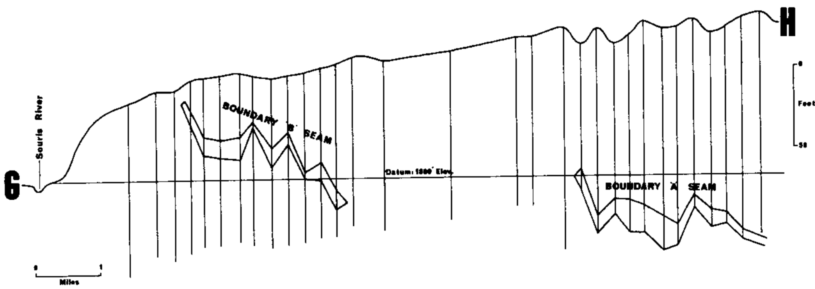
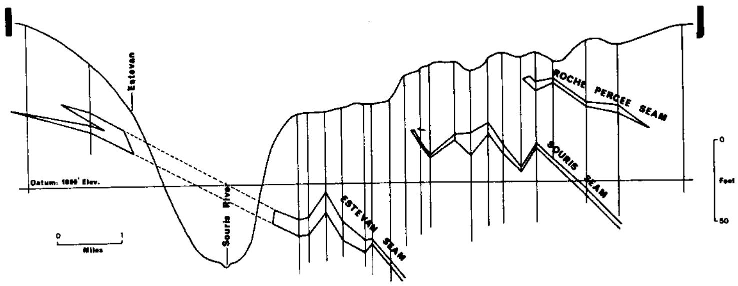


SECTION E-F

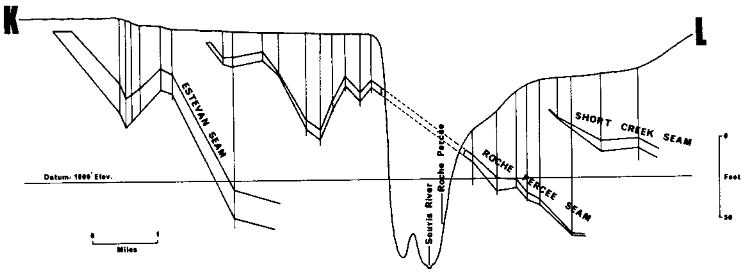
FIGURE 5. Cross sections through lignite beds, Estevan area.



SECTION G-H



SECTION I-J



SECTION K-L

FIGURE 6. Cross sections through lignite beds, Estevan area.

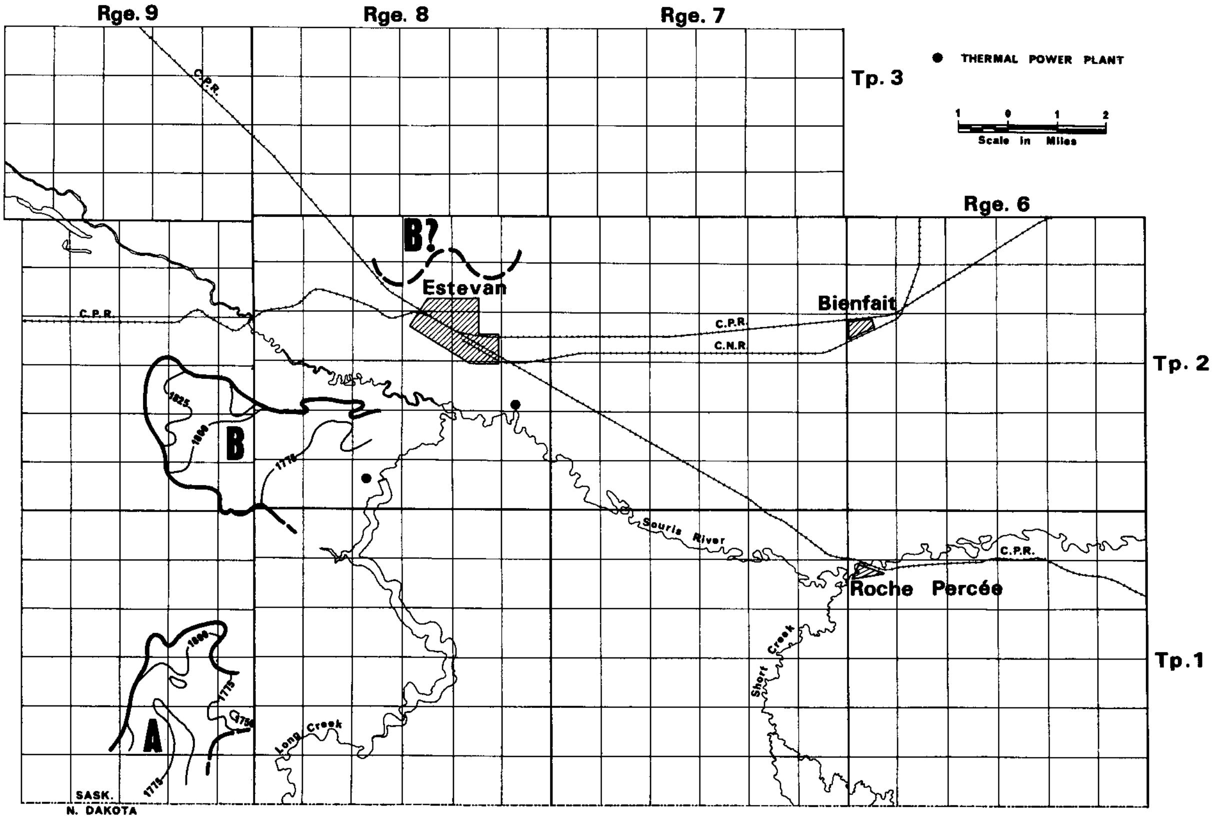


FIGURE 7. Structure contour map of the Boundary seam.

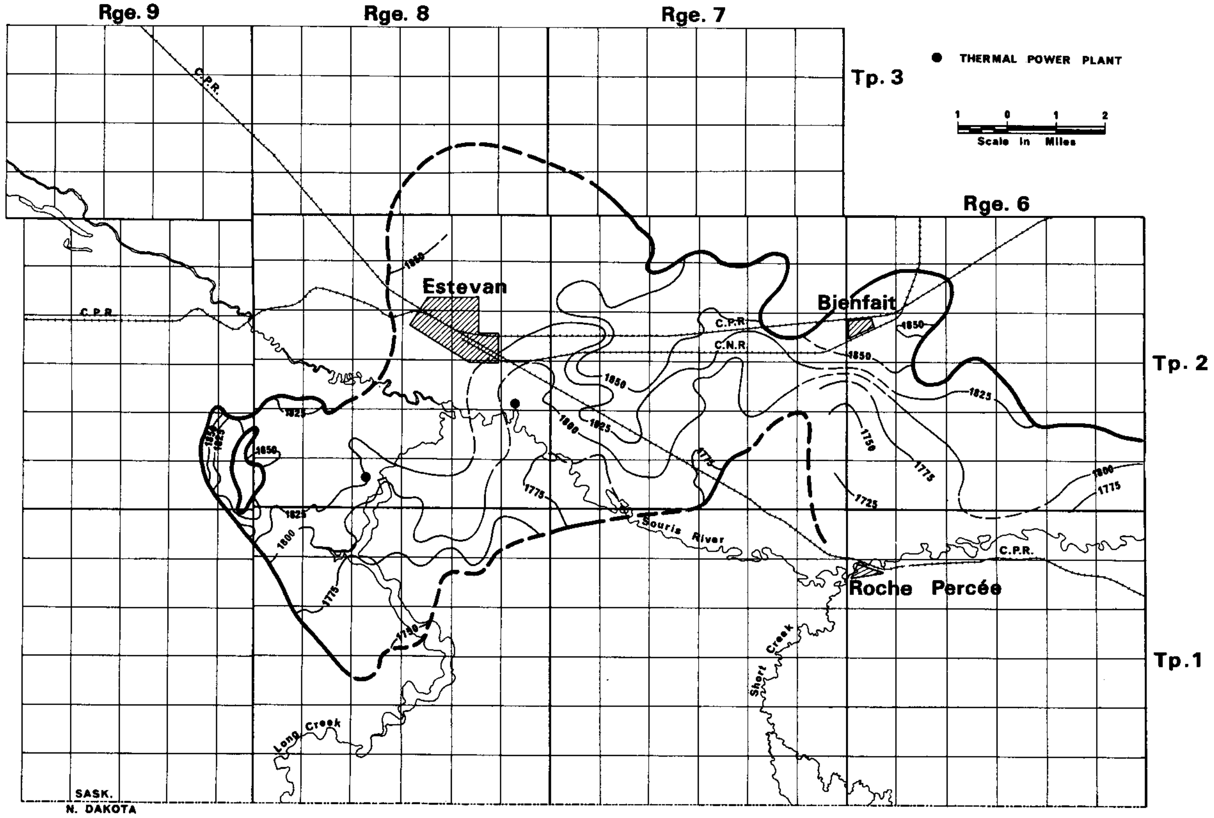


FIGURE 8. Structure contour map of the Estevan seam.

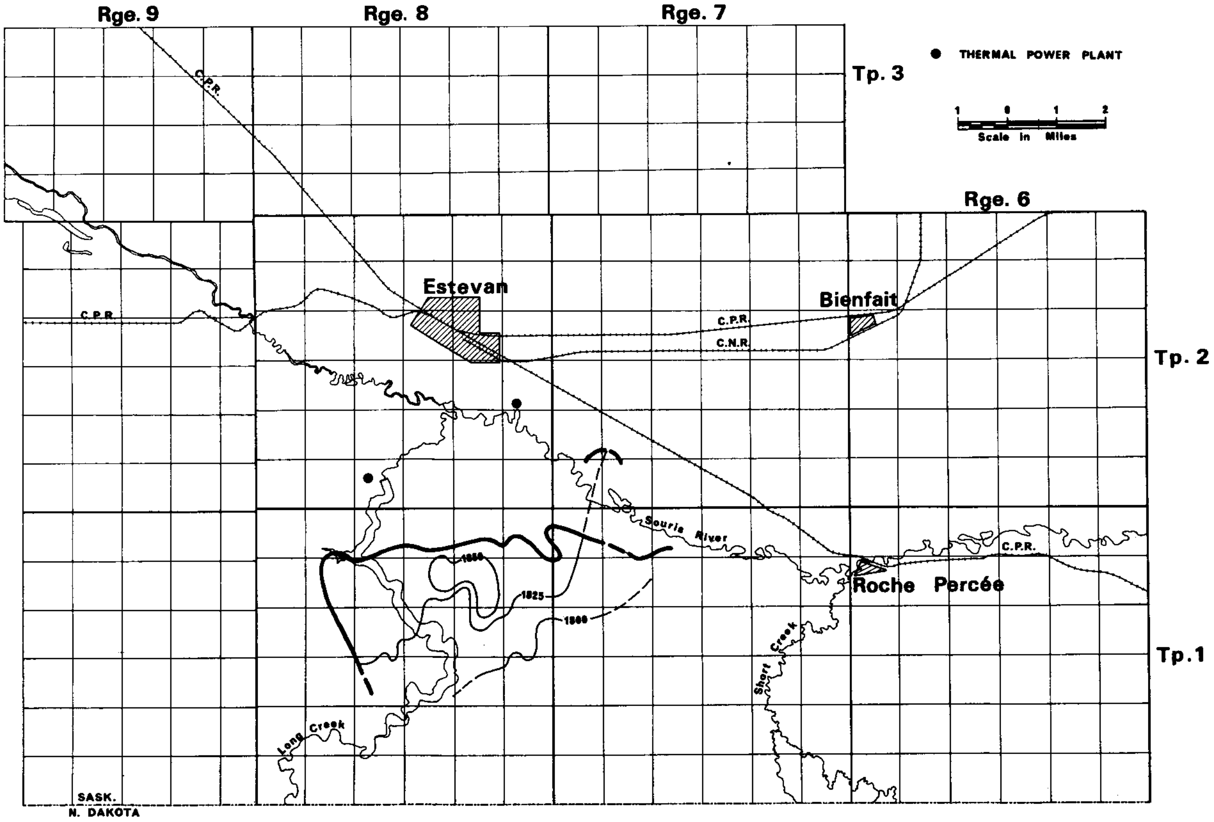


FIGURE 9. Structure contour map of the Souris seam.

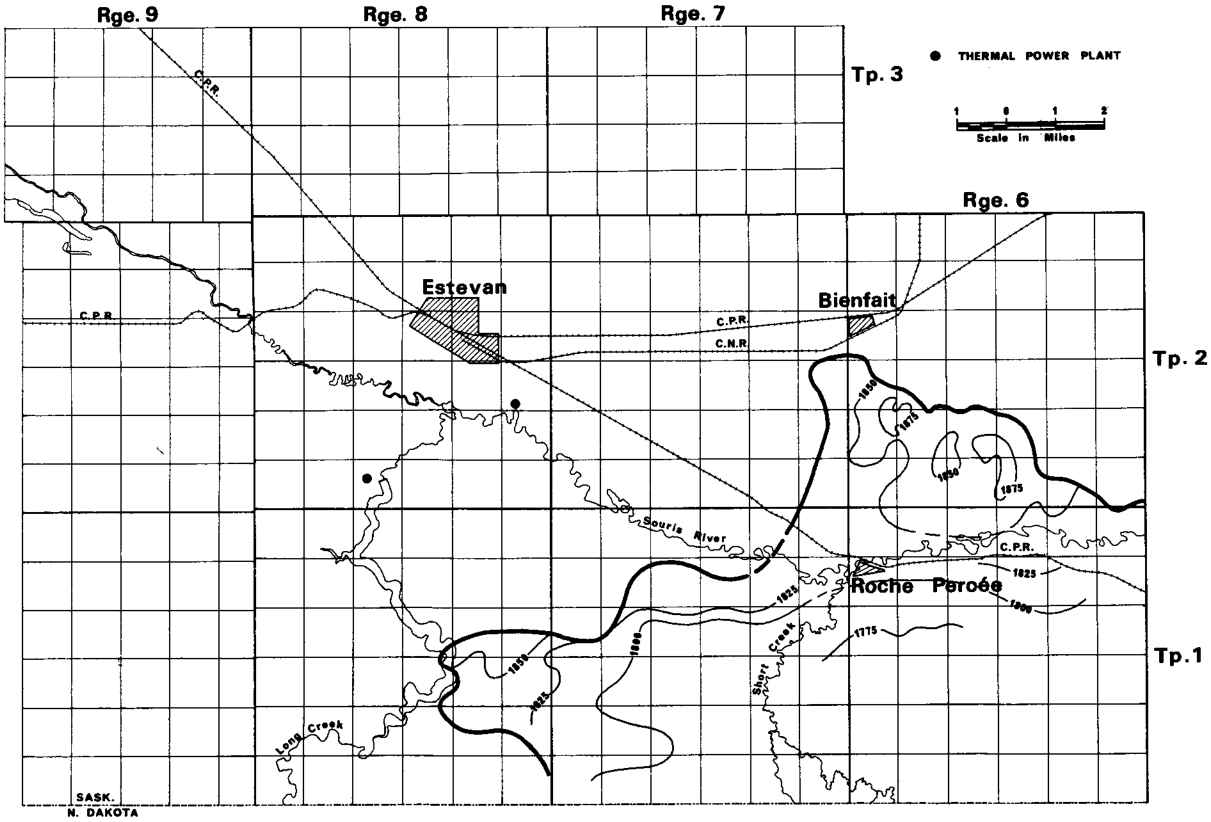


FIGURE 10. Structure contour map of the Roche Percée seam.

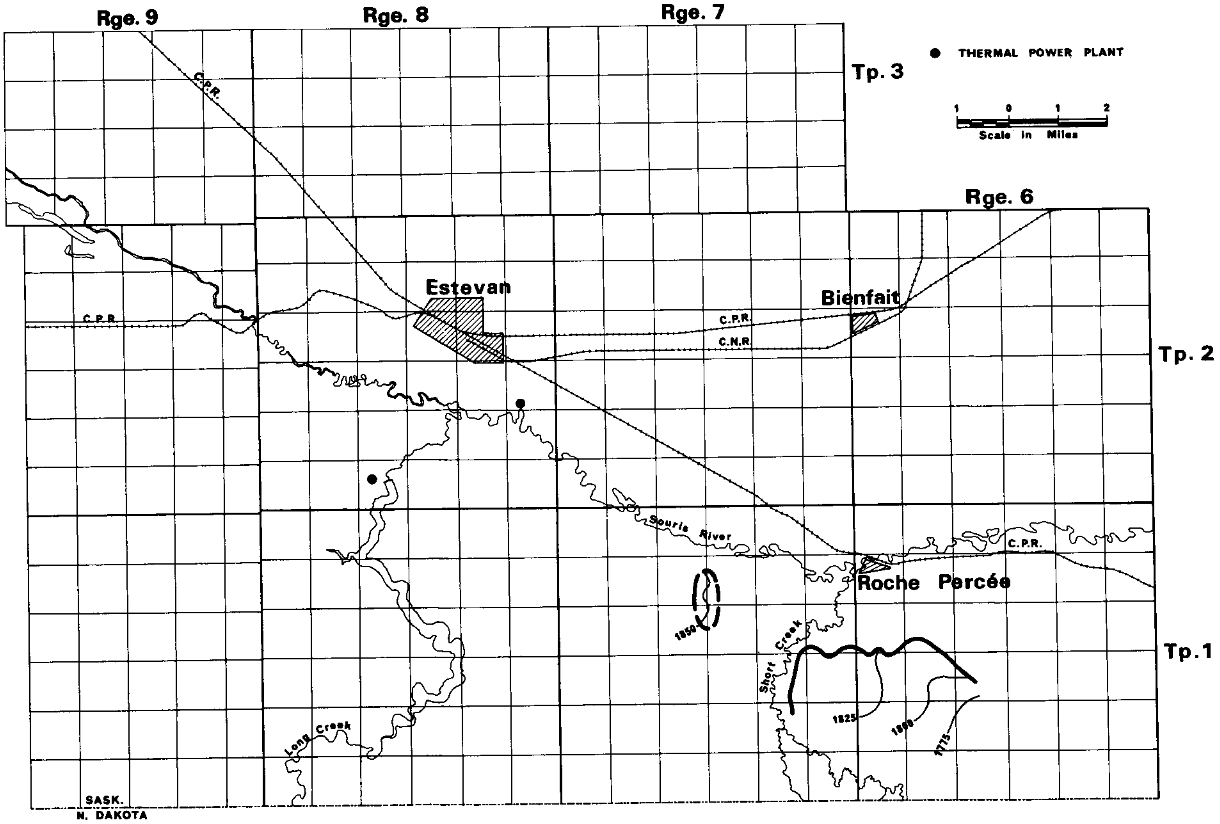


FIGURE 11. Structure contour map of the Short Creek seam.

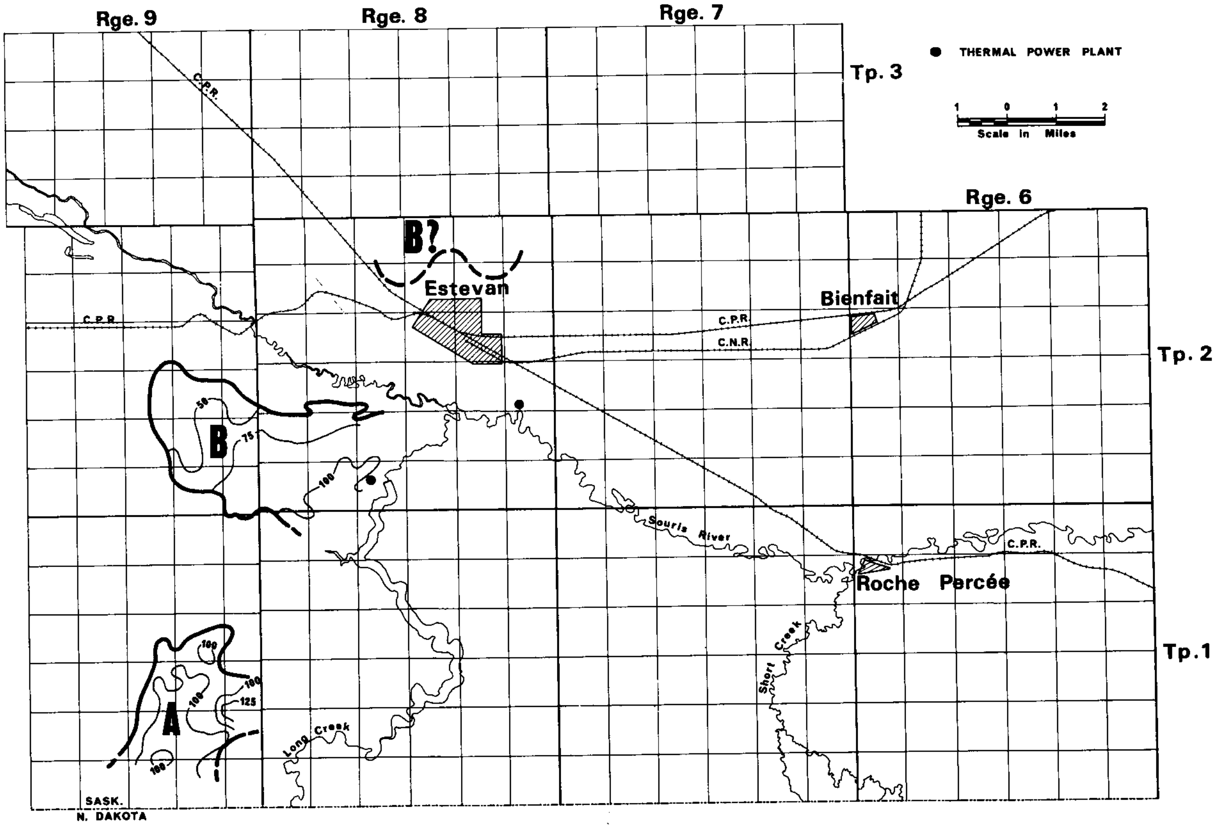


FIGURE 12. Overburden thickness, Boundary seam.

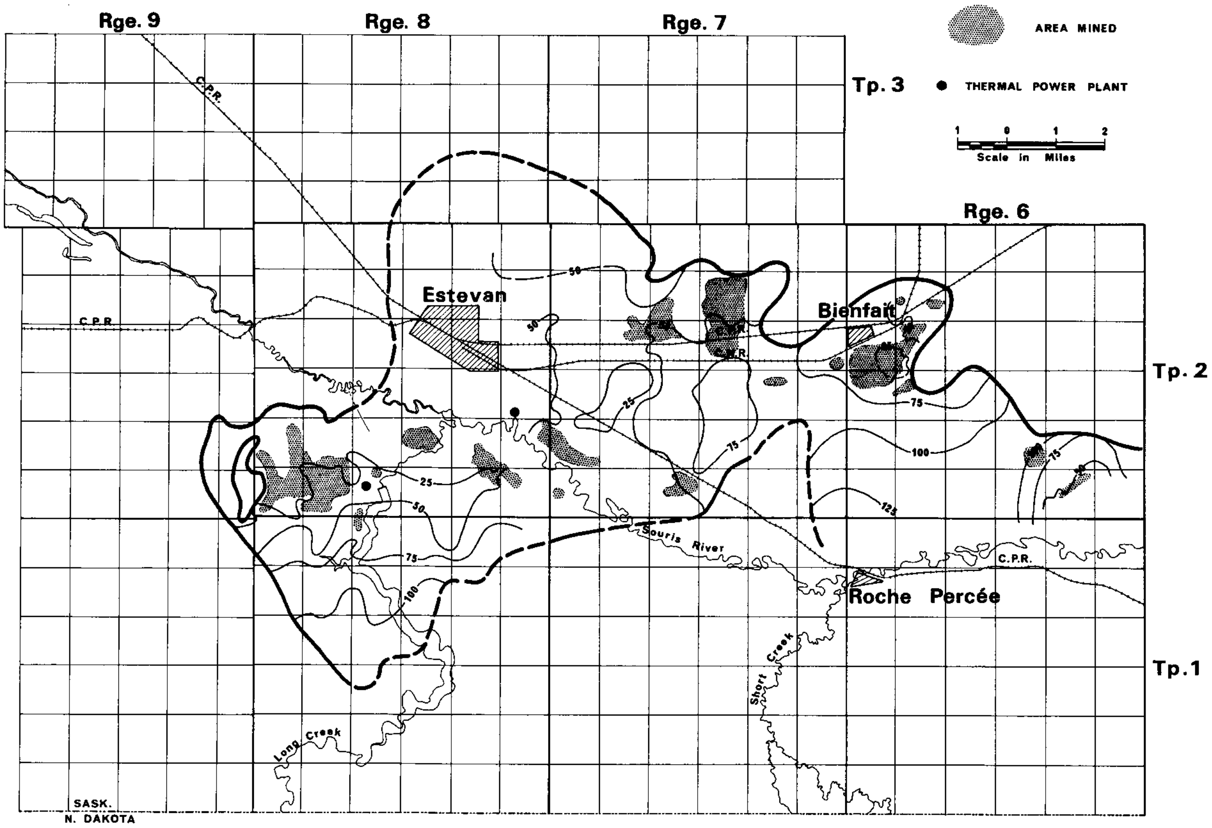


FIGURE 13. Overburden thickness, Estevan seam.

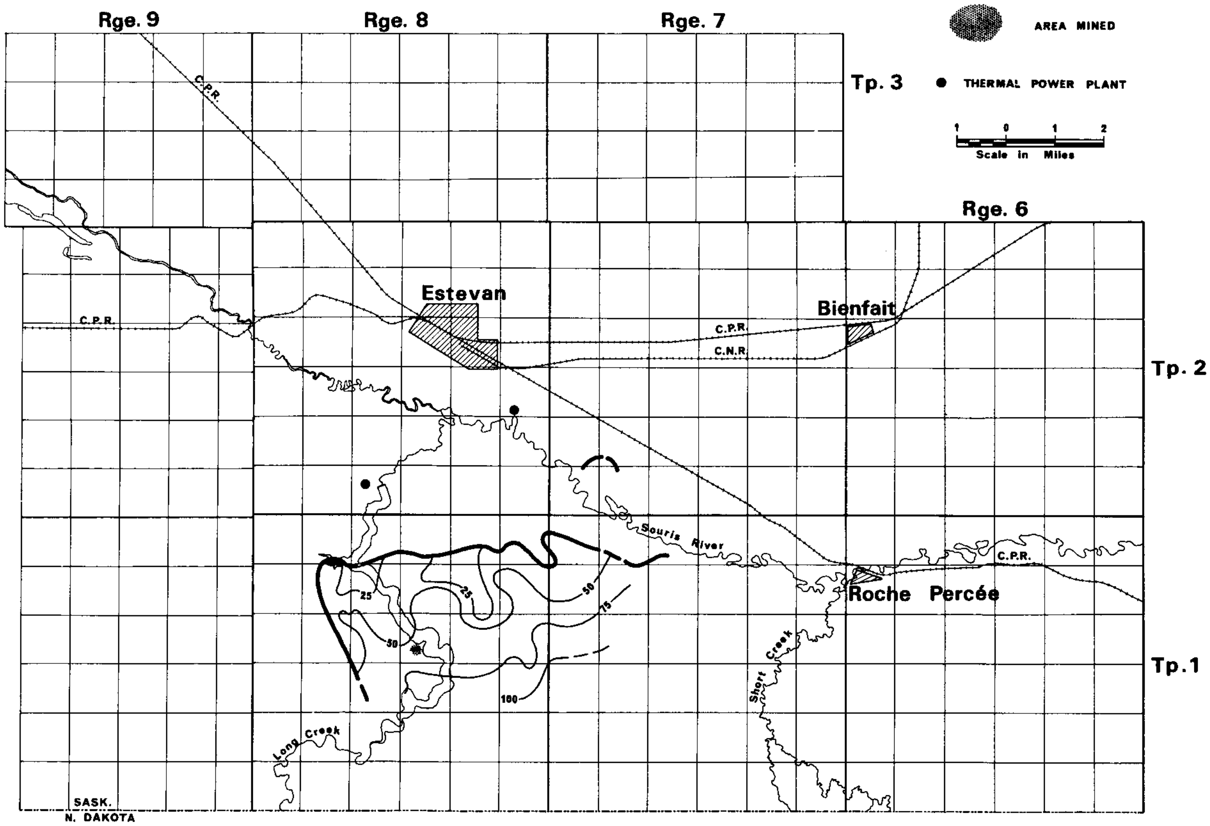


FIGURE 14. Overburden thickness, Souris seam.

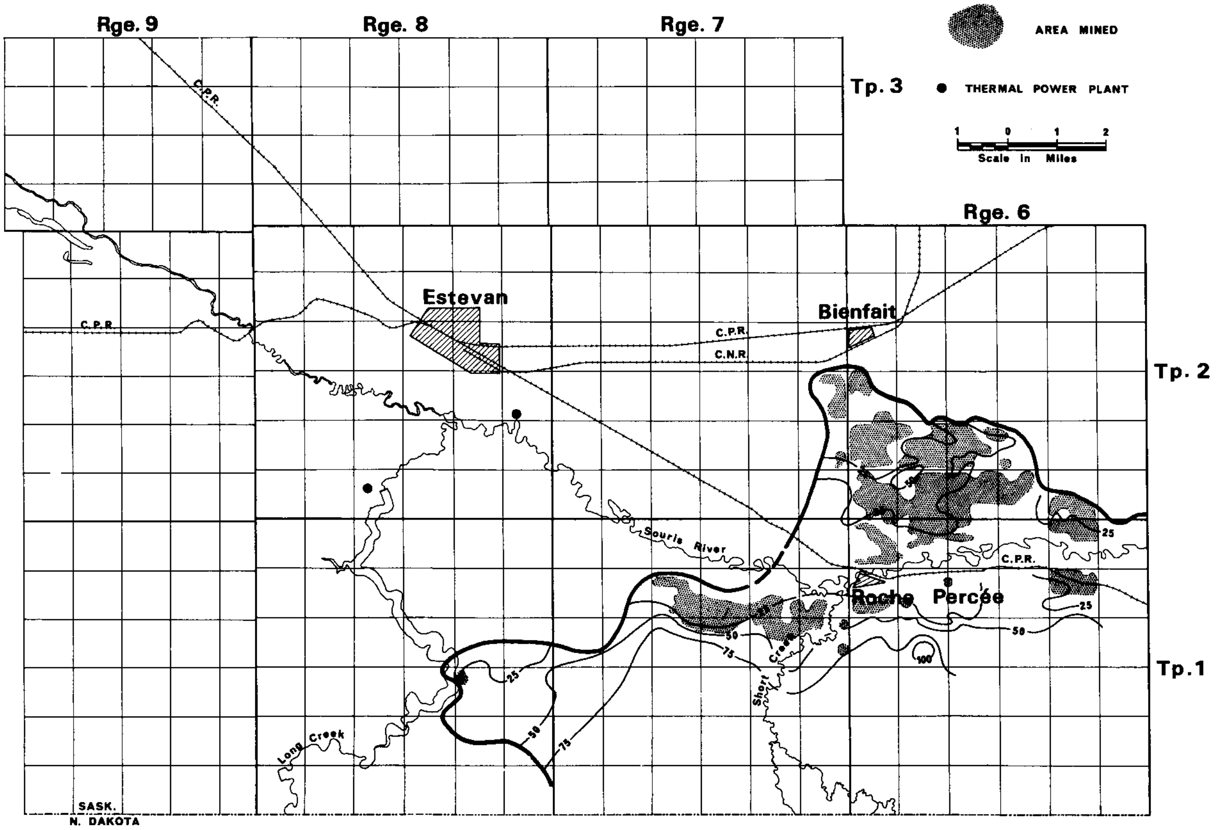


FIGURE 15. Overburden thickness, Roche Percée seam.

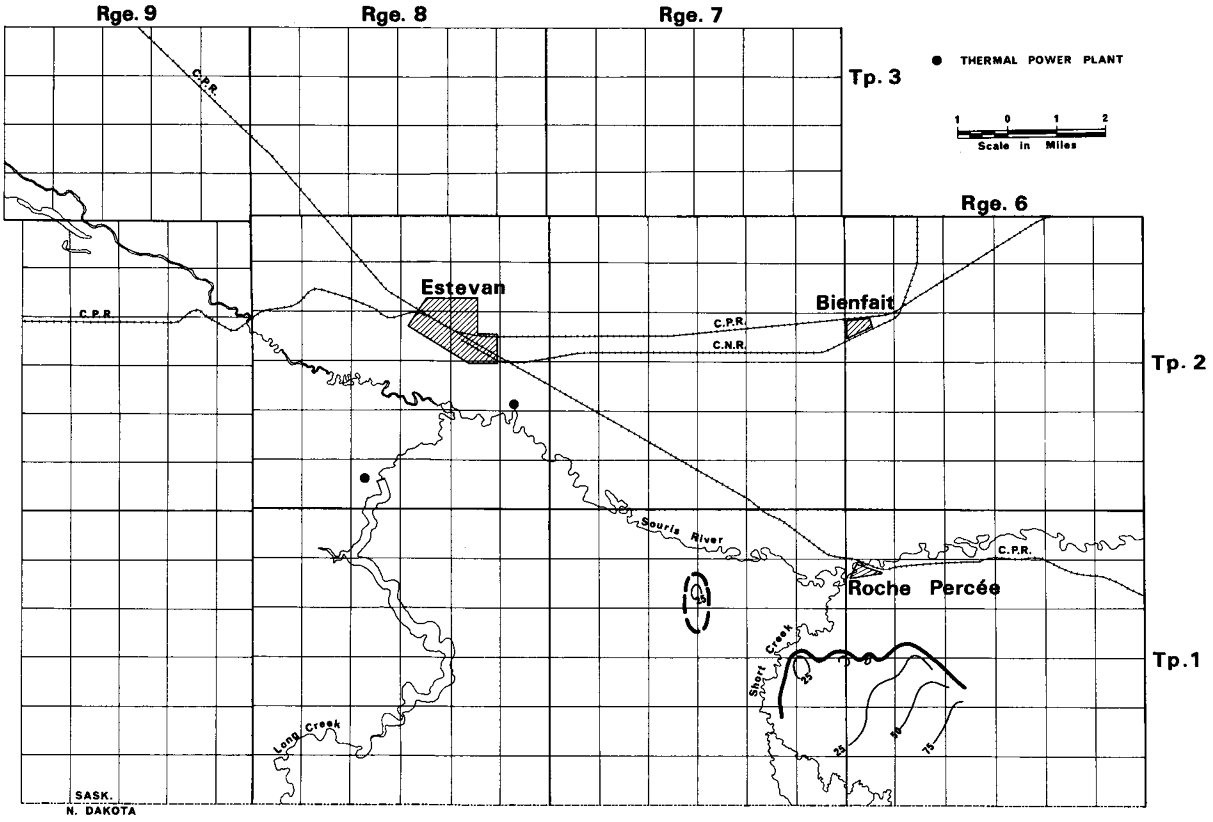


FIGURE 16. Overburden thickness, Short Creek seam.

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PETROLOGY OF THE ESTEVAN NO. 3 LIGNITE SEAM, SOUTHEASTERN SASKATCHEWAN

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ABSTRACT

The Estevan No. 3 lignite seam is in the Ravenscrag Formation of Paleocene age, southeastern Saskatchewan. The depositional environment was interpreted from the distribution of the petrographic macerals. Three environmental facies are recognized: forest-moor, reed-moor, and open-water. The 12-foot thick lignite seam at the Utility Coal Company mine, southwest of Estevan, is predominantly of forest-moor origin. Strong influences of reed-moor facies also are apparent, particularly in the upper one-third of the seam. The seam has the following maceral percentages: 62 per cent structured vitrinite, 6 per cent structureless vitrinite, 11 per cent groundmass vitrinite, 8 per cent fusinite and semifusinite, 7 per cent exinite, 1 per cent micrinite, and 5 per cent inorganics. The microlithotypes present are: 8 per cent carbargillite, 55 per cent vitrite, 10 per cent duroclarite, 4 per cent clarodurite, 11 per cent clarite, 4 per cent fusite, 7 per cent vitrinertite, and 1 per cent shale parting.

The lignite exposures at the Utility Coal Company Mine are notable because of associated leonardite deposits, which are believed to be the largest in Canada. Leonardite is a naturally oxidized lignite that underwent slow oxidation in the shallow subsurface by air penetration or by oxidizing groundwaters. It is characterized by high humic acids content. Infrared spectroscopy, differential thermal analysis, and X-ray diffraction techniques were used to study the lignite oxidation process resulting in leonardite.

INTRODUCTION

Coal, all of lignitic rank, is distributed across the northern margin of the Williston Basin in southern Saskatchewan. Latour and Chrismas (1970) estimate that Saskatchewan contains 10 per cent of Canadian coal resources or about 12 billion tons. The thickest lignite seams are in the Ravenscrag Formation of Paleocene age and have been the center of mining interest for the last one hundred years (Fig. 1). Presently, only the Estevan coalfield has operational strip mines. In the Estevan area seven seams are present with a thickness of 4 feet or more, to a stratigraphic depth of 750 feet. The number and thickness of seams apparently becomes fewer and thinner westward (MacKay, 1947). Only the upper 4 seams in the Estevan coalfield are worked. The Estevan No. 3 seam exposure on the property of the Utility Coal Company was selected for this detailed petrographic and chemical study. This seam, at an elevation of 1800 feet, is locally referred to as the Boulder Dam seam.

Acknowledgments

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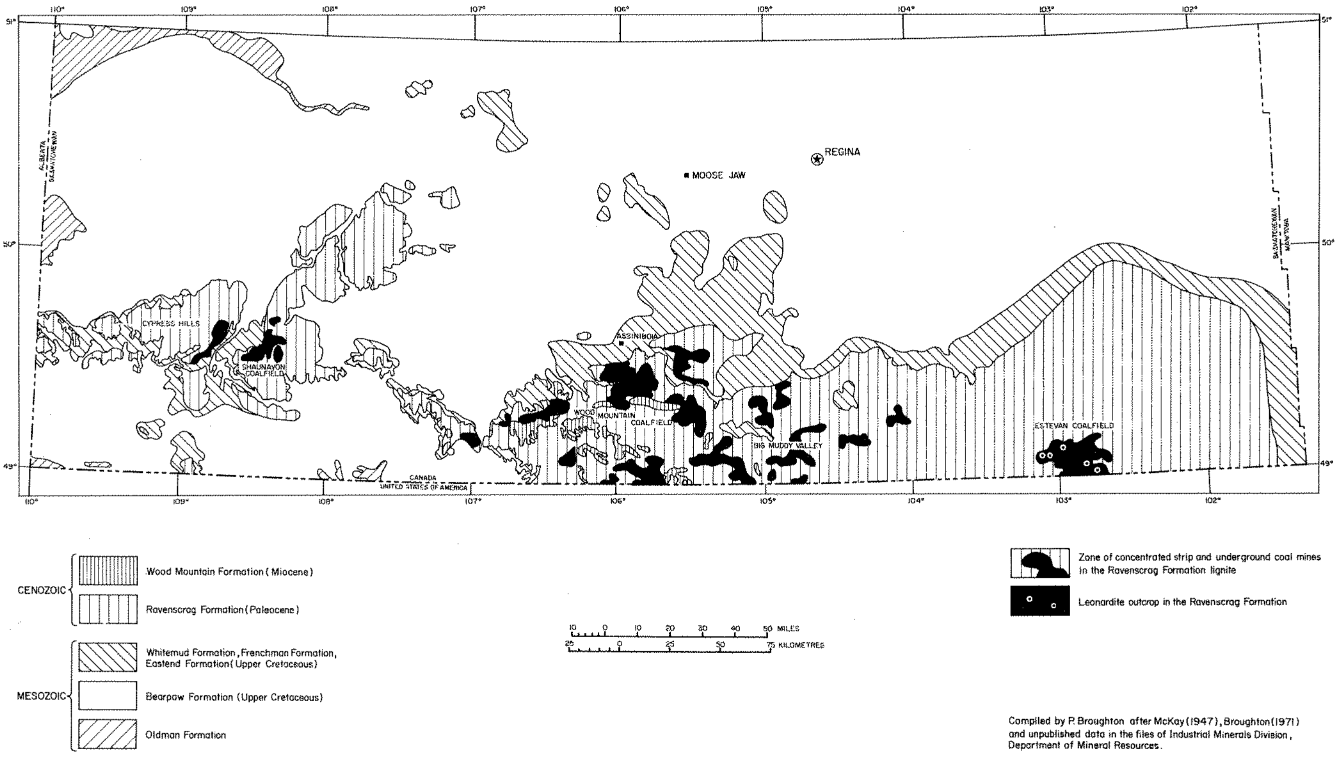
LITHOLOGY AND CORRELATION

Ravenscrag Formation

The Ravenscrag Formation is a succession of unconsolidated to poorly consolidated quartz sands, clays, friable shales, and lignite strata. It is partially exposed from the International Boundary northward to the 50th parallel and extends from the Manitoba to the Alberta provincial boundaries (Fig. 1). It is underlain by the Frenchman Formation of latest Cretaceous age and is equivalent to part of the Fort Union Group in North Dakota (Table 1). Local unconformities exist within the Ravenscrag Formation and between it and the Frenchman Formation.

Berry (1935) and Fraser ***et al.*** (1935) defined three Ravenscrag floral intervals, the lowest of which is now considered to coincide with the underlying Frenchman Formation. The Ravenscrag Formation is distinguished from the Frenchman Formation in that it contains thick coal seams, lacks dinosaur remains, and possesses a different floral assemblage. Contacts between the two formations are exposed in the southwestern and central portions of the province.

The Ravenscrag Formation exposures from the Cypress Hills along the Alberta border east to the Big Muddy Valley in the south-central part of the province (Fig. 1) have been divided into a lower grey and upper buff facies. The section at Ravenscrag Butte clearly exposes these two facies. There, the lower 75 feet are dominated by greyish-colored silts and clays. The upper 91 feet consist predominantly of buff-colored clays and siltstones. According to Russell (1948), the base of a 5-foot coal seam marks the contact between



Compiled by P. Broughton after McKay (1947), Broughton (1971) and unpublished data in the files of Industrial Minerals Division, Department of Mineral Resources.

FIGURE 1. Coal fields of southern Saskatchewan.

the grey and buff facies. He points out that the grey facies is dominated by clays and carbonaceous beds and the overlying buff facies is much more arenaceous.

From Big Muddy Valley east to the Manitoba border, there is a distinct lithologic change from the grey and buff facies into relatively arenaceous beds. These sands, often sharply cross-bedded, characterize the eastern Estevan-Bienfait area. In addition, drilling has revealed a number of grey clay beds in the subsurface Ravenscrag succession in this area.

The eastern and southeastern sand and clay successions have been correlated with the upper Ravenscrag beds to the west (Fraser ***et al.***, 1935). This correlation is based primarily on the thickness of beds (750 to 1000 feet) overlying the Bearpaw Formation in the southeast, as revealed by drilling data. However, the distinction between the Frenchman and Ravenscrag Formations is uncertain in this area, and the presence of minor coal seams in pre-Ravenscrag strata makes correlation of rock-units difficult. Nevertheless, the base of the Ravenscrag dips eastward, from near the surface at the Alberta border to possibly 1000 feet beneath the surface at Estevan.

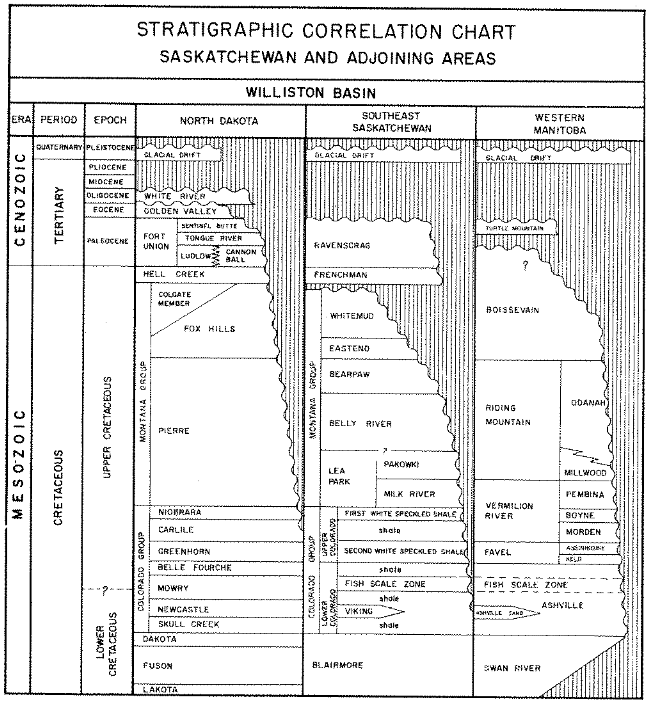
The correlation of the Ravenscrag Formation with contiguous strata of the Fort Union Group in North Dakota also is uncertain. The lower part of the Fort Union Group, the foraminifera-bearing Cannonball Formation, is considered to be equivalent to the lower Ravenscrag beds (Table 1), but the projected outcrop belts of Cannonball strata are adjacent in part to supposedly upper Ravenscrag beds along the International Boundary (Fig. 2). In view of this, the writer suggests that the Ravenscrag Formation of the Estevan area represents an abnormally thick succession of lower Ravenscrag beds, rather than both lower and upper strata. This would place the four thick lignite seams of the Estevan coal field in the central part of the Ravenscrag rather than in the upper part.

Correlation of the Ravenscrag Formation of southeastern Saskatchewan with the Cannonball Formation in North Dakota raises some questions concerning the possible extension of marine Paleocene beds into Canada. The fossil assemblages in the Ravenscrag beds preserved in the west, near the Alberta border, are entirely nonmarine. The only fossils known to the writer from the Ravenscrag in the Estevan area – poorly preserved gastropods and pelecypods found in thin shale beds above the two coal seams in the Utility Coal Company strip pits – also indicate a nonmarine environment. However, the marine origin of the Cannonball Formation in North Dakota is well established (Lemke, 1960), and foraminifera of Cannonball age have been described from the southern flanks of the Turtle Mountains, a few miles south of the International Boundary. Thus, although marine fossils have not been found in the Ravenscrag beds of southeastern Saskatchewan, it seems likely that the Cannonball sea invaded this area during Paleocene time, and that the nonmarine Ravenscrag strata of southwestern and south-central Saskatchewan may grade laterally into a hitherto unrecognized marine succession in the Estevan area (Fig. 2).

Estevan No. 3 Seam

Four of the seven coal seams in the Ravenscrag Formation are mined in the Estevan area. The No. 3 (Boulder Dam) seam is exposed in the Utility Coal Company strip mine southwest of Estevan at an elevation of 1800 feet. It is believed to be correlative with the seam exposed in the Klimax mine northeast of Estevan at an elevation of 1860 feet.

Table 1. Correlation of Cretaceous and Tertiary Rock-Units, Southeastern Saskatchewan and Adjoining Areas



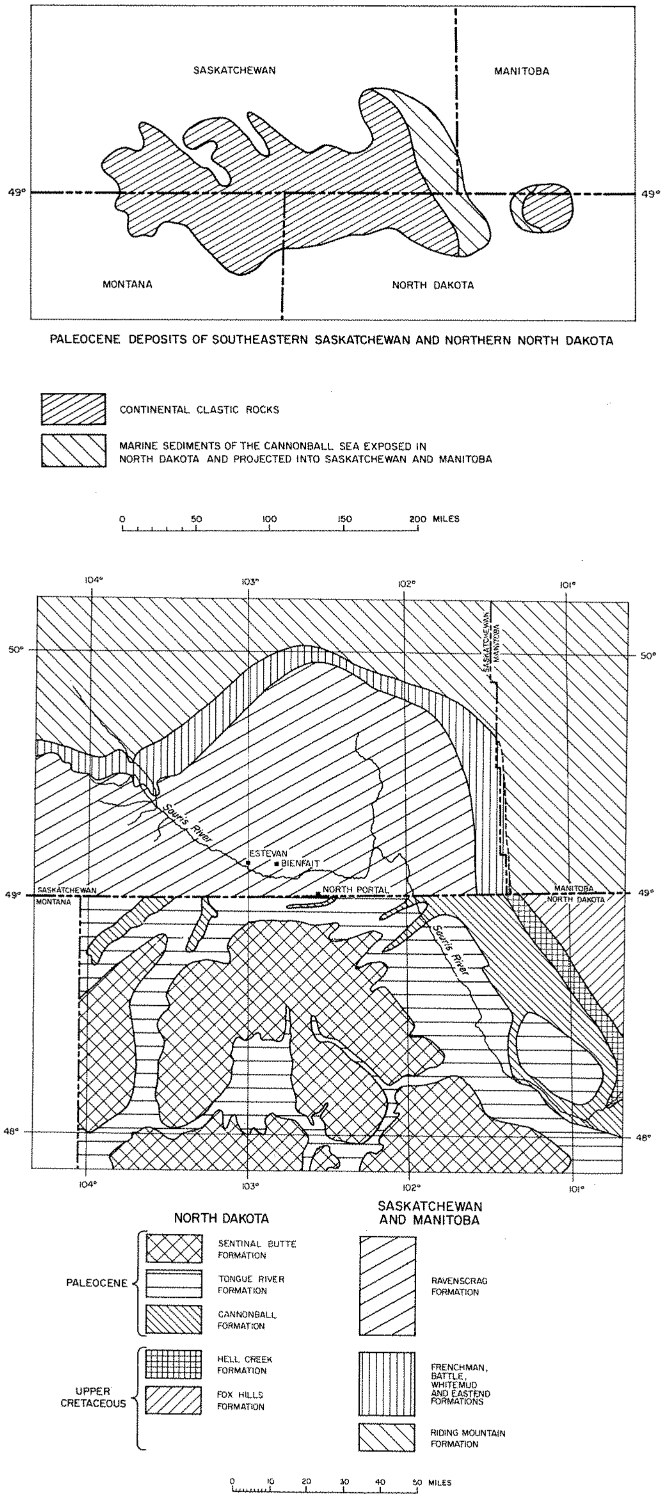


FIGURE 2. Geological map of southeastern Saskatchewan and adjoining areas (after MacKay, 1947; Hanson, 1956; Taylor et al.*, 1964).*

The No. 3 seam in the Utility mine is contained within silty to sandy grey clay, which grades into a greenish-grey chloritic variety in places. Overburden thickness varies between 15 and 60 feet on the Utility Coal Company property, of which the upper 5 to 20 feet is glacial drift.

The seam varies between 4 and 14 feet in thickness and contains irregular zones of locally weathered material, leonardite. ***Leonardite*** is the term applied to naturally oxidized lignite which has undergone slow oxidation in the shallow subsurface due to air penetration or circulation of groundwater. Leonardite deposits vary from thin films to essentially wholly altered lignite seams in excess of 10 feet thick. It is characterized by the generation of humic acid complexes, the presence of which can be easily distinguished in the field by testing with sodium hydroxide solution (the solution turns brown in the presence of leonardite).

Leonardite is widely distributed in association with shallow lignite deposits throughout southern Saskatchewan, western North Dakota and eastern Montana. Appreciable leonardite deposits in Saskatchewan are limited to the Estevan coal field (Fig. 1). The two largest Canadian deposits are the oxidized portions of the Estevan No. 3 seam on the Utility Coal Company property and are adjacent to the unweathered lignite section for petrographic study.

PETROGRAPHY

Methods

The column sample for petrographic analyses was collected from a working face in the Utility Coal Company mine. This 12 1/2-foot thick lignite column was removed in 67 oriented blocks, which were made into 287 thin sections. These thin sections represent an essentially continuous vertical succession of lignite. After thin section grinding and polishing, approximately 82 per cent of the original thickness remained on glass slides. The horizontal width averages about one-third of an inch. Due to the natural tendency for lignite to part along fossil charcoal seams, it is probable that the majority of this lost 18 per cent is fusinite. Percentages are based on 200 grain count traverses across discrete lithologic units within each thin section.

The sampled section does not include oxidized lignite (leonardite).

Terminology

European petrographic terminology has been standardized for higher rank coals using reflected light techniques. German researchers have advanced the now generally recognized Stopes-Heerlen system. This terminology, however, is particularly well adapted only to bituminous rank coals in which the high opaque content makes reflected light techniques desirable. The Thiessen system of petrographic terminology originated with the United States Bureau of Mines, and utilizes thin section techniques. Lignites and subbituminous coals are of sufficient translucency to make the use of transmitted light feasible. The correlation between the American Thiessen system and the European Stopes-Heerlen system is not exacting (Table 2). Despite certain difficulties, the Stopes-Heerlen terminology is now becoming standardized for use in thin sections, even though thin section techniques for lignite examination are currently being replaced by reflected light examination in North America.

The Thiessen system has three major elements: anthraxylon, attritus (translucent and opaque varieties), and fusain. The term ***anthraxylon*** is applied to cellular wood. The cell walls may be completely collapsed and grade into structureless gels. The second major component is ***attritus***, divided into translucent and opaque groups. The translucent attritus is a mixture of disseminated anthraxylon, spores, pollen, cuticles and resinous bodies. The opaque attritus represents an intense alteration of the above by bacterial activity. Finely divided fusain would be included in this category. The third major component is ***fusain***, which represents a relatively high degree of coalification. This charcoal-like substance is either charred remnants of a paleo-forest fire, or an end product of alteration by microorganisms.

The Stopes-Heerlen system has three major groups of macerals (petrographic components): vitrinite, exinite, and inertite. ***Vitrinite*** is the woody remains in the coal. It may be well structured with all the cells preserved, or grade into structureless vitrinite where cells become progressively destroyed and collapsed under greater compaction. Two individual macerals belong to this group: telinite, the cell-wall material; and collinite, the cell cavity filling. Groundmass vitrinite is finely divided and intimately associated with inertite and exinite. ***Exinite*** is comprised of pollen, spores, cuticles, resins, and algae. The spores and pollen are almost always compressed. Leaves and needles of plants have a protective skin of cutin (cuticle). This

Table 2. Petrographic Classifications of Coal Macerals

TRANSMITTED LIGHT			REFLECTED LIGHT	
THIESSEN SYSTEM			STOPES-HEERLEEN SYSTEM	
BANDED COMPONENTS	ATTRITUS CONSTITUENTS		MACERALS	MACERAL GROUP
ANTHRAXYLON			VITRINITE MORE THAN 14μ IN WIDTH	VITRINITE
ATTRITUS	TRANSLUCENT ATTRITUS	TRANSLUCENT HUMIC MATTER	VITRINITE LESS THAN 14μ IN WIDTH	
		SPORES, POLLEN CUTICLES, ALGAE	SPORINITE, CUTINITE, ALGINITE	EXINITE
		RESINOUS AND WAXY SUBSTANCES	RESINITE	
		BROWN MATTER (SEMI-TRANSLUCENT)	WEAKLY REFLECTING SEMIFUSINITE WEAKLY REFLECTING MASSIVE MICRINITE WEAKLY REFLECTING SCLEROTINITE	INERTITE
	OPAQUE ATTRITUS	GRANULAR OPAQUE MATTER	GRANULAR MICRINITE	
		AMORPHOUS (MASSIVE) OPAQUE MATTER, FINELY DIVIDED FUSAIN	FUSINITE LESS THAN 37μ IN WIDTH STRONGLY REFLECTING MICRINITE STRONGLY REFLECTING SCLEROTINITE	
FUSAIN			FUSINITE AND SEMIFUSINITE MORE THAN 37μ IN WIDTH	

substance is highly resistant to decomposition processes and usually forms a significant percentage of Saskatchewan lignites. Resinite is another important maceral in the exinite group, and includes all resinous and waxy bodies. They are usually found as isolated globular bodies, though they may be clustered. ***Inertite*** is the third major group of macerals in the Stopes-Heerlen system. It includes massive micrinite which may originate as a sediment of inert detritus. Fusinite, perhaps the most important maceral of the inertite group, may have formed as a result of forest fires. The oxidation effects of various microorganisms can likewise transform wood materials into semifusinite and fusinite substances. Generally speaking, fusinite of biological origin has swelled cell walls, whereas that of thermal origin does not. Scleretinite, another inert material, forms from the remains of fungal species. It is a characteristic component of Tertiary lignites.

A quantitative microscopic examination of the relative concentrations of maceral groups permits the Ravenscrag coal to be classified in accordance with microlithotypes listed in table 3.

Results

The results of petrographic analysis are given in figure 3, which utilizes the Stopes-Heerlen terminology system adapted to transmitted light. Typical macerals from Estevan No. 3 lignite seam are shown in plates 1 to 3.

Structured vitrinite is the most abundant maceral (62 per cent). The use of transmitted light makes it easier to recognize very weak structuring in the vitrinite, which would likely be indistinguishable in reflected light. Consequently, the percentage of structureless vitrinite, 6 per

Table 3. Composition of Coal Lithotypes

MONOMACERALIC MICROLITHOTYPES		
Vitrite	V[1]	> 95 per cent
Fusite	I[2]	> 95 per cent
Liptite	E[3]	> 95 per cent
BIMACERALIC MICROLITHOTYPES		
Clarite	V+E	> 95 per cent
	V	> I, E > I
Durite	I+E	> 95 per cent
	I	> V, E > V
Vitrinertite	V+I	> 95 per cent
	V	> E, I > E
TRIMACERALIC MICROLITHOTYPES		
Duroclarite	V+E+I	each > 5 per cent
	V	> I
Clarodurite	V+E+I	each > 5 per cent
	I	> V

V: vitrinite, I: inertite, E: exinite.

[1] V - vitrinite
[2] I - inertite
[3] E - exinite

cent, is relatively low. Most of the vitrinite shows collapse of the cell wall structures, though well-preserved cellular structures are common. Groundmass vitrinite (11 per cent) is disseminated humic matter characterized by an association with exinite macerals, particularly pollen. Structured vitrinite is distributed throughout the column, but is concentrated in the 35-110 cm, 140-220 cm, and 300-375 cm intervals. The structureless vitrinite is rather ill-defined and gradational but seems to be concentrated with groundmass vitrinite in the 210-310 cm interval. The groundmass vitrinite is concentrated in three broad zones: 0-30 cm, 110-145 cm, and 215-315 cm intervals.

The exinite group of macerals comprises 7 per cent of the column, and consists of cutinite, resinite, and pollenite. Exinite is usually associated with groundmass vitrinite in the three major intervals: 0-30 cm, 110-145 cm, and 210-310 cm. The pollen almost always is associated with groundmass vitrinite, but the resin bodies may be associated with structured vitrinite. Resinite is usually without inclusions, but in several slides, it contains what appears to be inclusions of leaf hairs. One example of pollenite inclusions in resinite was observed. Cutinite constitutes the dominant maceral in the exinite group. Spores and megaspores are relatively rare but distributed throughout the column.

Inertite, approximately 9 per cent, is a maceral group comprised of fusinite, semifusinite, and micrinite. The fusinite and semifusinite quite often have the corpovitrinite or cell filling replaced by secondary inorganic constituents. The precise determination of the percentage of fusinite is difficult because of the loss of fusinite during the preparation of the thin section, and because the percentage of associated inorganics in the cell voids is difficult to estimate. Consequently, the actual percentage of fusinite, as well as semifusinite, is probably considerably higher than that measured, perhaps as much as 15 per cent. When the fusinite has an inorganic cell filling, an estimation of its volume is subtracted from the fusinite per cent and added to the inorganic per cent. The fusinite is distributed both in discrete layers and as disseminated fragments of variable size. The micrinite is a minor constituent only, as is the inorganic percentage in most of the column.

The ash content is only significant in the 0-30 cm interval, where a carbargillite bed forms 20 to 40 per cent of the section. Petrographically, the overall inorganic content of the seam is 5 per cent by volume, which compares to 8.6 per cent by weight as determined by ashing at 700° C.

The distribution of macerals is reflected in the distribution of microlithotypes. Fusite occurs as small bodies, veinlets of discontinuous form, and as continous seams. The thickness of the fusite layers is variable but usually under 1/4 inch. Their horizontal continuity may exceed several feet, however, owing to the presence of stratified charred logs, which range to 4 feet in length. The fusite layers are distributed at all intervals in the column but are concentrated in zones with high percentages of structured vitrinite and vitrite. A thick layer of semifusinite occurs at the 60-80 cm interval. Although perhaps not fully adaptable to lignite terminology, the use of the microlithotype "vitrinertite" is used in this study to denote a zone of semifusinite and vitrinite mixture. Fusite constitutes 4 per cent and the vitrinertite 7 per cent of the column. Vitrite forms 55 per cent, clarite 11 per cent, clarodurite 4 per cent, and duroclarite 10 per cent. No durite was observed.

The lowest foot (0-35 cm) of the seam has a carbargillite and shale lithology. This interval is economically important, for it must be avoided during strip mining. The excavation of the seam continues down to the shale parting at 30 cm. Below this parting, the ash content is approximately 30 per cent, whereas above it is 8 to 9 per cent.

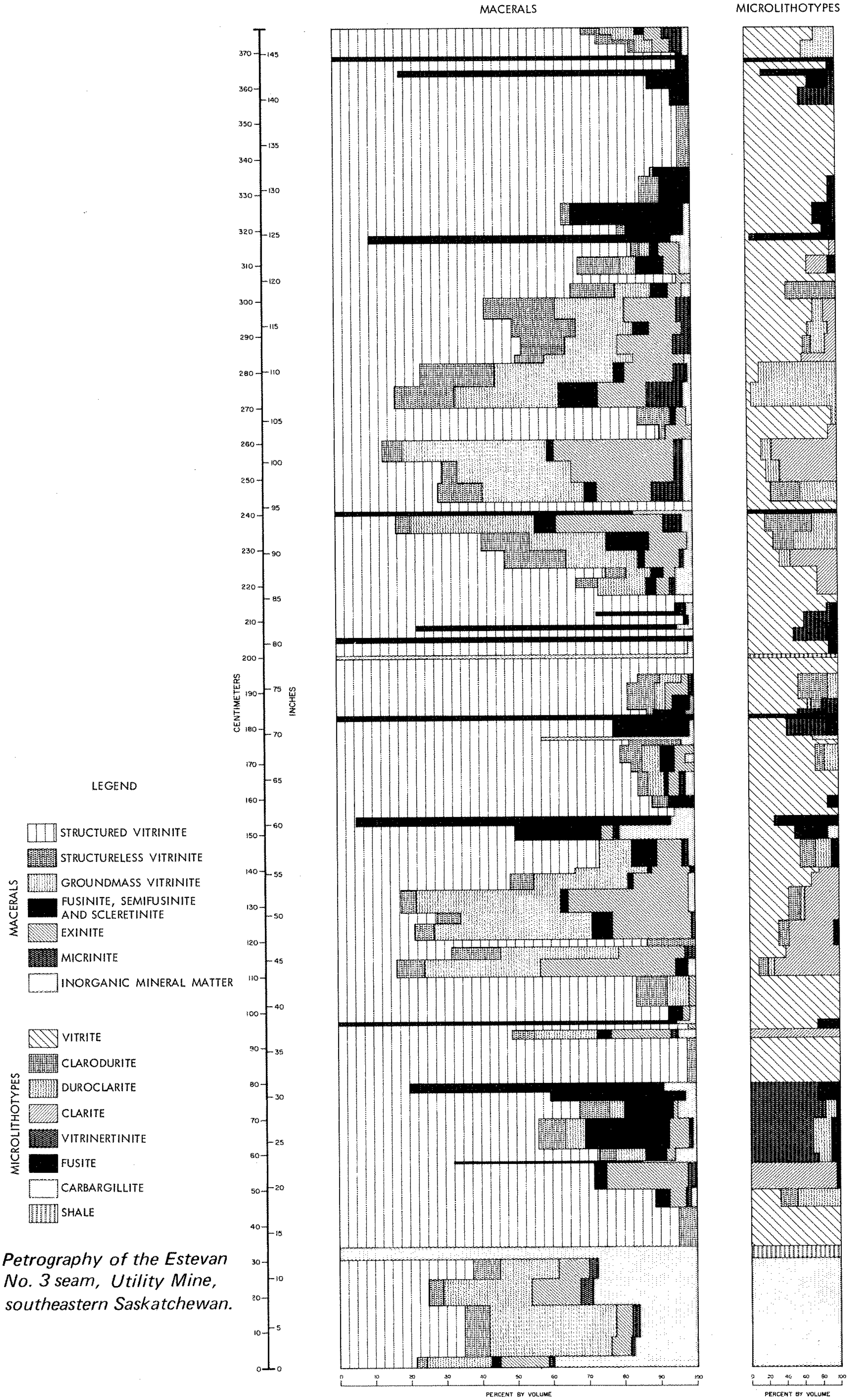


FIGURE 3. *Petrography of the Estevan No. 3 seam, Utility Mine, southeastern Saskatchewan.*

Proximate and ultimate analyses were not run on the particular column sample used in this study, but unpublished data for the seam are in the files of the Industrial Minerals Division of the Saskatchewan Department of Mineral Resources. The following proximate analysis is based on a channel sample collected August 22, 1963. The ultimate analysis is based on the average of 41 samples from the mine.

Proximate Analysis	Per Cent
Moisture	33.2
Ash	8.8
Volatile	32.0
Fixed carbon	26.0
Sulphur	0.4

Calorific Value - 6911 BTU/lb

Ultimate Analysis	Per Cent
Carbon	44.8
Hydrogen	3.0
Nitrogen	0.7
Sulphur	0.5
Oxygen	12.4

Density - 44.6 lbs/cu ft

Paleoenvironment

Teichmuller and Thomson (1958) correlated petrographic characteristics with environmental facies types in the Rhine brown coal. Cameron and Birmingham (1971) adapted these principles to Canadian lignites, particularly to their equivalent study of the lignite seam of the Klimax Mine. If it can be assumed that the German paleoenvironmental studies are adaptable on a worldwide basis, then certain environmental conclusions can be drawn from this study. Teichmuller and Thomas recognized three main facies.

(1) *Forest-moor.* This facies contains a high proportion of both resin-saturated and nonresinous cellular tissue, along with smaller amounts of gel and fusinite. These constitutents approach 50 per cent or more of the seam, the remainder being a humic detritus of decomposed wood tissues. The forest-moor coals have the highest concentration of fusinite.

(2) *Reed-moor.* The proportion of humic detritus increases to more than 80 per cent. The highest concentrations of exinite and groundmass vitrinite are in this facies.

(3) *Open-water.* This facies also tends to be high in humic detritus and exinite, but is characterized by high ash contents. Lithotype fusite is scarce.

If these principles are generally valid, the seam at the Utility Mine is predominantly of forest-moor origin, with associated strong influences of the reed-moor facies. The petrographic components (Fig. 3) are grouped in accordance with facies types in figure 4 with environmental interpretations. The lowest 1 foot of the seam is interpreted to represent an open-water facies, characterized by high inorganic percentages and lack of fusinite, although it does not have a high exinite content. The high ash content may indicate deposition near a basin margin. Upright root structures, or other autochthonous characteristics, have not been recognized anywhere in the Utility Mine seam exposures. Above the shale parting is a short interval characterized by the reed-moor facies, above which the forest-moor facies dominates for the remaining lower one-third of the seam. The upper two-thirds of the seam indicates predominantly forest-moor deposition with two periods of strong reed-moor influence, strongest in the upper one-third of the seam.

Petrographic Correlation

The paleoenvironmental interpretation of the Utility Mine seam compares favorably with that of the Klimax Mine seam about 10 miles to the northeast, which has been studied by Cameron and Birmingham (1971). Although the correlation between the two seams is uncertain, the compositions of both seams — characterized by high proportions of fusinite and fusite — indicate the predominance of a forest-moor environment with strong reed-moor influences, especially in the upper parts of the seams. However, the Utility Mine seam also has a major reed-moor facies in the lower part, and the carbargillite interval, at the base of the Utility Mine seam, is found in the upper one-third of the Klimax Mine seam.

Nevertheless, the distribution of petrographic facies is sufficiently similar to suggest that the two seams are stratigraphically equivalent.

INFRARED SPECTRAL ANALYSIS

Infrared spectroscopy studies on the Saskatchewan lignites have provided useful data relating to the chemical and structural distinctions between macerals. The analyses described below were designed to provide basic spectral patterns which would be useful for a rapid identification of

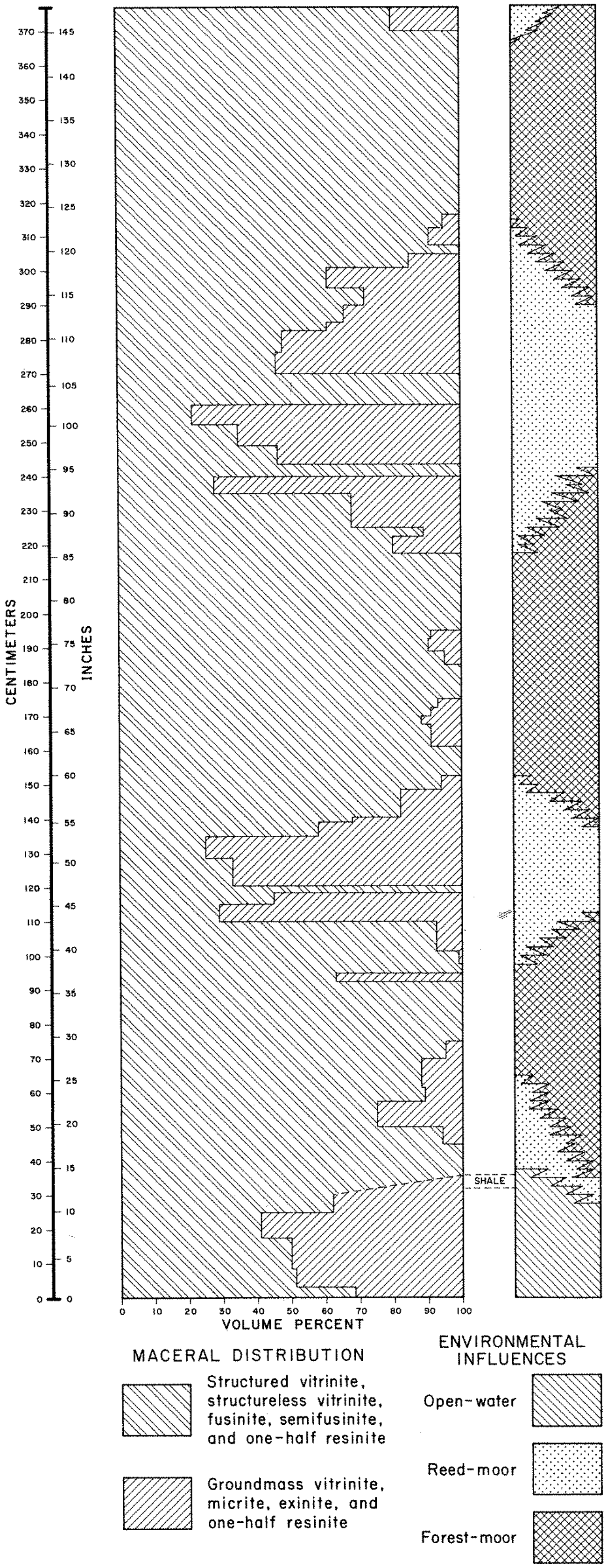


FIGURE 4. Interpretation of the depositional environment of the Estevan No. 3 seam based on the distribution of petrographic macerals.

the individual macerals as well as leonardite, without resorting to more time-consuming petrographic techniques.

The lignite macerals used for infrared examination were obtained from the section sampled for petrographic study. The bulk lignite sample is a split of a channel sample from this locality. The leonardite sample is a split of a grid sample across a 600-foot wide, 4-foot high exposure of oxidized lignite. Leonardite may be composed of as much as 90 per cent soluble humic and fulvic acids. The humic acids are believed to be present largely as insoluble calcium salts. The fulvic acids are soluble in both basic and acid solutions. Leonardites have variable oxygen contents ranging from 30 to 60 per cent, whereas lignites contain less than 25 per cent oxygen.

A Perkin-Elmer Model 621 Grating Infrared Spectrophotometer was used with samples of equal weight in KBr pellets. A thorough mixing in a vibratory shaker was employed to avoid the formation of false water peaks (normally at 2.95, 4.90, and 6.12 microns) from grinding hygroscopic potassium bromide. A series of samples was dried at 100° C in a vacuum oven for four hours and quickly transferred to the mulling agent to minimize effects of oxidation and moisture absorptions. There are no significant differences between spectral patterns obtained from macerals treated in this manner and from untreated macerals.

Spectral information on the structure of coal is obtained by reference to spectra-structure correlations. The assignment of specific bands to structures, although controversial, is detailed in a number of references (Friedel, 1966; Francis, 1961; Roy, 1965). A discussion of the individual spectral bands of lignite from the Estevan No. 3 seam is given below (Figs. 5 and 6). The effect of possible "contamination" by inorganic mineral constituents on the various spectral bands was assessed by examination of the spectrum obtained from the lignite ash (Fig. 5).

2.72 micron band. Assignment of the weak peak in this band is uncertain, but it probably is free OH. It is most pronounced in lignite and more so in leonardite but is essentially absent from the individual macerals. It is very faint in attrital mixtures of vitrinite and exinite.

2.8-4.0 micron band with 2.95 micron peak. Due to the apparent lack of aliphatic C-O absorption at 9.0 and

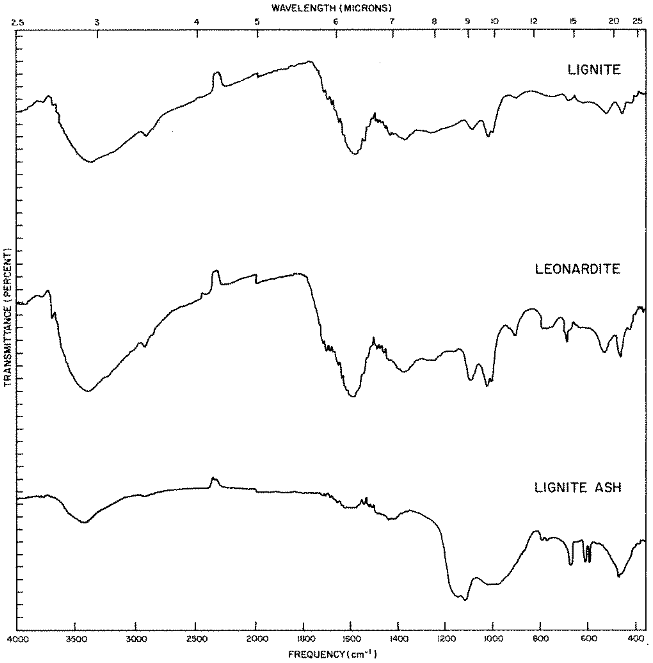


FIGURE 5. Infrared spectral patterns of lignite, leonardite, and lignite ash, Estevan No. 3 seam.

9.5 microns, and the presence of phenolic C-0 absorption in the 8 micron region, this intense and broad peak is assigned to phenolic and carboxylic OH. It is present in all the macerals, as well as lignite and leonardite, although very weak in fusinite. The peak in this range is skewed to the higher frequencies, from 3.0-4.0 microns, in which the broad absorption is apparently due to -OH groups that are more strongly hydrogen-bonded than the -OH groups contributing to the 3.0 band.

3.42 micron band. This weak peak is superimposed on the skewed broad phenolic OH peak above. It is present with about the same intensity in all the macerals, as well as in lignite and leonardite. In resinite it is the characteristic intense peak and is assigned to the aliphatic CH group. The intensity of this peak may constitute a practical semiquantitative estimate of the exinite percentage present in a sample.

3.5 micron band. A very weak peak is superimposed on the 3.42 peak. Like the above, it is interpreted as a aliphatic CH structure and is most pronounced in resinite. It is not present in fusinite.

5.8-5.9 micron band. This peak is assigned to carbonyl groups and is very weak to absent in medium to high rank coals. It is a strong distinct peak in resinite and in the humic acid extract from leonardite. It is largely overlapped by a broad 6.25 micron peak in leonardite and is completely overlapped by the 6.25 micron peak in lignite. The peak is weak in all other macerals and is usually hidden by the broad base of the 6.25 micron peak. The presence and intensity of this peak serves as an indicator of coal oxidation, thus easily identifying leonardite. The author postulates that the presence of a strong peak in this position indicates a nearly pure natural humic acid concentration.

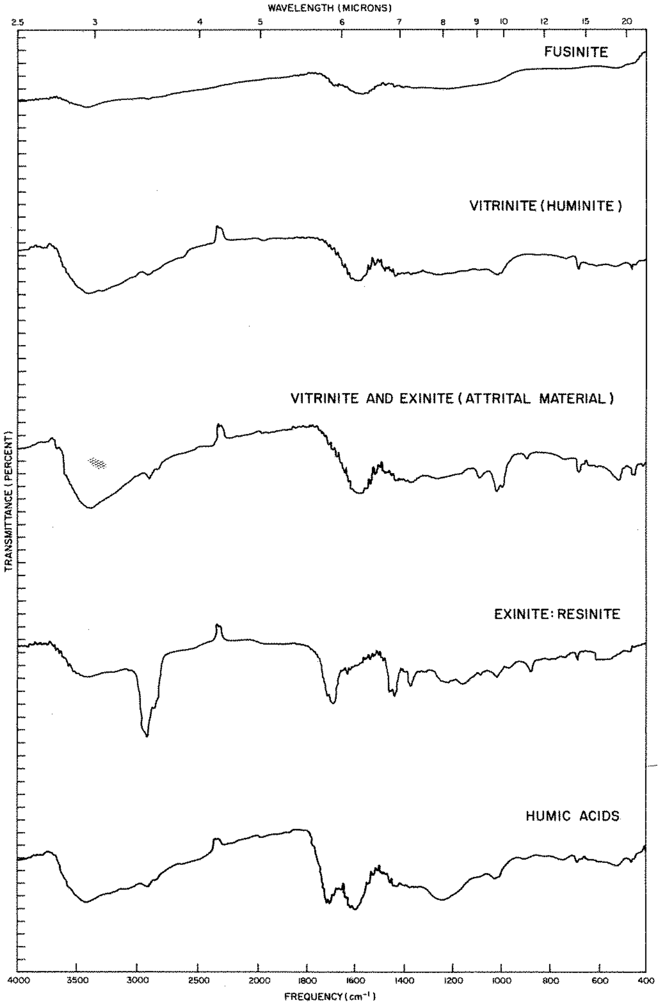


FIGURE 6. Infrared spectral patterns of coal macerals, Estevan No. 3 seam.

6.25 micron band. This intense and relatively broad peak is due either to aromatic structures, or chelated and conjugated carbonyl structures, or both. It is intense in vitrain, lignite, leonardite and humic acids but is absent to very weak in fusinite and resinite. Pronounced shoulders in the 6.3-6.7 micron region are assignable to aromatic structures.

6.9 micron band. This peak appears as a minor shoulder on the 7.2 micron peak in all lignite and leonardite macerals. Only in resinite is it an intense peak, representing a CH_2 and CH_3 structure, as well as aromatic CC or ionic carbonate. Since carbonate peaks in the ash spectrum are apparent at this wavelength, the effect of ionic carbonate on its intensity is prominent.

7.27 micron band. A broad, intermediate intensity peak from 7.2-7.3 microns is assigned to CH_3 groups. It is present in all the macerals, lignite and leonardite at about two-thirds the intensity of the 6.9 micron peak.

7.5-10.5 micron bands. This region is assigned to aromatic ethers and phenols. A very low intensity curve with indistinct peak positions is characteristic of vitrinite; attrital mixture of vitrinite, exinite and inertite; leonardite; and lignite. The curve is distinctly more intense in the humic acids but absent in fusinite. The 9.7 and 9.9 peaks are intense in leonardite and also lignite, but they are weaker for individual macerals. The higher ash content of leonardite is probably responsible for the high intensity peaks in this wavelength region. Also, the higher frequencies in this range may be due to the presence of kaolinite and other silicates.

11.0-11.1 micron band. A small but sharp peak in this region may be attributed to peroxides. The peak is strong in leonardite, but considerably weaker in the humic acid extraction, and appears to reflect a high silica contamination. It is absent in relatively silica-free vitrinite but of intermediate strength in silica-free resinite; thus, it is likely that the peak represents an overlap of silica and peroxide structures.

13.0 micron band. A broad, low intensity peak extends from 12.0 to 14.2 microns, with an indistinct peak at 13.0 microns. Assignment of the weak overlapping peaks in this area is uncertain, but they probably can be attributed to condensed aromatics or substitution in the benzene ring. This region is also strongly influenced by the inorganic constituents, especially in the intermediate strength band of leonardite if the pattern is compared to that from the humic acid extraction. Patterns from lignite and its macerals contain only very weak peaks in this region or none at all.

Infrared bands in higher wavelengths than 13 microns are attributed to inorganic constituents.

In summary, the infrared spectra of leonardite and lignite have the same general characteristics, first noted by Fowkes and Frost (1960) in their study of American leonardites. The characteristic difference is the greater intensity of the 5.8 micron peak in leonardite, reflecting an oxidation state. Sharp intensities of several inorganic peaks in frequencies higher than 8 microns also characterize leonardite. The lignite macerals have similar spectral patterns, but distinct differences are apparent. The prominent aliphatic CH group peak in resinite is notable. H-bonded (OH) is greatest in vitrinite, less in resinite, and least in fusinite. The presence of H-bonded (C-O) or polycyclic extended quinones is prominent in vitrinite, leonardite and humic acids, but less so in fusinite and resinite.

DIFFERENTIAL THERMAL ANALYSIS

Differential thermal analysis (DTA) was used to investigate the thermal properties of lignite macerals, lignite and leonardite from the Estevan No. 3 seam. This is believed to be the first such analysis of leonardite, although DTA curves of coal were first studied by Hollings and Cobb in 1923.

The experimental procedure utilized a closed tube sample holder in air, forming a slightly reducing atmosphere. The use of closed tube apparatus overcomes the masking effects of a broad exothermic curve when coals are burned in open tubes. The test samples from the Estevan No. 3 seam were analysed at 10° per minute from room temperature to 1000° C. A photographic recorder was utilized. Size of the air-dried samples was 400 mg, with an alumina standard. The resinite sample was 118 mg. The DTA curves are shown in figure 7.

All test samples showed loss of volatiles (water vapor) at approximately 100° C. Also, the samples generally each have one large exothermic peak and one large endothermic peak, which range between 175° and 225° C, and 270° and 325° C, respectively.

A comparison between the lignite and leonardite thermal curves shows several distinct trends, particularly in the

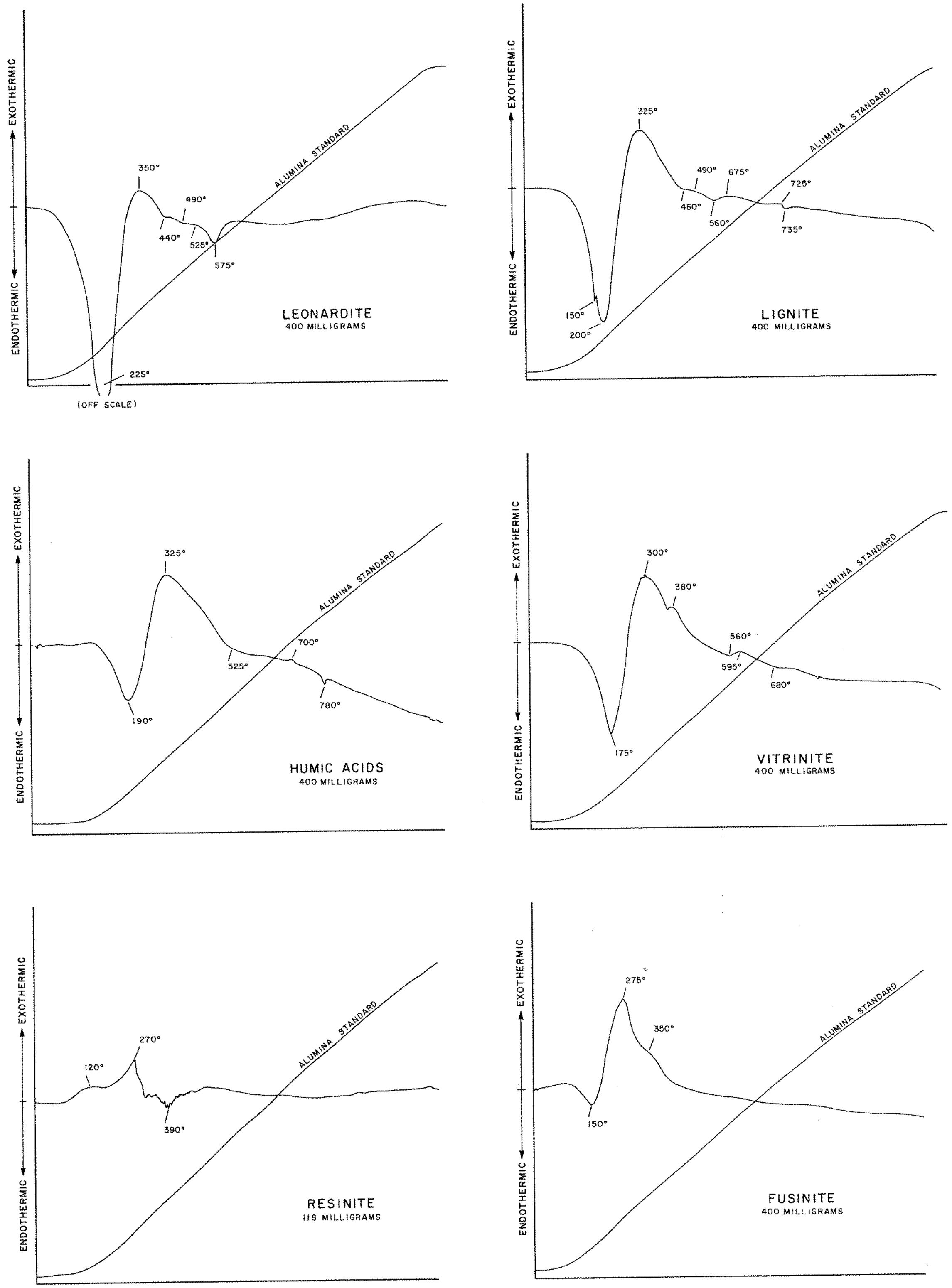


FIGURE 7. Differential thermal analyses of lignite, leonardite, and selected coal macerals, Estevan No. 3 seam.

location and intensity of the broad endothermic peak in the 200° C range, which is associated with the loss of bonded OH. The lignite peak at 200° shifts to 225° in leonardite, with a minor subpeak at 150° on the lignite peak. Also, the reaction is more intense in leonardite, reflecting the breakdown of the phenolic and carbonyl acid OH groups which have their highest concentration in leonardite. This high concentration is confirmed by the oxidation effects from the infrared studies. Likewise, the major combustion peak at 350° in leonardite is less intense and shifted to higher temperatures than the similar peak in lignite at 325°. The weathering-oxidation effects on lignite are also evidenced in the shift of the endothermic peak from 560° to 575° in leonardite, accompanied by a substantial increase in intensity. Although these effects are not fully understood, the structural breakdown of the high concentrations of humic acids, including concentrated phenolic and carbonyl OH groups, in leonardite may be a factor. Weak exothermic (725°) and endothermic (735°) thermal peaks in the lignite curve can only be assigned to inorganic thermal decompositions.

The vitrinite maceral curve is similar to that of lignite (79 per cent vitrinite) except for the slight displacement of the peak temperature positions. Also, the area under the endothermic peak at 175° is smaller for vitrinite, indicative of lower OH group percentages. However, the degree of combustion is virtually the same for the two materials, as determined by the area of the exothermic 300-325° curve.

The fusinite thermal curve indicates that there are organic structures still present in the maceral. It is apparent that what appears to be relatively pure petrographic carbon (charcoal) still contains an appreciable percentage of vitrinite volatiles. The phenolic OH groups apparently have been destroyed in the charcoaling process, for fusinite loses a small percentage of absorbed water at 150°. Combustion of the remaining volatile material in fusinite occurs over a narrower temperature range than vitrinite, peaking at 275°. No peaks occur above 450° C. The influence of inorganic contamination is uncertain but is assumed to be negligible because of the sampling procedure.

The thermal curve of resinite does not have any endothermic peak in the 100° to 300° range, unlike the other macerals. The major exothermic combustion peak is at 270°, with a minor hump at 120°. An endothermic reaction is indicated at 390°, but no reactions are apparent at higher temperatures.

In summary, endothermic reactions resulting from organic compound disintegration take place between 120 and 350° C. These compounds are characterized by structural groups rich in OH- and oxygen-containing groups, which decompose in a nonoxidizing atmosphere. Bonded OH content is relatively dominant in leonardite, less in lignite, and small but variable in the individual macerals. In lignite and leonardite secondary decomposition of organic constituents occurs between 500 and 600° C.

SUMMARY

Petrographic examination of a 12 1/2-foot columnar section of lignite from the Estevan No. 3 seam in southeastern Saskatchewan shows considerable variation in the distribution of coal macerals and lithotypes, which can be interpreted in terms of fluctuations in depositional environment. Structured vitrinite is the most abundant maceral (62 per cent) and is associated with a forest-moor environment which predominated during deposition of the seam. However, two intervals in which groundmass vitrinite and exinite are common are present; these are interpreted to reflect the influence of a reed-moor environment. The basal 1-foot interval is characterized by a high ash content and lack of fusinite, and is thought to represent an open-water facies deposited near a basin margin. The petrographic composition and paleoenvironmental interpretation of the Estevan No. 3 seam compare favorably with those of the Klimax Mine seam ten miles to the northeast, and it is suggested that the two seams are correlative on this basis.

An important feature of the Estevan No. 3 seam is the oxidation of the lignite to leonardite. Although lignite and leonardite have the same general infrared characteristics, the greater intensity of the 5.8 micron peak in leonardite reflects the oxidized state of this substance. Differential thermal analyses of lignite, leonardite and their various coal macerals support observations that leonardite has a lower potential as a fossil fuel.

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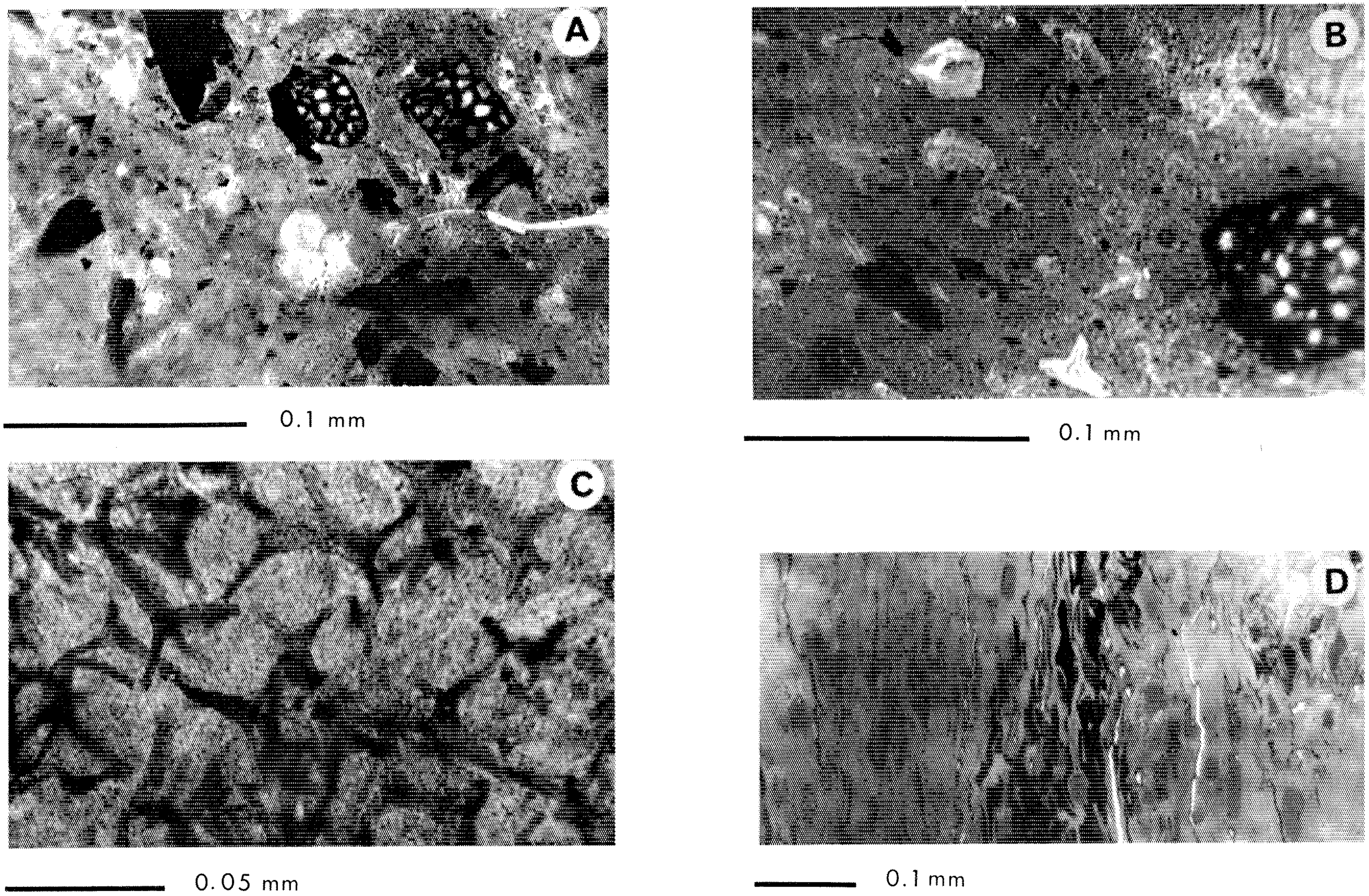

PLATE 1

A. Groundmass vitrinite with two large-celled fragments of fusinite, as well as disseminated inertinite, vitrinite, and resinite.

B. Groundmass vitrinite with scleretinite (upper left), pollen, and spores.

C. Unknown inclusions in resinite. These are thought to be leaf hairs, or remnants of telinite (cell walls).

D. Structured vitrinite with collapsed cell structure, with a zone of inertinite (center).

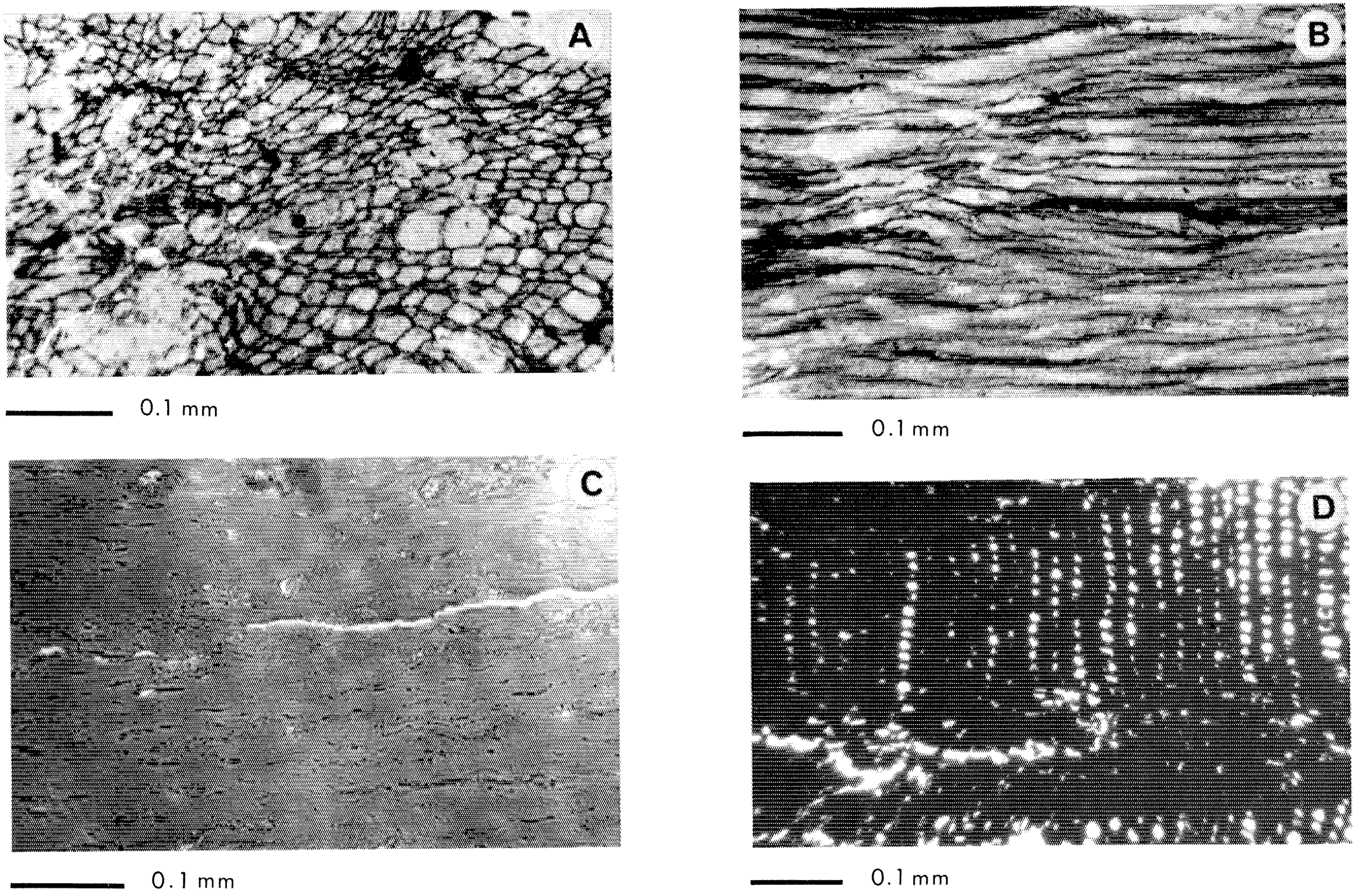

PLATE 2

A. Cross section of a limb structure. The cell cavities of vitrinite have been partly replaced by gypsum.

B. Longitudinal section of a limb structure, vitrinite.

C. Vitrinite with an advanced stage of cell collapse.

D. Fusinite. The cell cavity voids have been partially replaced by gypsum, calcite, and kaolinite.

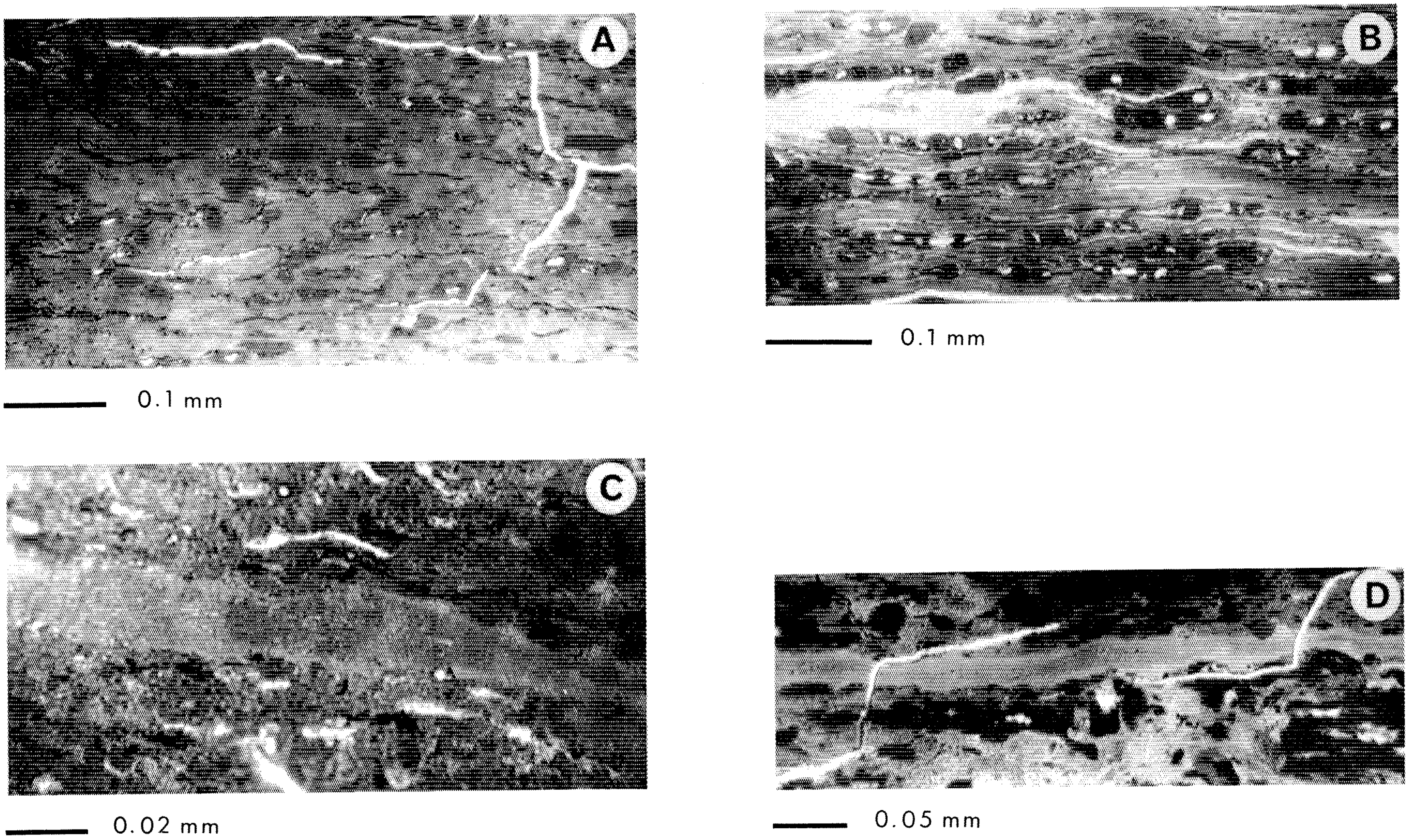

PLATE 3

A. Structured vitrinite with compressed cell cavities. The telinite (cell walls) is disseminated. The ovoid shapes are resinous cell fillings covering about 20 per cent of the area.

B. Well-structured vitrinite with distinct resinous cell fillings, and narrow bands of collinite (cell fillings) and telinite (cell walls).

C. Cutinite amid groundmass vitrinite.

D. Cutinite amid groundmass vitrinite and inertinite.

GEOLOGY AND EXPLORATION TECHNIQUES, SMOKY RIVER COAL FIELD, ALBERTA

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ABSTRACT

The Smoky River coal deposits, which are presently being mined by McIntyre Coal Mines Limited near the new town of Grande Cache, extend with stratigraphic continuity for a distance of at least 40 miles from northwest to southeast within the Rocky Mountain Foothills of west-central Alberta. Seams of low volatile coking coal occur within the lower half of the Lower Cretaceous Luscar Formation. Three to four coal seams of mineable thickness occur within the Commotion Formation-equivalent in the Luscar Formation, whereas one seam of mineable thickness is found within the upper portion of the Gething Formation-equivalent in the Luscar Formation. A pelecypod biozone in a shale and siltstone unit forms the Moosebar Formation-equivalent in the Luscar Formation.

Exploration has been carried out by bulldozing seam crops; diamond drilling, rotary drilling, electric-gamma and density logging; and bulk sampling of adits. Structural contour, isopach, isoburden, and isoquality maps of coal seams are produced from accurate small-scale topographic base maps and the compiled geologic data.

RANK STUDIES OF COALS IN THE ROCKY MOUNTAINS AND INNER FOOTHILLS BELT, CANADA

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ABSTRACT[1]

In this study the rank of coal has been determined by means of vitrinite reflectance measurements. For the regional changes the Kootenay coals of the Crowsnest Pass area have been examined; they show a progressive westward increase in rank. The changes in rank with stratigraphic position are illustrated with rank-depth curves of ten coal-bearing sections of Jurassic-Cretaceous age, that are situated between the Crowsnest coal field in the south and the Peace River canyon in the north. Both studies indicate pre-orogenic coalification, because the rank increases regularly with stratigraphic depth, but not with geologic age, depth of mining, or degree of tectonic disturbance.

For each of the ten curves plotted, the coalification gradient is calculated in terms of per cent reflectance(Ro)-change per 100 m increase in depth. By relating this gradient to that of a known curve (the Peel curve of the Netherlands), a reference for comparison is obtained, which is expressed as the Peel rank ratio. Different ratios were obtained, which probably are related to variations in the temperature gradients. The lowest ratio was found in the Peace River canyon area, and the highest occurs in the Canmore coal field.

The coalification gradient affects the availability of coking coals of most favorable rank, that is, the medium volatile coals. With a low gradient (and corresponding steep curve), medium volatile coals occur over a greater stratigraphic interval, with the possibility of a larger number of seams, than with a high gradient. Within limited areas of the same coal field, the rank as determined from vitrinite reflectance can be used for correlating coal seams, provided a high coalification gradient is present. This method has been employed successfully in the Canmore coal field on seams that lie not less than 120 feet apart stratigraphically.

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[1] The complete text of this contribution is to be published in The Geological Society of America Special Paper dealing with the Symposium held in Milwaukee, Wisconsin, in 1970 on "Carbonaceous Materials as Indicators of Metamorphism."

DEPOSITIONAL HISTORY OF THE COAL-BEARING UPPER JURASSIC-LOWER CRETACEOUS KOOTENAY FORMATION, SOUTHERN ROCKY MOUNTAINS, CANADA

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ABSTRACT[1]

The coal-bearing Kootenay Formation of Late Jurassic-Early Cretaceous age in Alberta and British Columbia is a classic example of a sedimentary succession built by deltaic progradation. The formation is composed of 3,500 feet of cyclicly alternating sandstones, shales and coal seams, with a few conglomeratic beds. The sandstones are poorly to moderately sorted, fine- to medium-grained lithic greywackes and protoquartzites. Shales are of illitic composition with minor amounts of kaolinite. The source area was composed of mainly sedimentary strata with a high content of argillaceous rocks. The Purcell Mountains and the Shuswap Complex are suggested for the location of the provenance area. Direction of transportation was to the northeast.

The Kootenay Formation is interpreted to represent a complete prograded delta sequence with prodelta facies at the base and alluvial plain deposits at the top. Deposition of terrigenous clastics was initiated by epeirogenic uplift of the source area in Late Jurassic time. Terrigenous clastics began to be deposited on a low-lying coastal plain, which advanced seaward by accretion. In the vertical section the offshore siltstones and mudstones of the open marine deposits grade upward into fine-grained sandstones and siltstones of the transitional prodelta facies of the Fernie Formation. The prodelta deposits in turn grade upward into delta front sheet sands and a barrier bar-spit sandstone complex of the Moose Mountain Member of the Kootenay Formation. The coal-bearing member of the Kootenay Formation, which is interpreted as a lower delta plain deposit, overlies the delta front sediments. Coals formed as peat in coastal swamps and in freshwater swamps of interdistributary flood basins in the lower delta plain. Coals of the latter type range to 30 feet in thickness. Most favorable conditions for thick coal seam development are assumed to be in the Elk Valley area, which underwent more rapid subsidence during deposition of the Kootenay Formation. The upper part of the formation (Elk Member) containing conglomeratic beds was deposited on an alluvial plain. Conditions for developing thick peat accumulations on the alluvial plain were unfavorable, mainly due to a higher frequency of flooding. As a result, the Elk Member is lacking coal beds of mineable thickness.

Uplifting of the depositional area in Neocomian time terminated sedimentation and initiated denudation of the previously deposited sediments. By additional strong uplifting of the inland area, the rejuvenated piedmont plain deposits represented by the Cadomin Conglomerate of Early Cretaceous age were spread over the erosion surface of the Kootenay Formation and deposited in an alluvial floodplain environment.

The study demonstrates the use of sedimentological studies as a tool for exploration and evaluation of coal basins.

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[1] The complete text of this contribution will be published in a forthcoming issue of the Bulletin of the Geological Society of America.

INDUCED POLARIZATION AND OTHER GEOPHYSICAL TECHNIQUES IN COAL EXPLORATION

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ABSTRACT

Various geophysical techniques have been applied to exploration for coal over a number of years, particularly in Europe. Until 1971, no serious attempt had been made to use surface geophysical methods in the exploration for coking, steam and lignite coal occurrences in the Western Canadian Sedimentary Basin. The induced polarization technique was introduced to the coal industry in 1971 as a tool for the direct detection and delineation of coal beds occurring beneath an overburden cover.

The physical properties of coal are discussed and related to the various geophysical methods. The most prominent method, that is, induced polarization, is discussed in detail. Case histories are used to demonstrate the salient points. Mention also is made of geophysical techniques used in boreholes for both the evaluation of and the exploration for coal.

Of all methods so far evaluated, it appears that induced polarization is probably the most dependable geophysical technique for both prospecting for and delineating coal occurrences.

PRELIMINARY GEOLOGY OF THE WHITERABBIT CREEK–UPPER RAM RIVER COAL AREA, ALBERTA

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ABSTRACT

The Whiterabbit Creek - Upper Ram River area lies along the Front Ranges of the Rocky Mountains in west-central Alberta. From northeast to southwest, the topographic profile of the area reflects the stratigraphy, consisting of mountainous ridges of Paleozoic and Triassic carbonates and arenites; valleys of Jurassic "Fernie shale"; slopes of shales and minor sandstones (equivalent to the Jurassic "Passage Beds"); a cliff-forming Jurassic and/or Lower Cretaceous "sandstone unit," overlain at intermediate elevations by the flat benches and gentle ridges of the Jurassic and/or Lower Cretaceous "interbedded unit," consisting of sandstone, shale and coal. This profile is repeated three times, reflecting the three thrust belts of the area.

Within the "interbedded unit" the coal seams range up to 30 feet in stratigraphic thickness. Observed thicknesses along the axes of folds are greater. At least two, and probably more seams of commercial thickness are apparent. Indications are that the stratigraphic thicknesses of coal are greater in the western part than in the eastern part of the area.

Structurally, the Whiterabbit Creek-Upper Ram River Area is within the McConnel thrust sheet, which in this region is exceptionally wide (approximately 15 miles) and is composed of three "subsidiary" overlapping thrust belts. These are parallel to the regional northwesterly strike, and structurally each belt is roughly a repetition of the next. Each belt contains a Paleozoic eastern front, a synclinal Mesozoic central area, and is bound by a Paleozoic thrust sheet in the southwest. The coal-bearing rocks of the "interbedded unit" are the youngest which outcrop along the synclinal axes of each belt.

APPENDIX

ORGANIZING COMMITTEE AND TECHNICAL PROGRAM, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL

held at
Chateau Lacombe
Edmonton, Alberta
November 18 and 19, 1971

ORGANIZING COMMITTEE

Chairman
M. A. Carrigy, Research Council of Alberta

Program
G. B. Mellon, Research Council of Alberta

Registration
H. R. Glover, Imperial Oil Enterprises Ltd.

Exhibits
M. J. MacDonald, Imperial Oil Enterprises Ltd.

Accommodation
P. M. Ryan, Imperial Oil Enterprises Ltd.

Public Relations
J. Steiner, University of Alberta
M. Curcio, Sterling Coal Valley Mining Company

Technical Supervision
G. D. Williams, University of Alberta

Social
I. J. McLaws, Research Council of Alberta
M. E. Holter, Research Council of Alberta

CAPG Representative
G. E. Hargreaves, Canadian Superior Oil Co. Ltd., Calgary, Alberta

TECHNICAL PROGRAM

Thursday, November 18

Opening Ceremonies

Greetings from the Government of Alberta
Honorable William D. Dickie
Minister of Mines and Minerals

Session 1

Chairman — Dr. R. Green, Research Council of Alberta

Coal deposits of Western and Northern Canada
B. A. Latour

Computer storage and retrieval of geologic data on coal deposits
G. D. Williams, G. J. Dickie, and J. Steiner

Coal deposits of the Alberta Plains
J. Steiner, G. D. Williams, and G. J. Dickie

Session 2

Chairman — Prof. T. H. Patching, University of Alberta

Rank studies of coals in the Rocky Mountains and Inner Foothills belt, Canada
P. A. Hacquebard and J. R. Donaldson

Petrography of Kootenay coals in the Upper Elk River and Crowsnest areas, British Columbia
A. R. Cameron

Petrography in coal processing
G. Norton and D. F. Symonds

Lignite coal resources of Saskatchewan
P. Guliov

Petrology of the Estevan No. 3 lignite seam, southeastern Saskatchewan
P. L. Broughton

Monetary evaluation of coal properties
H. A. Gorrell, C. A. S. Bulmer, and M. J. Brusset

Conference Dinner

Coal mining in the City of Edmonton
Dr. R. S. Taylor — Guest Speaker
Gas Arctic Systems

Friday, November 19

Session 3
Chairman – Dr. D. K. Norris, Geological Survey of Canada

Exploration techniques, Upper Elk coal field, British Columbia
J. A. Irvine

Induced polarization and other geophysical techniques in coal exploration
J. B. Prendergast and J. E. Wyder

Lignite exploration in the Ravenscrag Formation of southern Saskatchewan
S. H. Whitaker

Geology and exploration techniques, Smoky River coal fields, Alberta
D. D. Brown

Cretaceous stratigraphy, northeastern British Columbia
D. F. Stott

Session 4.
Chairman – Dr. C. R. Stelck, University of Alberta

Depositional history of the coal-bearing Upper Jurassic-Lower Cretaceous Kootenay Formation, southern Rocky Mountains, Canada
L. F. Jansa

Geology of the Luscar (Blairmore) coal beds, central Alberta Foothills
M. E. Holter and G. B. Mellon

The Cretaceous Gething Delta, northeastern British Columbia
D. F. Stott

Upper Cretaceous-Paleocene coal-bearing strata, northwest-central Alberta Plains
J. W. Kramers and G. B. Mellon

Preliminary geology of the Whiterabbit Creek-Upper Ram River coal area, Alberta
M. M. Suska